Chapter 18: Climate Resilient Development Pathways

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Executive Summary

Climate resilient development (CRD) is a process of implementing greenhouse gas mitigation and adaptation options to support sustainable development for all (18.1). Climate action and sustainable development are interdependent processes and climate resilient development is possible when this interdependence is leveraged. Pursuing these goals in an integrated manner increases their effectiveness in enhancing human and ecological well-being. Climate resilient development can help build capacity for climate action, including contributing to reductions in greenhouse gas emissions while enabling the implementation of adaptation options that enhance social, economic and ecological resilience to climate change as the prospect of crossing the 1.5°C global warming level in the early 2030s approaches (WG1 Table SPM1). For example, incorporating clean energy generation, healthy diets from sustainable food systems, appropriate urban planning and transport, universal health coverage and social protection, can generate substantial health and wellbeing co-benefits (*very high confidence*[1]) (7.4.4, Cross-Chapter Box HEALTH in Chapter 7). Similarly, universal water and energy access can help to reduce poverty and improve well-being while making populations less vulnerable and more resilient to adverse climate impacts (*very high confidence*) (18.1, Box 4.7).

Current development pathways combined with the observed impacts of climate change, are leading away from, rather than toward, sustainable development, as reported in recent literature (*moderate agreement, robust evidence*). While demonstrable progress has been made on some of the SDGs, significant gains across a range of targets are still necessary, as is enhancing synergies and balancing and managing trade-offs. Severe risks to natural and human systems are already observed in some places (high confidence), and could occur in many more systems, worldwide before mid-century (*medium confidence*), by end-century at all scales, from the local to the global, and at all latitudes and altitudes (*high confidence*). The COVID-19 pandemic revealed the vulnerability of development progress to shocks and stresses, potentially delaying the implementation of the 2030 Agenda for all (8.1, Cross-Chapter Box COVID in Chapter 7). Various global trends including rising income inequality, continued growth in greenhouse gas emissions, land use change, food and water insecurity, human displacement, and reversals of long-term increasing life expectancy trends in some nations run counter to the SDGs (*very high confidence*) as well as efforts to mitigate greenhouse gas emissions and adapt to a changing climate (18.2). These development trends contribute to worsening poverty, injustice and inequity, and environmental degradation. Climate change can exacerbate these conditions by undermining human and ecological well-being (18.2).

Social and economic inequities linked to gender, poverty, race/ethnicity, religion, age, or geographic location compound vulnerability to climate change and have created and could further exacerbate injustices, and constrain the implementation of CRD for all (*very high confidence*). Climate change intensifies existing vulnerability and inequality, with adverse impacts of climate change on the most vulnerable groups, including women and children in low-income households, Indigenous or other minority groups, small-scale producers and fishing communities, and low-income countries (*high confidence*). Most vulnerable regions and population groups, such as in East, Central and West Africa, South Asia, Micronesia and Melanesia and in Central America, present the most urgent need for adaptation (*high confidence*) (Ch 10, 12, 15). Climate justice initiatives explicitly address these multi-dimensional distributional issues as part of climate change adaptation. However, adaptation strategies can worsen social inequities, including gender, unless explicit efforts are made to change those unequal power dynamics, including spaces to foster inclusive decision-making. Drawing upon Indigenous knowledge and local knowledge can contribute to overcoming the combined challenges of climate change, food security, biodiversity conservation, and combating desertification and land degradation. (18.2; Cross-Chapter Box GENDER; Cross-Chapter Box INDIG}

Opportunities for climate resilient development vary by location (*very high confidence*). Over 3.3 billion people live in regions that are very high and highly vulnerable to climate change, while 2 billion people live in regions with low and very low vulnerability. Response to global greenhouse gas emissions

[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.

trajectories, regional and local development pathways, climate risk exposure, socio-economic and ecological vulnerability, and the local capacity to implement effective adaptation and greenhouse gas mitigation options, differ depending on local contexts and conditions (Table 18.3). As an example, underlying social and economic vulnerabilities in Australasia, exacerbate disadvantage among particular social groups and there is deep underinvestment in adaptation, given current and projected risks (Ch 11). There is also significant regional heterogeneity in climate change, exposure, and vulnerability, indicating different starting points for CRD, as well as mitigation, adaptation, and sustainable development opportunities, synergies, and trade-offs (18.5).

There are multiple possible pathways by which communities, nations and the world can pursue climate resilient development. Moving toward different pathways involves confronting complex synergies and trade-offs between development pathways, and the options, contested values, and interests that underpin climate mitigation and adaptation choices (*very high confidence*). Climate resilient development pathways are trajectories for the pursuit of climate resilient development and navigating its complexities. Different actors, the private sector, and civil society, influenced by science, local and Indigenous knowledges, and the media are both active and passive in designing and navigating CRD pathways (18.1, 18.4). Increasing levels of warming may narrow the options and choices available for local survival and sustainable development for human societies and ecosystems. Limiting warming to Paris Agreement goals will reduce the magnitude of climate risks to which people, places, the economy and ecosystems will have to adapt. Reconciling the costs, benefits, and trade-offs associated with adaptation, mitigation, and sustainable development interventions and how they are distributed among different populations and geographies is essential and challenging, but also creates the potential to pursue synergies that benefit human and ecological well-being. For example, in parts of Asia sustainable development pathways that connect climate change adaptation and disaster risk reduction can reduce climate vulnerability and increase resilience (Table 18.3. 10.6.2). Different actors and stakeholders have different priorities regarding these opportunities, which can exacerbate or diminish existing social, economic and ecological vulnerabilities and inequities. For example, in parts of Africa, intensive irrigation contributes to the development of agriculture but has come at a cost to ecosystem integrity and human well-being (Table 18.3., 9.15.2). Careful and explicit consideration for the ethical and equity dimensions of policies and practices associated with a climate resilient development pathway can help limit these negative externalities.

Prevailing development pathways are not advancing climate resilient development *(very high confidence)*. Societal choices in the near-term will determine future pathways. Some low-emissions pathways and climate outcomes are *unlikely*[2] to be realized (*very high confidence*). Rapid climate change is affecting every region across the globe and affecting natural and human systems relevant to the pursuit of the SDGs (18.1, 18.2, Fig. 18.1). Even the most ambitious greenhouse gas mitigation scenarios indicate climate change will continue for decades to centuries (WGI, 18.2). Increasing mitigation effort across multiple sectors exhibits opportunities for synergies with sustainable development, but also trade-offs that increase with mitigation effort that need to be balanced and managed (*high confidence*). The uncertainty associated with achieving specific pathways and climate outcomes is a risk factor to consider in planning, with plausibility and transformational challenges, as well as trade-offs and synergies, affected by technology, policy design, and societal choices (18.2). For instance, restrictions on utilization of individual mitigation options to manage trade-offs (e.g., bioenergy with CCS, afforestation, nuclear power) can also affect the mitigation cost to households (e.g., energy security, commodity prices) and the likelihood of a desired climate outcome being realized. Developing and transitional economies are estimated as low-cost mitigation opportunities, but are often at high risk from climate change due to their regional and development context (*high confidence*) (18.2,18.5). For example in Africa, competing uses for water such as hydropower generation, irrigation, and ecosystem requirements can create trade-offs among different management and development objectives (9.7.3). In Asia, intensive irrigation and other forms of water consumption can have a negative effect on water quality and aquatic ecosystems (Ch 10.6.3). Developed countries also,

[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.

face trade-offs, including in Australasia where adapting to fire risk in peri-urban zones introduces potential trade-offs among ecological values and fuel reduction in treed landscapes (Ch 11.3.5) and in North America where new coastal and alpine developments generate economic activity but enhance local social inequalities (15.4.10).

Systems transitions can enable climate resilient development, when accompanied by appropriate enabling conditions and inclusive arenas of engagement (*very high confidence*). Five systems transitions are considered: energy, industry, urban and infrastructure, land and ecosystems, and societal. Advancing climate resilient development in specific contexts may necessitate simultaneous progress on all five transitions. Collectively, these system transitions can widen the solution space and accelerate and deepen the implementation of sustainable development, adaptation, and mitigation actions by equipping actors and decision-makers with more effective options. For example, urban ecological infrastructure linked to an appropriate land use mix, street connectivity, open and green spaces, and job-housing proximity provides adaptation and mitigation benefits that can aid urban transformation. (Table 18.4, Cross-Working Group Box URBAN in Chapter 6) These system transitions are necessary precursors for more fundamental climate and sustainable-development transformations; but can simultaneously be outcomes of transformative actions. However, the way they are pursued may not necessarily be perceived as ethical or desirable to all actors. Hence, enhancing equity and agency are cross-cutting considerations for all five transitions. Such transitions can generate benefits across different sectors and regions, provided they are facilitated by appropriate enabling conditions including effective governance, policy implementation, innovation, and climate and development finance, which are currently insufficient (18.3, 18.4).

There is a rapidly narrowing window of opportunity to implement system transitions needed to enable CRD. Past choices have already eliminated some development pathways, but other pathways for climate-resilient development remain (*very high confidence*). In spite of a growth in national net-zero commitments, the current prospects of surpassing 1.5°C global mean temperatures by the 2030s are high (WG1 Table SPM1). There is strong evidence of the worsening of multiple climate impact drivers in all regions, that will place additional pressures on ecosystem services that support food and water systems, increasing the risks of malnutrition, ill-health and poverty in many regions (WG1 Fig SPM9, Table 18.4). This implies that significant additional adaptation will be needed. Over the near-term, implementing such transformational change could be disruptive to various economic and social systems. Over the long-term, however, they could generate benefits to human well-being and planetary health. Strengthening coordinated adaptation and mitigation actions can enhance the potential of local and regional development pathways to support CRD. Planning for CRD can support both adaptation and decarbonization via effective land-use, promoting resilient and low-carbon infrastructure; protecting biodiversity and integrating ecosystem services (Table 18.4), assuming advancing just and equitable development processes.

Prospects for transformation towards climate resilient development increase when key governance actors work together in inclusive and constructive ways to create a set of appropriate enabling conditions (18.4.2) (*high confidence*). These enabling conditions include effective governance and information flow, policy frameworks that incentivize sustainability solutions; adequate financing for adaptation, mitigation, and sustainable development; institutional capacity; science, technology and innovation; monitoring and evaluation of climate resilient development policies, programs, and practices; and international cooperation. Investment in social and technological innovation, could generate the knowledge and entrepreneurship needed to catalyze system transitions, and their transfer. The implementation of policies that incentivize the deployment of low-carbon technologies and practices within specific sectors such as energy, buildings, and agriculture could accelerate greenhouse gas mitigation and deployment of climate resilient infrastructure, in urban and rural areas. Civic engagement is an important element of building societal consensus and reducing barriers to action on adaptation, mitigation, and sustainable development. (18.4)

CRD pathways are determined through engagement in different arenas degree to which the emergent pathways foster just, and climate resilient development depends on how contending societal interests, values and worldviews are reconciled through inclusive and participatory interactions between governance actors in these arenas of engagement (18.4.3) (*high confidence*). These interactions occur in many different arenas (e.g., governmental, economic and financial, political, knowledge, science & technology, and community) that represent the settings, places, and spaces in which societal actors interact to influence the nature and course of development. For instance, the Agenda 2030 highlights the importance of multi-level adaptation governance, including non-state actors from civil society and the private sector. This implies the need for wider arenas and modes of engagement around adaptation that facilitate coordination, convergence, and productive contestation among these diverse actors to collectively solve problems and to unlock the synergies between adaptation and mitigation and sustainable development.

Regional and national differences mean different capacities for pursuing climate resilient development pathways. Economic sectors and global regions are exposed to different opportunities and challenges in facilitating climate resilient development, suggesting adaptation and mitigation options should be aligned to local and regional context and development pathways (*very high confidence*). Given their current state of development, some regions may prioritize poverty and inequality reduction, and economic development over the near-term as a means of building capacity for climate action and low-carbon development over the long-term. For example, Africa, South Asia, and Central and South America are highly exposed, vulnerable and impacted by climate change, which is amplified by poverty, population growth, land use change and high dependence on natural resources for commodity production. In contrast, developed economies with mature economies and high levels of resilience may prioritize climate action to transition their energy systems and reduce greenhouse gas emissions. Some interventions may be robust in that they are relevant to a broad range of potential development trajectories and could be deployed in a flexible manner. For example, conservation of land and water could be achieved through a variety of means and offer benefits to populations in the global North and South alike. However, other types of interventions, such as those that are dependent upon emerging technologies, may require a specific set of enhanced enabling conditions or factors including infrastructure, supply chains, international cooperation, and education and training that currently limit their implementation to certain settings (18.5). Notwithstanding national and regional differences, development practices that are aligned to people, prosperity, partnerships, peace and the planet as defined in Agenda 2030, could enable more climate resilient development (see Figure 18.1).

People, acting through enabling social, economic and political institutions, are the agents of system transitions and societal transformations that facilitate climate resilient development founded on the principles of inclusion, equity, climate justice, ecosystem health, and human well-being (*very high confidence*). While much literature on climate action has focused on the role of technology and policy as the factors that drive change, recent literature has focused on the role of specific actors – citizens, civil society, knowledge institutions (including local and Indigenous Peoples and science), governments, investors and businesses. Greater attention to, and transparency of, which actors' benefit, fail to benefit, or are impacted by mitigation and adaptation choices actions could better support climate-resilient and sustainable development. For example, grounding adaptation actions in local realities could help to ensure that adaptive actions do not worsen existing gender and other inequities within society (e.g., leading to maladaptation practices) *(high confidence)*. Differences in the ability of different actors to effect change ultimately influence which interventions for sustainable development or climate action are implemented and thus what development outcomes are achieved. Recent literature has focused on the social, political, and economic arenas of engagement, in which these different actors interact. More focused attention on these arenas of engagement could prove beneficial to reconciling divergent views on climate action, integrating Indigenous knowledge and local knowledges, elevating diverse voices that have historically been marginalized from the policy discourse, thereby reducing vulnerability, deepening adaptive capacity and the ability to implement CRD (18.4; Cross-Chapter Box GENDER; Cross-Chapter Box INDIG)

Pursuing climate resilient development involves considering a broader range of sustainable development priorities, policies and practices, as well as enabling societal choices to accelerate and deepen their implementation *(very high confidence)*. Scientific assessments of climate change have traditionally framed solutions around the implementation of specific adaptation and mitigation options as mechanisms for reducing climate-related risks. They have given less attention to a fuller set of societal priorities and the role of non-climate policies, social norms, lifestyles, power relationships and worldviews in enabling climate action and sustainable development. Because climate resilient development involves different actors pursuing plural development trajectories in diverse contexts, the pursuit of solutions that are equitable for all requires opening the space for engagement and action to a diversity of people, institutions, forms of knowledge, and worldviews. Through inclusive modes of engagement that enhance knowledge sharing and realize the productive potential of diverse perspectives and worldviews, societies could alter institutional structures and arrangements, development processes, choices and actions that have precipitated dangerous climate change, constrained the achievement of SDGs, and thus limited pathways to achieving CRD (Box 18.1, 18.4). There are only a few decades remaining to chart CRD pathways that catalyze the transformation of prevailing development practices and offer the greatest promise and potential for human well-being and planetary health.

18.1 Ways Forward for Climate Resilient Development

The links between climate change and development have been long recognized by various research communities (Nagoda, 2015; Winkler et al., 2015; Webber, 2016; Carr, 2019) and have been assessed by Working Group II in every IPCC Assessment Report since AR3 (Smit et al., 2001; Yohe et al., 2007; Denton et al., 2014). For the AR1-3 reports, these links were largely framed in the context of sustainable development, a concept that has been well described in the literature for decades (Brundtland, 1987). The AR5 introduced the framing of climate resilient pathways, which narrowed the discussion around sustainable development to specifically address the contributions of mitigation and adaptation actions to the reduction of risk to development and the various institutions, strategies, and choices involved in risk management (Denton et al., 2014). That assessment concluded that identifying and implementing appropriate technical and governance options for mitigation and adaptation as well as development strategies and choices that contribute to climate resilience are central to the successful implementation of such strategies. The AR5 also recognized that transformation of current development pathways in terms of wider political, economic and social systems may be necessary (Denton et al., 2014).

The literature presenting research findings on climate resilient development (CRD) and pathways and processes for successfully achieving CRD has expanded significantly in the several years since the AR5 (*very high confidence*). This includes both qualitative studies of development as well as illustrative, quantitative analyses of development trajectories linked to specific scenarios, such as the Shared Socioeconomic Pathways (SSPs) (18.2.2). Furthermore, the literature describing the role of system transitions and societal transformation in enabling climate action (Box 18.1, 18.3), compliance with the Paris Agreement (18.1.3, 18.2.1), and achievement of the Sustainable Development Goals (18.1.3; Box 18.4) has expanded significantly (*very high confidence*). This expansion is comprised of studies spanning a broad range of disciplinary perspectives, some of which have been underrepresented in prior IPCC assessments (*high agreement, limited evidence)* (Minx et al., 2017; Pearce et al., 2018b)).

This chapter therefore focuses on assessing this more recent literature and the diverse scientific understandings of CRD and the pathways for pursuing it. Notably, this chapter takes off where Chapters 16 and 17 end: recognizing the decision-making context to address the representative key risks and their intersections with development, among others. This chapter therefore highlights not only how climate risk undermines CRD, but also how current patterns of development contribute to climate risk, both generally and in different sectoral and regional contexts. In particular, the chapter focuses on achieving CRD through systems transitions, discussing these in relation to societal transformation, and how different actors engage one another in order to pursue policy and practice consistent with CRD.

18.1.1 Understanding Climate Resilient Development

Past IPCC Assessment Reports have consistently examined an extensive literature on the links between climate change, adaptation, and sustainable development (Smit et al., 2001; Klein et al., 2007; Yohe et al., 2007). However, studies that explicitly refer to CRD as a concept or a guide for policy and practice remain modest (*very high confidence*). The concept of CRD appeared in scholarly literature as well as development program documents over a decade ago (Kamal Uddin et al., 2006; Garg and Halsnæs, 2007) and has been used in more recent IPCC assessment reports and special reports (e.g., Denton et al., 2014; Roy et al., 2018). Similarly, the use of the term climate resilient development pathways dates to 2009 (Ayers and Huq, 2009), but its use accelerated after appearing in UNFCCC publications around the launch of the Green Climate Fund (UNFCCC, 2011). While this chapter prioritizes the CRD literature, it also recognizes a broad range of literature, disciplinary expertise, and development practice is relevant to the concept of CRD.

Much of this literature is assessed in recent IPCC Special Reports (Rogelj et al., 2018; Roy et al., 2018; Bindoff et al., 2019; Hurlbert et al., 2019; Oppenheimer et al., 2019), but new studies have continued to emerge. More specific uses of CRD found in the literature describe development that seeks to achieve poverty reduction and adaptation to climate change simultaneously without explicit mention of mitigation (USAID, 2014)), as well as mitigation and poverty reduction, described as 'low-carbon development,' without explicit mention of adaptation (Alam et al., 2011; Fankhauser and McDermott, 2016). Other similar terms include 'climate safe', 'climate compatible' and 'climate smart' development (Huxham et al., 2015; Kim et al., 2017b; Ficklin et al., 2018; Mcleod et al., 2018), each with varying nuances. Climate-compatible development coined by Mitchell and Maxwell (2010) specifically describes a 'triple win' of adaptation, mitigation and development (Antwi-Agyei et al., 2017; Favretto et al., 2018) (see also 8.6). In this spirit, AR5 specifically referred to climate-resilient development as "*development trajectories that combine adaptation and mitigation to realize the goal of sustainable development*" (Denton et al., 2014). This chapter builds on the AR5 and, for the purposes of assessment, formally defines CRD as *a process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development for all.* This extension of the earlier definition reflects the emphasis in recent literature on equity as a core element of sustainable development as well as the objective of the SDGs to "*create conditions for sustainable, inclusive and sustained economic growth, shared prosperity and decent work for all, taking into account different levels of national development and capacities*" (United Nations, 2015: 3/35).

Past, present, and future concentrations of greenhouse gases in the atmosphere are the direct result of both natural and anthropogenic greenhouse gas emissions which are, in turn, a function of past and current patterns of human and economic development (*very high confidence*, WGI SPM). This includes development processes that drive land use change, extractive industries, manufacturing and trade, energy production, food production, infrastructure development, and transportation. These patterns of development are therefore drivers of current and future climate risk to specific sectors, regions, and populations (Byers et al., 2018), as well as the demand for both mitigation and adaptation as a means of preventing climate change from undermining development goals. The Sustainable Development Goals (SDGs) represent targets for supporting human and ecological well-being in a sustainable manner. Yet, while progress is being made toward a number of the Sustainable Development Goals (SDGs), success in achieving all of the SDGs by 2030 across all global regions remains uncertain (*high agreement, medium evidence*) (United Nations, 2021). Moreover, current commitments to reduce greenhouse gas emissions are not yet consistent with limiting changes in global mean temperature elevation to less than 2°C or 1.5°C (*very high confidence*) (IPCC, 2018a) (see also 18.2).

Atmospheric concentrations of greenhouse gases are just one of a number of planetary boundaries which define safe operating spaces for humanity and therefore opportunities for achieving sustainable and climate-resilient development. Exceeding these boundaries poses increased risk of large-scale abrupt or irreversible environmental changes that would threaten human and ecological well-being (*very high confidence*) (Rockström et al., 2009a; Rockström et al., 2009b; Butler, 2017; Schleussner et al., 2021). Other planetary boundaries reported in the literature such as biodiversity loss, changes in land systems, and freshwater use are also directly influenced by patterns of development as well as climate change (18.2; 18.5). Current rates of species extinction, conversion of land for crop production, and exploitation of water resources exceed planetary boundaries, thereby undermining CRD. Moreover, studies indicate that achievement of the sustainable development goals, while consistent with maintaining some planetary boundaries, could undermine others (O'Neill et al., 2018; Hickel, 2019; Randers et al., 2019) (18.2), suggesting significant shifts in current patterns of development are necessary to maintain development within planetary boundaries.

Exceedance of planetary boundaries contributes to human and ecological vulnerability to climate change and other shocks and stressors. People and regions that already face high rates of natural resource use, ecosystem degradation, and poverty are more vulnerable to climate change impacts, compounding existing development challenges in regions that are already strained (IPCC, 2014a; Hallegatte et al., 2019). The International Monetary Fund, for example, found that for a medium and low-income developing country with an annual average temperature of 25°C, the effect of a 1°C increase in temperature is a reduction in economic growth by 1.2% (Acevedo et al., 2018). Countries whose economies are projected to be hard hit by an increase in temperature account for only about 20% of global Gross Domestic Product (GDP) in 2016, but are home to nearly 60% of the global population. This is expected to rise to more than 75% by the end of the century. These economic impacts are a function of the underlying vulnerability of low- and middle-income developing economies to the impacts of climate change (see 18.5). Such vulnerability was also evidenced and enhanced by the COVID-19 pandemic which slowed progress on the SDGs in multiple nations (Naidoo and Fisher, 2020; Srivastava et al., 2020; Bherwani et al., 2021).

18.1.2 Pathways for Climate Resilient Development

One approach for operationalizing the concept of climate-resilient development in a decision-making context is to link the concept of CRD to that of pathways (Figure 18.1). A pathway can be defined as *"a trajectory in* *time, reflecting a particular sequence of actions and consequences against a background of autonomous developments, leading to a specific future situation"* (Haasnoot et al., 2013; Bourgeois, 2015). As such, a pathway represents changes over time in response to policies and practices as well spontaneous and exogenous events. For example, the SR1.5 report suggested that CRD pathways are "*a conceptual and aspirational idea for steering societies towards low-carbon, prosperous and ecologically safe futures*" (Roy et al., 2018: 468), and a way to highlight the complexity of decision-making processes at different levels. Here, consistent with the aforementioned definition of CRD, we define CRD pathways as *development trajectories that successfully integrate mitigation, adaptation, and sustainable development to achieve development goals*.

As illustrated in Figure 18.1, the ultimate aim of CRD pathways is to support sustainable development for ensuring planetary health and human well-being. CRD is both an outcome at a point in space and time, as observed through SDG achievement indicators, but also a process consisting of actions and social choices made by multiple actors—government, industry, media, civil society, and science (18.4). These actions and social choices are performed within different dimensions of governance—politics, institutions (norms, rules), and practice, and bounded by ethics, values and worldviews. The development outcomes and processes pertain to political, economic, ecological, socio-cultural, knowledge-technology, and community arenas (Figure 18.2). A CRDP will, for example, aspire to achieve ecological outcomes in terms of planetary health and achievement of Paris Agreement goals as well as human well-being, solidarity and social justice, in addition to political, economic, and science-technology outcomes. These outcomes are enabled by achieving progress in core system transitions that catalyze broader societal transformations (Figure 18.3).

While there are many possible successful pathways to future development in the context of climate change, history has shown that pathways that are positive for the vast majority, often induce notable impacts and costs, especially on marginal and vulnerable people (Hickel, 2017; Ramalho, 2019), placing them in direct contradiction with the commitment to 'leave no one behind' (United Nations, 2015). Similarly, contemporary scenario analyses find that there are plausible development trajectories that lead toward sustainability (Figure 18.1, 18.2.2). Yet, a number of plausible trajectories that perpetuate or exacerbate unstainable forms of development also appear in the literature (Figure 18.1, 18.2.2). A significant challenge lies in identifying pathways that address current climate variability and change, while allowing for improvements in human well-being. Furthermore, while a given pathway might lead to a set of desired outcomes for one region or set of actors, the process of getting there may come at high environmental, socio- and economic cost to others *(very high confidence*) (Raworth, 2017; Faist, 2018). Frequently, considerations of social difference and equity are not prioritized in the evaluation of different development choices. The assumption that a growing economy lifts opportunity for all, could for example, further marginalize those who are the most vulnerable to climate change (Matin et al., 2018; Diffenbaugh and Burke, 2019; Hickel et al., 2021).

Placing pathways and climate actions within development processes implies a broadening of enablers to include the ethical-political quality of socio-environmental processes that are required to shift such processes in directions that support CRD and the pursuit of sustainability outcomes. This chapter therefore departs from the AR5s alignment of CRD with adaptation pathways and the emphasis on decision points that enable one to manage (or fail to manage) climate risk towards a framing that integrates a range of possible futures each offering different opportunities, risks, and trade-offs to different actors and stakeholders (see WGII AR5, IPCC, 2014b, Figure SPM.9). Instead, CRD emerges from everyday formal and informal decisions, actions, and adaptation or mitigation policy interventions. This is inclusive of system transitions, increased resilience, environmental integrity, social justice, equity, and reduced poverty and vulnerability, all facets of human well-being and planetary health. Rather than encompassing a formula or blueprint for particular actions, sustainable development is a process that provides a compass for the direction that these multiple actions should take (Anders, 2016). This creates opportunities for actors to apply a diverse toolkit of adaptation, mitigation, and sustainable development interventions, thereby opening up the solution space.

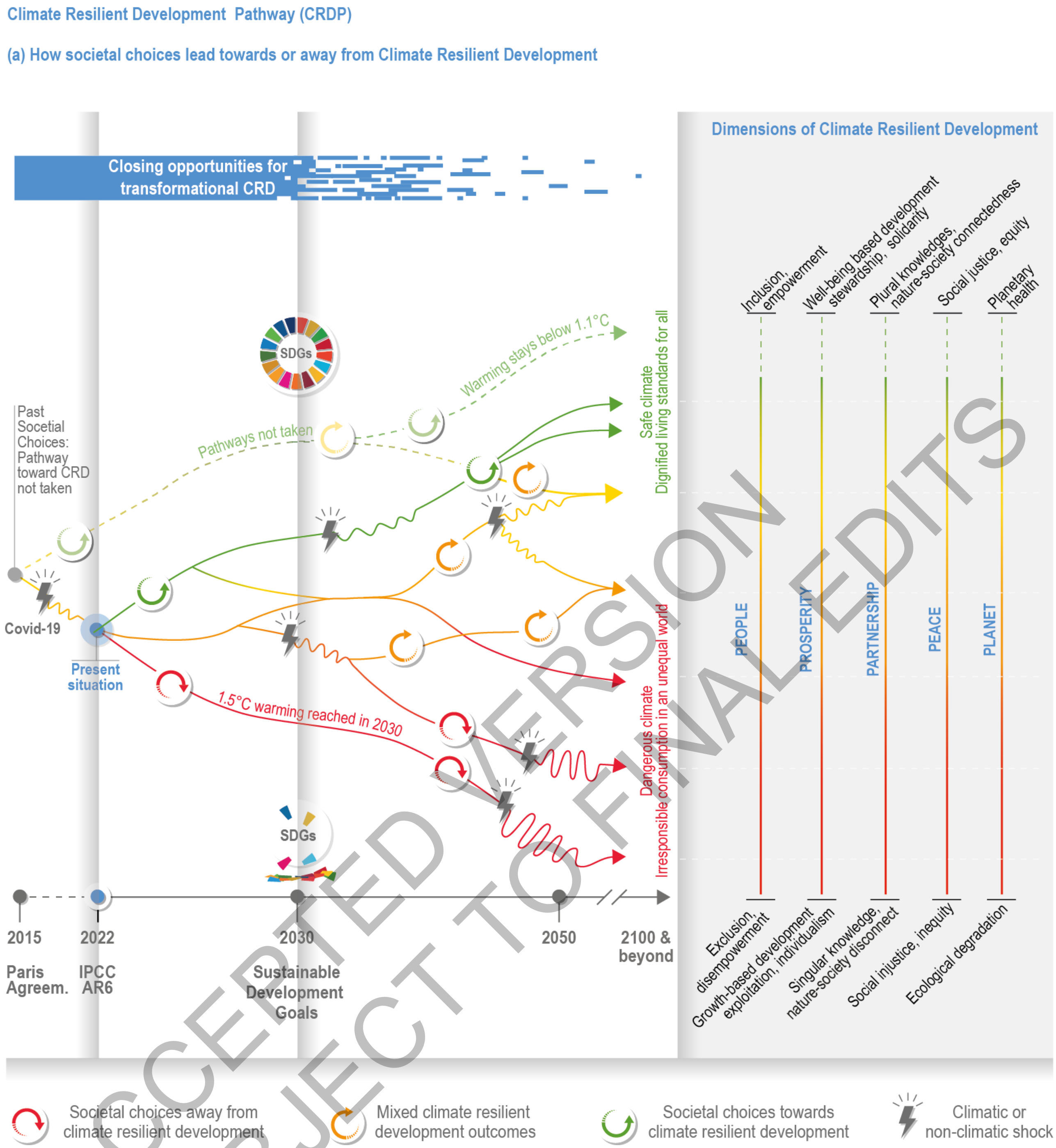

Figure 18.1: Climate Resilient Development Pathways. Climate resilient development is a process that takes place through societal choices towards (green pathways) or away from (red pathways) five development dimensions (people, prosperity, partnership, peace, planet) on which the SDGs build. Some societal choices have mixed outcomes for CRD (orange pathways). This figure builds on figure SPM.9 in AR5 WGII depicting climate resilient pathways) by describing how CRDPs emerge from societal choices within multiple arenas – rather than solely from discrete decision points. Societal choices, often contested, are made in these arenas through interactions between key actors in civil society, the private sector and government (see Figure 18.2). The quality of interactions between these actors in these arenas determine whether societal choices shift development towards or away from CRD. For example, inclusion vs exclusion and influence over choices shapes the quality of these interactions, and the outcomes of emergent societal choices. These qualities thus also characterize alternative futures resulting from different pathways, along five development dimensions (people, prosperity, partnership, peace, planet) on which the SDGs build. five CRD dimensions underline the close interconnectedness between the biosphere and humans, the two necessarily intertwined in interactions, actions, transitions, and futures (Figure 18.3). There is a narrow and closing window of opportunity to make transformational changes to move towards and not away from development futures that are more climate-resilient and sustainable. Pathways not taken (dotted line) show that the pathways towards the highest CRD futures are no longer available due to past societal choices and increasing temperatures. Present societal choices determine whether we shift towards CRD in future or whether pathways will be limited to less CRD.

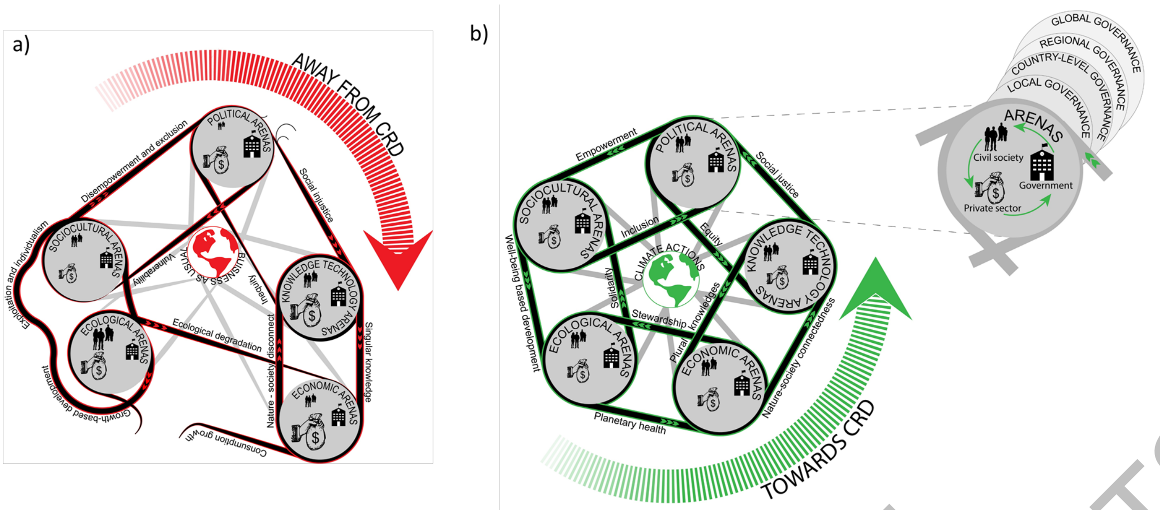

Figure 18.2: Societal choices in arenas of engagement shaping actions and systems. The settings, places and spaces in which key actors from government, civil society and the private sector interact to influence the nature and course of development can be called arenas of engagement, including political, economic, socio-cultural, ecological, knowledge-technology and community arenas. For instance, political arenas include formal political settings such as voting procedures to elect local representatives as well as less formal and transparent political arenas. Streets, town squares and post-disaster landscapes can become sites of interaction and political struggle as citizens strive to have their voices heard. Arenas exist across scales from the local to national level, and beyond. Arenas of engagement can take the form of "struggle arenas" – in which power and influence are used to include/exclude, set agendas, and make and implement decisions – with inevitable winners and losers. The quality of interactions in these arenas leads to development outcomes that can be characterized as CRD dimensions that underpin the SDGs – people, prosperity, partnership, peace, planet (see Figure 18.1). a) Interactions characterized by inequitable relations and domination of some actors over others may lead to societal choices away from CRD, including exacerbating disempowerment and vulnerability among marginalized groups. b) Prospects for moving towards CRD increase when governance actors work together constructively in these different arenas. Interactions and actions that are inclusive and synchronous, as opposed to fragmented or contradictory, enable system transitions and transformational change towards CRD (Figure 18.3b, Box 18.3). b) Well-intentioned efforts often fail to be transformative, but instead entrench inequities. Instead, marginalized groups and future trends in vulnerability need to be placed at the center of efforts to chart CRDPs. Unlocking the productive potential of conflict that often characterizes interactions in these arenas of engagement is central to advancing human well-being and planetary health. Moreover, the window for doing so is closing rapidly to avert dangerous climate change and unsustainable development.

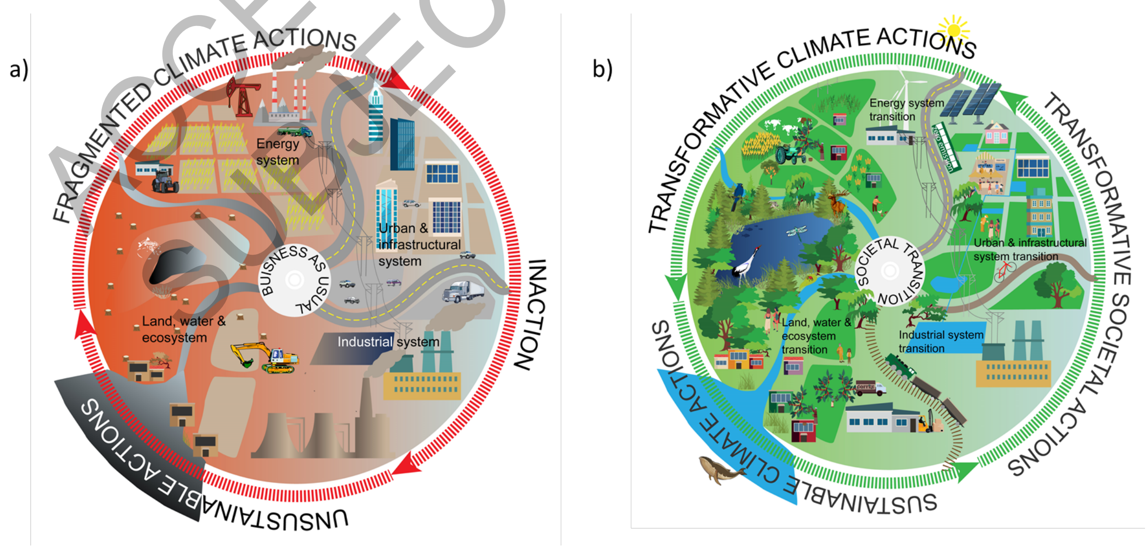

Figure 18.3: Transformative actions and system transitions a) Societal choices that generate fragmented climate action or inaction and unsustainable development perpetuate business as usual development. b) Societal choices that support CRD involve transformative actions that drive five systems transitions (energy, land and other ecosystems, urban and infrastructure, industrial and societal). There is close interdependence between these systems. The system transition

framework allows for a comprehensive assessment of the synergies and trade-offs between mitigation, adaptation and sustainable development. For example, land and water use in one system impacts the other systems and their surrounding ecosystems, thus reflecting how agricultural practices can have an impact on energy usage in urban centers. Finally, societal system transitions within each of the other systems enable the transitions to occur

This understanding of CRD implies that different actors – governments, businesses, and civic organizations – will have to design and navigate their own CRD pathways toward climate resilient and sustainable development. This includes determining the appropriate balance of adaptation, mitigation, and sustainable development actions and investments that are consistent with individual actors' development circumstances and goals while also ensuring that the collective actions remain consistent with global agreements and goals (such as the SDGs, Sendai Framework, and the Paris Agreement; 18.1.3), planetary boundaries, and other principles of CRD including social justice and equity (Roy et al., 2018). Empowering individual actors to pursue CRD in context-specific manner while coordinating action among actors and a diversity of scales, local to global, is a key challenge associated with achieving CRD (*high agreement, limited evidence*).

18.1.3 Policy Context for Climate Resilient Development

As reflected in Chapter 1 of the AR6 WGII report, CRD is emerging as one of the guiding principles for climate policy, both at the international level (Denton et al., 2014; Segger, 2016), as reflected in the Paris Agreement (Article 2, UNFCCC, 2015), and within specific countries (Simonet and Jobbins, 2016; Kim et al., 2017b; Vincent and Colenbrander, 2018; Yalew, 2020). This framing of development recognizes the risks posed by climate change to development objectives (18.2; see also Chapter 16); the opportunities, constraints and limits associated with reducing risk through adaptation; synergies and trade-offs between mitigation, adaptation, and sustainable development (18.2.5, 18.5, Box 18.4); and the role of system transitions in enabling large-scale transformations that limit future global warming to less than 1.5°C while boosting resilience (IPCC, 2018a) (18.3, Box 18.1).

Since the AR5, the volume of research at the nexus of climate action and sustainable development has changed markedly (*very high confidence*). A rapidly growing, multi-disciplinary literature has emerged on climate resilient development (Mitchell et al., 2015; Clapp and Sillmann, 2019; Hardoy et al., 2019; Yalew, 2020) and associated pathways (Naess et al., 2015; Winkler and Dubash, 2016; Brechin and Espinoza, 2017; Solecki et al., 2017; Ellis and Tschakert, 2019) (18.2.2). Nevertheless, the concept of resilience generally, and climate resilient development specifically, has come under increasing criticism in recent years (*very high confidence*) (Joakim et al., 2015; Schlosberg et al., 2017; Mikulewicz, 2018; Mikulewicz, 2019), suggesting the need to enhance understanding of how resilience is being operationalized at the program and project level and the net implications for human and ecological well-being.

This expansion of research has been accompanied by a shift in the policy context for climate action including an increasingly strong link between climate actions and sustainable development. In particular, the SDGs represent a near-term framework linking sustainability and human development in a manner that not only addresses planetary health and human wellbeing, but also help better plan and implement mitigation and adaptation actions to achieve these linked goals (Conway et al., 2015; Griscom et al., 2017; Allen et al., 2018b; Roy et al., 2018; P.R. Shukla E. Calvo Buendia, 2019). The SDGs explicitly identify climate action (SDG 13) among the goals needed to achieve sustainable development. Meanwhile, the text of the Paris Agreement makes explicit mention of the importance of considering climate "in the context of sustainable development" (Articles 2, 4, 6) or as "contributing to sustainable development" (Article 7) (Article 7, UNFCCC, 2015). Similarly, sustainable development appears prominently within the text of the Sendai Framework for Disaster Risk Reduction (UNDRR, 2015), and the Global Assessment Reports on Disaster Risk Reduction (Undrr, 2019). At the micro-level, a growing literature recognizes that climate impacts tend to exacerbate existing inequalities within societies, even at the level of gender inequalities within households (Sultana, 2010; Arora-Jonsson, 2011; Carr, 2013). Thus, climate change impacts threaten even short-term gains in sustainable development, which could be rolled back over longer adaptation and mitigation horizons. For example, the COVID-19 pandemic is estimated to have reversed gains over the past several years in terms of global poverty reduction (*very high confidence*) (Phillips et al., 2020; Sultana, 2021; Wilhelmi et al., 2021) (Cross-Chapter Box COVID in Chapter 7), reflecting the risks posed by global, systemic threats to development.

The WGII AR5 Report noted that adapting to the risks associated with climate change becomes more challenging at higher levels of global warming (IPCC, 2014a). This was evidenced by contrasting impacts and adaptive capacity for 2° and 4°C of warming. This relationship between levels of warming, climate risk, and reasons for concern (see Chapter 16) is also relevant to the concept of CRD. For example, recent literature on CRD emphasizes the urgency of climate action that achieve significant reduction in greenhouse gas emissions as well as the implementation of adaptation options that result in significant gains in human and natural system resilience (*very high confidence*) (Haines et al., 2017; Shindell et al., 2017; Xu and Ramanathan, 2017; Fuso Nerini et al., 2018). This was explored extensively in the IPCC's SR1.5 report in its comparison of impacts associated with 1.5°C versus 2°C climate objectives and synergies and trade-offs with the SDGs (IPCC, 2018a). However, the SR1.5 report and other literature also identified potential trade-offs between aggressive mitigation and the SDGs (see also Frank et al., 2017; Hasegawa et al., 2018). This indicates that while future magnitudes of warming are a fundamental consideration in climate-resilient development, such development involves more than just achieving temperature targets. Rather, CRD considers the possible transitions that enable those targets to be achieved including the evaluation of different adaptation and mitigation options and how the implementation of these strategies interacts with broader sustainable development efforts and goals. This interdependence between patterns of development, climate risk, and the demand for mitigation and adaptation action is fundamental to the concept of CRD (Fankhauser and McDermott, 2016). Therefore, climate change and sustainable development cannot be assessed or planned in isolation of one another.

18.1.4 Assessing Climate Resilient Development

In operationalizing the aforementioned definitions of CRD and CRD pathways this chapter builds its assessment around five core elements that provide insights relevant to policymakers actively pursuing the integration of climate resilience into development. First, as noted above, climate change poses a potential risk to the achievement of development goals, including global goals such as the SDGs, as well as nationally- or locally-specific goals. Accordingly, Chapter 16's discussion of key risks, their implications for the SDGs, and the options for risk management are fundamental to the pursuit of CRD. This includes the opportunities for implementing adaptation, mitigation, or other risk management options. Yet, the management of climate risk must be accompanied by interventions that address social and ecological vulnerabilities that enhance climate risk.

Second, CRD is dependent on achieving transitions in key systems including energy, land and ecosystem, urban and infrastructure, and industrial systems (*very high confidence*) (Box 18.1, Figure 18.3). In this context, CRD links to the discussion of system transitions in the SR1.5 report (IPCC, 2018b; IPCC, 2018a). However, in building on the SR1.5, here the assessment of CRD also recognizes the importance of transitions in societal systems that drive innovation, preferences for alternative patterns of consumption and development, and the power relationships among different actors that engage in CRD. In particular, the rate at which actors can achieve system transitions has important implications for the pursuit of CRD. Transitions that are slow to evolve or that are more incremental in nature may not be sufficient to enable CRD in comparison with faster transitions that contribute to more fundamental system transformations.

Third, equity and social justice are consistently identified in the literature as being central to climate resilient development (*very high confidence*; 18.1.1, 18.3.1.5, 18.4, 18.5). This includes designing and implementing adaptation, resilience, and climate risk management options in a manner that promotes equity in the allocation of the costs and benefits of those options. Similarly, the literature on CRD emphasizes equity should be pursued in the implementation of options for greenhouse gas mitigation, transitions in energy systems, and low-carbon development. This emphasis on equity is consistent with the SDGs which place an emphasis on reducing inequality and achieving sustainable development for all.

Fourth, success in CRD and alignment of development interventions to CRD pathways (CRDPs) is contingent on the presence of multiple enabling conditions (*very high confidence*, 18.4.2), that operate at different scales ranging from those that provide capacity to implement specific adaptation options to those that enable large-scale transformational change (Box 18.1). The qualities that describe sustainable development processes (e.g., social justice, alternative development models, equity and solidarity as described above and in Figure 18.1) lead to short-term outcomes and conditions, such as those represented by SDGs, that in an iterative fashion enable or constraint subsequent efforts toward CRD. For example, success or failure in achieving the SDGs or the Paris Agreement would shape future efforts in pursuit of CRD and the options available to different actors.

Fifth, CRD involves processes involving diverse actors, at different scales operating within an environmental, developmental, socio-economic, cultural, and political context, as typified in the SDG and the Paris Agreement negotiations *(very high confidence*) (Kamau et al., 2018) (18.4). The dependence of CRD on processes of negotiation and reconciliation among diverse actors and interests leads to the dismissal of the notion that there is a single, optimal pathway that captures the objectives, values, and development contexts of all actors, even for a particular sector, country or region. Rather, preferences for different pathways and specific actions in pursuit of those pathways will be subjected to intense scrutiny and debate among diverse actors within various arenas of engagement (18.4), meaning the settings, places and spaces in which key actors from government, civil society and the private sector interact to influence the nature and course of development.

18.1.5 Chapter Roadmap

This chapter engages with understanding CRD and the pathways to achieving it by building on the concepts introduced in Chapter 1 of this Working Group II report as well as the regional and sectoral context presented in other chapters (18.5). Notably, this chapter takes off where Chapters 16 and 17 end: recognizing the significance of the representative key risks for CRD as well as the decision-making context of different actors who are implementing policies and practices to pursue different CRD pathways and manage climate risk. Therefore, the chapter assesses options for pursuing CRD as well as the broader system transitions and enabling conditions in support of CRD.

This chapter hosts three Cross-Chapter Boxes, which have their natural home here. The Cross-Chapter Box on Gender, Justice and Transformative Pathways (Cross-Chapter Box GENDER) assesses literature specifically on gender and climate change to uncover the importance of a justice focus to facilitate transformative pathways, both toward CRD, as well as a means to achieving gender equity and social justice. The Cross-Chapter Box on The Role of Indigenous Knowledge in Understanding and Adapting to Climate Change (Cross-Chapter Box INDIG) highlights that achieving CRD requires confronting the uncertainty of a climate change future. There are many perspectives about what future is desired and how to reach it. Integrating multiple forms of knowledge is a strategy to build resilience and develop institutional arrangements that provide temporary solutions able to satisfy competing interests (Grove, 2018). Indigenous knowledge is proven to enhance resilience in multiple contexts (e.g., Chowdhooree, 2019; Inaotombi and Mahanta, 2019). Meanwhile, Cross-Chapter Box FEASIB acts as an appendix to the WGII report, synthesizing information on the feasibility associated with different adaptation options for reducing risk.

In assessing the opportunities and constraints associated with the pursuit of sustainable development, this chapter proceeds in Section 18.2 to assess the links between sustainable development and climate action, including examination of current patterns of development and consideration for synergies and trade-offs among different strategies and options. Then, in Section 18.3, the chapter assesses five systems transitions to identify the shifts in development that would enable CRD. Section 18.4 assesses the role of different actors in the pursuit of CRD as well as the public and private arenas in which they engage. Section 18.5 synthesizes CRD assessments from different WGII sectoral and regional chapters to identify commonalities and differences. The chapter concludes in Section 18.6 with a summary of key opportunities for enhancing the knowledge needed to enable different actors to pursue CRD.

[START BOX 18.1 HERE]

Box 18.1: Transformations in Support of Climate Resilient Development Pathways

Transformational changes in the pursuit of CRDPs involve interactions between individual, collective, and systems change (see Figures 18.1–18.3). There are complex interconnections between transformation and transition (Feola, 2015; Hölscher et al., 2018), and they are sometimes used as synonyms in the literature (Hölscher et al., 2018). Much of the transitions literature focuses on how societal change occurs within existing political and economic systems. Transformations are often considered to involve deeper and more fundamental changes than transitions, including changes to underlying values, worldviews, ideologies, structures, and power relationships (Göpel, 2016; O'Brien, 2016; Kuenkel, 2019; Waddock, 2019). Systems transitions alone are insufficient to achieve the rapid, fundamental and comprehensive changes required for humanity and planetary health in the face of climate change (*high confidence)*. Transformative action is increasingly urgent across all sectors, systems and scales to avert dangerous climate change and meet the SDGs (Pelling et al., 2015; IPCC, 2018a; IPCC, 2021b; Shi and Moser, 2021; Vogel and O'Brien, 2021) (*high confidence*). The SR1.5 identified transformative change as necessary to achieve transitions within land, water and ecosystems systems; urban and infrastructural systems; energy systems; and industrial systems. This box summarises key points in the transformations literature relevant to climate resilient development.

Transformative actions aimed at 'deliberately and fundamentally changing systems to achieve more just and equitable outcomes', (Shi and Moser, 2021: 2) shift pathways towards CRD (*high confidence)*. Transformative action in the context of CRD specifically concerns leveraging change in the five dimensions of development (people, prosperity, partnership, peace, planet) that drive societal choices and climate actions towards sustainability (18.2.2; Figure 18.1). Climate actions that support CRD are embedded in these dimensions of development; for example, social cohesion and equity, individual and collective agency, and democratising knowledge processes have been identified as steps to transform practices and governance systems for increased resilience (Ziervogel et al., 2016b; Nightingale et al., 2020; Colloff et al., 2021; Vogel and O'Brien, 2021) (*high confidence)*. Transformative actions toward sustainability and increased well-being, which are dominant components of climate resilient development, include those that explicitly redress social drivers of vulnerability, shift dominant worldviews, decolonialise knowledge systems, activate human agency, contest political arrangements, and insert a plurality of knowledges and ways of knowing (Görg et al., 2017; Fazey et al., 2018a; Brand et al., 2020; Gram-Hanssen et al., 2021; Shi and Moser, 2021). They alter the governance and political economic arrangements through which unsustainable and unjust development logics and knowledges are implemented (Patterson et al., 2017; Shi and Moser, 2021) by shifting the goals of a system or altering the mindset or paradigm from which a system arises, e.g from individualism and nature-society disconnect to solidarity and nature-society connectedness along the CRD dimensions in figure 18.1, and connecting inner and external dimensions of sustainability, (Göpel, 2016; Abson et al., 2017; Wamsler and Brink, 2018; Fischer and Riechers, 2019; Horcea-Milcu et al., 2019; Wamsler, 2019).

There is no blueprint for how transformation is generated. An expanding literature suggests that transformation takes place through diverse modalities and context-dependent actions (O'Brien, 2021). Transformation may require actions that disrupt moral or social boundaries and structures that are perpetuating unsustainable systems and pathways (Vogel and O'Brien, 2021) (*high confidence*). Extreme events and long-term climatic changes can trigger a realigning of practices, politics and knowledges (Carr, 2019; Schipper et al., 2020b) (*high confidence*). While some see opportunities for generating social and political conditions needed for CRD in such actions and events (Beck, 2015; Han, 2015; Shim, 2015; Mythen and Walklate, 2016; Domingo, 2018), this is not guaranteed. Climate shocks, when managed within socio-political systems in ways that safeguard rather than alter practices and structures, can also reinforce rather than shift the status quo (Mosberg et al., 2017; Carr, 2019; Marmot and Allen, 2020; Arifeen and Nyborg, 2021) (*high confidence*). Further, in the absence of equitable and inclusive decision-making and planning, realignments resulting from disruptive actions and events can limit inclusiveness and lead to poor or coercive decision-making processes that undermine the equity and justice foundations of sustainable development (Orlove et al., 2020; Shi and Moser, 2021) and lead to adverse socio-environmental outcomes that generate transformations away from CRD (Vogel and O'Brien, 2021) *(high confidence*, see also CCP2).

Evidence for transformative actions largely exists at the community or city level. While identifying how to rapidly and equitably generate transformations at a global scale has remained elusive, there is *high agreement* but *limited evidence* from studies of ecosystem services that suggest facilitating a wide range of locally-appropriate management decisions and actions can bring about positive global-scale outcomes (Millennium Ecosystem, 2005). Diverse local efforts to transform towards sustainability in the face of climate change have been observed, such as community mobilization for equitable and just adaptation actions and alternative visions of societal well-being (Shi, 2020b) and farmer-led shifts in agricultural production systems (Rosenberg, 2021). There has been an increase in transformative actions taking place through city-level resilience building aimed at shifting inequitable relations and opening up space for a plurality of actors (Rosenzweig and Solecki, 2018; Ziervogel et al., 2021) (*high confidence)*.

Prospects for transformation towards climate resilient development increase when key governance actors work together in inclusive and constructive ways through engagement in political, knowledge-technology, ecological, economic, and socio-cultural arenas (*high confidence*,18.4.3). Yet, the interactions between key governance actors involve struggles and negotiations in addition to collaborations (Kakenmaster, 2019; Muok et al., 2021). Transformative actions meet resistance by precisely the political, social, knowledge and technical systems and structures they are attempting to transform (Blythe et al., 2018; Shi and Moser, 2021) (*high confidence*). There is expanding evidence that many adaptation efforts have failed to be transformative, but instead entrenched inequities, exacerbated power imbalances and reinforced vulnerability among marginalized groups, and that, instead, marginalized groups and future trends in vulnerability need to be placed at the center of adaptation planning (Atteridge and Remling, 2018; Mikulewicz, 2019; Owen, 2020; Eriksen et al., 2021a; Eriksen et al., 2021b; Garschagen et al., 2021) (*high confidence*). Beyond the enablers, drivers, or modalities, another question tackled in the literature is how to evaluate transformation by establishing criteria for transformation assessments (Ofir, 2021; Patton, 2021; Williams et al., 2021), experience-based lessons on managing transformative adaptation processes (Vermeulen et al., 2018), climate policy integration (Plank et al., 2021), investment criteria (Kasdan et al., 2021), political economy analysis frameworks for climate governance (Price, 2021).

[END BOX 18.1 HERE]

[START BOX 18.2 HERE]

Box 18.2: Visions of Climate Resilient Development in Kenya

The Government of Kenya's (GoK) ambition is to transform Kenya into a 'newly industrializing, middle-income country providing a high-quality life to all its citizens by 2030 in a clean and secure environment' (Government of Kenya, 2008). Dryland regions in Kenya occupy 80-90 per cent of the land mass, are home to 36% of the population (Government of Kenya, 2012) and contribute about 10 per cent of Kenya's Gross Domestic Product (GDP) (Government of Kenya, 2012) which includes half of its agricultural GDP (Kabubo-Mariara, 2009). In dryland regions, pastoralism has long been the predominant form of livelihood and subsistence (Catley et al., 2013; Nyariki and Amwata, 2019). The GoK seeks to improve connectivity and communication infrastructure within the drylands to better exploit and develop livestock, agriculture, tourism, energy, and extractive sectors (Government of Kenya, 2018). It argues that the transformation of dryland regions is crucial to enhance the development outcomes for the more than 15 million people who inhabit these areas (Government of Kenya, 2016: 17) and to help the country to realize its wider national ambitions including a 10 percent year on year growth in GDP (Government of Kenya, 2012). A key element within this vision is the promotion and implementation of the Lamu Port South Sudan Ethiopia (LAPSSET) project, a 2,000km long, 100 km wide economic and development corridor extending from Mombasa to Sudan and Ethiopia (Enns, 2018). Supporters of the LAPSSET project argue that it will help achieve priorities laid out in the Vision 2030 by opening up poorly connected regions, enabling the development of pertinent economic sectors such as agriculture, livestock and energy, and supporting the attainment of a range of social goals made possible as the economy grows (Stein and Kalina, 2019).

However, the development narrative surrounding LAPSSET remains controversial in its assumptions, not least because it is being promoted in the context of a highly complex and dynamic social, economic and biophysical setting (Cervigni and Morris, 2016; Atsiaya et al., 2019; Chome, 2020; Lesutis, 2020). Some of the key trends driving contemporary and likely future change in dryland regions are changing household organization, evolving customary rules and institutions at local and community levels, and shifting cultures and aspirations (Catley et al., 2013; Washington-Ottombre and Pijanowski, 2013; Tari and Pattison, 2014; Cormack, 2016; Rao, 2019). Dryland regions are also witnessing demographic growth and change in land-use patterns linked to shifts in the composition of livestock (for example from grazers to browsers), a decrease in nomadic and increase in semi-nomadic pastoralism, and transition to more urban and sedentary livelihoods (Mganga et al., 2015; Cervigni et al., 2016; Greiner, 2016; Watson et al., 2016). At a landscape level, land is becoming more fragmented and enclosed, often associated with increases in subsistence and commercial agriculture, and the establishment of conservancies and other group or private land holdings (Reid et al., 2014; Carabine et al., 2015; Nyberg et al., 2015; Greiner, 2016; Mosley and Watson, 2016). In addition, there are political dynamics associated with Kenya Vision 2030 and decentralization, the influence of international capital, foreign investors and incorporation into global markets (Cormack, 2016; Kochore, 2016; Mosley and Watson, 2016; Enns and Bersaglio, 2020), as well as increasing militarization and conflict in the drylands (Lind, 2018). Allied to these social and political dynamics are ongoing processes of habitat modification and degradation and biophysical changes linked in part to climate variability (Galvin, 2009; Mganga et al., 2015). The interconnected nature of these drivers will intersect with LAPSSET in myriad ways. For example, the implementation of LAPSSET may accentuate some trends, such as increases in land enclosure and a shift towards more urban and sedentary livelihoods (Lesutis, 2020). Conversely, the perceived threat LAPSSET could pose to pastoral lifestyles may lead to greater visibility, solidarity and strength of pastoralist institutions (Cormack, 2016).

There is a recognized need to adapt and chose development pathways that are resilient to climate change whilst addressing key developmental challenges within dryland regions, notably, poverty, water and food insecurity, and a highly dispersed population with poor access to services (Government of Kenya, 2012; Bizikova et al., 2015; Herrero et al., 2016). The current vision for development of dryland regions comes with both opportunities and threats to achieve a more climate resilient future. For example, the growth in and exploitation of renewable energy resources, made possible through increased connectivity, brings climate mitigation gains but also risks. These risks include the uneven distribution of costs in terms of where the industry is sited compared with where benefits primarily accrue, and may exacerbate issues around water and food insecurity as strategic areas of land become harder to access (Opiyo et al., 2016; Cormack and Kurewa, 2018; Enns, 2018; Lind, 2018). Whilst LAPSSET will bring greater freedom of movement for commodities, benefitting investors, improving access to markets and urban centers, supporting trade, or ease of movement for tourists supporting economic goals, it can also result in the relocation of people and impede access to certain locations for the resident populations. Mobility is a key adaptation behavior employed in the short and long term to address issues linked with climatic variability (Opiyo et al., 2014; Muricho et al., 2019). With modelled changes in the climate suggesting decreases in income associated with agricultural staples and livestock-dependent livelihoods, development that constrains mobility of local populations could retard resilience gains (Ochieng et al., 2017; ASSAR, 2018; Enns, 2018; Nkemelang et al., 2018). The likely increase in urban populations and the growth in tourism and agriculture may lead to increases in water demand at a time when water availability could become more constrained owing to the reliance on surface water sources and the modelled increases in evapotranspiration due to rising mean temperature, more heatwave days and greater percentage of precipitation falling as storms (ASSAR, 2018; Nkemelang et al., 2018; USAID, 2018). These pressures could make it harder to meet basic health and sanitation goals for rural and poorer urban populations, issues compounded further by likely increases in child malnutrition and diarrheal deaths linked to climate change (WHO, 2016; ASSAR, 2018; Hirpa et al., 2018; Nkemelang et al., 2018; Lesutis, 2020). Development must pay adequate attention to these interconnections to ensure that costs and benefits of achieving climate mitigation and adaptation goals are distributed fairly within a population.

[END BOX 18.2. HERE]

18.2 Linking Development and Climate Action

The AR5 examined the relationship between climate and sustainable development in Chapter 13 (Olsson et al., 2014) and Chapter 20 (Denton et al., 2014) in Working Group II and Chapter 4 (Fleurbaey et al., 2014) in Working Group III. It concluded that dangerous levels of climate change would limit efforts to reduce poverty (Denton et al., 2014; Fleurbaey et al., 2014). Since the AR5, the adoption of the Paris Agreement and Agenda 2030 have demonstrated increased international consensus regarding the need to pursue climate change as a component of sustainable development. For example, climate change impacts *"undermine the ability of all countries to achieve sustainable development"* (United Nations, 2015) and can reverse or erase improvements in living conditions and decades of development (Hallegatte and Rozenberg, 2017). However, recent analysis shows that actions to meet the goals of the Paris Agreement can undermine progress toward some SDGs (*high agreement, medium evidence*) (Pearce et al., 2018b; Liu et al., 2019; Hegre et al., 2020) (18.2.5.3). Meanwhile efforts to achieve the SDGs can contribute to worsening climate change (*high agreement, medium evidence*) (Fuso Nerini et al., 2018). These findings in the literature highlight the importance of identifying clear goals and priorities for both climate action and sustainable development as well as mechanisms for capitalizing on potential synergies between them and for managing trade-offs. In assessing literature relevant to the intersection between climate action and development, we first explore the implications of different patterns of development and development trajectories followed by more focused assessment of the links between development and climate risk.

18.2.1 Implications of Current Development Trends

Understanding the interactions between climate change, climate action, and sustainable development necessitates consideration for the current development context in which different communities, nations, and regions find themselves. For example, wealthy economies of the global North will encounter different opportunities and challenges vis-à-vis climate change and sustainable development than developing economies of the global South. Moreover, all economies are already following an existing development trajectory that has implications for the type and scale of interventions associated with pursuing CRD and managing climate risk. Some nations may experience particular challenges with reducing greenhouse gas emissions due to the carbon-intensive nature of their energy systems *(very high confidence)* (18.3.1.1). Others may experience acute challenges with adaptation due to existing vulnerability associated with poverty and social inequality *(very high confidence*) (18.2.5.1). Overcoming such challenges is fundamental to the pursuit of CRD.

While demonstrable progress has been made toward the SDGs and improving human well-being, globally and in specific nations, some observed patterns of development are inconsistent with sustainable development and the principles of CRD *(very high confidence*) (van Dooren et al., 2018; Eisenmenger et al., 2020; Leal Filho et al., 2020). A significant literature, for example, links development to the loss of biodiversity and the extinction crisis (Ceballos et al., 2017; Gonçalves-Souza et al., 2020; Oke et al., 2021). Meanwhile, in human systems, indicators such as the limited convergence in income, life expectancy, and other measures of well-being between poor and wealthy countries (with notable outliers such as China) (Bangura, 2019), and the increase in income inequality and the decline in life expectancy and well-being in rich countries (Rougoor and van Marrewijk, 2015; Alvaredo et al., 2017; Goda et al., 2017; Harper et al., 2017; Goldman et al., 2018), suggest limitations of the current development paradigm to successfully deliver universal human and ecological well-being, by the 2030s or even mid-century (TWI, 2019).

18.2.2 Understanding Development in Climate Resilient Development

Development in this report is defined as efforts, both formal and informal, to improve standards of human well-being, particularly in places historically disadvantaged by colonialism and other features of early global integration. Development is not limited to the SDGs, however these represent an internationally agreed sub-set of goals. Prior IPCC reports employed development as a typological framing of the current state of a given country or population (IPCC, 2014a) (Section 1.1.4). Such framings frequently rest upon measures of economic activity, using them as proxies for the wider well-being of the population whose activity is measured. For example, the level of gross domestic product (GDP) is often equated with levels of social welfare, even though as a measure of market output it can be an inadequate metric for gauging well-being over time particularly in its environmental and social dimensions (Van den Bergh, 2007; Stiglitz et al., 2009).

The result of this broad framing linking economic growth to human well-being has been decades of policies, programs, and projects aimed at growing economies at scales from the household to regional and global. However, linking development to past and current modes of economic growth creates significant challenges for CRD, as it implies that the very processes that have contributed to current climate challenges, including economic growth and the resource use and energy regimes it relies upon, are also the pathways to improvements in human well-being. This places climate resilience and development in opposition to one another.

While there are many possible successful pathways to future development in the context of climate change, history shows that pathways positive for the vast majority of people, typically induce significant impacts and costs, especially on marginal and vulnerable people (Hickel, 2017). Frequently, considerations for social difference and equity are side-lined in these processes, for example through the assumption that a growing economy lifts opportunity for all, further marginalizing those who are the most vulnerable to climate change (Matin et al., 2018; Diffenbaugh and Burke, 2019).

The Agenda 2030 and its 17 SDGs and 169 targets seeks to 'leave no one behind' through five pillars (5Ps): People, Planet, Prosperity, Peace and Partnership (United Nations, 2015). The five pillars align with the dimensions of development that influence motion toward or away from CRD. The focus on **people** refers to inclusion rather than exclusion, and the extent to which people are empowered or disempowered to make decisions about their well-being, determine their futures and be in a position to assert their rights. This means being able to make decisions that determine whether people are on a pathway toward or away from CRD (Figures 18.1–18.3. The focus on **planet** refers to protecting the planet, ensuring a balance of ecosystems, biodiversity and human activities, and giving equal space and respect for its integrity. The focus on **prosperity** refers to equity in well-being grounded in unanimity over shared goals and resources, rather than individualism, and economic, social and technological progress grounded in stewardship and care, rather than exploitation. The focus on **partnership** refers to mutual respect embedded in solidarity that recognizes multiple worldviews and their respective knowledges, rather than singular or hierarchy of knowledge, and acknowledges inherent nature-society connections, rather than posing nature as opposites or competitors. The focus on **peace** emphasizes the need for just and equitable societies. These five pillars are interrelated but local and national contexts situate current status differently around the world. Successful achievement of Agenda 2030 is aligned with a safe climate with adequate mitigation and adaptation, and effective and inclusive systems transitions. With these conditions, a high CRD world can be attained, noting that when approached individually, the transformative potential of the SDGs is limited (Veland et al., 2021).

The need for transformational changes across sectors and scales to address the urgency and scope of action needed to enable a climate resilient future in which goals like the SDGs might be realized requires attention to the specific ways in which development action is defined and enacted (Box 18.1).

18.2.2.1 Development Perspectives

Development is about 'improvement'. However there have been different and oftentimes conflicting viewpoints on the improvement of 'what' and 'how' to improve. The diversity of positions has resulted in a multitude of metrics to track development, some more influential than others on policy. Alternative measures of development, while numerous, generally seek to nuance the connection between economic growth and human well-being. Because they maintain core notions of progress and, in some cases, economic growth seen in more mainstream models of development, they are less vehicles for transformation than continuations of thinking and action fundamentally at odds with the needs of climate resilient development. These include the Measure of Economic Welfare (Nordhaus and Tobin, 1973), the Index of Sustainable Economic Welfare (Cobb and Daly, 1989), the Genuine Progress Indicator (Escobar, 1995), the Adjusted Net Saving Index or the Genuine Savings Index (GSI), The Human Development Index (HDI), the Inequality-adjusted Human Development Index (UNDP, 2016a), the Gender Development Index, the Gender Inequality Index, and the Multidimensional Poverty Index, the Index of Sustainable Economic Welfare (ISEW) (Daly and Cobb, 1989), the Genuine Progress Indicator (GPI) (Kubiszewski et al., 2013), Gross National Happiness (GNH) (Ura and Galay, 2004), Measures of Australia's Progress (MAP) (Trewin and Hall, 2004), the OECD Better Life Index (OECD, 2019a), and the Happy Planet Index (NEF, 2016).

In terms of their historical trajectory, different perspectives on development can be broadly divided into five categories.

a) *Development as economic growth (1950s onwards)*: Equating development with economic growth was a natural outcome of the dominance of economics as the major discipline to study problems of newly independent countries in the 1950s (Escobar, 1995), measured through GDP. Environment was not a policy concern in the immediate period after decolonization. The GDP measure has withstood the test of time, in spite of being an inexact measure of human well-being, and is the widely used metric globally to track development. Recent improvements to GDP have tried to account for environmental factors (Gundimeda et al., 2007; United Nations, 2021).
b) *Development as distributional improvements (1970s onwards)*: That economic growth does not automatically result in decline in poverty and improved distribution of income became apparent in the 1970s. Welfare measures were thus promoted that involved 'redistribution with growth' (Chenery, 1974). These distributional concerns have re-emerged in the last two decades with the widening gap between the richer and poorer groups of the population (Chancel and Piketty, 2019) and also the

increased attention to 'ecological distribution conflicts' (Martinez-Alier, 2021). The political economy perspective, highlighting continued dependencies of countries in the Global South on the Global North, now evolved into political ecology highlighting environmental concerns between and within countries. Environment was not yet a policy priority, despite that the links between development and environment were becoming clearer.

c) *Development as participation (1980s onwards)*: Bottom-up responses emphasizing sustainable livelihoods and local-level development emerged in the 1980s. The movement which involved independent and uncoordinated efforts by grassroots activists, social movements and NGOs became 'mainstreamed' into development in the 1990s (Chambers, 2012). The multidimensional nature of poverty was acknowledged at the global policy level (World Bank, 2000) and there was wider acceptance of the role of non-economics social sciences as well as critical approaches in research on development and poverty (Thomas, 2008). Participatory development involved decentralization and local planning, emphasizing protection of local natural resources in addition to improving living standards.

d) *Development as expansion of human capabilities (1980s onwards)*: The human development and capabilities approach was the first formidable response to the GDP-centric view of development (Sen, 2000; Deneulin and Shahani, 2009). Studies showed that improvements in income did not necessarily improve human well-being in other dimensions such as health and education, or more broadly put, 'freedoms' (Ruggeri Laderchi et al., 2003). The capabilities idea was influential in global policy making through Human Development Reports and metrics such as Human Development Index (HDI) and Multidimensional Poverty Index (MPI). However, environmental sustainability was not a major component in this approach until much later (Alkire and Jahan, 2018). Recent improvements to HDI such as the Planetary pressures-adjusted HDI (United Nations, 2020) is a step in this direction.

e) *Development as post-growth (2010 onwards)*: The late 1980s saw a big push towards taking the environment to the center of the global policy agenda (World Commission on Environment and Development, 1987). However, progress in addressing environmental questions has been slow. As compared to Millennium Development Goals (MDGs), SDGs aim to tackle environmental concerns by explicitly tracking progress on multiple indicators. Nevertheless, the approach in these policy propositions sits largely within the economic growth framework itself. The climate change challenge and the financial crisis of 2008 led many scholars, ecological economists and environmental social scientists in particular, to argue for a post-growth world. Post-growth (Jackson, 2021), degrowth (Kallis, 2018; Hickel et al., 2021) and other environmentalist scholarship takes inspiration from critiques of development such as post-development (Escobar, 1995). The argument here is not for better metrics but for imagining and working towards systemic change in the wake of the climate crisis. The challenge however is how to account for historical differences in economic growth and living standards between Global North and Global South and to protect the interests of Global South in the spirit of 'common but differentiated responsibilities' to climate change adaptation and mitigation. As empirical studies in Global South have demonstrated (Lele et al., 2018), developing countries face multiple stressors, climate change being just one among them, and there are multiple normative concerns in developing country contexts, such as equity and justice, and not merely resilience (*very high confidence)*.

To achieve climate resilient development requires framings of development that move away from linear paradigms of development as material progress by focusing on diversity and heterogeneity, wellbeing and equality, not only in contemporary practices, but also pathways of change over time (Gibson-Graham, 2005; Gibson-Graham, 2006). Such approaches, which are fundamentally aligned with ecological and ecosystem-based environmental assessments which identified heterogeneity of approaches and actions as the most effective path to a sustainable world (Millennium Ecosystem Assessment, 2005), emphasize the importance of cultural, linguistic and religious diversity, not merely as alternative sources of information about the world, but as different paradigms of well-being (Kallis, 2018). These include indigenous and local knowledges that provide alternatives to these framings of the world (Cross-Chapter Box INDIG). This broad reframing of development includes a focus on visions such as 'buen vivir' (Cubillo-Guevara et al., 2014; Walsh, 2018; Acosta et al., 2019), ecological Swaraj (Kothari et al., 2014; Demaria and Kothari, 2017; Shiva, 2017), and Ubuntu (Dreyer, 2015; Ewuoso and Hall, 2019), among others. All are linked by relationships with nature radically different from the Western mechanistic vision, presenting not only framings of development and the environment that yield locally-appropriate climate resilient development pathways, but serve as examples of alternative ways of living in balance with nature that might inform similar thinking in other places.

18.2.2.2. Complexity of Development and Climate Action

Differing perspectives on development are in part determined by the multiple diverse priorities held by different actors and nations. Another reason is that development is not a linear process with a single goal, and active development planning requires simultaneously taking multiple processes and factors into account. This is well illustrated by growing attention to climate security. The AR5 delivered conflicting messages regarding climate change and security (Gleditsch and Nordås, 2014), yet the understanding of climate-related security risks has made substantial progress in recent years (von Uexkull and Buhaug, 2021). Although there remains a considerable research gaps in certain regions (Adams et al., 2018), a large body of qualitative and quantitative studies from different disciplines provides new insight into the relationship of climate change and security (Buhaug, 2015; De Juan, 2015; Brzoska and Fröhlich, 2016; Abrahams and Carr, 2017; Sakaguchi et al., 2017; Moran et al, 2018; Scheffran, 2020). Though not the only cause (Sakaguchi et al., 2017; Mach et al., 2019), climate change undermines human livelihoods and security, because it increases the populations vulnerabilities, grievances, and political tensions through an array of indirect – at times non-linear – pathways, thereby increasing human insecurity and the risk of violent conflict (van Baalen and Mobjörk, 2018; Koubi, 2019; von Uexkull and Buhaug, 2021). Indeed, context, as well as timing and spatial distribution matter and need to be accounted for (Abrahams, 2020).

In line with this better understanding, climate change and security have been reframed in the political space, to focus more on human security. The solutions to climate-related security risks cannot be military, but are linked to development and people's vulnerabilities in complex social and politically fragile settings (Abrahams, 2020). This has resulted in integration of climate-related security risk into institutional and national frameworks (Dellmuth et al., 2018; Scott and Ku, 2018; Aminga and Krampe, 2020), including several NDCs (Jernnäs and Linnér, 2019; Remling, 2021). One example is the UN Climate Security Mechanism – set up in 2018 between UNDP, UNEP and UN DPPA to help the UN more systematically address climate-related security risks and devise prevention and management strategies. Yet, work remains in bridging these concerns with practical responses on the ground (Busby, 2021). Especially since emerging research building on the maladaptation literature, shows that this practice cannot just mean adding adaptation and mitigation to the mix of development strategies in a given location, as this may have unintended and unanticipated effects and might even backfire completely (Dabelko et al., 2013; Magnan et al., 2020; Mirumachi et al., 2020; Schipper, 2020; Swatuk et al., 2021). In extremely underdeveloped, fragile contexts such as Afghanistan, the local-level side effects of climate adaptation and mitigation projects might result in different development outcomes and question the potential for sustainable peace (Krampe et al., 2021). Given the clearer understanding of the intertwined nature of climate change, security, and development – especially in fragile and conflict affected regions – a rethinking of how to transfer this knowledge into policy solutions is necessary for the formulation of climate resilient development.

18.2.3 Scenarios as a Method for Representing Future Development Trajectories

Sustainable development represents specific development processes and priorities that can affect climate risk. As a result, sustainable development both shapes the context in which different actors experience climate change and represents a potential opportunity, particularly by reducing climate risk by addressing vulnerability, inequity, and shifting development toward more sustainable trajectories (IPCC, 2012; Denton et al., 2014; IPCC, 2014b; IPCC, 2014a; IPCC, 2018a; IPCC, 2019b). As assessed in past IPCC special reports and assessment reports, this same literature has also illustrated how different socioeconomic conditions affect mitigation options and costs. For example, variations in future economic growth, population size and composition, technology availability and cost, energy efficiency, resource availability, demand for goods and services, and non-climate-related policies (e.g., air quality, trade) individually and collectively have all been shown to result in different climates and contexts for mitigation and adaptation.

One common approach for exploring the implications of different development trajectories is the use of scenarios of future socioeconomic conditions, such as the Shared Socioeconomic Pathways (SSPs) (O'Neill et al., 2017). The SSPs represent sets of future global societal assumptions based on different societal, technological, and economic assumptions that result in different development trajectories. Such scenarios often correspond to a small set of scenario archetypes (Harrison et al., 2019; Sitas et al., 2019; Fergnani and Song, 2020) in that they reflect core themes regarding the future of development such as sustainability versus rapid growth. Scenarios with assumptions more closely aligned with sustainability agendas (e.g., SSP1-Sustainability) commonly imply lower greenhouse gas emissions and projected climate change (see WGIII

AR6 Chapter 3), lower mitigation costs for ambitious climate goals (see WGIII AR6 Chapter 3), lower climate exposure due in large part to the size of society (see Chapter 16), and greater adaptive capacity (Roy et al., 2018) (see also Chapter 16). In contrast, scenarios with rapid global economic and fossil energy growth (e.g., SSP5-Fossil-Fueld Development) imply higher emissions and project climate change, higher mitigation costs, as well as greater social and economic capacity to adapt to climate change impacts (Hunt et al., 2012) (Table 18.1).

The SSPs incorporate various assumptions regarding population, GDP, and greenhouse gas emissions, for example, that are relevant to development and climate resilience. In addition, the SSPs have been used to explore a broad range of development outcomes for human and ecological systems (Table 18.1), including multiple studies explore futures for food systems, water resources, human health, and income inequality. Limited, top-down modelling studies have used the SSPs to explore issues such as societal resilience (Schleussner et al., 2021) or gender equity (Andrijevic et al., 2020a). Such studies indicate that different development trajectories have different implications for future development outcomes, but results vary significantly among different climate (e.g., representative concentration pathways [RCPs]) and development contexts, resulting in *limited agreement* among different SSPs (Table 18.1). Nevertheless, for some outcomes, SSPs are associated with generally similar outcomes. Over the near-term (e.g., 2030), those outcomes are strongly influenced by development inertia and path dependence, reducing differences among SSPs. Outcomes diverge later in the century, but fewer studies explore futures beyond 2050. Collectively, the scenarios reflect trade-offs associated with different development trajectories (Roy et al., 2018), with some SSPs foreshadowing outcomes that are positive in some contexts, but negative in others (Table 18.1). For example, pathways that lead to poverty reduction can have synergies with food security, water, gender, terrestrial and ocean ecosystems that support climate risk management, but also poverty alleviation projects with unintended negative consequences that increase vulnerability (e.g., Ley, 2017; Ley et al., 2020).

Table 18.1: Implications of different socioeconomic development pathways for CRD indicators. Studies presented in the above table include qualitative storylines and quantitative scenarios for two or more SSPs. Arrows and color coding reflect the positive or negative impacts on sustainability based on aggregation of results for the 2030-2050 time horizon across the identified studies. Confidence language reflects the number of studies upon which results are based (evidence) and the agreement among studies regarding the direction of change (agreement).

Development Indicator	**Relevant SDG**	**Shared Socioeconomic Pathway**					**Confidence Evidence/ Agreement**	**References**
		Sustainability (SSP1)	**Middle of the Road (SSP2)**	**Regional Rialry (SSP3)**	**Inequality (SSP4)**	**Fossil-fueled Development (SSP5)**		
Agriculture, Food, & Forestry • *Agriculture production* • *Forestry production* • *Food security* • *Hunger*	SDG 2	↗	↔	↘	↘	↘	*Low Agreement/ Robust Evidence*	(Hasegawa et al., 2015; Palazzo et al., 2017; Riahi et al., 2017; Duku et al., 2018; Chen et al., 2019; Daigneault et al., 2019; Mitter et al., 2020; Mora et al., 2020)
Health & Well-Being • *Excess mortality* • *Air quality*	SDG 3	↔	↔	↔	↘	↘	*Medium Agreement/ Robust Evidence*	(Chen et al., 2017; Mora et al., 2017; Aleluia Reis et al., 2018; Asefi-Najafabady

• *Vector-borne disease* • *Life Satisfaction*								et al., 2018; Chen et al., 2018; Harrington and Otto, 2018; Marsha et al., 2018; Sellers and Ebi, 2018; Ikeda and Managi, 2019; Rohat et al., 2019; Wang et al., 2019; Chae et al., 2020)
Water & Sanitation • *Water use* • *Sanitation access* • *Sewage discharge*	SDG 6	↗	↘	↘	↔	↔	*High Agreement/ Medium Evidence*	(Wada et al., 2016) (van Puijenbroek et al., 2014; Yao et al., 2017) (Mouratiadou et al., 2016; Graham et al., 2018)
Inequality • *Gini coefficient*	SDG 10	↗	↗	↗	↔	↗	*Medium Agreement/ Limited Evidence*	(Rao et al., 2019b; Emmerling and Tavoni, 2021; Gazzotti et al., 2021)
Ecosystems and Ecosystem Services • *Aquatic resources* • *Urban expansion* • *Habitat provision* • *Carbon sequestration* • *Biodiversity*	SDG 14 SDG 15	↘	↘	↘	↘	↘	*High Agreement/ Medium Evidence*	(Li et al., 2017; Chen et al., 2019; Li et al., 2019b; Chen et al., 2020b; Song et al., 2020b; McManamay et al., 2021; Pinnegar et al., 2021)

Legend
↓ Balance of studies suggest large increasing threat to sustainable development
↘ Balance of studies suggest moderate increasing threat to sustainable development
↔Studies suggest both threats and benefits to sustainable development
↗ Balance of studies suggest moderate increasing benefit to sustainable development
↑ Balance of studies suggest large increasing benefit to sustainable development

Table Notes:
Studies presented in the above table include qualitative storylines and quantitative scenarios for two or more SSPs. Arrows and color coding reflect the positive or negative impacts on sustainability based on aggregation of results for

the 2030-2050 time horizon across the identified studies. Confidence language reflects the number of studies upon which results are based (evidence) and the agreement among studies regarding the direction of change (agreement).

While the scenarios literature is useful for characterizing the potential climate risk implications of different global societal futures, important limitations impact their use in climate risk management planning *(very high confidence*). The first is the often highly geographically aggregated nature of the SSPs and other scenarios, which, in the absence of application of nesting or downscaling methods, often lack regional, national, or sub-national context, particularly regarding social and cultural determinants of vulnerability (van Ruijven et al., 2014). Furthermore, there is limited understanding of the cost and what is required to transform from today into each socioeconomic future, or the opportunity to shift from one pathway to another (18.3). Furthermore, the characteristics of the pathways suggest that they are not equally likely, there are relationships implied in assumptions that are uncertainties to consider (e.g., land productivity improvements are land saving), it is difficult to identify the role of different development characteristics, and policy implementation is stylized. In general, global assessments are not designed to inform local planning given that there are many local circumstances consistent with a global future and unique local development context and uncertainties to manage—demographic, economic, technological, cultural, policy.

Overall, pursuing sustainable development in the future is shown to have synergies and trade-offs in its relationships with every element of climate risk: the emissions and mitigation determining hazard, the size, location, and composition of development determining exposure; and the adaptive capacity determining vulnerability. Importantly, the scenarios literature overall has found trade-offs such that none of the global societal projections achieve all the sustainable development goals *(very high confidence*) (Roy et al., 2018) (18.2.5.3). Historical evidence supports this as well, for example, finding low-cost energy and food access historically associated with higher emissions but greater adaptive capacity, and energy efficiency innovation contributing to lower emissions and greater adaptive capacity (e.g., Blanford et al., 2012; Blanco et al., 2014; Mbow et al., 2019; USEPA, 2019). The literature suggests that trade-offs in the pursuit of sustainable development are inevitable. Managing those trade-offs, as well as capitalizing on the synergies, will be important for CRD, particularly given trade-offs have distributional implications that could contribute to inequities (18.2.5.3).

18.2.4 Climate Change Risks to Development

Over the next decade, additional climate change is expected regardless of the scale of greenhouse gas mitigation efforts (IPCC, 2021a). Across the global scenarios analyzed in the AR6, global average temperature changes relative to the reference period 1850-1900 range from 1.2˚C to 1.9˚C for the period 2021–2040 and 1.2˚C to 3.0˚C for the period 2041-2060 (WGI AR6 SPM *very likely* range). However, the feasibility of emissions pathways (particularly, RCP8.5) affect the plausibility of the associated climate projections, potentially lowering the upper end of these ranges (see WGIII AR6 Chapter 3). There is significant overlap between climate scenario ensemble ranges from different emissions scenarios through 2050, more so than through 2100 (Lee et al., 2021). There is also overlap between emissions scenario ensembles consistent with different temperature outcomes (see WGIII AR6 Chapter 3). Emissions pathway ranges represent uncertainties for policy-makers and organizations to consider and manage (Rose and Scott, 2018, 2020) regarding, among other things, economic growth and structure, available technologies, markets, behavioral dynamics, policies, and non-CO_2 climate forcings (see WGIII AR6 Chapter 3), while climate pathway ranges represent bio-physical climate system and carbon cycle uncertainties (Lee et al., 2021). For all climate projections and variables, there is significant regional heterogeneity and uncertainty in projected climate change *(very high confidence*) (IPCC, 2021a). Figure 18.4 (left panel) presents examples for average and extreme temperature precipitation change (see also 18.5 and Tables 18.4−18.5 for more regional detail). Similarly, for all emissions projections, there is significant regional, sectoral, and local heterogeneity and uncertainty regarding potential pathways for climate action (see WGIII AR6 Chapter 3 and Chapter 4). Not all uncertainties are represented in projected emissions pathway ensembles, such as policy timing and design (e.g., Rose and Scott, 2018) or climate projection ensembles.

The projected ranges for near-term and mid-term global average warming levels are estimated to result in increasing key risks and reasons for concern (Chapter 16). Chapter 16 developed aggregate "Representative Key Risks" (RKRs) as indicators for subsets of approximately one hundred sectoral and regional key risks indicators. The RKRs include risks to coastal socio-ecological systems, terrestrial and ocean ecosystems, critical physical infrastructure, networks and services, living standards and equity, human health, food security, water security, and peace and migration. The majority of these risks are directly linked to sustainable development priorities and the SDGs (Chapter 16, WGII AR6 sectoral and regional chapters; (Roy et al., 2018; IPCC, 2019d; IPCC, 2019b). Therefore, climate risks represent a potential additional challenge to pursuing sustainable development priorities, but also potential opportunities due to geographic variation in climate impacts. In addition, positive synergies have been found between sustainable development and adaptation, but trade-offs are also possible (e.g., Roy et al., 2018).

For all RKRs, additional global average warming is expected to increase risk. However, the increases vary significantly by RKR, and across the underlying key risks represented within each RKR. Geographic variation in key risk implications is only partially assessed in Chapter 16, but evidence can be drawn from the WGII individual regional chapters. Regionally, key risks are found to be potentially greatest in developing and transition economies (Chapter 16 and sectoral chapters), which is also where the least-cost emissions reductions are shown to be (see WGIII AR6 Chapter 3). See Figure 18.4 for an example of key risk geographic heterogeneity (see also 18.5 for regional detail). Chapter 16 also maps the RKRs to an updated aggregate "Reasons for Concern" (RFC) framing. Thus, increasing RKR risk implies increasing RFC associated with unique and threatened systems, extreme weather events, distribution of impacts, global aggregate impacts, and large-scale singular events.

Climate risks are found to vary with future warming levels, the development context and trajectory, as well as by the level of investment in adaptation. Together, these three dimensions define risk – with projected climate changes defining the hazard, development defining the exposure, and development and adaptation defining vulnerability. However, how these different dimensions interact and the level of scientific understanding vary significantly among different types of risk. For human systems, in general, the poor and marginalized are found to have greater vulnerability for a given hazard and exposure level. With some level of global average warming expected regardless of mitigation efforts, human and natural systems will be exposed to new conditions, but some level of adaptation should also be expected.

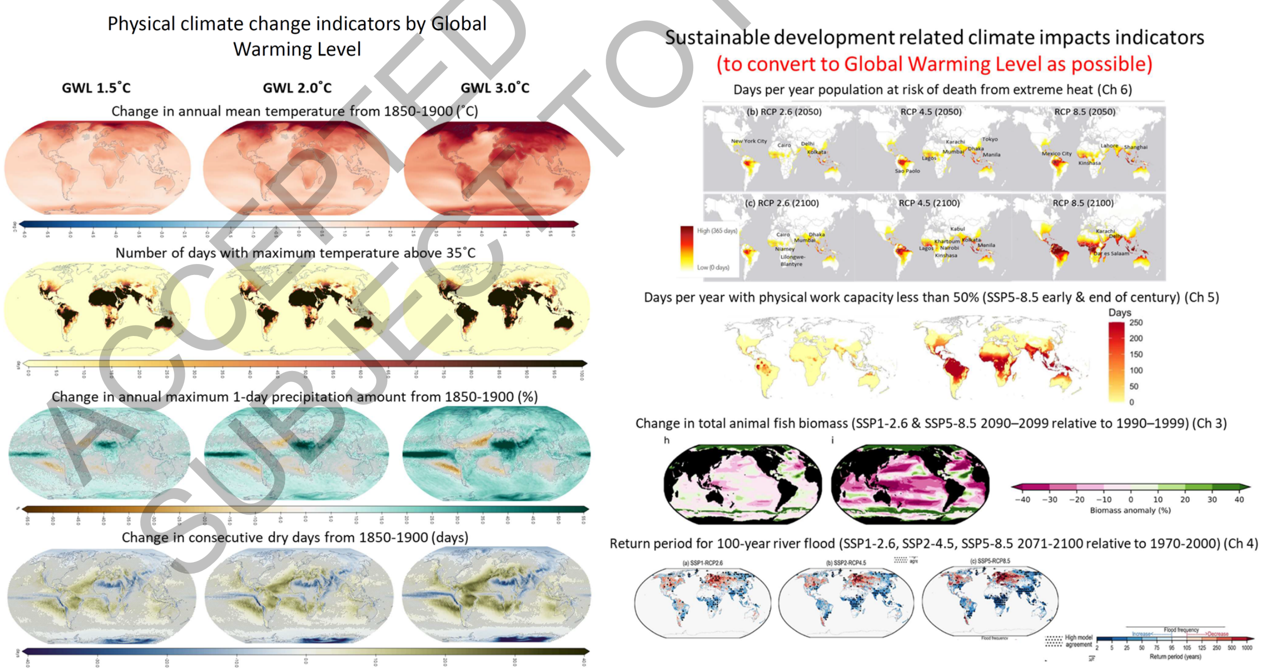

Figure 18.4: Regional projected select climate change and sustainable-development-related climate impact variables by global warming level. Sources: WGI and WGII AR6 reports.

18.2.5 Options for Managing Future Risks to Climate Resilient Development

The pursuit of CRD requires not only the implementation of individual adaptation, mitigation, and sustainable development initiatives, but also their careful coordination and integration. This section assesses the literature on CRD in the context of key climate change risks (Chapter 16); gaps in adaptation that contribute to risk; potential synergies and trade-offs among mitigation, adaptation and sustainable development; and the mechanisms for managing those trade-offs.

18.2.5.1 Adaptation

18.2.5.1.1 Adaptation and climate-resilient development

Given adaptation is recognized as a key element of addressing climate risk and CRD, the capacity for adaptation implementation is an important consideration for CRD. The AR5 noted a significant overlap between indicators of sustainable development and the determinants of adaptive capacity, and suggested that adaptation presents an opportunity to reduce stresses on development processes and the socio-ecological foundations upon which they depend (Denton et al., 2014). At the same time, it also noted that building adaptive capacity for sustainable development might require transformational changes that shift impacted systems to new patterns, dynamics, or places (Denton et al., 2014). Thus, adaptation interventions and pathways can further the achievement of development goals such as food security (Campbell et al., 2016; Douxchamps et al., 2016; Richardson et al., 2018; Bezner Kerr et al., 2019) and improvements in human health (Watts et al., 2019) including in systems where animals and humans live in close proximity *(very high confidence*) (Zinsstag et al., 2018). However, to do so requires not only the avoidance of incremental adaptation actions that extend current unsustainable practices, but also the ability to manage and overcome the barriers which arise when the limits of incremental adaptation are reached (*high agreement; medium evidence)* (Few et al., 2017; Vermeulen et al., 2018; Fedele et al., 2019).

Since AR5, the scientific community has deepened its understanding of the relationship between adaptation and sustainable development *(very high confidence*), particularly with regard to the place of resilience at the intersection of these two arenas. The literature has moved forward in its identification of specific overlaps in sustainable development indicators and determinants of adaptive capacity, how adaptation might reduce stress on development processes and their socio-ecological foundation, and how building adaptive capacity might facilitate needed transformative changes. Broadly speaking, work on these topics comes from one of two perspectives. One perspective speaks to adaptation practices that might further sustainable development outcomes, while another perspective draws on deeper understandings of the socio-ecological dynamics of the systems in which we live, and which we may have to transform in the face of climate change impacts. These two literatures are not yet well-integrated, leaving gaps in our knowledge of how best to implement adaptation in a manner that achieves sustainable development.

The literature considering adaptation and development in practice since AR5 suggests that efforts to connect adaptation to sustainable development should address proximate and systemic drivers of vulnerability (Wise et al., 2016) while remaining flexible and reversable to avoid the lock-in of undesirable or mal-adaptive trajectories (Cannon and Müller-Mahn, 2010; Wise et al., 2016). Such goals require critical reflection on processes for decision-making and learning. In the AR5, more inclusive, participatory adaptation processes were presumed to benefit development planning by including a wider set of actors in discussions of future goals (Denton et al., 2014). The post-AR5 literature expands on these critical perspectives to provide context regarding when participation is most effective. For example, (Eriksen et al., 2015) emphasize the need to build participatory adaptation processes to avoid subsuming adaptation goals to development-as-usual while (Kim et al., 2017b) argues that this practice is most effective when it is focused on development efforts and considers how climate change will challenge the goals of those efforts. Adaptation, while presenting an opportunity to foster transformations needed to address the impacts of climate change on human well-being, is also a contested process that is inherently political (*medium agreement, medium evidence*) (Eriksen et al., 2015; Mikulewicz, 2019; Nightingale Böhler, 2019; Eriksen et al., 2021b). How adaptation can challenge development and create a situation where CRD effectively becomes transformative adaptation, adaptation that generates transformation of broader aspects of development, remains unclear (*medium agreement, limited evidence*) (Few et al., 2017; Schipper et al., 2020c).

The critical literature on socio-ecological resilience, which has grown substantially since the last AR *(very high confidence*), speaks to some of these questions. Since AR5, the IPCC and the wider literature on socio-ecological resilience have shifted their use of the term to reflect not only the capacity to cope with a hazardous event or trend or disturbance, but also the ability to adapt, learn, and transform in ways that maintains a socio-ecology's essential function, identity and structure (WGII Chapter 1, Glossary). This change in usage is significant in that it shifts resilience from an emergent property of complex socio-ecological systems to a deeply human product of efforts to manage ecology, economy, and society to specific ends. This definition of resilience recognizes the need to define what is an essential identity, function, and structure for a given system, questions rooted not in ecological dynamics, but in politics, agency, difference, and power that emerge around the management of ecological dynamics (Cote and Nightingale, 2011; Brown, 2013; Cretney, 2014; Forsyth, 2018; Matin et al., 2018; Carr, 2019).

By connecting this framing of socio-ecological dynamics to the literature on the principles for adaptation efforts that meet development goals, new work has begun to identify 1) how adaptation can reduce stress on development processes, 2) how it might facilitate transformative change, and 3) where adaptation interventions might either drive system rigidity and precarity, or otherwise challenge development goals (Castells-Quintana et al., 2018; Carr, 2020). For example, Jordan (2019) draws upon these contemporary framings of resilience to highlight the ways in which coping strategies perpetuate the gendered norms and practices at the heart of women's vulnerability in Bangladesh. Forsyth (2018) draws upon this work to highlight the ways in which the theory of change processes used by development organizations tend to exclude local experiences and sources of risk, and thus foreclose the need for transformative pathways to achieve development goals. Carr (Carr, 2019; 2020) draws upon evidence from sub-Saharan Africa to develop more nuanced understandings of the ways in which different stressors and interventions either facilitate or foreclose transformative pathways, while pointing to the existence of yet poorly-understood thresholds for transformation in systems that can be identified and targeted by interventions.

18.2.5.1.2 Adaptation Gaps

Adaptation gaps are defined as "the difference between actually implemented adaptation and a societally set goal, determined largely by preferences related to tolerated climate change impacts and reflecting resource limitations and competing priorities" (UNEP, 2014; UNEP, 2018a). Adaptation deficit is a similar concept, described as an inadequate or insufficient adaptation to current conditions (see Ch 1). Adaptation gaps or deficits arise from a lack of adequate technological, financial, social, and institutional capacities to adapt effectively to climate change and extreme weather events, which are in turn linked to development *(very high confidence)* (Fankhauser and McDermott, 2014; Milman and Arsano, 2014; Chen et al., 2016; Asfaw et al., 2018) (18.2.2).

Currently, there is no consensus around approaches to assess the effectiveness of adaptation actions across contexts and therefore measure adaptation gaps at a global scale (Singh et al., 2021a). UNEP (2021) suggests that comprehensiveness, inclusiveness, implementability, integration and monitoring and evaluation can be used to assess them (see also Cross-Chapter Box FEASIB). However, limited information is available about future trends in national-level adaptation, and the development of monitoring and evaluation mechanisms. Despite the challenges of measurement associated with adaptation gaps, available evidence from smaller scales across several regions, communities, and businesses suggest that significant adaptation gaps have existed in historical contexts of climate change, while expectations of extreme heat, increasing storm intensity, and rising sea levels will create the context for the emergence of new gaps *(very high confidence)* (Hallegatte et al., 2018; UNEP, 2018a; Dellink et al., 2019; UNEP, 2021). These adaptation gaps create risks to well-being, economic growth, equity, the health of natural systems, and other societal goals. The negative impacts of these gaps can be compounded by adaptation efforts that are considered maladaptive or by development actions that are labelled as adaptation (see Chapter 16).

A higher level of adaptation finance is critical to enhance adaptation planning and implementation and reduce adaptation gaps, particularly in developing countries *(very high confidence)* (UNEP, 2021) (Cross-Chapter Box FINANCE in Chapter 17, 18.4.2.2). However, adaptation finance is not keeping pace with the rising adaptation costs in the context of increasing and accelerating climate change, as "annual adaptation costs in developing countries alone are currently estimated to be in the range of US$70 billion, with the expectation of reaching US$140–300 billion in 2030 and US$280–500 billion in 2050" (UNEP, 2021). Investment in attaining SDGs helps bridge adaptation gaps (Birkmann et al., 2021), but care needs to be taken to avoid maladaptation through mislabeling. Integration of the indigenous and local knowledge systems is anticipated to reduce existing adaptation gaps and secure livelihood transitions.

Analysis of investments by four major climate and development funds (the Global Environment Facility, the Green Climate Fund, the Adaptation Fund and the International Climate Initiative) by UNEP (2021) suggests that support for green and hybrid adaptation solutions has been increasing over the past two decades. These could be effective at reducing climate risks and bridging adaptation gaps while simultaneously bringing important additional benefits for the economy, environment, livelihoods (UNEP, 2021) (see also Cross-Chapter Box NATURAL in Chapter 2).

Lately, the evidence of adaptation activity in the health sector has been increasing (Watts et al., 2019), yet substantial adaptation gaps persist (UNEP, 2018a; UNEP, 2021), including gaps in humanitarian response to climate-related disasters (Watts et al., 2019). It is the under-investment in climate and health research in general and health adaptation in particular that has led to adaptation gaps in the health sector (Ebi et al., 2017).

Costs of implementing efficient adaptation measures and water-related infrastructure in water-deficient regions have received attention at the global and regional level to bridge the 'adaptation gap' (Hallegatte et al., 2018; UNEP, 2018a; Dellink et al., 2019; UNEP, 2021). Livelihood sustainability the drylands, which cover more than 40% of land surface area, are home to roughly 2.5 billion people, and support approximately 50% of the livestock and 45% of the food production, is threatened by a complex and interrelated range of social, economic, and environmental changes that present significant challenges to rural communities, especially women (Abu-Rabia-Queder and Morris, 2018; Gaur and Squires, 2018). Adaptation deficits in arid and semi-arid regions are of high order (see CCP 3). In order to reduce adaptation deficit in arid and semi-arid regions comprehensive and efficient adaptation interventions integrating better water management, use of non-traditional water sources, changes in reservoir operations, soil ecosystem rejuvenation, and enhanced institutional effectiveness are needed (18.5) (Makuvaro et al., 2017; Mohammed and Scholz, 2017; Morote et al., 2019). Communities facing the lack of adequate technological, financial, human, and institutional capacities to adapt effectively to current and future climate change often encounter adaptation deficits. In order to address current adaptation barriers and adaptation deficits, there is a need to promote efficient adaptation measures, coupled with inclusive and adaptive governance involving marginalized groups such as indigenous communities and women.

Although unevenly distributed urban adaptation gaps exist in all world regions (see Chapter 6). Such gaps are higher in the urban centers of the poorer nations. Chapter 6 identified the critical capacity gaps at city and community levels that are responsible for adaptation gaps are: "ability to identify social vulnerability and community strengths, and to plan in integrated ways to protect communities, alongside the ability to access innovative funding arrangements and manage finance and commercial insurance; and locally accountable decision-making with sufficient access to science, technology and local knowledge to support the application of adaptation solutions at scale".

Insufficient financial resources are the main reasons for the coastal adaptation gap particularly in the Global South (see CCP2). Engaging the private sector with a range of financial tools is crucial to address such gaps (see CCP2). An urgent and transformative action to institutionalize locally-relevant integrative adaptation pathways is crucial for closing coastal adaptation gaps. Additional efforts are in place for assessing global adaptation progress (see Cross-Chapter Box PROGRESS in Chapter 17].

18.2.5.1.3 Adaptation implementation

As discussed in Chapter 16, adaptation is a key mechanism for managing climate risks (Chapter 16), and therefore for pursuing CRD. The lower estimates in Table 18.2 are associated with higher levels of adaptation and more conducive development conditions. Furthermore, additional adaptation demand is associated with greater levels of climate change. Adaptation is a broad term referring to many different levels of response and options for natural and human systems, from individuals, specific locations, and specific technologies, to nations, markets, global dynamics, and strategies at the system level. Adaptation also includes endogenous reflexive and exogenous policy responses. Perspectives on limits to adaptation, synergies, trade-offs, and feasibility therefore depend on where the boundaries are drawn and the objective. Overall, there are a broad range of adaptation options relevant to reducing risks posed by climate change to development. However, current understanding of how such options are implemented in practice, their effectiveness across a range of possible climate futures, and their potential limits, is modest.

Past assessments have evaluated individual adaptation options in terms of economic, technological, institutional, socio-cultural, environmental/ecological, and geophysical feasibility (de Coninck et al., 2018). This analysis has been updated for AR6 (Cross-Chapter Box FEASIB). These assessments identify types of barriers that could affect an option's feasibility. Among other things, this work finds that every adaptation option evaluated had at least one feasibility dimension that represented a barrier or obstacle. The barriers also imply that there are trade-offs in these feasibility dimensions to consider. Overall, insights from this work are high-level and difficult to apply to a specific adaptation context. The feasibility and ranking of adaptation opportunities, as well as the list of opportunities themselves, for a given location will vary from location-to-location, with different criteria and weighting of criteria that reflect the relevant social priorities and differences in markets, technology options, and policies for managing risks and trade-offs. Integrated evaluation of criteria and options is needed, that accounts for the relevant geographic context and interactions between options and systems (18.5).

Sustainable development is regarded as generally consistent with climate change adaptation, helping build adaptive capacity by addressing poverty and inequalities and improving inclusion and institutions (Roy et al., 2018). Some sustainable development strategies could facilitate adaptation effectiveness by addressing wider socio-economic barriers, addressing social inequalities, and promoting livelihood security (Roy et al., 2018). With a common goal of reducing risks, sustainable development and adaptation are relatively synergistic. However, trade-offs have been found and important to consider and potentially manage. Synergies have been found between adaptation and poverty reduction, hunger reduction, clean water access, and health; while, trade-offs have also been found, particularly when adaptation strategies prioritize one development objective (e.g., food security or heat-stress risk reduction) or promote high-cost solutions with budget allocation and equity implications (Roy et al., 2018) (18.2.5.3, 18.5). There are also opportunities for managing the trade-offs, in particular distributional effects—by recognizing that there are trade-offs and considering alternatives and complementary strategies to offset the trade-offs (Section 18.2.5.3).

[START BOX 18.3 HERE]

Box 18.3: Climate Resilient Development in Small Islands

Small Islands are particularly vulnerable to climate change and many are already pursuing climate resilient development pathways that enable integrated responses (Allen et al., 2018a; Mycoo, 2018; Hay et al., 2019; Robinson et al., 2021). Countries, such as Belize, have opted for a systems-approach and are working across the SDGs to increase integration (Allen et al., 2018a). This includes rethinking disaster reconstruction mechanisms in the Caribbean and introducing more diversified and sustainable tourism economies that can better withstand external shocks such as disruptions and loss of markets from COVID-19 (Sheller, 2021). In the Seychelles, various government and tourism industry initiatives are focused on the promotion of sustainable tourism ventures that lower emissions, protect and promote biodiversity conservation (e.g. new marine protected areas with mitigation and adaptation benefits), and are climate resilient (Robinson et al., 2021). In 2016 the Seychelles signed the world's first nature-for-debt swap wherein an NGO (The Nature Conservancy) agreed to pay off Seychelles' public debt to the Paris Club (foreign creditors) in return for the Seychelles government establishing marine conservation areas (Silver and Campbell, 2018).

One key area where enhanced climate risk integration is critical is infrastructure-related decisions especially on coastal areas (World Bank, 2017). However, despite increasing awareness of climate risks and experienced impacts, decisions on for example infrastructure locations still reflect cultural preferences. For example, Hay et al. (2019) report that despite recommendations to relocate the redevelopment site of the Parliamentary Complex in Samoa away from the coast, multiple cultural and historical factors influenced the decisions to redevelop at the original site. In the Solomon Islands, however, emerging evidence suggests that adaptation efforts to enhance the resilience of infrastructure are also serving to help urban areas address problems associated with rapid urbanization and provide new opportunities for sustainable development (Robinson et al., 2021).

Energy system transitions in small islands can produce synergies with SDG implementation, and can lead to transformational outcomes. The Pacific island territory of Tokelau has demonstrated a nationwide energy transition, sourcing 100% of their energy needs from solar power (Michalena and Hills, 2018), and many other countries such as Fiji, Niue, Tuvalu, Vanuatu, Solomon Islands and Cook Islands also have 100% renewable energy targets. Benefits of small island distributed energy systems (such as solar photovoltaic (PV) systems) include less need for large, centralized infrastructure; reduced reliance on volatile fossil fuel markets; enhanced international climate negotiations power and enhanced local job markets/skills (Dornan, 2015; Cole and Banks, 2017; Weir, 2018). Additionally, renewable systems can enhance resilience to hydro-meteorological disasters (Weir and Kumar, 2020). For example, well secured ground based PV systems withstood cyclones in the Pacific island of Tonga during cyclone Gita and across the Caribbean during Hurricane Maria with power restored in days rather than weeks associated with more centralized systems (Weir and Kumar, 2020). Yet, a multitude of challenges remain. In the Pacific islands region, these include: the high up front capital investment of renewables; lack of private sector investment; limited renewable energy data for policy making; land tenure/rent costs; ongoing infrastructure maintenance skills and requirements; political turnover; failed experimentation; difficulty in obtaining and transporting replacement parts and a highly corrosive environment for equipment (Dornan, 2015; Cole and Banks, 2017; Lucas et al., 2017; Weir, 2018; Weir and Kumar, 2020). The example of Pacific energy transitions demonstrates that a nuanced and context specific analysis of synergies and trade-offs for energy transitions is required in order to lessen the impact on fragile economies and maximize benefits for remote populations.

Labor migration is increasingly recognized as a significant factor that can contribute to climate resilient development pathways for small islands. In the Pacific Islands region, labor mobility schemes are already allowing for climate change adaptation and economic development to occur in labor migrants' countries of origin (Smith and McNamara, 2015; Klepp and Herbeck, 2016; Dun et al., 2020). Dun et al. (2020) demonstrates that temporary or circular migrants from the Solomon Islands, working in Australia under its Seasonal Worker Program (similar programs operate in other developed countries), are using the money they earn to invest in adaptation and development activities back home. Similarly, labor migrants from Vanuatu, Kiribati, and Samoa contribute to development and in-situ climate change adaptation (at a household, village, and regional level) that enable discussions about more resilient futures for their countries (Barnett and McMichael, 2018; Parsons et al., 2018).

[END BOX 18.3 HERE]

[START BOX 18.4 HERE]

Box 18.4: Adaptation and the Sustainable Development Goals

The achievement of the SDGs represents near-term positive sustainability as well as indicating the quality of development processes and actions (inclusion and social justice, degrowth and alternative development models, planetary health, well-being, equity, solidary, plural knowledges and human-nature connectivity) that enable CRD in the long term (18.2.2.2, 18.2.5.3). A key question is the extent to which adaptation actions (or non-action) may contribute to (or undermine) SDG achievement, and in particular to shift the quality of development processes and engagement within the political, economic, ecological, socio-ethical and knowledge-technology arenas and hence contribute to CRDPs. Here, the relationship between adaptation and SDGs is illustrated through an examination of SDG3 good health and well-being and SDG16 peace, justice and strong institutions. These two are foundational to social equity and justice that underpin sustainability outcomes as well as enablers of CRD.

Table Box 18.4.1 (below) provides a set of examples of how adaptation actions can either contribute to or undermine SDG achievement, for SDGs 2, 3, 6, 11 and 16. In general, evidence suggests positive effects of formal interventions as well as household and community-based adaptation strategies on discrete social variables among target populations, particularly if they are shaped by the local context and needs, with real participation and leadership by target populations (Remling and Veitayaki, 2016; Buckwell et al., 2020; McNamara et al., 2020; Owen, 2020). For example, integrated adaptation approaches to the Water-Energy-Food (WEF) Nexus aiming to build resilience in those sectors can lead to increased resource use efficiency and coherent strategies for managing the complex interactions and tradeoffs among the water, energy and food SDGs (Mpandeli et al., 2018; Nhamo et al., 2020). One such approach could involve cultivating indigenous crops suited to harsh growing conditions, which would allow for agricultural expansion for food and energy without increased water withdrawals (Mpandeli et al., 2018). Overall, adaptation commitments aiming to build resilience of vulnerable populations have typically shown to contribute to SDGs focused on ending extreme poverty (SDG 1), improving food security (SDG 2), improving access to water (SDG 6), ensuring clean energy (SDG 7), tackling climate change (SDG 13) and halting land degradation and deforestation (SDG 15) (Antwi-Agyei et al., 2018).

However, evidence also suggests limitations of adaptation actions, with the objectives and actions often being too narrow to address social justice and enable CRD. As such, adaptation actions can sometimes undermine SDG achievement through exacerbating social vulnerability, inequity and uneven power relations (Antwi-Agyei et al., 2018; Atteridge and Remling, 2018; Paprocki, 2018; Mikulewicz, 2019; Satyal et al., 2020; Scoville-Simonds et al., 2020). This is due to adaptation practices often not accounting for the differentiated ways in which minority groups are especially vulnerable. For example, designs of emergency shelters should consider the fear of social stigma or abuse faced by women and girls (Pelling and Garschagen, 2019).

Such maladaptive adaptation practices can undermine SDG achievement through increasing vulnerability of marginalized groups by failing to address the underlying root causes of vulnerability and poverty that are related to political economy, power dynamics and vested interests more broadly, instead treating the symptoms as the cause (Magnan et al., 2016; Ajibade and Egge, 2019; Schipper, 2020). For example, evidence exists of flood defense measures through large scale infrastructure development leading to the violent displacement of poor communities, forcibly resettling people in areas far from their employment or pushing up land and housing costs without providing compensation (Fuso Nerini et al., 2018; Reckien et al., 2018). Moreover, sectoral approaches to adaptation that fail to acknowledge the linkages between SDGs can counter development efforts and generate further tradeoffs (Terry, 2009; Rasul and Sharma, 2016; von Stechow et al., 2016; Klinsky et al., 2017; Hallegatte et al., 2019).

The literature recommends a set of strategies for ensuring that adaptation actions are aligned with SDG achievement and do not further perpetuate poverty and inequality. These include ensuring that marginalized voices are central to adaptation decision-making, with participatory approaches that empower and compensate affected communities (Moser and Ekstrom, 2011; Broto et al., 2015; Pelling and Garschagen, 2019; Palermo and Hernandez, 2020). Gender mainstreaming and gender transformative approaches within climate policies can also help ensure gender-sensitive design of adaptation projects, with appropriate equity analyses of policy (Klinsky et al., 2017) decisions to identify the actual implications of trade-offs for vulnerable groups (Beuchelt and Badstue, 2013; Alston, 2014; Bowen et al., 2017; Fuso Nerini et al., 2018).

In addition, a substantial literature also argues for policy coherence measures that adopt whole-of-government approaches and mainstream and nationalize SDG targets within national climate policies (Nilsson et al., 2012; Le Blanc, 2015; Ari, 2017; Collste et al., 2017; Dzebo et al., 2017; Nilsson and Weitz, 2019). Institutional coordination mechanisms that aim to break down silos between different agencies and actors at the national level are suggested as beneficial for avoiding tradeoffs between adaptation actions and SDGs (Mirzabaev et al., 2015; Howlett and Saguin, 2018; Scherer et al., 2018). However, these need to be paired with an investigation of the deep-seated ideologies and vested interests that are creating goal conflicts and negatively impacting marginalized groups to begin with (Purdon, 2014; Bocquillon, 2018). Ultimately, adaptation measures need to acknowledge and address the underlying drivers that make certain groups particularly vulnerable, such as social disenfranchisement, unequal power dynamics and historical legacies of colonialism and exploitation (Magnan et al., 2016; Schipper, 2020)

Table Box 18.4.1: Examples of linkages between adaptation and the SDGs. For several key SDGs aligned with the concept of CRD, the table below identifies evidence from the literature where adaptation policies and practices contribute to achievement of the SDG as well as where they undermine achievement of the SDG.

SDG	***Evidence of adaptation contributing to SDG***	***Evidence of adaptation undermining SDG***
SDG 2: Zero Hunger	Adaptation measures implemented by smallholder farmers (e.g. adjustments in farm operations timing, on-farm diversification, soil-water management)	Some adaptation policies can increase land and food prices, negatively impacting smallholder farmers (Fuso Nerini et al., 2018; Zavaleta et al., 2018; Albizua et al., 2019)

	exhibit higher levels of productivity and technical efficiency in food production (Bai et al., 2019; Sloat et al., 2020; Khanal et al., 2021) Some climate smart agriculture measures (e.g. intercropping) can significantly increase yields and contribute to zero hunger (Lipper et al., 2014; Arslan et al., 2015; Saj et al., 2017)	Potential tradeoffs for food production through adaptation actions within the water or energy sector, if integrated approaches not taken (Howells et al., 2013; FAO, 2014; Biswas and Tortajada, 2016)
SDG 3: Good Health and Wellbeing	Increased resilience of societies and reduced vulnerability through investments in public health care and access (Marmot, 2020; Mullins and White, 2020) Adaptation measures that leverage solidarity, equity and nature connectedness contribute to physical and psychological health and wellbeing (Gambrel and Cafaro, 2009; Capaldi et al., 2015; Soga and Gaston, 2016; Woiwode, 2020)	Societal measures beyond adaptation required to address underlying causes of inequities that drive poor health and well-being, including cuts in public spending and neoliberalization and commodification of healthcare (Hall, 2020; Walsh and Dillard-Wright, 2020)
SDG 6: Clean Water and Sanitation	Integrated water resources management as an adaptation strategy (Tan and Foo, 2018; Sadoff et al., 2020)	Potential tradeoffs for water security through adaptation actions within the food or energy sector, if integrated approaches not taken (Howells et al., 2013; Rasul and Sharma, 2016; Mpandeli et al., 2018) Local, regional, or national "grabs" for water from shared resources to with poorly defined property rights (Olmstead, 2014)
SDG 11: Sustainable Cities and Communities	Vulnerability reducing adaptation measures that aim to upgrade informal settlements, create affordable housing and protect populations living in disaster prone areas (Major et al., 2018; Sanchez Rodriguez et al., 2018; Ajibade and Egge, 2019)	Need to ensure that adaptation measures understand how power dynamics and cultural norms shape urban form and communities' vulnerability and adaptive capacity (Sanchez Rodriguez et al., 2018) Risk of built infrastructure aiming to increase resilience ignoring local population needs and creating low-skilled jobs that concentrate land, capital and resources in the hands of the elite (Ajibade and Egge, 2019)
SDG 16: Peace, Justice and Strong Institutions	Potential for adaptation projects to support livelihoods incomes and resource management, and thereby reduce tensions and the risk of conflicts (Matthew, 2014; Dresse et al., 2018; Barnett, 2019)	Studies from Bangladesh, Cambodia and Nepal found that climate change adaptation-related policies and projects were an underlying cause of natural resource-based conflicts, as well as land dispossession and exclusion, entrenchment of dependency relations, elite capture, and inequity (Sovacool, 2018; Sultana et al., 2019) Adaptation projects can reinforce top-down knowledge and decision-making processes, asymmetric power relations and elite capture of adaptation resources (Nightingale, 2017; Eriksen et al., 2021b) Need for conflict-sensitive adaptation approaches that aim to 'do no harm' (Babcicky, 2013; Ide, 2020)

[END BOX 18.4 HERE]

18.2.5.2 Mitigation

Mitigation entails greenhouse gas emissions reductions, avoidance, and removal and sequestration, as well as management of other climate forcing factors (WGIII AR6). There are numerous individual and system mitigation options throughout the economy and within human and natural systems (very high confidence) (Chapter 16; 18.5). Limiting global average warming has been found to reduce climate risks (IPCC, 2018a; IPCC, 2019b), and limiting global average warming to any temperature level has also been found to be associated with broad ranges of emissions pathways representing socioeconomic, technological, market, physical uncertainties (very high confidence) (Rose and Scott, 2018; Rose and Scott, 2020). Pathways consistent with limiting warming to 2˚C and below have been found to require significant deployment of mitigation options spanning energy, land use, and societal transformation (WGIII AR6 Chapter 3 and Chapter 4; 18.3). and substantial economic, energy, land use, policy, and societal transformation (WGIII AR6 Chapter 3 and Chapter 4). Such emissions pathways would represent deviations from current trends that raise issues about their feasibility and therefore plausibility (Rose and Scott, 2018; Rose and Scott, 2020).

The technical and economic challenge of limiting warming has been found to increase non-linearly with greater ambition, fewer mitigation options, less than global cooperative policy designs, and delayed mitigation action (WGIII AR6 Chapter 3; Table 18.2). Table 18.2 provides a high-level summary of pathway characteristic ranges based on the WGIII AR6 assessment. Global pathways find large regional differences in mitigation potential, as well as the degree of regional non-linearity with greater mitigation ambition. These represent opportunities for mitigation, but how this effort and cost would be facilitated and distributed respectively is a policy question.

Table 18.2 illustrates that greater climate ambition implies more aggressive emissions reductions in each region, and earlier regional peaking of emissions (if they have not peaked to date). Near-term regional emissions increases are possible, even for 1.5°C compatible pathways, but significantly lower emissions than today are shown in all regions by 2050. Increases in total regional energy consumption, as well as fossil energy, are observed for many pathways, even in the most ambitious where energy consumption growth is potentially slower compared to less ambitious pathways. By 2050, regional fossil energy declines, but is not eliminated in any region. Regional growth in electricity use is substantial in all pathways, even the most ambitious, with the growth continuing and accelerating with time and regional dependence on electricity (share of total energy consumption) also growing significantly. The broad ranges are an indication of uncertainty and risk for regional transitions, noting that full uncertainty is likely broader than what is captured by emissions scenario databases (Rose and Scott, 2018; Rose and Scott, 2020). Among other things, pathways commonly assume idealized climate policies with immediate implementation; and model infeasibilities (i.e., models unable to solve) increase with climate ambition and pessimism about mitigation technologies (e.g., Clarke et al., 2014; Bauer et al., 2018; Rogelj et al., 2018; Muratori et al., 2020), highlighting the increasing challenge and potential for actual infeasibility with lower global warming targets. Together, Table 18.2 provides insights into the increasingly demanding system and development transitions associated with lower global warming levels, as well as some of the low-carbon transition uncertainties and risks (see also Figure 18.5).

Past assessment has evaluated representative mitigation strategies in terms of economic, technological, institutional, socio-cultural, environmental/ecological, and geophysical viability, as well as relationships to sustainable development goals (de Coninck et al., 2018). The strategies assessment analysis has been updated for AR6 (Cross-Chapter Box FEASIB). These assessments identify types of barriers that could affect an option's feasibility. Among other things, this work finds that, other than public transport and non-motorized transport, every other mitigation option evaluated had at least one feasibility dimension that represented a barrier or obstacle. The barriers also imply that there are trade-offs in these feasibility dimensions to consider. The assessment of mitigation option-sustainable development relationships identifies related literature and derives aggregate characterizations. Concerns about the potential sustainable development implications of some mitigation technologies may be motivation for precluding the use of some mitigation options. For instance, the potential food security and environmental quality implications of bioenergy have received significant attention in the literature (e.g., Smith et al., 2013). However, constraining or precluding the use of bioenergy without or with CCS could have significant implications for the cost of pursuing ambitious climate goals, and potentially the attainability of those goals (e.g., Clarke et al., 2014; Bauer et al., 2018; Rogelj et al., 2018; Muratori et al., 2020). Bioenergy is not unique in this regard. Social and sustainability concerns have also been raised about the large-scale deployment of many low-carbon technologies, e.g., REDD+, wind, solar, nuclear, fossil with CCS, and batteries. See WGIII Chapter 3 for examples of the potential implications of limiting or precluding different low-carbon technologies.

Overall, like with adaptation options, insights from this aggregate feasibility and sustainable development mapping work are high-level and difficult to apply to a specific mitigation context. The feasibility, ranking, and sustainable development implications of mitigation options, as well as the list of options themselves, for a given location will vary from location-to-location, with different criteria and weighting of criteria that reflect the relevant social priorities and differences in markets, technology options, and policies for managing risks and trade-offs. Integrated evaluation of criteria and options is needed here as well, that accounts for the relevant geographic context and interactions between options, systems, and implications.

Analyses of the potential implications of mitigation on sustainable development has various strands of literature—studies exploring general greenhouse gas mitigation feedbacks to society, assessments of mitigation implications on specific societal objectives other than climate, and literature evaluating mitigation implications specifically for sustainable development objectives (WGIII AR6 Chapter 3, Chapter 4, Chapter 17). In general, mitigation alters development opportunities by constraining the emissions future society can produce, which affects markets, resource allocation, economic structure, income distribution, consumers, and the environment (besides climate) (very high confidence). Examples of general development feedbacks from mitigation, include estimated price changes, macroeconomic costs, and low carbon energy and land system transformations (e.g., WGIII AR6 Chapter 3 and Chapter 4) (Fisher et al., 2007; Clarke et al., 2014; Popp et al., 2014; Rose et al., 2014; Weyant and Kriegler, 2014; Bauer et al., 2018; Rogelj et al., 2018). Examples of mitigation implications for specific other variables of societal interest include evaluating potential effects on air pollutant emissions, crop prices, water, and land use change (e.g., McCollum et al., 2018b; Roy et al., 2018), while the literature evaluating mitigation implications specifically for sustainable development objectives includes evaluations on energy access, food security, and income equality (e.g., Roy et al., 2018; Arneth et al., 2019; Mbow et al., 2019). Proxy indicators are frequently used to represent whether there might be implications for a sustainable development objective. For example, changes in energy prices are used as a proxy for effects on energy security (e.g., Roy et al., 2018). This is common with aggregate modelling studies, like those associated with global or regional emissions scenarios and energy systems.

Figure 18.5, derived from WGIII scenarios data, illustrates estimated relationships between mitigation and various sustainable development proxy variables for different global regions. Figure 18.5 illustrates synergies and trade-offs with mitigation, as well as regional heterogeneity, that can intensify with the level of climate ambition—synergies in air pollutants, such as black carbon, NOx, and SO2; and trade-offs in overall economic development, household consumption, food crop prices, and energy prices for electricity and natural gas. For comparison, recent IPCC assessments also observed similar synergies and trade-offs but did not directly make comparisons regarding overall development nor evaluate potential climates above 2˚C (Rogelj et al., 2018; Roy et al., 2018; Mbow et al., 2019). Regional non-linearity in the economic costs of mitigation with greater climate ambition (i.e., costs rising at an increasing rate with lower warming goals) can be significant within individual models (Rose and Scott, 2018; Rose and Scott, 2020). Figure 18.5 also illustrates transition risks in the potential for significant synergistic and trade-off implications with, for instance, potentially large regional commodity price implications and household consumption losses, as well as more significant air pollution benefits. Note that the 1.5˚C results in Figure 18.5 (and Table 18.2) are biased by model infeasibilities. Many models are unable to solve, especially with less optimistic assumptions, resulting in small sample sizes and a different representation of models compared to the 2˚C and higher results.

Results like those in Figure 18.5 illustrate that mitigation-development trade-offs and balancing of societal priorities are inevitable and need to be considered. For instance, Roy (2018) found that none of the 1.5˚C and 2˚C pathways assessed achieved all of the UN's Sustainable Develop Goals (SDGs). A newer literature is developing evaluating the potential for managing SDG trade-offs. For instance, Roy et al. (2018) discuss the potential for policies that address distributional implications, such as payments, food support, revenue recycling, as well as education, retraining, and technology outreach, subsidies, or prioritization. Recent studies have begun to estimate potential payments to offset trade-offs, such as related to food, water, and energy access (e.g., McCollum et al., 2018a). These analyses estimate investments to address specific trade-offs; however, with mitigation redirecting resources away from other productive activities, there is a need to also evaluate the aggregate economy-wide, distributional, and welfare effects, including the redistribution effects of managing sustainable development trade-offs.

There are a wide range of mitigation options and systems to consider, with assessment suggesting that a diverse portfolio is practical for pursing climate policy ambitions. However, local context will impact mitigation choices, with unique sustainable development priorities, available mitigation options, sustainable development synergies and trade-offs, and policy design and implementation possibilities.

Table 18.2: Emissions pathway regional characteristics from WGIII scenarios database for pathways associated with different global warming levels (1.5˚C, 2˚C, 3˚C, and 4˚C). Sample sizes: n = 13-15, 151-160, 66, and 34 emissions pathways for 1.5˚C, 2˚C, 3˚C, and 4˚C global warming levels respectively. Sample size ranges for the same warming level indicate that the sample size varies by variable due to differences in model reporting. Sample size varies by warming level due to model infeasibilities and differences in model reporting.

Variable	Peak global warming to 2100	Asia	Latin America	Middle East / Africa	OECD	Reforming Economies
Peak CO2 emissions year	1.5˚C	2020	2010 to 2030	2010 to 2030	2010 to 2020	2015 to 2030
	2˚C	2015 to 2030	2010 to 2035	2010 to 2030	2010 to 2020	2015 to 2030
	3˚C	2020 to 2080	2010 to 2100	2030 to 2100	2010 to 2002	2015 to 2100
	4˚C	2030 to 2100	2010 to 2100	2070 to 2100	2010 to 2100	2040 to 2100

Variable	Peak global warming to 2100	Asia		Latin America		Middle East / Africa		OECD		Reforming Economies	
		2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
Net CO2 emissions (% from 2010)	1.5˚C	-36 to 10%	-89 to -55%	-61 to 19%	-98 to 68%	-26 to 40%	-73 to -41%	-56 to -24%	-96 to -78%	-42 to 14%	-95 to -48%
	2˚C	-31 to 50%	-89 to -29%	-62 to 31%	-98 to -3%	-30 to 67%	-66 to 8%	-50 to -11%	-96 to -48%	-52 to 33%	-105 to -27%
	3˚C	10 to 50%	-5 to 69%	-58 to 16%	-132 to 50%	7 to 84%	37 to 158%	-44 to 2%	-69 to -12%	-18 to 34%	-35 to 41%
	4˚C	26 to 80%	18 to 205%	-49 to 26%	-41 to 36%	19 to 121%	78 to 225%	-30 to 8%	-55 to 5%	-13 to 36%	0 to 77%
Energy consumption growth (% from 2010)	1.5˚C	9 to 57%	1 to 87%	18 to 68%	17 to 146%	31 to 57%	51 to 91%	-16 to 8%	-43 to 3%	-21 to 10%	-41 to 21%
	2˚C	17 to 91%	16 to 130%	3 to 72%	8 to 162%	18 to 82%	42 to 145%	-16 to 10%	-36 to 25%	-15 to 37%	-33 to 29%
	3˚C	43 to 80%	70 to 129%	-9 to 74%	17 to 170%	21 to 82%	81 to 174%	-16 to 13%	-28 to 21%	-3 to 37%	-6 to 86%
	4˚C	47 to 109%	88 to 245%	20 to 65%	36 to 163%	47 to 95%	94 to 254%	-9 to 7%	-15 to 31%	-8 to 37%	-4 to 66%
Fossil energy use growth (% from 2010	1.5˚C	-23 to 39%	-51 to 7%	-12 to 47%	-66 to 30%	-4 to 40%	-38 to -2%	-47 to -9%	-86 to -40%	-38 to 5%	-85 to -17%
	2˚C	-33 to 66%	-73 to 18%	-20 to 65%	-78 to 63%	-6 to 71%	-78 to 61%	-47 to -8%	-78 to -28%	-51 to 31%	-84 to 18%
	3˚C	15 to 70%	29 to 103%	-20 to 65%	-10 to 124%	7 to 79%	31 to 158%	-37 to 3%	-61 to 3%	-24 to 32%	-26 to 43%
	4˚C	38 to 112%	39 to 264%	12 to 63%	24 to 176%	41 to 115%	103 to 301%	-26 to -5%	-45 to 10%	-14 to 29%	-5 to 66%
Electricity consumption growth (% from 2010)	1.5˚C	58 to 178%	141 to 463%	86 to 156%	275 to 430%	95 to 155%	296 to 791%	3 to 26%	32 to 103%	2 to 45%	45 to 173%
	2˚C	41 to 232%	109 to 580%	11 to 156%	68 to 489%	27 to 172%	88 to 749%	-2 to 35%	16 to 143%	-8 to 112%	18 to 187%
	3˚C	57 to 198%	126 to 472%	34 to 129%	140 to 364%	75 to 175%	260 to 600%	-3 to 39%	15 to 128%	3 to 112%	38 to 221%
	4˚C	107 to 243%	203 to 568%	49 to 127%	157 to 416%	87 to 200%	332 to 752%	10 to 33%	20 to 88%	36 to 83%	78 to 190%
Electricity share of energy consumption growth (% from 2010)	1.5˚C	-6 to 67%	12 to 166%	26 to 47%	61 to 181%	24 to 70%	100 to 258%	-2 to 21%	23 to 126%	-14 to 39%	9 to 145%
	2˚C	-10 to 69%	2 to 156%	-13 to 79%	-1 to 161%	-9 to 72%	10 to 227%	-11 to 22%	11 to 121%	-18 to 57%	-11 to 143%
	3˚C	-7 to 69%	5 to 134%	-9 to 79%	20 to 146%	-4 to 80%	42 to 149%	-12 to 33%	7 to 87%	-12 to 57%	6 to 100%
	4˚C	28 to 66%	40 to 120%	18 to 44%	46 to 95%	30 to 55%	87 to 142%	4 to 25%	13 to 69%	27 to 59%	43 to 98%

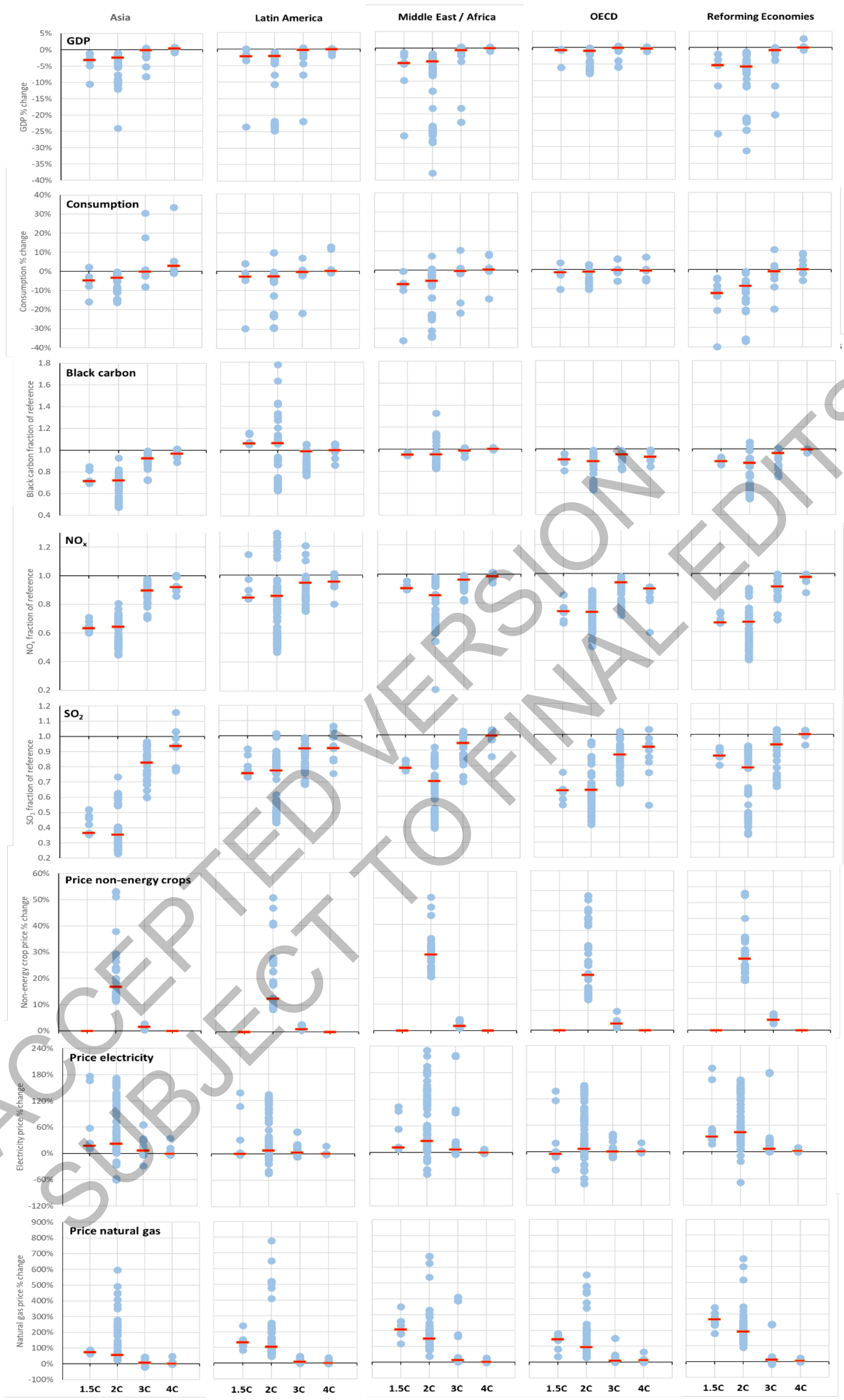

Figure 18.5: Implications of mitigation for different global mean temperature outcomes on various development and sustainable development proxy variables. Example of 2050 global implications of mitigation for different global mean temperature outcomes on various development and sustainable development proxy variables. Developed from the

scenarios associated with (Bauer et al., 2018). Data sample sizes (not shown, but to be added) vary across temperature levels and variables due to model infeasibilities and model differences in reporting.

18.2.5.3 Combining adaptation, mitigation, and sustainable development options

In practice, adaptation, mitigation, and sustainable development interventions are likely to be implemented in portfolio packages rather than as individual discrete options in isolation (*high agreement, limited evidence*). However, there is a dearth of literature estimating optimal portfolios of global adaptation and mitigation strategies. This is not surprising given the geographic-specific nature of climate impacts and adaptation and the information and computational complexity of representing that detail, as well as mitigation options and interactions. There are, however, different literatures relevant to considering potential combinations of adaptation, mitigation, and sustainable development.

At the most aggregate level, there is a long-standing literature exploring economically optimal global trade-offs between climate risks and mitigation (e.g., Manne and Richels, 1992; Nordhaus, 2017; Rose, 2017), as well as global stochastic analysis exploring global risk hedging for a small number of uncertainties (e.g., (Lemoine and Traeger, 2014). Recent work has found optimal global emissions and climate pathways to be highly sensitive to uncertainties and plausible alternative assumptions, with uncertainties throughout the causal chain from society to emissions to climate to climate damages shown to imply a wide range of different possible economically optimal pathways (Rose, 2017). Among other things, this work identifies assumptions consistent with limiting warming to different temperature levels. For example, the combination of potential annual climate damages of 15% of global GDP at 4˚C of warming and a less sensitive climate system were consistent with an economically efficient global pathway limiting warming to 2˚C. In addition, this work highlights the importance of characterizing and managing uncertainties. These types of global aggregate analyses inform discussions regarding long-run global pathways and goals but are of limited value to local near-term planning.

As discussed in Section 18.2.5.3.1, there are synergies and trade-offs mitigation, adaptation, and sustainable development. For instance, the literature on the global cost-effectiveness of mitigation pathways provides insights regarding aggregate synergies and trade-offs between mitigation and sustainable development (e.g., Figure 18.5). Furthermore, linkages between mitigation and adaptation options have been shown, such as expected changes in energy demand due to climate change interacting with energy system development and mitigation options, changes in future agricultural production practices to manage the risks of potential changes in weather patterns affecting land based emissions and mitigation strategies, or mitigation strategies placing additional demands on resources and markets which increases pressure on and costs for adaptation, or ecosystem restoration that provides carbon sequestration and natural and managed ecosystem resiliency benefits, but also could constrain mitigation and impact consumer welfare (WGIII AR6).

Non-linearities are an important consideration in evaluating risk management combinations. Non-linearities have been estimated in global and regional mitigation costs and potential economic damages from climate change (WGIII AR6 Chapter 3; (Clarke et al., 2014; Burke et al., 2015; Rose, 2017). Non-linear mitigation costs mean increasingly higher costs for each additional incremental reduction in emissions (or incremental reduction in global average temperature). Non-linear estimated economic climate damage means increasingly higher damages for each additional incremental increase in climate change (e.g., global average temperature) *(very high confidence*). Non-linearities are also suggested in estimated changes in key risks and adaptation costs (Chapter 16, WGII sector and regional chapters). However, to date, they have not been as explicitly characterized. These non-linearities imply non-linearities in climate risk management synergies and trade-offs with sustainable development. Not only do trade-offs vary by climate level, as do synergies, but they increase at an increasing rate and their relative importance can shift across climate levels *(very high confidence*). Some of this is evident in results like those shown in Figure 18.5 for mitigation (keeping in mind differences in sample sizes across temperature levels). Uncertainty about the degree of non-linearity in mitigation, climate damages, key risks, and adaptation costs creates uncertainties in the strength of the trade-offs and synergies, but also represents opportunities. For instance, additional mitigation options and more economically efficient policy designs have been shown to reduce mitigation costs and the non-linearities in mitigation costs *(very high confidence*) (WGIII AR6 Chapter 3). The same is true for adaptation options and adaptation costs.

Infeasibilities of mitigation and adaptation options (Section 18.4.2.2.1 and 18.4.2.2.2), as well as global pathways (WGIII AR6 Chapter 3), are also relevant to consideration of combinations of risk management options. Infeasibility of options implies higher costs and greater cost non-linearity due to fewer and/or more expensive options, while infeasibility of pathways bounds some of the uncertainty about the pathways relevant to decision-making and planning.

18.2.5.3.1 Trade-offs in adaptation, mitigation, and climate-resilient development

Since AR5, a growing body of literature has emerged that frames adaptation processes as endogenous socioeconomic dynamics, exogenous driving forces, and explicit decisions (Barnett et al., 2014; Maru et al., 2014; Butler et al., 2016; Kingsborough et al., 2016; Werners et al., 2018). Central to this framing is a shift away from viewing adaptation as discrete sets of options that are selected and implemented to manage risk, to thinking about adaptation as a social process that evolves over time, includes multiple decision-points, and requires dynamic adjustments in response to new information about climate risk, socioeconomic conditions, and the value of potential adaptation responses *(very high confidence)* (Haasnoot et al., 2013; Wise et al., 2016). This aligns adaptation with aspects of development thinking, including questions around the capacity and agency of different actors to effect change, the governance of adaptation, and the contingent nature of adaptation needs and effectiveness on the future evolution of society and climate change risk.

While ensuring development and adaptation produce synergies that allow for the achievement of sustainable development is challenging, modelling exercises suggest that there are pathways where synergies among the SDGs are realized *(very high confidence)* (Roy et al., 2018; Van Vuuren et al., 2019) (18.5), particularly if longer time-horizons are used. These pathways require progress on multiple social, economic, technological, institutional, and governance aspects of development including building human capacity, managing consumption behavior, decarbonization of the global economy, improving food and water security, modernizing cities and infrastructure, and innovations in science and technology (Van Vuuren et al., 2019) (18.3). In addition, Olsson et al, (Olsson et al., 2014) and Roy et al. (2018) emphasize the importance of integrating considerations for social justice and equity in the pursuit of sustainable development (Gupta and Pouw, 2017).

The significant overlaps and linkages between development and adaptation practice and a lack of conceptual clarity about adaptation pose a conundrum for scholars (e.g., Bassett and Fogelman, 2013; Webber, 2016), who raise concerns that this potentially leads to trade-offs or mislabeling (Few et al., 2017). This framing of adaptation and development can result in competition between attainment of sustainable development and policies to reduce the impacts of climate change (Ribot, 2011). Such trade-offs are illustrated by (Moyer and Bohl, 2019) who use a baseline development trajectory based on current trends to project progress on SDGs by 2030. This work concluded that only marginal gains are likely to be achieved under that pathway over the next decade (Barnes et al., 2019).

Emerging evidence also suggests that many adaptation-labelled strategies may exacerbate existing poverty and vulnerability or introduce new inequalities, for example by affecting certain disadvantaged groups more than others, even to the point of protecting the wealthy elite at the expense of the most vulnerable (Eriksen et al., 2019). Pelling et al. (2016) find that adaptation has been conceived and implemented in such a manner that most projects preserve rather than challenge the status quo. Specifically, the potential for knowledge and the goals of adaptation to be contested by different actors and stakeholders and the need to sustain progress over extended periods of time can constrain the ability to effectively implement actions that lead to sustainable development outcomes that are protected from the impacts of climate change while also delivering climate mitigation outcomes, that is, for climate resilient development (Bosomworth et al., 2017; Bloemen et al., 2019). This creates the possibility for specific adaptation actions to result in outcomes that undermine greenhouse gas mitigation and/or broader development goals (Fazey et al., 2016; Wise et al., 2016; Magnan et al., 2020). For example, a study in Bangladesh revealed how local elites and donors used adaptation projects as a lever to push vulnerable populations away from their agrarian livelihoods and into uncertain urban wage labour (Paprocki, 2018). These types of outcomes are categorised as maladaptation, interventions that increase rather than decrease vulnerability, and/or undermine or eradicate future opportunities for adaptation and development (Barnett and O'Neill, 2010; Juhola et al., 2015; Magnan et al., 2016; Antwi-Agyei et al., 2017; Schipper, 2020). This inadvertent impact on equity appears to fundamentally contradict a benevolent understanding of transformative adaptation that also champions social justice (Patterson et al., 2018), thus posing long-term maladaptation in opposition to transformative adaptation (Magnan et al., 2020).

Similarly, mitigation efforts, while reducing emissions, can also increase climate impacts vulnerability and undermine adaptation efforts. The same can be said for some poverty alleviation and sustainable development efforts that increase vulnerability for specific segments of the population. For example, in Central America, an evaluation of twelve rural renewable energy projects (either for CDM, early warning systems or rural electrification goals) found that some mitigation and poverty alleviation projects increased vulnerability to families—by excluding them, not adhering to local safety and quality codes and standards, or significantly altering community power dynamics and contributing to conflict (Ley, 2017; Ley et al., 2020).

Synergies between adaptation, mitigation and sustainable development might be promoted by prioritizing those CRD strategies most likely to generate synergies *(very high confidence)* (Roy et al., 2018; Karlsson et al., 2020). This could include focusing on poverty alleviation that improves adaptive capacity (e.g., Kaya and Chinsamy, 2016; Kuper et al., 2017; Ley, 2017; Sánchez and Izzo, 2017; Stańczuk-Gałwiaczek et al., 2018; Ley et al., 2020); renewable energy systems that improve water management and preservation of river ecological integrity (e.g., Berga, 2016; Rasul and Sharma, 2016); or internalizing positive externalities, such as subsidies for mitigation options thought to also improve water use efficiency (e.g., Roy et al., 2018). Similarly, trade-offs might be managed by prioritizing strategies such as disqualifying mitigation options thought to have negative social implications (Section 18.2.5.3.1), internalizing externalities, such as placing a fee or constraint on a negative externality or related activity (e.g., WGIII AR6 Chapter 13) (Bistline and Rose, 2018), or using complementary policies, such as transfer payments to offset negative mitigation, adaptation, or sustainable development strategy implications *(very high confidence)* (e.g., McCollum et al., 2018b). Roy et al. (2018) discusses the latter, noting, for instance, the possibility of complementary sustainable development payments to avoid global energy access, food security, and clean water trade-offs.

SR1.5 and AR6 assessments of system transitions also find opportunities for synergies and managing trade-offs (18.3; Cross-Chapter Box FEASIB). Within each system, mitigation and adaptation options are assessed for their specific benefits and the impacts they can have on one another, as well as with sustainable development. For example, within energy system transitions, the three adaptation options (power infrastructure resilience, reliability of power systems, efficient water use management) have strong synergies with mitigation. While not all mitigation options have strong synergies, the trade-offs can be managed when adaptation and sustainable development goals are also considered. Under land and other ecosystems system transitions, the main trade-off is the competition for land-use between potential alternative uses, e.g., sustainable agriculture, afforestation/reforestation, purpose-grown biomass for energy. On the other hand, assessment of urban and infrastructure system transitions finds mainly synergies between mitigation and adaptation options with trade-offs that are considered manageable, and there is growing evidence of rural landscape infrastructure benefits to adaptation.

Overall, this literature is relatively new and still developing. It highlights the importance of sets of societal priorities and policy design. However, it is not well developed in terms of joint optimization of multiple priorities, evaluating alternative mechanisms and shifts in trade-offs, and evaluating redistribution implications with transfers.

18.2.5.3.2 Risk management combinations with lower to higher climate change

The different strands of literature discussed above can be integrated to help inform thinking about combinations of approaches to risk management. Globally, low climate change projections, versus higher climate change projections, imply greater mitigation, lower climate risks, and less adaptation. This implies greater mitigation trade-offs in terms of overall economic development, food crop prices, energy prices, and overall household consumption, but lower climate risk, with sustainable development synergies like human health and lower adaptation trade-offs, and an uneven distribution of effects *(very high confidence)* (Roy et al., 2018).

Sustainable development considerations could be used to prioritize mitigation options, but as noted earlier there are trade-offs, with a potentially significant impact on the economic cost of mitigation, as well as a potential trade-off in terms of the climate outcomes that are still viable (WGIII AR6 Chapter 3). For instance, all of the 1.5˚C scenarios used in IPCC (2018a) deploy carbon dioxide removal technologies

(Rogelj et al., 2018). Without these technologies, most models cannot generate pathways that limit warming to 1.5˚C, and those that do adopt strong assumptions about global policy development and socioeconomic changes. Sustainable development might also affect the design of policies by prioritizing specific sustainable development objectives. However, there are trade-offs here as well, with costs and the distribution of costs varying with alternative policy designs. For instance, prioritizing air quality has climate co-benefits but does not ensure the lowest cost climate strategy (Arneth et al., 2009; Kandlikar et al., 2009). Similarly, prioritizing land protection has a variety of co-benefits but could increase food prices significantly, as well as the overall cost of climate mitigation (IPCC, 2019b). In this context with lower climate risk and adaptation levels and larger mitigation effort, managing mitigation trade-offs could be a sustainable development priority. Furthermore, sustainable development could also be tailored to facilitate adaptation as well as manage mitigation costs.

Globally, high climate change projections imply lower mitigation effort, higher climate risks, and greater adaptation. This implies lower mitigation trade-offs, but greater climate risk with greater demand of adaptation and potential for trade-offs in terms of competing sustainable development priorities. Sustainable development considerations could affect adaptation options. For instance, constraining options such as relocation or facilitating adaptation capacity and community resilience. Sustainable development might also be tailored to affect the climate outcome by shaping the development of emissions. In this context with greater climate risk and adaptation levels and less mitigation effort, facilitating adaptation and managing adaptation costs and trade-offs could be a sustainable development priority.

Locally, there are many qualitative similarities to the global perspective in thinking about risk management combinations across lower versus higher climates. However, there is one very important difference. Local decision makers are confronted with uncertainty about what others will do beyond their local jurisdiction. With future climate a function of the sum of global decisions, sustainable development planning needs to consider the possibility of more and less emissions reduction action globally and the potential associated climates. This implies the need for sustainable development to manage for the possibility of higher climates by further facilitating adaptation and managing adaptation trade-offs. Prioritizing sustainable development locally is also supported by the insight that the impacts on poverty depend at least as much or more on development than on the level of climate change (*very high confidence*) (Wiebe et al., 2015; Hallegatte and Rozenberg, 2017).

There is nothing in the current literature to suggest that CRD is necessarily associated with a specific climate outcome, like limiting global average warming 1.5˚C or 2˚C, or a specific pathway. Instead, there are many possible pathways for climate-resilient development (*medium agreement, limited evidence*) (e.g., David Tàbara et al., 2018; O'Brien, 2018). The current literature suggests that different mixes of adaptation and mitigation strategies, and sustainable development and trade-off management priorities, measures, and reallocations (Section 18.5.3.1), will be appropriate for different expected climates and locations (18.1.2); while trade-offs between climates will be dictated by relative non-linearities, feasibilities, shifts in priorities, and trade-off and reallocation options across future climates.

Finally, it is important to note that there is currently limited information available regarding the following: (1) local implications of 1.5˚C versus warmer futures with respect to avoided impacts and sustainable development implications and interactions and applying global conclusions to local, national, and regional settings can be misleading, (2) local context-specific synergies and trade-offs with respect to adaptation, mitigation, and sustainable development for 1.5˚C futures, and (3) standard indicators for monitoring factors related to CRD (Roy et al., 2018).

18.3 Transitions to Climate Resilient Development

A key finding emerging from the IPCC SR1.5 is the critical role that system transitions play in enabling mitigation pathways consistent with a 1.5°C or less world (IPCC, 2018a; IPCC, 2019b).Such transitions are similarly critical for the broader pursuit of climate-resilient development, and the various AR6 special reports as well as subsequent literature provide new evidence of why such transitions are needed for CRD, as well as both the opportunities for accelerating system transitions and their limitations for delivering on the goals of CRD.

18.3.1 System Transitions as a Foundation for Climate Resilient Development

In the AR6, system transitions are defined as "*the process of changing (the system in focus) from one state or condition to another in a given period of time*" (IPCC, 2018a; IPCC, 2019b). In the climate change solution space, system transitions represent an important mechanism for linking and enabling mitigation, adaptation, and sustainable development options and actions (*very high confidence*). SR1.5C identified the need for rapid and far-reaching transitions in four systems – energy, land and terrestrial ecosystems, urban and infrastructure, and industrial systems (IPCC, 2018b; IPCC, 2018a) (1.5.1 and 18.1). The SRCCL expanded on this with a focus on terrestrial systems, while SROCC added additional evidence from ocean and cryosphere systems. This section assesses the four system transitions discussed in the SR1.5C assessment in the context of CRD, while also extending the assessment to consider societal transitions as a cross-cutting, fifth transition important for climate-resilient development. Literature to support this assessment is also drawn from AR6 regional and sectoral chapters, which is synthesized later in this chapter (18.5).

As discussed in Box 18.3 (Hölscher et al., 2018), system transitions are linked to system transformation, which is defined as "*a change in the fundamental attributes of a system including altered goals or values*" (Figure 18.1) (IPCC, 2018a). In a systems context, transitions focus on 'complex adaptive systems; social, institutional and technological change in societal sub-systems', while transformations are "*large scale societal change processes … involving social-ecological interactions"* (IPCC, 2018a) (Box 18.1). Although system transitions are often identified in the literature as being necessary processes for large-scale transformations (Roggema et al., 2012; Hölscher et al., 2018), thereby making them a core enabler of CRD. Yet, they are not necessarily transformative in themselves.

18.3.1.1 Energy Systems

Recent observed changes in global energy systems include continued growth in energy demand, led by increased demand for electricity by industry and buildings *(very high confidence*) (AR6 WGIII Chapter 2). Growth in energy demand has also been driven by increased demand for industrial products, materials, building energy services, floor space, and all modes of transportation. This growth in demand, however, has been moderated by improvements in energy efficiency in industry, buildings, and transportation sectors (*very high confidence*) (AR6 WGIII Chapter 2). There is also a trend of moving away from coal towards cleaner fuels, due to lower natural gas prices and lower cost renewable technologies, and structural changes away from more energy-intensive industry.

Features of sustainable development such as enhanced energy access, energy security, reductions in air pollution, and economic growth continue to be the dominant influence on the evolution of energy systems and decision-making regarding energy investments and portfolios (*very high confidence*) (WGIII AR6 Chapter 6). To date, climate policy has been comparatively less influential in driving energy transitions globally. Yet, there are examples at the local, regional, and national level of policy incentivizing rapid changes in energy systems (*very high confidence*) (WGIII AR6 Chapter 6). Many sustainable development priorities have co-benefits in terms of climate mitigation, such as air pollution and conservation policies reducing short-lived climate forcers and sequestering carbon respectively, as well adaptation benefits, such as improved energy access and environmental quality enhancing adaptive capacity (*very high confidence*) (WGIII AR6 Chapter 6) (de Coninck et al., 2018). Alternatively, sustainable development projects can have negative climate implications with, for instance, hydroelectric projects shut down by droughts or floods resulting in greater use of bunker and fuel oil, as well as natural gas.

In addition to sustainable development priorities driving change in energy systems, observed energy system trends have implications for sustainable development (e.g., IEA et al., 2019). Observed changes in energy system size, rate of growth, composition and operations impact energy access, equity, environmental quality and wellbeing, with both synergies and trade-offs, including recent improvements in global access to affordable, reliable, and modern energy services. For instance, in some countries, such as the United States, there has been a significant shift away from coal as a fuel source for electricity generation in favor of natural gas. More recently, however, renewables have emerged as the dominant form of new electricity generation (Gielen et al., 2019). Similarly, for energy access in developing countries, renewable energy or hybrid distributed generation systems are increasingly being prioritized due to challenges associated with access, costs and environmental impacts from traditional fossil fuel-based energy technologies (Mulugetta et al., 2019).

Energy systems have been a historical driver of climate change, but are also adversely affected by climate change impacts, including short-term shocks and stressors from extreme weather as well as long-term shifts in climatic conditions (*very high confidence*). The potential for such factors is often incorporated into local system designs, operations, and response strategies. There have been changes in observed weather and extreme event hazards for the energy system, but to date many are not attributable solely to anthropogenic climate change (USGCRP, 2017; IPCC, 2021a). Nevertheless, with observed extremes shifting outside of what has been observed historically, existing design criteria and operations may not be optimal for future climate conditions and contingencies (Chapter 16; sectoral and regional chapters). Overall, there is limited historical evidence on the efficacy of adaptation responses in reducing vulnerability of energy systems (*high agreement, limited evidence*). However, sustainable development trends, such as improving incomes, reducing poverty, and improving health and education have reduced vulnerability (Chapter 16), and improvements in system resiliency to extreme weather events and more efficient water management have occurred that have synergies with adaptation and sustainable development in general.

Available literature indicates that greenhouse gas emissions reductions have been achieved in response to climate actions including financial incentives to promote renewable energy, carbon taxes and emissions trading, removal of fossil fuel subsidies, and promotion of energy efficiency standards *(very high confidence)* (WGIII AR6 Chapter 6). Such policies tend to lead to a lower carbon intensity of GDP, due to structural changes in the use of energy and the adoption of new energy technologies. However, other drivers of change are also present and thus ongoing energy transitions and their future evolution are a response to both climatic and non-climatic considerations, with broader sustainable development priorities being a significant driver of change (see WGIII AR6 Chapter 6).

18.3.1.2 Urban and infrastructure systems

Urban areas their associated infrastructure are critical targets for CRD processes. This is a function of urban areas being the dominant settlement pattern with over 55% of the global population living in cities (World Bank, 2021). As a consequence, urban areas are also the focal point for energy use, land use change, and consumption of natural resources, thereby making them responsible for an estimated 70% of global CO2 emissions (Johansson et al., 2012; Ribeiro et al., 2019). The trend toward increasing urbanization is anticipated to create both challenges and opportunities for sustainable development, as well as climate action (Güneralp et al., 2017; Li et al., 2019a).

The built environment is increasingly exposed to climate stresses and more frequent co-occurrences of climate shocks than in the past. This has the potential to increase rates of building and infrastructure degradation, increase damage from extreme weather events. The existing adaptation gaps and everyday risks within many cities, particularly those of the global South, combined with escalating risk from climate change, makes rapid progress in enhancing urban resilience a high priority for CRD (Pelling et al., 2018; Davidson et al., 2019; Lenzholzer et al., 2020). Strategic investments in disaster risk reduction, including climate-resilient green infrastructure, updated building codes, and land use planning can provide significant long-term cost savings and social benefits. Moreover, evaluating the relative merits of "fail safe" versus "safe to fail" approaches to infrastructure planning can help to identify more design principles that are more robust to the uncertainties of climate change and urbanization (Kim et al., 2017a; Kim et al., 2019).

Much of the literature on urban resilience and sustainability focuses on addressing discrete challenges for urban infrastructure sub-systems. Climate change has the potential to enhance stress on lifeline infrastructure services such as the provision of electricity, water and wastewater, communications, and transportation – sub-systems which often underdeveloped in many regions of the world (Arku and Marais, 2021; Sitas et al., 2021). For example, a warming and more variable climate can increase stress on electricity grids by reducing transmission efficiency, increasing cooling demand requirements, and by increasing exposure to climate shocks such as heat waves, floods, and storms (Bartos and Chester, 2015; Auffhammer et al., 2017; Perera et al., 2020). Accordingly a significant focus on the energy transition is on achieving the dual goals of reducing the carbon footprint of energy while also increasing resilience of energy supply to current and future threats.

For example, renewable energy generation and storage technologies that modular and distributed and provide enhanced resilience to shocks and stresses from climate change (Venema and Temmer, 2017a).

Similarly, building and maintaining urban water systems that are resilient to climate shocks requires significant changes in water demand, infrastructure, and management. Enhancing redundancy in water supply and the flexibility to shift between surface and groundwater options aids adaptation. Decentralized water supply and sanitation options are now feasible and can provide greater resilience than most centralized systems (Parry, 2017), provided they have adequate supply (Leigh and Lee, 2019; Rabaey et al., 2020). Water conservation and green infrastructure options for stormwater management are proven approaches for reducing climate risks (Venema and Temmer, 2017b), with adaptation and mitigation co-benefits. Water demand management and rainwater harvesting contribute to climate change mitigation and increase adaptive capacity by increasing resilience to climate change impacts such as drought and flooding (Paton et al., 2014; Berry et al., 2015). In addition, they can contribute to restoring urban ecosystems that offer multiple ecosystem services to citizens (Berry et al., 2015) (see WGIII AR6 Chapter 8). The context-appropriate development of green spaces, protecting ecosystem services and developing nature-based solutions, can increase the set of available urban adaptation options (IPCC, 2018b), while creating opportunities for more complex and dynamic approaches to urban water management (Franco-Torres et al., 2020). For example, the Netherlands' 'Room for the River' policy focuses on ont only achieving higher flood resilience, but also improving the quality of riverine areas for human and ecological wellbeing (Busscher et al., 2019).

An overarching focus of urban sustainability is the reversal of long-standing trends of ecosystem fragmentation and degradation that have resulted in growing separation between human and natural systems within urban environments (IPBES, 2019) (see WGIII AR6 Chapter 8). Urban ecosystems and the integration of nature-based solutions and green infrastructure into urban areas can yield benefits that facilitate achievement of the SDGs. There has been growing recognition of urban ecosystems as social, cultural, and economic assets that can support economic development while also enhancing resilience to extreme weather events and improving air and water quality (Shaneyfelt et al., 2017; Matos et al., 2019). Investing in urban ecosystems and green infrastructure can provide lower-cost solutions to multiple urban development challenges when compared to traditional infrastructure systems (Terton, 2017). Relatedly, agriculture, while largely a rural system, is increasingly expanding within urban areas. Urban agriculture enables citizens to fulfil some of their food needs, improving urban resilience to food shortages, enhancing biodiversity, and increasing coping capacity during disasters (Demuzere et al., 2014; Clucas et al., 2018) (see WGIII AR6 Chapter 8). Strengthening urban agroecosystems therefore increases resilience to supply shocks from climate change impacts and can contribute to community cohesion (Temmer, 2017a).

Overall, the discourse in the literature regarding the future of cities emphasizes the importance of viewing cities as more than just their physical infrastructure that can be made more resilient through engineering solutions (Davidson et al., 2019). Rather, urban areas are increasingly conceptualized as complex socioecological or sociotechnical systems (*very high confidence*) (Patorniti et al., 2017; Patorniti et al., 2018; Visvizi et al., 2018; Savaget et al., 2019). Such frameworks integrate physical, cyber, social, and ecological elements of cities in pursuit of resilience and sustainability transitions, and they recognize the role of governance and engagement processes as being central to system change (Temmer, 2017b). Nevertheless, some authors have cautioned that urban transitions will be associated with synergies as well as trade-offs with respect to sustainable development (*very high confidence*) (Maes et al., 2019; Sharifi, 2020).

[START BOX 18.5 HERE]

Box 18.5: The Implications of the Belt and Road Initiative (BRI) for Climate Resilient Development

In 2013, Chinese President Xi Jinping announced plans for a grand transcontinental infrastructure initiative. China would work with partner countries under two programs termed the Silk Road Economic Belt and the 21st Century Maritime Silk Road. Together, these have come to be known as the Belt and Road Initiative (BRI). Set to encompass 4.4 billion people and a cumulative GDP of around $21 trillion, the BRI has been implemented in over 120 countries with wide infrastructure funding gaps, as exemplified by the China-Myanmar Gas Pipeline, Gwadar Port in Pakistan, Trans-Mongolian Railway, China Belarus Industrial Park, and urban rehabilitation in Ethiopia. Its stated objectives even extend beyond infrastructure connectivity to include trade promotion, financial integration, policy coordination and cultural dialogue. Having been written into the Communist Party's constitution in 2017, the BRI will be China's flagship international development strategy for years to come.

The 126 countries participating in the BRI account for 23% of global GDP, but also 28% of global carbon emissions (PBCSF, 2019). By 2050, even based on an optimistic scenario, the total carbon emission by these countries will be 17% higher than what would be allowed under a 2°C carbon budget (Duan et al., 2018). The BRI covers regions with high reserve of carbon-based fuels and could have significant impact on global energy consumption and carbon emission patterns. For example, according to the EIA statistics, the proven reserves of oil, natural gas, and coal in nations under the BRI make up 58.8%, 79.9%, and 54.0% of the world's total (China Meteorological Administration, 2019).

Meanwhile, countries along the BRI are highly vulnerable to the impact of climate change, spanning highly diverse climate zones with fragile ecological conditions. Currently, many of the regions have a low level of infrastructure development and high population densities (The People's Republic of China, 2017). Changes in temperature, precipitation, vegetation and hydrological conditions could in turn pose threats to the development and operation of infrastructure projects in these regions. Given the scope and scale of the BRI, a key question is whether it will incentivize continued exploitation of available fossil fuel resources or provide the innovation and economic development needed to transition participating nations to more resilient and less carbon-intensive economies.

BRI and its commitment to climate resilient development (CRD)

Recognizing these feedbacks between the BRI and climate change, the Chinese government, included climate change in developing the key guiding documents on BRI development in 2015. These include "*taking into consideration the impact of climate change, strengthening exchange and cooperation with countries along the Belt and Road, leveraging the support and guarantee function of Chinese meteorological departments in promoting the BRI*" (NDRC, 2015). The second BRI Forum held in 2019 reiterated the importance of green development "*as the foundation of the BRI*" and promoted green infrastructure development and green investment, in addition to plans for increasing capacity in response to climate change, promoting low-carbon infrastructure, energy source, climate-related disaster alarm system, climate finance integration, as well as low-carbon technology development.

The Chinese Meteorological Administration, the governmental agency responsible for climate change related issues, responded to BRI official guidelines by establishing BRI integrated meteorological service system and proposed meteorological development plan 2017-2025 (China Meteorological Administration, 2019), which includes policy coordination on climate change, promoting intergovernmental cooperation, completing BRI disaster prevention and relief mechanisms, strengthening climate change support capacity, enhancing prediction and evaluation capacity related with climate change (China Meteorological Administration, 2019). China has established South-South cooperation in support of other countries to mitigate climate change. Efforts have been made to promote joint research with countries along the BRI on regional climate change, climate change prediction, and develop products in response to climate conditions in different regions.

The China Clean Development Mechanism Fund (CCDMF) is a national climate fund that supports low carbon growth and climate resilience in China (UNFCCC, 2017). More than USD 81 million in grants committed to support over 200 projects. A combination of funding enterprises, mobilizing market capital and achieving verified emission reduction effects contributes to a direct reduction of over seven million tons of CO2 equivalent. Government representatives from Brazil, Vietnam, and Cambodia have already visited CCDMF to learn more about this type of climate financing.

Trade-offs between BRI and CRD

Despite the implementation of such financing mechanisms for low-carbon development, their net effect is not necessarily sufficient to offset the carbon footprint generated by overseas fossil fuel projects funded or financed by China. As such, BRI stakeholders must navigate a number of trade-offs among different objectives of the initiative.

For the Chinese government and state-owned enterprises, an immediate trade-off is that between the short-term profits gained through carbon-intensive infrastructure investments overseas and long-term sustainable development with the introduction of low-carbon technology in infrastructure development. On one hand, the energy solutions that China proposes tend to involve carbon-intensive infrastructures such as coal factories, which increases carbon emissions of these countries. But at the same time, China also provides climate finance for these countries in support of renewable energy projects such as hydropower projects and solar panel production facilities.

For the governments and people hosting BRI projects, the tradeoff is between short-term economic prosperity and long-term sustainable development. Infrastructure development driven by carbon-intensive technologies are cheaper and more consistent for developing countries (for example, electricity generated through coal-based power plants is more consistent than that generated through hydropower stations), which is conducive to more rapid industrialization of these countries, generating immediate urbanization and economic prosperity. Yet the industrialization process would exacerbate carbon emission and accelerate the climate change process, with long-term impact on food security, livelihood, migration, water demand, disease control, posing potential hazards to sustainable development in these regions.

Winners and losers in incorporating CRD into BRI development

An emphasis on CRD within the BRI could create a number of opportunities for sustainable development. For example, adherence to CRD principles of low-carbon development would incentive growth of renewable energy, clean technologies, thereby growing the global market for such goods and services. This could have significant benefits for developing nations of the BRI in terms of enabling sustainability transitions that might otherwise not be feasible. However, a CRD orientation of the BRI would also have consequences for fossil fuel and carbon-intensive industries. This could affect both private and state-owned enterprises in BRI nations resulting in stranded assets, loss of some forms of employment.

[END BOX 18.5 HERE]

18.3.1.3 Land, Oceans, and Ecosystems

Land, oceans, and terrestrial ecosystems are in transition globally, with anthropogenic factors including climate change being a major driving force *(very high confidence)* (IPBES, 2019) (Box 6). Seventy-five per cent of the land surface has been significantly altered, 66 percent of the ocean area is experiencing increasing cumulative impacts, and over 85 percent of wetland areas have been lost (IPBES, 2019). Since 1970, only four out of eighteen recognized ecosystem services assessed have improved in their functioning: agricultural production, fish harvest, bioenergy production and material harvests. The other 14 ecosystem services have declined (IPBES, 2019), raising concerns about the capacity of ecosystems and their services to support sustainable and climate-resilient development.

Given the pressures on land, oceans, and ecosystems, enhancing resilience to climate change and other pressures of human development is a core priority of transition in these systems. Yet, there are a few recorded initiatives that provide evidence of successful improvement in ecosystem resilience (*high agreement, limited evidence*). Similarly, although there is significant evidence that a broad range of adaptation initiatives have been pursued across global regions and sectors, including a rapid expansion of nature- or ecosystem-based solutions (Mainali et al., 2020), there is limited evidence of how these planned climate adaptation efforts have contributed to enhanced ecosystem resilience. Additional research is necessary to evaluate these efforts in terms of their performance and also to identify mechanisms for scaling them up in different contexts. As an example, Paik (Paik et al., 2020) record the increased diffusion of salt tolerant rice varieties in the Mekong River Delta, which is at risk of sea-level rise and an associated saline intrusion. This is a low-cost adaption to saline ingress, that increases food productivity and reduces the risk of outmigration for this vulnerable agricultural region.

Evidence of the interactions between ecosystems and resilience come from a range of sources including both regional and sectoral examples (Box 18.2; Tables 18.7–18.8. For example, regional examples suggest that the use of land to produce biofuels could increase the resilience of production systems and address mitigation needs (Box 2.2). Nevertheless, the potential of BECCS to induce maladaptation needs deeper analysis (Hoegh-Guldberg et al., 2019). Climate Smart Forestry (CSF) in Europe provides an example of the use of sustainable forest management to unlock the EU's forest sector potential (Nabuurs et al., 2017). This is in response to diverse climate impacts ranging from pressure on spruce stocks in Norway and the Baltics, on regional biodiversity in the Mediterranean region, and the opportunity to use afforestation and reforestation to store carbon in forests (Nabuurs et al., 2019). CSF considers the full value chain from forest to wood products and energy and uses a wide range of measures to provide positive incentives to firmly integrate climate objectives into the forestry sector. CSF has three main objectives; (i) reducing and/or removing greenhouse gas emissions; (ii) adapting and building forest resilience to climate change; and (iii) sustainably increasing forest productivity and incomes (Verkerk et al., 2020).

Other solutions focus on specific subsectors. Mutually supportive climate and land policies have the potential to save resources, amplify social resilience, support ecological restoration, and foster engagement and collaboration between multiple stakeholders. (IPCC, 2019f, C.1). Land-based solutions can combat desertification in specific contexts: water harvesting and micro-irrigation, restoring degraded lands using drought-resilient ecologically appropriate plants, agroforestry, and other agroecological and ecosystem-based adaptation practices (IPCC, 2019f, B.4.1). Reducing dust and sand storms and sand dune movement can lessen the negative effects of wind erosion and improve air quality and health. Depending on water availability and soil conditions, afforestation, tree planting and ecosystem restoration programs, using native and other climate resilient tree species with low water needs, can reduce sand storms, avert wind erosion, and contribute to carbon sinks, while improving micro-climates, soil nutrients and water retention (IPCC, 2019f, B.4.2).

Coastal blue carbon ecosystems, such as mangroves, salt marshes and seagrasses, can help reduce the risks and impacts of climate change, with multiple co-benefits. Over 150 countries contain at least one of these coastal blue carbon ecosystems and over 70 contain all three. Successful implementation of measures of carbon storage in coastal ecosystems could assist several countries in achieving a balance between emissions and removal of greenhouse gases. Carbon storage in marine habitats can be up to 1,000 tC ha–1, higher than most terrestrial ecosystems. Conservation of these habitats would also sustain a wide range of ecosystem services, assist with climate adaptation by improving critical habitats for biodiversity, enhancing local fishery production, and protect coastal communities from SLR and storm events (IPCC, 2019b). Ecosystem-based adaptation is a cost-effective coastal protection tool that can have many co-benefits, including supporting livelihoods, contributing to carbon sequestration and the provision of a range of other valuable ecosystem services (IPCC, 2019b).

Diversification of food systems is another component of land, ocean, and ecosystem transitions that are consistent with CRD. Balanced diets, featuring plant-based foods, such as those based on coarse grains, legumes, fruits and vegetables, nuts and seeds, and animal-sourced food produced in resilient, sustainable and low-GHG emission manner, are major opportunities for adaptation and mitigation and improving human health. By 2050, dietary changes could free several million sq. km of land and provide a mitigation potential of 0.7 to 8.0 GtCO2eq yr-1, relative to business-as-usual projections.

For coastal systems, many frameworks for climate resilience and adaptation have been developed since the AR5 (Hoegh-Guldberg et al., 2014; Settele et al., 2014) with substantial variations in approach between and within countries, and across development status. Few studies have assessed the success of implementing these frameworks due to the time-lag between implementation, monitoring, evaluation and reporting (IPCC, 2019g). As an example, the Nature-Based Climate Solutions for Oceans initiative has the potential to: restore, protect and manage coastal and marine ecosystems, adapt to climate change, improve coastal resilience, and enhance their ability to sequester and store carbon (Hoegh-Guldberg et al., 2019).

Polar regions will be profoundly different in the future. The degree and nature of that difference will depend strongly on the rate and magnitude of global climate change, which will influence adaptation responses regionally and worldwide. Future climate-induced changes in the polar oceans, sea ice, snow and permafrost will drive habitat and biome shifts, with associated changes in the ranges and abundance of ecologically important species (IPCC, 2019g). Innovative tools and practices in polar resource management and planning show strong potential in improving society's capacity to respond to climate change. Networks of protected areas, participatory scenario analysis, decision support systems, community-based ecological monitoring that draws on local and indigenous knowledge and self-assessments of community resilience contribute to strategic plans for sustaining biodiversity and limit risk to human livelihoods and wellbeing. Experimenting, assessing, and continually refining practices while strengthening links with decision making has the potential to ready society for the expected and unexpected impacts of climate change (IPCC, 2019g).

[START BOX 18.6 HERE]

Box 18.6: The Role of Ecosystems in Climate-Resilient Development

Ecosystems and their services closely relate to CRD. Climate change has impacted ecosystems across a range of scales, and those impacts have been exacerbated by other ecological impacts associated with human activities. Ecosystem based adaptation strategies have been developed and is crucial to CRD. However, knowledge and evidence still missing, and cultural services—in contrast to provision and regulation services as main benefits and supporting services as co-benefits—are less well addressed in the literature.

Ecosystems play a key role in CRD

A key element of CRD is ensuring that actions taken to mitigate climate change do not compromise adaptation, biodiversity, and human needs. Maintaining ecosystem health, linked to planetary health, is an integral part of the goals of CRD. The 2005 Millennium Ecosystem Assessment defined ecosystem services as "*the benefits people obtain from ecosystems*", and categorized the services in to provisioning, regulating, supporting, and cultural services (Millennium Ecosystem Assessment, 2005; IPBES, 2019). The 2019 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) broadened the definition to "*the contributions, both positive and negative, of living nature to the quality of life for people*", and developed a classification of 18 categories (IPBES, 2019).

Table Box 18.6.1 demonstrates how ecosystem services connect to sustainable development goals (SDGs) and CRD. MEA's provisioning service generally connects to the IPBES' material services, mostly contributing to the SDG cluster associated with nature's contribution to people (NCP) (Millennium Ecosystem Assessment, 2005; IPBES, 2019) and to "**D**evelopment" in CRD. MEA's regulating and supporting services connect to IPBES' non-material services, contributing to SDG clusters of Nature and Driver of change in nature and NCP and to "**R**esilience" in CRD. MEA's cultural services connect to IPBES' non-material services, contributing to SDG clusters of good quality of lift (GQL) and to **E**nabling conditions for CRD.

Table Box 18.6.1: Ecosystem services (based on the Millennium Ecosystem Assessment, MEA, and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, IPBES, classifications) and their connections to sustainable development goals (SGCs) and climate resilient development (CRD) (Millennium Ecosystem Assessment, 2005; IPBES, 2019).

Ecosystem services		SDGs	CRD
MEA	**IPBES**		
Provisioning services	11 Energy 12 Food and feed 13 Materials and assistance 14 Medicinal, biochemical, and genetic resources	1 No poverty 2 Zero hunger 3 Good health and well-being 11 Sustainable cities communities 7 Affordable clean energy 8 Decent work and economic growth 9 Industry, innovation, and infrastructure 12 Responsible consumption and production	**D**evelopment
Regulating services	3 Regulation of air quality 4 Regulation of climate 5 Regulation of ocean acidification 6 Regulation of freshwater quantity, location, and timing 7 Regulation of freshwater and coastal water quality	6 Clean water and sanitation 13 Climate action	**C**limate adaptation and mitigation

	9 Regulation of hazards and extreme events 10 Regulation of organisms detrimental to humans		
Supporting services	1 Habitat creation and maintenance 2 Pollination and dispersal of seeds 8 Formation, protection, and decontamination of soils and sediments 18 Maintenance of options	14 Life below water 15 Life on land	
Cultural services	15 Learning and inspiration 16 Physical and psychological experiences 17 Supporting identities	4 Quality education 5 Gender equality 10 Reduce inequality 16 Peace, justice, and strong institutions 17 Partnerships for the goals	**Enabling Conditions**

Climate change impacts on ecosystems and their services

Climate change connects to ecosystem services through two links: climate change and its influence on ecosystems as well as its influence on services (Chapter 2.2). The key climatic drivers are changes in temperature, precipitation, and extreme events, which are unprecedented over millennia and highly variable by regions (Chapter 2.3, 3.2; Cross-Chapter Box EXTREMES in Chapter 2). These climatic drivers influence physical and chemical conditions of the environment, and worsen the impacts of non-climate anthropogenic drivers including eutrophication, hypoxia, sedimentation (Chapter 3.4). Such changes have led to changes in terrestrial, freshwater, oceanic and coastal ecosystems at all different levels, from species shifts and extinctions, to biome migration, and to ecosystem structure and processes changes (Chapter 2.4, 2.5, 3.4, Cross-Chapter Box MOVING PLATE in Chapter 5). Changes in ecosystems leads to changes in ecosystem services including food and limber prevision, air and water quality regulation, biodiversity and habitat conservation, and cultural and mental support (Chapter 2.4, 3.5). Table Box 18.6.2 presents examples of climate change's impact on ecosystems and their services from other chapters in the WGII report. The degradation of ecosystem services is felt disproportionately by people who are already vulnerable due to historical and systemic injustices, including women and children in low-income households, Indigenous or other minority groups, small-scale producers and fishing communities, and low-income countries (Chapter 3.5, 4.3, 5.13).

Table Box 18.6.2: Examples of key risks to ecosystems from climate change and their connections to ecosystem services (ES) in the WGII report and cross-chapter papers (CCPs). (See Table 1 for the description of the categories of ES)

Climate factors	Key risk	ES			
		P	R	S	C
***Terrestrial and freshwater ecosystems* (Chapter 2, 4, 5; CCP 1; CCP 7; CCP 3; CCP 5)**					
- Increase in average and extreme temperatures - Changes in precipitation amount and timing - Increase in aridity - Increase in frequency and severity of drought - Increased atmospheric CO_2	Species extinction and range shifts	X		X	X
	Ecosystem structure and process change	X	X		
	Ecosystem carbon loss	X	X		
	Wildfire		X	X	
	Water cycle & scarcity	X	X		
***Ocean and coastal* (Chapter 3; CCP 1; CCP 6)**					
- Ocean warming - Marine heatwaves - Ocean acidification - Loss of oxygen - Sea level rise - Increased atmospheric CO_2 - Extreme events	Species extinction and range shifts	X		X	X
	Ecosystem structure and process change	X	X		
	Habitat loss	X		X	
	Ocean carbon sink less effective		X		
	Erosion and land loss	X	X		
***Food, Fiber, and other Ecosystem Products* (Chapter 5)**					
- Global warming	Species distribution	X			

- Water stress - Extreme events - Ocean acidification - Salt intrusion	Timing of key biological events change	X			
	Corp productivity and quality decrease	X			
	Diseases and insect	X			

Adaptation practices and enabling conditions for CRD

Ecosystem protection and restoration, ecosystem-based adaptation (EbA), and nature-based solution (NbS) can lower climate risk to people and achieve multiple benefits including food and material provision, climate mitigation, and social benefits (Chapter 2.6, 3.6, 4.6, 5.13,6.3, 8.6). Table Box 18.6.3 presents some examples of ecosystem adaptation practices reported in WGII sectoral and regional chapters and CCPs, as well as their co-benefits, potential for maladaptation, and enabling conditions. Many of the strategies focus on integrated systems (managing for multiple objectives and trade-offs) as well as the fair use of resources. However, there is limited evidence of the extent to which adaptation is taking place and virtually no evaluation of the effectiveness of adaptation in the scientific literature (Chapter 2.6, 3.5). Enabling conditions for the successful implementation ecosystem-based practice include regional and community-based based approaches, multistakeholder and multi-level governance approaches, Integration of Local Knowledge and Indigenous Knowledge, finance, and social equity (Chapter 2.6, 3.6).

Table Box 18.6.3: Examples of adaptation practices and their connections to ecosystem services (ES) and climate resilient development pathways (CRDP) in the WGII sectoral and regional chapters and cross-chapter papers (CCPs). (See Table 1 for the description of the categories of ES and CRDP)

Adaptation practices (and - *examples*)	Main benefit (and & co-benefit; - trade off; + enabling conditions; X barrier and potential maladaptation)	ES			
		P	R	S	C
Agroforestry (Table 2.7; Table 5.ES; Chapter 5.10.4; Chapter 5.12.5.2; Box 5.10; Table 16.2) - *Climate Adaptation and Maladaptation in Cocoa and Coffee Production* (Box 5.7)	Food provision **&** Fuel (wood) provision, carbon sequestration, biodiversity and ecosystem conservation, diversification and improved economic incomes, water and soil conservation, and aesthetics + Secure tenure arrangements, supporting Indigenous knowledge, inclusive networks and socio-cultural values, access to information and management skill **X** Higher water demand; disruption of hydrology; loss of native biodiversity; reduced resilience of certain plants; degraded soil and water quality; improper and increased use of agrochemicals, pesticides, and fertilizers	***	**		**
Forest maintenance and restoration (Box 2.2; Table 16.2; Table Cross-Chapter Box NATURAL.1 in Chapter 2) - *Protected area planning in Thailand* (Chapter 2.6.5.3) - *Conserving Joshua trees in* the *Joshua National Park* (Chapter 2.6.5.6) - *Addressing Vulnerability of Peat Swamp Forests in South East Asia* (Chapter 2.6.5.10) - *Reduce emissions from deforestation and forest degradation (REDD+)* (Chapter 5.6.3.3; Table 16.2)	Ecosystem conservation **&** Food provision, fuel provision, job creation, carbon sequestration, biodiversity conservation, air quality regulation, water and soil conservation, vector-borne disease control, improved mental health, cultural benefits, natural resources relative conflict prevention + Cooperation of indigenous peoples and other local communities **X** Planting large scale non-native monocultures leads to loss of biodiversity and poor climate change resilience, increased vulnerability to landslide, increased sensitivity of new tree species, reduced resilience of certain plants, high water demand, trees planted damaged buildings during heavy storms, lack of carbon rights in national legislations	**	**	***	**
Traditional practices/indigenous knowledge and local knowledge (IKLK) (Table 2.7; Chapter 5.6.3; Chapter 5.14.2.2; Table 16.2) - *Crop and livestock farmers on observed changes in climate in the Sahel* (Box 5.6)	Food and material provision **&** Carbon sequestration + Partnerships between key stakeholders such as researchers, forest managers, and local actors, indigenous and local knowledge	***	**		

- *Karuk Tribe in northern California* (Chapter 5.6.3.2)					
Restoring natural fire regimes (Table 2.7) - *Protecting Gondwanan wildfire refugia in Tasmania, Australia* (Chapter 2.6.5.8)	Fire regulation **&** Biodiversity conservation		***		
Natural flood risk management (Table 2.7) - *Natural Flood Management (NFM) in England, United Kingdom* (Chapter 2.6.5.2)	Water security, flood regulation, sediment retention **&** Biodiversity and ecosystem conservation		***	**	
Coastal ecosystem conservation (Table Cross-Chapter Box NATURAL.1 in Chapter 2) (Table 16.2)(Table 2.7) - *African penguin on-site adaptation* (Chapter 2.6.5.5)	Coastal protection against sea level rise and storm surges **&** Fisheries, carbon sequestration, biodiversity and ecosystem conservation, flood regulation, water purification, recreation, and cultural benefits **X** NH_4 emissions, digging channels and sand walls around homes, loss of recreational value of beaches, shifted the flood impacts to poor informal urban settlers, erosion and degraded coastal lands		**	***	**
Eco-tourism within protected areas (Table 2.7)	Tourism **&** Habitat protection	***		**	
Aquaculture (Chapter 5.9.4; Table 16.2; Table Cross-Chapter Box NATURAL.1 in Chapter 2)	Food provision **&** Biodiversity conservation + Farmer incentives, participatory adaptation to context **X** Lack of financial, technical or institutional capacity; short value chains; productivity varies by system; over-fertilizing; deforestation of mangroves; salt intrusion; increased flood vulnerability	***		*	
Water-energy-food (WEF) nexus (Box 4.7) - *Food Water Energy Nexus in Asia* (Chapter 10.6.3) - *New Zealand's Land, Water and People Nexus under a changing climate* (Box 11.7)	Water, energy, and food provision **X** Insufficient data, information, and knowledge in understanding the WEF inter-linkages; lack of systematic tools to address trade-offs involved in the nexus	***			
Urban greening (Table 2.7; table 16.2; Table Cross-Chapter Box NATURAL.1 in Chapter 2) - *Ecosystem based adaptation in Durban, South Africa* (Chapter 2.6.5.7)	Urban flood management, water savings, urban heat island mitigation **&** Reduced carbon emissions, air and noise regulation, improved mental health, energy savings, recreation, and aesthetics + Meaningful partnerships, long-term financial commitments, and significant political and administrative **X** Storage of large quantities of water in the home; water contamination; increased breeding sites for mosquitoes and flies; vectors and diseases; intensified cultivation of marginal lands; clearing of virgin forests for farmland; frequent weeding; increased competition for water and nutrients; reduced soil fertility, invasive species		***		**

[END BOX 18.6 HERE]

18.3.1.4 Industrial systems

Industrial emissions have been growing faster since 2000 compared to emissions in any other sector, driven by increased extraction and production of basic materials (Crippa et al., 2019; IEA, 2019) (*very high confidence)*. About one-third of the total emissions are contributed by the industry sector, if indirect emissions from energy use are considered (Crippa et al., 2019). The COVID-19 pandemic has caused a significant decrease in demand for fuels, oil, coal, gas, and nuclear energy (IEA, 2020). However, there is concern that the rebound in the crisis will reverse this trend (IEA, 2020). Accordingly, the literature suggests a combined set of measures is beneficial for facilitation a transition of industrial systems in support of CRD. This includes (i) dematerialization and decarbonization of industrial systems, (ii) establishment of supportive governance, policies, and regulations, and (iii) implementation of enabling corporate strategies.

Decarbonization and dematerialization strategies have been proposed as key drivers for the transition of industrial systems (Fischedick et al., 2014; Worrell et al., 2016). The former involves limiting carbon emissions from industrial processes (IEA, 2017; Hildingsson et al., 2019), while the latter involves improving material efficiency, developing circular economies, raw material demand management, environmentally friendly product and process innovations, and environmentally friendly supply chain management (Worrell et al., 2016; Petrides et al., 2018).

Recent modelling suggests that stocks of manufactured capital, including buildings, infrastructure, machinery, and equipment, stabilize as countries develop and decouple from GDP (*high agreement, medium evidence)*. For instance, Bleischwitz et al. (2018) confirmed the occurrence of a saturation effect for materials in four energy-intensive sectors (steel, cement, aluminum and copper) in five industrialized countries (Germany, Japan, the United Kingdom, the United States and China). High growth in the supply of materials may still drive global demand for new products in the coming years for developing countries that are still far from saturation levels. Therefore, accelerating industrial transitions to drive the decoupling of industrial emissions from economic growth and facilitate broader transformation in industrial systems can be one component of CRD.

Continued transitions in the industrial sector will be contingent on technological innovation. Although technologies exist to drive emissions in industrial sectors to very low or zero emissions, but they require 5 to 15 years of innovation, commercialization, and intensive policies to ensure uptake (Åhman et al., 2017) (*high agreement, medium evidence*). For instance, several options exist to reduce GHG emission related to steel production process including increasing the share of the secondary route (Pauliuk et al., 2013), hydrogen-based direct reduced iron (Vogl et al., 2018), aqueous electrolysis rout (Cavaliere, 2019), and plasma process (Quader et al., 2016).

Industrial transitions are also contingent upon consumer behavior in terms of preferences for, and rates of, consumption of industrial products. Sustainable consumption can play an important role in sustainable production (Allwood et al., 2013; Allwood et al., 2019). This suggests feedbacks between industrial production and consumption in driving industrial transitions. For example, sustainable consumption can be triggered and/or enabled through sustainable production processes that provide more sustainable options to consumers as well as public or private promotional campaigns that promote those options. Meanwhile, demand from consumers for more sustainable options helps to drive the expansion of markets and innovation among industrial producers to meet that demand.

18.3.1.5 Societal systems

This chapter contributes a fifth system transition in addition to the four which have already been introduced by SR1.5: the societal systems transition. While society and people also feature in the other systems transitions, the purpose of defining a fifth transition is to explicitly highlight the challenges associated with changes in behavior, attitudes, values and consciousness required to achieve CRD. One caveat of considering transitions in societal systems is the limit to which the nature of change is known: transitions accomplish reconfigurations towards a relatively known destination. Historical and current differences between and within nations translate to a multitude of equally valid but diverse priorities for development, for example the understanding of development toward progress as linear has been challenged as being a Western concept by scholars of colonialization (Sultana et al., 2019). Thus societal transitions are understood as being intrinsically diverse for the purpose of achieving climate resilient development.

The four systems transitions identified in SR1.5 already include a component of societal change – for example, attitude change is part of public acceptance that facilitates shifts in energy including changing electricity to renewables (Ch 4 SR1.5 4.3.1.1) and developing nuclear power (4.3.1.3), and behavioral change is a part of shifting irrigation practices to drive required land and ecosystems transitions (4.3.2.1).

Extracting societal transitions also allows for a detailed examination of other societal dimensions that facilitate systems transitions, for example justice issues relating to water and energy access and distribution, and land use. Societal transition, sometimes known as 'societal transformation', is an established concept in different literatures, as described below. Transformation and transition are terms often used as synonyms (Hölscher et al., 2018) although different schools of thought understand them as sub-components of each other, eg. transition driving transformation, or transformation driving transition. For a more detailed discussion on the differences between transition and transformation represented in the literature, see Box 18.1.

Societal transitions for the purpose of this report are understood as the collection of shifts in attitudes, values, consciousness and behavior required to move toward CRD. This builds on the SR1.5 (IPCC, 2018a: 599) definition of societal (social) transformation: "A profound and often deliberate shift initiated by communities toward sustainability, facilitated by changes in individual and collective values and behaviors, and a fairer balance of political, cultural, and institutional power in society." This includes accepting IK/LK as an equally valid form of knowledge as compared with Western, scientific knowledge (see Cross-Chapter Box INDIG) and recognition of the role of shifting gender norms to achieve climate resilience (see Cross-Chapter Box GENDER). Changes associated with societal transitions are not specific to defined systems (e.g. energy, industry, land/ecosystems or urban/infrastructure). Rather, these sectoral systems are embedded within broader societal systems, including e.g. political systems, economic systems, knowledge systems, cultural systems (Davelaar, 2021; Turnhout et al., 2021; Visseren-Hamakers et al., 2021). Changes that happen in these broader social systems can therefore prompt changes in all systems embedded within them, meaning that societal transition is key to transforming across a range of sectors and topics (Leventon et al., 2021). Furthermore, societal transition requires changes in individual behaviors, but also in the broader conditions that shape these behaviors. These broader conditions are largely related to questions of power, in enforcing dominant political economies and social-technological mindsets (Stoddard et al., 2021). This section also briefly describes the various trains of research on societal transitions and transformation.

Because of the multiple sectors, interests and scales that are involved in societal transitions, understanding and creating evidence on transitions requires shifting across system boundaries and finding ways to transcend disciplinary silos. Relevant research includes work within the topic of transformation and transitions (Hölscher et al., 2018). Transformations literature can be split into multiple sub-concepts and requires engagement with multiple schools of thought (Feola, 2015; Feola et al., 2021). Much focus within transformations research is currently related to biodiversity conservation (Massarella et al., 2021), and transitions work tends towards a focus in urban areas (Loorbach et al., 2017). Though there is also work in both that is more broadly labelled as sustainability transformations or transitions (Luederitz et al., 2017). Furthermore, there is likely to be much relevant literature that does not explicitly label itself as transformations or transitions (Feola et al., 2021). For example, we could look to political science theories on policy change (Leventon et al., 2021) and historical perspectives on social change. Bridging these divides will require a deeper rethinking in the research community to undo power structures that marginalize diverse knowledges (Caniglia et al., 2021; Lahsen and Turnhout, 2021).

There are a number of concepts proposed as pathways to creating societal transitions; usually centered around the idea of working with individuals and communities to change their mindsets as a way to change the way they manage their local environments or behave. Transformations work explores how values are pathways towards sustainability, for example by changing values, through making values explicit, through negotiation, and by eliciting values (Horcea-Milcu et al., 2019). Human nature connections is a further concept that is identified as a way to shift values and behaviors across a range of disciplines (Ives et al., 2017). The role of learning and indigenous knowledge is also explored (Lam et al., 2020). These three concepts have had particular salience in discussions around transformations for biodiversity conservation and restoration, related to the IPBES assessment on Values (Pascual et al., 2017; Peterson et al., 2018). They largely focus on the need to engage with people's values, connections and knowledge to better manage the social-ecological system they are in.

Focusing on bottom-up and community-led transformations, there is emphasis on the role of grassroots organizations in transformations. Community actions around specific locations or topics have parallels to the idea of transformative spaces. They are sites of innovative activity (Seyfang and Smith, 2007). Grassroots organizations can bridge the local and the political scales by politicizing actors and creating new interactions between individuals and political processes (Novák, 2021). They are a collective approach to pushing for both individual and societal change (Sage et al., 2021).

Despite a current lack of empirical evidence, there are numerous frameworks emerging for exploring societal transitions across levels. There is focus on pathways for sustainability transitions, which tends to look at projected, normative scenarios for the future, and explore or back-cast the institutional and societal changes that are required to get there (Westley et al., 2011; Sharpe et al., 2016). There is also work that looks at scaling up of smaller sustainability initiatives, through processes of scaling up, scaling out and scaling deep (Moore et al., 2015; Lam et al., 2020). In particular, systems thinking provides an organizing framework for bringing together multiple disciplines and perspectives, to understand problem framings, and normative and design aspects of social systems and behaviors (Foster-Fishman et al., 2007). Within this, Meadows (1999) framework of leverage points for systems transformation has been operationalized within the sustainability transformations debate (Abson et al., 2017). Here, system properties relating to system paradigms and design are leverage points where interventions can create greatest system change; shallower leverage points relate to materials and processes. This framework is increasingly being used across a range of sustainability problems as boundary objects for cross-disciplinary, critical research (Fischer and Riechers, 2019; Leventon et al., 2021; Riechers et al., 2021).

Analyses of societal transitions have had limited engagement with adaptation questions. The focus of the sub-field of sustainability transitions on a few industrialized nations, mostly in North America and Europe, limited the field's development to assumptions born from the experiences in those areas. More recent studies have sought to understand sustainability transitions in other countries, especially emerging economies (Wieczorek, 2018; Köhler et al., 2019). In particular, China has received attention from scholars on sustainability transitions (Huang et al., 2018; Lo and Castán Broto, 2019; Castán Broto et al., 2020; Huang and Sun, 2020). As a result, some pressing issues related to societal transitions for adaptation have received limited attention compared with that paid to other system transitions. However, more recently, scholarship has begun examining transitions that have turned to nature and nature-based solutions. Adaptive transitions are an intermediary step towards sustainability transitions whereby multiple actions at material and institutional levels are combined towards improving adaptation outcomes (Pant et al., 2015; Scarano, 2017).

Table 18.3: Specific options for facilitating the five system transitions that can support CRD

Transition	Examples	Reference
Energy Systems	• Fuel switching from coal to natural gas • Expansion of renewable energy technologies • Financial incentives to promote renewable energy • Reduced energy intensity of industry • Improvements in power system resilience and reliability • Increased water use efficiency in electricity generation • Energy demand management strategies	(Gielen et al., 2019) (Mulugetta et al., 2019) (IEA et al., 2019) AR6 WGIII Chapter 2
Urban and infrastructure systems	• Increased investment in physical and social infrastructure • Enhance urban and regional planning • Enhanced governance and institutional capacity supports post-disaster recovery and reconstruction (Kull, 2016)	(IPCC, 2018b): D3.1)
Land, Oceans, and Ecosystems	• Expanding access to agricultural and climate services • Strengthening land tenure security and access to land • Empowering women farmers • Improved access to markets • Facilitating payments for ecosystem services	(IPCC, 2019f): C2.1) (IPCC, 2019f): C4.5) (IPCC, 2019f): C4)

	• Promotion of healthy and sustainable diets • Enhancing multi-level governance by supporting local management of natural resources • Strengthening cooperation between institutions and actors • Building on local, indigenous and scientific knowledge funding, and institutional support • Monitoring and forecasting • Education and climate literacy and social learning and participation	
Industrial systems	• Promote material efficiency and high-quality circularity • Materials demand management (IEA 2019, 2020) • Application of new processes and technologies for GHG emission reduction • Carbon pricing or regulations with provisions on competitiveness to drive innovation and systemic carbon efficiency • Low-cost, long-term financing mechanisms to enable investment and reduce risk • Better planning of transport infrastructure • Labour market training and transition support • Electricity market reform • Regulations – standards and labelling, material efficiency • Mandating technologies and targets • Green taxes and carbon pricing, preferential loans and subsidies • voluntary action agreements, expanded producer responsibilities • information programs: monitoring, evaluation, partnerships, and research and development • government provisioning of services—government procurements, technology push and market-pull	(Åhman et al., 2017; Bataille et al., 2018; Material, 2019) (Tanaka, 2011; Schwarz et al., 2020) (Ciwmb, 2003) (Romero Mosquera, 2019) (Tanaka, 2011) (Ryan et al., 2011; Boyce, 2018) (Taylor, 2008) (UNEP, 2018b) (Kaza et al., 2018) (Söderholm and Tilton, 2012) (Bataille et al., 2018) (Ghisetti et al., 2017) (Taylor, 2008; Fischedick et al., 2014; Hansen and Lema, 2019) (Crippa et al., 2019; IEA, 2019) (Cavaliere, 2019; IEA, 2020)(Vogl et al., 2018)(Pauliuk et al., 2013; Quader et al., 2016)
Societal Systems	• Inclusive governance • Empowerment of excluded stakeholders, especially women and youth • transforming economies • finance and technology aligned with local needs • overcoming uneven consumption and production patterns • allowing people to live a life in dignity and enhancing their capabilities • involving local governments, enterprises and civil society organisations across different scales	(Fazey et al., 2018b; O'Brien, 2018; Patterson et al., 2018) (MRFCJ, 2015; Dumont et al., 2019) (Popescu et al., 2017; David Tàbara et al., 2018) (de Coninck and Sagar, 2015; IEA, 2015; Parikh et al., 2018) (Dearing et al., 2014; Häyhä et al., 2016; Raworth, 2017) (Klinsky and Winkler, 2018), (Hajer et al., 2015; Labriet et al., 2015; Hale, 2016; Pelling et al., 2016; Kalafatis, 2017; Lyon, 2018) (Holden et al., 2017) (Cundill et al., 2014; Butler et al., 2016; Ensor, 2016; Fazey et al., 2016;

	• reconceptualising development around well-being rather than economic growth (Gupta and Pouw, 2017), • rethinking, prevailing values, ethics and behaviour • improving decision-making processes that incorporate diverse values and world views • creating space for negotiating diverse interests and preferences	Gorddard et al., 2016; Aipira et al., 2017; Chung Tiam Fook, 2017; Maor et al., 2017) (O'Brien and Selboe, 2015; Gillard et al., 2016; DeCaro et al., 2017; Harris et al., 2018; Lahn, 2018; Roy et al., 2018) Sections 5.6.1 and 5.5.3.1

[START CROSS-CHAPTER BOX GENDER HERE]

Cross-Chapter Box GENDER: Gender, Climate Justice and Transformative Pathways

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Key Messages

- Gender and other social inequities (e.g., racial, ethnic, age, income, geographic location) compound vulnerability to climate change impacts (*high confidence*). Climate justice initiatives explicitly address these multi-dimensional inequalities as part of a climate change adaptation strategy. [Box 9.2: Vulnerability Synthesis: Differential Vulnerability by Gender and Age in Ch 9]

- Addressing inequities in access to resources, assets, and services as well as participation in decision-making and leadership is essential to achieving gender and climate justice (*high confidence*).

- Intentional long-term policy and program measures and investments to support shifts in social rules, norms, and behaviours are essential to address structural inequalities and support an enabling environment for marginalised groups to effectively adapt to climate change (*very high confidence*). [Equity and Justice box in Ch 17]

- Climate adaptation actions are grounded in local realities so understanding links with SDG 5 is important to ensure that adaptive actions do not worsen existing gender and other inequities within society (e.g., leading to maladaptation practices) *(high confidence).* [17.5.1]

- Adaptation actions do not automatically have positive outcomes for gender equality. Understanding the positive and negative links of adaptation actions with gender equality goals, (i.e., SDG 5), is important to ensure that adaptive actions do not exacerbate existing gender-based and other social inequalities [16.1.4.4]. Efforts are needed to change unequal power dynamics and ´to foster inclusive decision-making for climate adaptation to have a positive impact for gender equality *(high confidence).*

- There are very few examples of successful integration of gender and other social inequities in climate policies to address climate change vulnerabilities and questions of social justice, (*Very high confidence*).

Gender, climate justice, and climate change

This Cross-Chapter Box highlights the intersecting issues of gender, climate change adaptation, climate justice, and transformative pathways. A gender perspective does not centre only on women or men but examines structures, processes, and relationships of power between and among groups of men and women and how gender, particularly in its non-binary form, intersects with other social categories such as race, class, socio-economic status, nationality, or education to create multidimensional inequalities (Hopkins, 2019). A gender transformative approach aims to change structural inequalities. Attention to gender in climate change adaptation is thus central to questions of climate justice that aim for a radically different future (Bhavnani et al., 2019). As a normative concept highlighting the unequal distribution of climate change impacts and opportunities for adaptation and mitigation, climate justice (Wood, 2017; Jafry et al., 2018; Chu and Michael, 2019; Shi, 2020a) calls for transformative pathways for human and ecological wellbeing. These address the concentration of wealth, unsustainable extraction, and distribution of resources (Schipper et al., 2020a; Vander Stichele, 2020) as well as the importance of equitable participation in environmental decision-making for climate justice (Arora-Jonsson, 2019).

Research on gender and climate change demonstrates that an understanding of gendered relations is central to addressing the issue of climate change. This is because gender relations mediate experiences with climate change, whether in relation to water (Köhler et al., 2019) (see also Sections 4.7, 4.3.3; 4.6.4, 5.3), forests (Arora-Jonsson, 2019), agriculture (Carr and Thompson, 2014; Balehey et al., 2018; Garcia et al., 2020) (see also Chapter 4, Section 5.4), marine systems (Mcleod et al., 2018; Garcia et al., 2020) (see also Section 5.9) or urban environments (Reckien et al., 2018; Susan Solomon et al., 2021) (see also Chapter 6). Climate change has direct negative impacts on women's livelihoods due to their unequal control over and access to resources (e.g., land, credit) and because they are often the ones with the least formal protection (Eastin, 2018) (see also Box 9.2 in Ch 9). Women represent 43% of the agricultural labour force globally, but only 15% of agricultural landholders (OECD, 2019b). Gendered and other social inequities also exist with non-land assets and financial services (OECD, 2019b) often due to social norms, local institutions, and inadequate social protection (Collins et al., 2019b). Men may experience different adverse impacts due to gender roles and expectations (Bryant and Garnham, 2015; Gonda, 2017). These impacts can lead to irreversible losses and damages from climate change across vulnerability hotspots (Section 8.3).

Participation in environmental decision-making tends to favour certain social groups of men, whether in local environmental committees, international climate negotiations (Gay-Antaki and Liverman, 2018) or the IPCC (Nhamo and Nhamo, 2018). Addressing climate justice reinforces the importance of considering the legacy of colonialism on developing regional and local adaptation strategies. Scholars have criticized climate programs for setting aside forestland that poor people rely on and appropriating the labor of women in the global South without compensatory social policy or rights; where women are expected to work with Non Timber Forest Products to compensate for the lack of logging and for global climate goals but where their work of social reproduction and care is paid little attention (Westholm and Arora-Jonsson, 2015; Arora-Jonsson et al., 2016). A global ecologically unequal exchange, biopiracy, damage from toxic exports, or the disproportionate use of carbon sinks and reservoirs by high-income countries enhance the negative impacts of climate change, women in LDC's and SIDS also endure the harshest impacts of the debt crisis due to imposed debt measures in their countries (Appiah and Gbeddy, 2018; Fresnillo Sallan, 2020). The austerity measures derived as conditionalities for fiscal consolidation in public services increases gender-based violence (Castañeda Carney et al., 2020) and brings additional burdens for women in the form of increasing unpaid care and domestic work (Bohoslavsky, 2019).

Gendered vulnerability

Land, ecosystem, and urban transitions to climate-resilient development need to address gender and other social inequities to meet sustainability and equity goals, otherwise, marginalised groups may continue to be excluded from climate change adaptation. In the water sector, increasing floods and droughts and diminishing groundwater and runoff have gendered effects on both production systems and domestic use (Sections 4.3.1, 4.3.3, 4.5.3). Climate change is reducing the quantity and quality of safe water available in many regions of the world and increasing domestic water management responsibilities (*high confidence*). In regions with poor drinking water infrastructure, it is forcing, primarily women and girls, to walk long distances to access water, and limiting time available for other activities, including education and income generation (Eakin et al., 2014; Kookana et al., 2016; Yadav and Lal, 2018). Water insecurity and the lack of water, sanitation, and hygiene (WASH) infrastructure have resulted in psychosocial distress, gender-based violence, as well as poor maternal and child health and nutrition (Collins et al., 2019a; Wilson et al., 2019; Geere and Hunter, 2020; Islam et al., 2020; Mainali et al., 2020) (Sections 4.3.3 and 4.6.4.4) (*high confidence*). Climate-related extreme events also affect women's health – by increasing the risk of maternal and infant mortality, disrupting access to family planning and prevention of mother to child transmission regimens for HIV positive pregnant women (Undrr, 2019) (see also Section 7.2). Women and the elderly are also disproportionately affected by heat events (Section 7.1.7.2.1, 7.1.7.2.3, 13.7.1).

Extreme events impact food prices and reduce food availability and quality, especially affecting vulnerable groups, including low-income urban consumers, wage labourers, and low-income rural households who are net food buyers (Green et al., 2013; Fao, 2016) (Section 5.12). Low-income women, ethnic minorities, and Indigenous communities are often more vulnerable to food insecurity and malnutrition from climate change impacts, as poverty, discrimination, and marginalisation intersect in their cases (Vinyeta et al., 2016; Clay et al., 2018) (Section 5.12). Increased domestic responsibilities of women and youth, due to migration of men, can increase their vulnerability due to their reduced capacity for investment in off-farm activities and reduced access to information (Sugden et al., 2014; O'Neil et al., 2017) (Section 4.3; 4.6) (*high confidence*).

In the forest sector, the increased frequency and severity of drought, fires, pests and diseases, and changes to growing seasons, has led to reduced harvest revenues, fluctuations in timber supply and availability of wood (Lamsal et al., 2017; Fadrique et al., 2018; Esquivel-Muelbert et al., 2019). Climate programs in the global South such as REDD+ have led to greater social insecurity and the conservation of the forests have led to more pressure on women to contribute to household incomes but without enough supporting market access mechanisms or social policy (Westholm and Arora-Jonsson, 2015; Arora-Jonsson et al., 2016). In countries in the global North, reduced harvestable wood and revenues have led to employment restructuring that has important gendered effects and negatively affects community transition opportunities (Reed et al., 2014).

Integrating gender in climate policy and practice

Climate change policies and programs across regions reveal wide variation in the degree and approach to addressing gender inequities (see Table SMCCB GENDER.2). In most regions where there are climate change policies that consider gender, they inadequately address structural inequalities t resulting from climate change impacts, or how gender and other social inequalities can compound risk (*high confidence*). Experiences show that it is more frequent to address specific gender inequality gaps in access to resources. Regionally, Central and South American countries (section 12.5.8) have a range of gender-sensitive or gender-specific policies such as the intersectoral coordination initiative Gender and Climate Change Action Plans (PAGcc), adopted in Perú, Cuba, Costa Rica, and Panamá (Casas Varez, 2017), or the Gender Environmental policy in Guatemala that has a focus on climate change (Bárcena-Martín et al., 2021). However, countries often have limited commitment and capacity to evaluate the impact of such policies (Tramutola, 2019). In North and South America, policies have failed to address how climate change vulnerability is compounded by the intersection of race, ethnicity, and gender (Radcliffe, 2014; Vinyeta et al., 2016) (see also section 14.6.3). gender is rarely discussed in African national policies or programmes beyond the initial consultation stage (Holvoet and Inberg, 2014; Mersha and van Laerhoven, 2019), although there are gender and climate change action strategies in countries such as Liberia, Mozambique, Tanzania, and Zambia (Mozambique and IUCN, 2014; Zambia and IUCN, 2017). European climate change adaptation strategies and policies are weak on gender and other social equity issues (Allwood, 2014; Boeckmann and Zeeb, 2014; Allwood, 2020), while in Australasia, there is a lack of gender-responsive climate change policies. In Asia, there are several countries that recognize gendered vulnerability to climate change (Jafry, 2016; Singh et al., 2021b), but policies tend to be gender-specific, with a focus on targeting women, for example in the national action plan on climate change as in India (Roy et al., 2018) or in national climate change plan as in Malaysia (Susskind et al., 2020).

Potential for Change and Solutions

The sexual division of labour, systemic racism and other social structural inequities lead to increased vulnerabilities and climate change impacts for social groups such as women, youth, Indigenous peoples, ethnic minorities. Their marginal positions not only affect their lives negatively but their work in maintaining healthy environments is ignored and invisible in policy affecting their ability to work towards sustainable adaptation and aspirations in the SDGs (Arora-Jonsson, 2019). However, attention to the following has the potential to bring about change:

Creation of new, deliberative policy-making spaces that support inclusive decision-making processes and opportunities to (re)negotiate pervasive gender and other social inequalities in the context of climate change for transformation (Tschakert et al., 2016; Harris et al., 2018; Ziervogel, 2019; Garcia et al., 2020). (*high confidence*)

Increased access to reproductive health and family planning services, which contributes to climate change resilience and socio-economic development through improved health and well-being of women and their children, including increased access to education, gender equity, and economic status (Onarheim et al., 2016; Starbird et al., 2016; Lopez-Carr, 2017; Hardee et al., 2018) (Sections 7.4) (*high confidence*).

Engagement with women's collectives is important for sustainable environments and better climate decision-making whether at the global, national, or local levels (Westholm and Arora-Jonsson, 2018; Agarwal, 2020). The work of such collectives in maintaining their societies and environments and in resisting gendered and community violence is unacknowledged (Jenkins, 2017; Arora-Jonsson, 2019) but is indispensable especially when combined with good leadership, community acceptance, and long-term economic sustainability (Chu, 2018; Singh, 2019) (Section 4.6.4). Networking by gender experts in environmental organizations and bureaucracies has also been important for ensuring questions of social justice (Arora-Jonsson and Sijapati, 2018).

Investment in appropriate reliable water supplies, storage techniques, and climate-proofed WASH infrastructure as key adaptation strategies that reduce both burdens and impacts on women and girls (Alam et al., 2011; Woroniecki, 2019) (Sections 4.3.3 and 4.6.44).

Improved gender-sensitive early warning system design and vulnerability assessments to reduce vulnerabilities, prioritising effective adaptation pathways to women and marginalized groups (Mustafa et al., 2019; Tanner et al., 2019; Werners et al., 2021).

Established effective social protection, including both cash and food transfers, such as the universal public distribution system (PDS) for cereals in India, or pensions and social grants in Namibia, that have been demonstrated to contribute towards relieving immediate pressures on survival and support processes at the community level, including climate effects (Kattumuri et al., 2017; Lindoso et al., 2018; Rao et al., 2019a; Carr, 2020).

Strengthened adaptive capacity and resilience through integrated approaches to adaptation that include social protection measures, disaster risk management, and ecosystem-based climate change adaptation (*high confidence*), particularly when undertaken within a gender-transformative framework (Gumucio et al., 2018; Bezner Kerr et al., 2019; Deaconu et al., 2019) (Cross-Chapter Box NATURAL in Chapter 2, Section 5.12, Section 5.14).

For example, gender-transformative and nutrition-sensitive agroecological approaches strengthen adaptive capacities and enable more resilient food systems by increasing leadership for women and their participation in decision-making and a gender-equitable domestic work (*high confidence)* (Gumucio et al., 2018; Bezner Kerr et al., 2019; Deaconu et al., 2019) (Cross-Chapter Box NATURAL in Chapter 2, Section 5.12, Section 5.14)

New initiatives such as the Sahel Adaptive Social Protection Program represent an integrated approach to resilience that promotes coordination among social protection, disaster risk management, and climate change adaptation. Accompanying measures including, health, education, nutrition, family planning, among others (Daron et al., 2021).

Climate change adaptation and SDG 5

Adaptation actions may reinforce social inequities, including gender unless explicit efforts are made to change (Nagoda and Nightingale, 2017; Garcia et al., 2020) (*high evidence and high agreement*). Participation in climate action increases if is inclusive and fair (Huntjens and Zhang, 2016). Roy et al. (2018) assessed links among various SDGs and mitigation options. Adaptation actions are grounded in local realities especially in terms of their impacts so understanding links with the goals of SDG 5 becomes more important to make sure that adaptive actions do not worsen prevalent gender and other social inequities within society (*high evidence, high agreement)*. In the IPCC 1.5°C Special Report, Roy et al. (2018) assessed links between various SDGs and mitigation options, adaptation options were not considered. The current SDG 13 climate action targets do not specifically mention gender as a component for action, which makes it even more imperative to link SDG 5 targets and other gender-related targets to adaptive actions under SDG 13 to ensure that adaptation projects are synergistic rather than maladaptive (16.3.2.6, Table 16.6) (Susan Solomon et al., 2021).

This assessment is based on a systematic rapid review of scientific publications (McCartney et al., 2017; Liem et al., 2020) published on adaptation actions in 9 sectors from 2014 to 2020 (see Table SMCCB GENDER.1) and how they integrated gender perspectives impacting gender equity. The assessment is based on over 17,000 titles and abstracts that were initially found through keyword search and were reviewed. Finally, 319 relevant papers on case studies, regional assessments, and meta-reviews were assessed. Gender impact was classified by various targets under SDG 5. Following the approach taken in Roy et al. (2018) and (Hoegh-Guldberg et al., 2019), the linkages were classified into synergies (positive impacts or co-benefits) and trade-offs (negative impacts) based on the evidence obtained from the literature review which is finally used to develop net impact (positive or negative) scores (See Table Cross-Chapter Box GENDER.1 and Supplementary Material)

Table Cross-Chapter Box GENDER.1: Interrelations between SDG5 (gender equality) and adaptation initiatives in 9 major sectors

Sector	**Adaptation categories**			
	Ecosystem-based	***Technological /infrastructure /information***	***Institutional***	***Behavioural / cultural***
Terrestrial & freshwater ecosystem	□□		□□	
Ocean & coastal ecosystem	□□	□	□□□	
Mountain ecosystem	□	□□	□	□□
Food, fibre & others	□□		□□	□□
Urban water & sanitation	□	□□		□□
Poverty, livelihood & Sustainable Development			□	□□
Cities, settlement & key infrastructure	□□	□□	□□	□□□
Health, well-being, and changing communities' structure	□□□□	□□	□□□	□□
Industrial system transition			□□	□□□

Colour code	**Description**
(blue)	All net positive links
(orange)	All net negative links

Confidence levels	**Symbol**
Very High	□□□□□
High	□□□□

	Number of net positive links > number of net negative links
	Number of net negative links > number of net positive links
	no literature/options

Medium	□□□
Low	□□
Very low	□

Table Notes:
Potential net synergies and trade-offs between a sectoral portfolio of adaptation actions and SDG 5 are shown. Colour codes showing the relative strength of net positive and net negative impacts and confidence levels. The strength of net positive and net negative connections across all adaptation actions within a sector are aggregated to show sector-specific links. The links are only one-sided on how adaptation action is linked to gender equality (SDG5) targets and not vice versa. Adaptation options assessed in Ecosystem-based actions are: 22 in number, options in Technological /infrastructure /information are 10, in Institutional are 17 and in Behavioural/ cultural are 13. The assessment presented here is based on literature presenting impacts on gender equality and equity of various adaptation actions implemented in various local contexts and in regional climate change policies (Table SMCCB GENDER.2).

Adaptation actions being implemented in each sector in different local contexts can have positive (synergies) or negative (trade-offs) effects with SDG5. This can potentially lead to net positive or net negative connections at an aggregate level. How they are finally realized depends on how they are implemented, managed, and combined with various other interventions in particular, place-based circumstances. Ecosystem-based adaptation actions and terrestrial & freshwater ecosystems have higher potential for net positive connections (Roy et al., 2018) (Table Cross-Chapter Box GENDER.1 and Supplementary Material). Adaptation in terrestrial and freshwater ecosystems has the strongest net positive links with all SDG-5 targets (*medium evidence, low agreement*). For example, community-based natural resource management increases the participation of women, especially when they are organised into women's groups (Pineda-López et al., 2015; de la Torre-Castro et al., 2017) (Supplementary Material). For poverty, livelihood and sustainable development sector adaptation actions have generated more net negative scores (*low evidence, low agreement*) (Table Cross-Chapter Box GENDER.1). For example, patriarchal institutions and structural discriminations curtail access to services or economic resources as compared to men, including less control over income, fewer productive assets, lack of property rights, as well as less access to credit, irrigation, climate information, and seeds which devaluate women's farm-related adaptation options (Adzawla et al., 2019; Friedman et al., 2019; Ullah et al., 2019) (Supplementary Material).

Among the adaptation actions, ecosystem-based actions have the strongest net positive links with SDG-5 targets (Table Cross-Chapter Box GENDER.1, Table SMCCB GENDER.1). In the health, well-being and changing communities' sector, this is with *high evidence and medium agreement*, while in all other sectors there is *medium evidence and low agreement*. Net negative links are most prominent in institutional adaptation actions (Table Cross-Chapter Box GENDER.1). For example, in mountain ecosystems, changes in gender roles in response to climatic and socioeconomic stressors is not supported by institutional practices, mechanisms, and policies that remain patriarchal (Goodrich et al., 2019). Additionally, women often have less access to credit for climate change adaptation practices, including post-disaster relief, for example, to deal with salinization of water or flooding impacts (Hossain and Zaman 2018). Lack of coordination among different city authorities can also limit women's contribution in informal settlements towards adaptation. Women are typically underrepresented in decision-making on home construction and planning and home-design decisions in informal settlements, but examples from Bangladesh show they play a significant role in adopting climate-resilient measures (e.g., the use of corrugated metal roofs and partitions which is important in protection from heat) (Jabeen, 2014; Jabeen and Guy, 2015; Araos et al., 2017; Susan Solomon et al., 2021).

Towards climate-resilient, gender-responsive transformative pathways

The climate change adaptation and gender literature call for research and adaptation interventions that are 'gender-sensitive' (Jost et al., 2016; Thompson-Hall et al., 2016; Kristjanson et al., 2017; Pearce et al., 2018a) and "gender-responsive", as established in Article 7 of the Paris Agreement (UNFCCC, 2015). In addition, attention is drawn to the importance of 'mainstreaming' gender in climate/development policy (Alston, 2014; Rochette, 2016; Mcleod et al., 2018; Westholm and Arora-Jonsson, 2018). Many calls have been made to consider gender in policy and practice (Ford et al., 2015; Jost et al., 2016; Rochette, 2016; Thompson-Hall et al., 2016; Kristjanson et al., 2017; Mcleod et al., 2018; Lau et al., 2021; Singh et al., 2021b). Rather than merely emphasising the inclusion of women in patriarchal systems, transforming systems that perpetuate inequality can help to address broader structural inequalities not only in relation to gender but also other dimensions such as race and ethnicity (Djoudi et al., 2016; Pearse, 2017; Gay-Antaki, 2020). Adaptation researchers and practitioners play a critical role here and can enable gender-transformative processes by creating new, deliberative spaces that foster inclusive decision-making and opportunities for renegotiating inequitable power relations (Tschakert et al., 2016; Ziervogel, 2019; Garcia et al., 2020).

To date, empirical evidence on such transformational change is sparse, although there is some evidence of incremental change (e.g., increasing women's participation in specific adaptation projects, mainstreaming gender in national climate policies). Even when national policies attempt to be more gendered, there is criticism that they use gender-neutral language or include gender analysis without proposing how to alter differential vulnerability (Mersha and van Laerhoven, 2019; Singh et al., 2021b). More importantly, the mere inclusion of women and men in planning does not necessarily translate to substantial gender-transformative action, for example in National Adaptation Programmes of Action across sub-Saharan Africa (Holvoet and Inberg, 2014; Nyasimi et al., 2018) and national and sub-national climate action plans in India (Singh et al., 2021b). Importantly, there is often an overemphasis on the gender binary (and household headship as an entry point), which masks complex ways in which marginalisation and oppression can be augmented due to the interaction of gender with other social factors and intra-household dynamics (Djoudi et al., 2016; Thompson-Hall et al., 2016; Rao et al., 2019a; Lau et al., 2021; Singh et al., 2021b).

Climate justice and gender transformative adaptation can provide multiple beneficial impacts that align with sustainable development. Addressing poverty (SDG 1), energy poverty (SDG 7), WaSH (SDG 6), health (SDG 3), education (SDG 4) and hunger (SDG 2) —along with inequalities (SDG 5 and SDG 10) - improves resilience to climate impacts for those groups that are disproportionately affected (women, low-income and marginalised groups). Inclusive and fair decision-making can enhance resilience (SDG 16; Section 13.4.4), although adaptation measures may also lead to resource conflicts (SDG 16; Section 13.7). Nature-based solutions attentive to gender equity also support ecosystem health (SDGs 14 and 15) (Dzebo et al., 2019). Gender and climate justice will be achieved when the root causes of global and structural issues are addressed, challenging unethical and unacceptable use of power for the benefit of the powerful and elites (MacGregor, 2014; Wijsman and Feagan, 2019; Vander Stichele, 2020). Justice and equality need to be at the centre of climate adaptation decision-making processes. A transformative pathway needs to include the voice of the disenfranchised (MacGregor, 2020; Schipper et al., 2020a).

[END CROSS-CHAPTER BOX GENDER HERE]

18.3.2 Accelerating Transitions

Successfully implementing climate actions and managing trade-offs between mitigation, adaptation and sustainable development (18.2.4) has important time considerations that imply significant urgency, making substantive progress in system transitions critical for CRD. Both the SDGs and the Sendai Framework, for example, have target dates of 2030. Meanwhile, the Paris Agreement sets specific time horizons for NDCs and the SR1.5 indicated that limiting warming to 1.5°C would similarly require substantial climate action by 2030 (IPCC, 2018a). While the literature is unambiguous regarding the need for significant system transitions to achieve CRD (Section 18.1.3), the current pace of global emissions reductions, poverty alleviation, and development of equitable systems of governance is incommensurate with these policy time tables (Rogelj et al., 2010; Burke et al., 2016; Oleribe and Taylor-Robinson, 2016; Kriegler et al., 2018; Frank et al., 2019; Sadoff et al., 2020). As noted previously in the AR5, "*delaying action in the present may reduce options for climate-resilient pathways in the future*" (Denton et al., 2014: 1123). Accordingly, significant acceleration in the pace of system transitions is necessary to enable the implementation of mitigation, adaptation, and sustainable development initiatives consistent with CRD *(very high confidence*).

Studies since the AR5 directly address the issue of how to accelerate transitions within the broader system transitions, sustainability transitions, and socio-technical transitions literature (Frantzeskaki et al., 2017; Gliedt et al., 2018; Gorissen et al., 2018; Johnstone and Newell, 2018; Kuokkanen et al., 2019; Markard et al., 2020). Such literature explores several core themes to facilitate acceleration, which are aligned with the discussion later in this chapter on arenas of engagement for CRD (Section 18.4.3). One dominant theme is accelerating the implementation of sustainability or low-carbon policies that target specific sectors or industries (Bhamidipati et al., 2019). For example, Altenburg and Rodrik (Altenburg and Rodrik, 2017) discuss green industrial polices including taxes, mandated technology phase outs, and the removal of subsidies as means of constraining polluting industries. Kivimaa et al. (Kivimaa and Martiskainen, 2018; Kivimaa et al., 2019a; Kivimaa et al., 2019b; Kivimaa et al., 2020) and Vihemäki et al. (2020) discuss low-carbon transitions in buildings, noting the important role that intermediaries play in facilitating policy reform. Nikulina et al. (2019) identify mechanisms for facilitating policy change in personal mobility including political leadership, combining carrots and sticks to incentivize behavioral change, and challenging current policy frameworks. These various examples reflect a fragmented approach to system transitions, suggesting a large portfolio of such transition initiatives would be required to accelerate change or more fundamental and cross-cutting policy drivers are needed (*high agreement, limited evidence*). Policies that seek to promote social justice and equity, for example, could ultimately catalyze a broader range of sustainability and climate actions than policies designed to address a specific sector or class of technology (Delina and Sovacool, 2018; White, 2020).

In contrast with formal government policies, a second theme in accelerating transitions is that of civic engagement (see also 18.4.3), which is reported to be an important opportunity for driving transitions forward (*high agreement, medium evidence*). Ehnert et al. (2018) describe local organizations and civic engagement in policy processes as an important engine for sustainability activities in European states. Similarly, Ruggiero et al. (2021) note the potential to use civic organizations to appeal to local identities in order to mobilize citizens to pursue energy transition initiatives among communities in the Baltic Sea region. Gernert et al. (2018) attribute such influence to the ability of grassroots movements to bypass traditional social and political norms and thereby experiment with new behaviors and processes. Moreover, civic engagement is also the foundation for collective action including protest and civil disobedience (Welch and Yates, 2018, Section 18.5.3.7). However, Haukkala (2018) observes that while green-transition coalitions in Finland could be an agent of change driving energy transitions, the diversity of views among the various grassroots actors could make consensus building difficult, thereby slowing transition initiatives.

A third theme is that of innovation, generally, and sustainability-oriented innovation, specifically (de Vries et al., 2016; Geradts and Bocken, 2019; Loorbach et al., 2020), which creates opportunities for overcoming existing transition barriers *(very high confidence*). For example, Valta (2020) describes the role of innovation ecosystems – partnerships among companies, investors, governments, and academics – in accelerating innovation (see also World Economic Forum, 2019). Burch et al. (Burch et al., 2016) describe the role of small and medium-sized business entrepreneurship in promoting rapid innovation. Innovation extends beyond pure technology considerations to consider innovation in practices and social organization (Li et al., 2018; Psaltoglou and Calle, 2018; Repo and Matschoss, 2020). Zivkovic (2018), for example, discusses "innovation labs" as accelerators for addressing so-called wicked problems like climate change through multi-stakeholder groups. Meanwhile, Chaminade and Randelli (2020) describe a case study where structural preconditions and place-based agency were important drivers of transitions to organic viticulture in Tuscany, Italy.

The fourth theme is that of transition management (Goddard and Farrelly, 2018), particularly vis a vis, disruptive technologies (Iñigo and Albareda, 2016; Kuokkanen et al., 2019) or broader societal disruptions (Brundiers, 2020; Davidsson, 2020; Hepburn et al., 2020; Schipper et al., 2020b). Recent literature has given attention to how actors can use disruptive events, such as disasters, as a window-of-opportunity for accelerating changes in policies, practices, and behaviors (*high agreement, medium evidence*) (Brundiers, 2018; Brundiers and Eakin, 2018). This is consistent with concepts in resilience thinking around 'building back better' after disasters (Fernandez and Ahmed, 2019). For example, Hepburn et al. discuss fiscal recovery packages for COVID-19 as a means of accelerating climate action, with a particular influence on clean physical infrastructure, building efficiency retrofits, investment in education and training, natural capital investment, and clean research and development (Andrijevic et al., 2020b).

18.4 Agency and Empowerment for Climate Resilient Development

As reflected in the discussion of societal transitions (18.3), people and their values and choices play an instrumental role in CRD. The agency of people to act on CRD is grounded in their worldviews, beliefs, values, and consciousness (Woiwode, 2020) and is shaped through social and political processes including how policies and decision-making recognize the voices, knowledges and rights of particular actors over others *(very high confidence)* (Harris and Clarke, 2017; Nightingale, 2017; Bond and Barth, 2020; Muok et al., 2021). Since the AR5, evidence on diverse forms of engagement by and among social, political and economic actors to support climate resilient development and sustainability outcomes, has increased. New forms of decision-making and engagement are emerging within the formal policy making and planning sphere, including co-production of knowledge, interventions grounded in the arts and humanities, civil participation and partnerships with business (Ziervogel et al., 2016a; Roberts et al., 2020). In addition, the set of actors that drive climate and development actions are recognized to extend beyond government and formal policy actors to include civil society, education, industry, media, science and art (Ojwang et al., 2017; Solecki et al., 2018; Heinrichs, 2020; Omukuti, 2020). This makes the power dynamics among actors and institutions critical for understanding the role of actors in CRD (Buggy and McNamara, 2016; Camargo and Ojeda, 2017; Silva Rodríguez de San Miguel, 2018).

The formal space for national, sub-national and international adaptation governance emerged at COP 16 (UNFCCC, 2010) when adaptation was recognized as a similar level of priority as greenhouse gas mitigation. The Paris Agreement (UNFCCC, 2015) built on this and the 2030 Sustainable Development Agenda (United Nations, 2015) to link adaptation to development and climate justice. It also highlighted the importance of multi-level adaptation governance, including new non-state voices and climate actors that widen the scope of adaptation governance beyond formal government institutions. For example, individuals can act as agents of changes in their own behavior, such as via change in their consumption patterns, but also generate change within organizations, fields of practice, and the political landscape of governance. Accordingly, these interactions among actors across different scales implies the need for wider modes of, and arena for, engagement around adaptation in order to accommodate a diversity of perspectives (*high agreement, medium evidence*) (Chung Tiam Fook, 2017; Lesnikowski et al., 2017; IPCC, 2018a).

In most regions, such new institutional and informal arrangements are at an early stage of development (*high agreement, limited evidence*). Further clarification and strengthening are needed to enable the fair sharing of resources, responsibilities, and authorities to enable climate action to enable climate-resilient development (Wood et al., 2017; IPCC, 2018a; Reckien et al., 2018). These are strongly linked to contested and complementary worldviews of climate change and the actors that use these worldviews to justify, direct, accelerate and deepen transformational adaptation and climate action.

18.4.1 Political Economy of Climate Resilient Development

Political economy studies (i.e., the origins, nature and distribution of wealth, and the ideologies, interests, and institutions that shape it) explicitly addressing CRD are quite limited. Yet, there is an extensive post-AR5 literature on political economy associated with various elements relevant to CRD including climate change and development (Naess et al., 2015); vulnerability, adaptation, and climate risk (Sovacool et al., 2015; Sovacool et al., 2017; Barnett, 2020); energy, decarbonization, and negative emissions technologies (Kuzemko et al., 2019; Newell, 2019); degrowth and low-carbon economies (Perkins, 2019; Newell and Lane, 2020); solar radiation management (Ott, 2018); planetary health and sustainability transitions and transformation (Kohler et al., 2019) (Gill and Benatar, 2020).

Four key insights regarding the nexus of political economy and CRD emerge from this literature. First, political economy drives coupled development-climate change trajectories and determines vulnerability, thereby potentially subjecting those least responsible for climate change to the greatest risk (Sovacool et al., 2015; Barnett, 2020). The prevailing political economy is itself now at risk as its legitimacy, viability and sustainability are called into question (Barnett, 2020). Yet, as underpinning ideologies, interests and institutions change, the drivers of vulnerability are often appropriated, the adaptation agenda is depoliticized, and market-based solutions advocated (Barnett, 2020).

Second, assessment of this literature suggests four attributes of the political economy of adaptation influence development trajectories in diverse settings, from Australia to Honduras and the Maldives (Sovacool et al., 2015), as delivered through the Global Environment Facility's Least Developed Countries Fund (Sovacool et al., 2017). These include enclosure (public resources or authority captured by private interests); exclusion (stakeholders are marginalized from decision-making); encroachment (natural systems and ecosystem services compromised); and entrenchment (inequality exacerbated). These attributes hamper adaptation efforts, and reveal the political nature of adaptation (Dolšak and Prakash, 2018) and by extension CRD. Paradoxically, development initiatives labelled as 'risk' reduction or resilience building or 'equitable and environmentally sustainable', such as coastal restoration efforts in Louisiana, USA, can compound inequity and climate risk, and perpetuate unsustainable development (Gotham, 2016; Eriksen et al., 2021b).

Third, a long-held view is that the effects of mitigation are global while those of adaptation are local. A political economy perspective, however, underscores cross-scale linkages, and shows that local adaptation efforts, vulnerability and climate resilience are manifest in development trajectories that are shaped by both local and trans-local drivers, and defined by unequal power relations that cross scales and levels (Sovacool et al., 2015; Barnett, 2020; Newell, 2020), including in key sectors like energy (Baker et al., 2014) and agriculture (Houser et al., 2019), as well as emergent blocs like BRICS (Power et al., 2016; Schmitz, 2017); and sub-national constellations, like cities (Fragkias and Boone, 2016; Béné et al., 2018).

Fourth, transitions towards CRD may be technically and economically feasible but are 'saturated' with power and politics (Tanner and Allouche, 2011) (18.3), necessitating focused attention to political barriers and enablers of CRD (Newell, 2019). With a narrow window of time to contain dangerous levels of global warming, political economy research calls for CRD trajectories that counter the globalized neoliberal hegemony (Newell and Lane, 2020), especially given the pandemic, and the intersection of economic power and public health, environmental quality, climate change, and human and indigenous rights (Bernauer and Slowey, 2020; Schipper et al., 2020b).

Given these insights, CRD can be understood as the sum of complex multi-dimensional processes consisting of large numbers of actions and social choices made by multiple actors from government, the private sector, and civil society, with important influences by science and the media *(very high confidence)*. These actions and social choices are determined by the available solution space and options, along with a range of enabling conditions (Section 18.4.2) that are largely bounded by individual and collective worldviews, and related ethics and values. This view is consistent with sustainable development being a *process constituted by multiple actions that are contested and have path dependencies and context-sensitive synergies and trade-offs with natural and embedded human systems* as well as bounded by multiple and contested knowledges and worldviews (Goldman et al., 2018; Heinrichs, 2020; Nightingale et al., 2020; Schipper et al., 2020b).

18.4.2 Enabling Conditions for Near-Term System Transitions

Given actors, institutions, and their engagement is fundamental to supporting system transitions needed for CRD (18.3) this section assesses recent literature with respect to how the values, choices and behaviors of those actors enable or constrain specific enabling conditions. Such enabling conditions represent opportunities for policymakers to pursue actions that contribute to CRD beyond direct risk management options such as climate adaptation and greenhouse gas mitigation (18.2.5.1, 18.2.5.2).

18.4.2.1 Governance and Policy

An overarching enabling conditions for achieving system transitions and transformations is the presence of enabling governance systems *(very high confidence).* Recent literature on the translation of governance into system transitions in practice suggests four key actions are important. The first is the critical reflection on so-called 'development solutions,' alternatively framed by some as 'empty promises,' that worsen climate risk, inequity, injustice and ultimately lead to unsustainable development (Mikulewicz, 2018; Mikulewicz and Taylor, 2020). Examples include development aid (Scoville-Simonds et al., 2020), large-scale development projects such as biofuel production in Ethiopia (Tufa et al., 2018), and urban growth management in Vietnam (DiGregorio, 2015). The second is the recognition that while the power of different actors and institutions is often tied to access to resources and the ability to constrain the actions of others, other dimensions of power such as its ability to produce knowledge as well as its contingency on circumstances and relationships are also important in enabling energy transitions: (Avelino et al., 2016; Avelino and Wittmayer, 2016; Lockwood et al., 2016; Ahlborg, 2017; Avelino and Grin, 2017; Partzsch, 2017; Smith and Stirling, 2018). Third, governance systems can help to develop productive interactions between formal government institutions, the private sector, and civil society including the provision 'safe arenas' for social actors to deliberate and pursue transitional and transformational change (Haukkala, 2018; Törnberg, 2018;

Strazds; Ferragina et al., 2020; Koch, 2020) (18.3.1, Box 18.1). Fourth, governance can address challenges such as climate change from a systems perspective and pursue interventions that address the interactions among development, climate change, equity and justice, and planetary health (Harvey et al., 2019; Hölscher et al., 2019). This is evidenced by recent experience with the COVID-19 pandemic response as well as ongoing escalation of disaster risk associated with extreme weather events (Walch, 2019; Cohen, 2020; Schipper et al., 2020b; Wells et al., 2020).

One output from systems of governance is formal policy frameworks and policies that influence processes and outcomes of system transitions that support CRD (18.1.3). The Paris Agreement, for example, provides a framework for CRD by defining a mitigation-centric goal of 'limiting warming to well below 2°C and enabling a transition to 1.5°C' (UNFCCC, 2015). It also provides for a broadly defined global adaptation goal (UNFCCC, 2015: Art. 7.1). The Nationally Determined Contributions (NDCs) are the core mechanism for achieving and enhancing climate ambitions under the Paris Agreement. However, the pursuit of a given NDC within a specific country will likely necessitate a range of other policy interventions that have more immediate impact on technologies and behavior, implicating transitions in energy, industry, land, and infrastructure *(very high confidence* (18.3.1). SDG-relevant activities are increasingly incorporated into climate commitments in the NDCs (at last count 94 NDCs also addressed SDGs), contributing to several (154 out of the 169) SDG targets (Brandi and Dzebo; Pauw et al., 2018). This reflects the potential of the NDCs as near-term policy instruments and sign-posts for progress toward CRD (*medium agreement, limited evidence*) (McCollum et al., 2018b).

As reflected by the SDGs (and SDG 13 specifically), the mainstreaming of climate change concerns into development policies is one mechanism for pursuing sustainable development and CRD *(very high confidence*). However, such mainstreaming has also been critiqued for perpetuating 'development as usual', reinforcing established development logics, structures and worldviews that are themselves contributing to climate change and vulnerability (O'Brien et al., 2015) and for obscuring and depoliticizing adaptation choices into technocratic choices (Murtinho, 2016; Webber and Donner, 2017; Benjaminsen and Kaarhus, 2018; Khatri, 2018; Scoville-Simonds et al., 2020). The coordinated implementation of sustainable development policy and climate action is nonetheless crucial for ensuring that the attainment of one does not come at the expense of others (Stafford-Smith et al., 2017). For example, aggressive pursuit of climate policies that facilitate transitions in energy systems can undermine efforts to secure sustainability transitions in other systems (18.3.1.1, 18.2.5.3, Table 18.7).

Several non-climate international policy agreements provide context for CRD such as the 1948 UN Universal Declaration of Human Rights, the UN Declaration on the Rights of Indigenous Peoples (Hjerpe et al., 2015); the Convention on Biological Diversity (CBD; UNFCCC, 1992) as well as the more recent Sendai Framework for Disaster Risk Reduction (UNDRR, 2015) and the 'new humanitarianisms' which seeks to reduce the gap between emergency assistance and longer term development (Marin and Naess, 2017). Collectively they provide a global policy framework that protects people's rights that are potentially threatened by climate change (Olsson et al., 2014). These policies are relevant to transitions across multiple systems, particular in societal systems toward more equitable and just development.

18.4.2.2 Economics and Sustainable Finance

18.4.2.2.1 Economics

System transitions toward CRD is contingent on reducing the costs of current climate variability on society while making investments that prepare for the future effects of climate change. Climate change and responses to climate change will affect many different economic sectors both directly and indirectly (Stern, 2007; IPCC, 2014a; Hilmi et al., 2017). As a consequence, the characteristics of economic systems will play an important role in determining their resilience *(very high confidence*). These effects will occur within the context of other developments, such as a growing world population, which increases environmental pressures and pollution (González-Hidalgo and Zografos, 2019; González-Hidalgo and Zografos, 2020). This impact is higher for developing countries than for high-income countries (Liobikienė and Butkus, 2018). While looking for sustainable climate-resilient policies, many complex and interconnected systems, including economic development, must be considered in the face of global-scale changes (Hilmi and Safa, 2010).

Miller (2017) discusses some of the planning for, and application of, adaptation measures that improve sustainability noting the importance of considering a range of factors including complexities of interconnected systems, the inherent uncertainties associated with projections of climate change impacts, and the effects of global-scale changes such as technological and economic development for decision makers. For example, addressing climate impacts in isolation is unlikely to achieve equitable, efficient, or effective adaptation outcomes *(very high confidence*). Instead, integrating climate resilience into growth and development planning allows decision makers to identify what sustainable development policies can support climate resilient growth and poverty reduction and understand better how patterns and trends of economic development affect vulnerability and exposure to climate impacts across sectors and populations, including distributional effects (Doczi, 2015). Markkanen and Anger-Kraavi (2019) highlighted that climate change mitigation policy can influence inequality both positively and negatively. Although higher levels of poverty, corruption and economic and social inequalities can increase the risk of negative outcomes, these potential negative effects would be mitigated if inequality impacts were taken into consideration in all stages of policy making *(very high confidence*).

The primary objective of economic and financial incentives around carbon emissions is to redirect investment from high to low carbon technologies (Komendantova et al., 2016). Recent years have seen policy interventions to incentivize transitions in energy, land, and industrial systems to address climate change and sustainability focus on price-based, as opposed to quantity-based, interventions. Price-based interventions aim at leveraging market mechanisms to achieve greater efficiency in the allocation of resources and costs of mitigating climate change. For example, carbon pricing initiatives around the world today cover approximately 8 gigatons of carbon dioxide emissions, equivalent to about 20% of global fossil energy fuel emissions and 15% of total carbon dioxide greenhouse gas emissions (Boyce, 2018). Meanwhile, environmental taxes and green public procurement push producers to eliminate the negative environmental effects of production (Danilina and Trionfetti, 2019). There are several advantages for environmental taxation including environmental effectiveness, economic efficiency, the ability to raise public revenue, and transparency *(very high confidence*). These gains can provide more resource-efficient production technologies and positively affect economic competitiveness (Costantini et al., 2018).

Policies encouraging eco-innovation, defined as "*new ideas, behavior, products, and processes that contribute to a decreased environmental burden*" (Yurdakul and Kazan, 2020), can positively affect economic competitiveness. By implementing policies to encourage eco-innovation, countries enhance their energy efficiency. These gains can provide more resource-efficient production technologies and positively affect economic competitiveness *(very high confidence*) (Liobikienė and Butkus, 2018) (Costantini et al., 2018). Other than eco-innovation, it is important to also consider exnovation, meaning the phasing out of old technologies, as otherwise the expansion of supply could lead to a rebound due to cheaper prices for carbon-based products (Arne Heyen et al., 2017; David, 2017). Hence, decarbonization strategies that set limits to carbon-based trajectories can be beneficial. Quantity-based interventions—or so-called 'command-and-control' policies—involve constraints on the quantity of energy consumption or greenhouse gas emissions through laws, regulations, standards and enforcement, with a focus on effectiveness rather than efficiency.

For a transition from dirty (more advanced) technologies to clean (less advanced) ones, market-based instruments such as carbon taxes should be considered alongside subsidies and other incentives that stimulate innovation (Acemoglu et al., 2016). Research and development in energy technologies, for example, can help reduce costs of deployment and therefore the costs of operating in a carbon-constrained world. Hémous (2016) indicates that a unilateral environmental policy which includes both clean research subsidies and trade tax can ensure sustainable growth, but unilateral carbon taxes alone might increase innovation in polluting sectors and would not generally lead to sustainable growth.

18.4.2.2.2 Climate finance

Achieving progress on system transitions will be contingent on the ability of actors and institutions to access the financing they need to invest in innovation, adaptation and mitigation, and broader system change *(very high confidence*). By greening their investment portfolios, investors can support reduction in vulnerability to the consequences of climate change and the reduction of greenhouse gas emissions. Finance can contribute to the reduction of GHG emissions, for example, by efficiently pricing the social cost of carbon, by reflecting the transition risks in the valuation of financial assets, and by channeling investments in low-carbon technologies (OECD, 2017). At the same time, there is a growing need to spur greater public and private capital into climate adaptation and resilience including climate-resilient infrastructure and nature-based solutions to climate change. For instance, the Green Climate Fund, established within the framework of the UNFCCC, is assisting developing countries in adaptation and mitigation initiatives to counter climate change.

Recent evidence sheds light on the magnitude and pervasiveness of climate risk exposure for global banks and financial institutions. According to Dietz et al. (2016), up to about 17% of global financial assets are directly exposed to climate risks, particularly the impacts of extreme weather events on assets and their outputs. However, when indirect exposures via financial counterparts are considered, the share of assets subject to climate risks is much larger (40-54%) (Battiston et al., 2017). Hence, the magnitude of climate-change-related risks is substantial, and similar to the ones that started the 2008 financial crisis (*high agreement, limited evidence*).

Financial actors increasingly recognize that the generation of long-term, sustainable financial returns is dependent on a stable, well-functioning and well-governed social, environmental and economic systems *(very high confidence*) (Shiller, 2012; Schoenmaker and Schramade, 2020). Institutional approaches to a variety of environmental domains (Krueger et al., 2019), which seek to integrate the pursuit of green strategies with financial returns include targeted investments in green assets (e.g., green bonds, clean energy public equity) and specialized funds/vehicles for as renewable energy infrastructure (Tolliver et al., 2019; Gibon et al., 2020); cleantech venture capital and alternative finance (Gianfrate and Peri, 2019); investment screening to steer capital to green industries (Nielsen and Skov, 2019; Ambrosio et al., 2020); and active ownership to influence organizational behavior (Silvola and Landau, 2021).

Despite the expansion of green mandates across the investment chain, definitions of some of the asset classes associated with green investing are ambiguous and poorly defined. The EU taxonomy for sustainable activities is a promising step in the right direction. For example, a “green” label for bonds is often stretched to encompass financing facilities of issuers that misrepresent the actual environmental footprint of their operations (the so-called risk of “greenwashing”). Even in cases where the bonds’ proceeds are actually used to finance green projects, investors often remain exposed to both the green and “brown” assets of the issuers (Gianfrate and Peri, 2019; Flammer, 2020). The heterogeneity of metrics and rating methodologies (along with inherent conflict of interests between issuers, investors and score/rating providers) results in inconsistent and unreliable quantification of the actual environmental footprint of corporate and sovereign issuers (Battiston et al., 2017; Busch et al.).

In order to promote financial climate-related disclosures for companies and financial intermediaries, the financial system could play a key role in pricing carbon and in allocating capital toward low-carbon emission companies (Aldy and Gianfrate, 2019; Bento and Gianfrate, 2020; Aldy et al., 2021). Stable and predictable carbon-pricing regimes would significantly contribute to fostering financial innovation that can help further accelerate the decarbonization of the global economy even in jurisdictions which are more lenient in implementing climate mitigation actions *(very high confidence*) (Baranzini et al., 2017). A growing number of financial regulators are intensifying efforts to enhance climate-related disclosure of financial actors. In particular, the Financial Stability Board created the Task Force on Climate-related Financial Disclosures (TCFD) to improve and increase reporting of climate-related financial information. Several countries are considering implementing mandatory climate risk disclosure in line with TCFD’s recommendations. Central Banks are also considering mandatory disclosure and climate stress-testing for banks. For instance, in November 2020 the European Central Bank (ECB) published a guide on climate-related and environmental risks explaining how the ECB expects banks to prudently manage and transparently disclose such risks under current prudential rules. The ECB also announced that banks in the Euro-zone will be stress tested on their ability to withstand climate change related risks. In addition to disclosure requirements and stress-testing, some Central Banks are considering the possibility of steering or tilting the allocation of their assets to favor the less polluting issuers (Schoenmaker, 2019). This, in turn, would translate into lower cost of capital for cleaner sectors, significantly accelerating the greening of the real economy.

[START BOX 18.7 HERE]

Box 18.7: 'Green' Strategies of Institutional Investors

Negative and positive screening. Investors assess the carbon footprint of issuers and identify the best and worst performers (Boermans and Galema, 2019). The issuers with excessive carbon footprint are divested and fall into the "exclusion lists" (negative screening). Alternatively, the investors commit to pick only the best in class (positive screening). As a bare minimum, screening approaches force more transparent environmental reporting from issuers. In the most optimistic scenario, in order to avoid exclusion lists issuers may progressively divest their non-green operations. In the long term, the combination of positive and negative screening will reward sustainable issuers relative to non-green sectors, thus reducing the cost of capital for less polluting entities.

Active ownership. Equity investors can exercise the voting rights at shareholders' meetings in relation to governance and business strategy, including the environmental performance. In addition, institutional investors engage with the management and the boards of directors of investee companies. Active ownership is therefore defined as the full exercise of the rights that accrue to the "owners" of the securities issued by companies (Dimson et al., 2015; Dimson et al., 2020). Active owners are entitled to question and challenge the robustness of financial analyses and the risk assessment behind strategic decisions including the environmental footprint ones. For instance, since fossil fuel businesses face the prospect of dramatic business decline (Ansar et al., 2013) and must revisit their business model to survive, active ownership by institutional investors may foster the transition to cleaner production and supply chain. Companies more exposed to carbon risks particularly need the active support of long-term shareholders. In turn, investors adopting an active ownership approach can manage their holdings' exposure to climate change risks, thus protecting the value of their investments on a long-term horizon (Krueger et al., 2019).

Specialized financial instruments and investors. New asset classes have been created to address the climate change challenge. Also specialized investment funds and vehicles came to life with the primary objective of addressing climate issues. While these financial instruments and funds prioritize the achievement of climate objectives, they do not sacrifice financial returns and are able to attract private capital. To mention a few examples:

- *Green bonds* are typically issued by companies, banks, municipalities, and governments with the commitment to use the proceeds exclusively to finance or refinance green projects, assets or business activities. These bonds are equivalent to any other bond issued by the same entity except for the label of "greenness" that ideally is verified ex-ante at the launch and ex-post when the proceeds are actually used by the issuer. Early evidence show that green bonds do not penalize financially issuers (Gianfrate and Peri, 2019; Flammer, 2020).
- *Carbon funds* are designed to help countries achieve long-term sustainability typically financing forest conservation. They are intended to reduce climate change impacts from forest loss and degradation.
- *Project finance.* New renewable energy initiatives are likely to recur more and more to project finance. Project finance relies on the creation of a special purpose vehicle (SPV), which is legally and commercially self-contained and serves only to run the renewable energy project. The SPV is financed without (or very limited) guarantees from the sponsors (typically energy companies: investors are therefore paid back on the basis only of SPV's future cash flows only and cannot recourse on the sponsors' assets (Steffen, 2018).
- *Cleantech venture capital*. These funds invest exclusively in early-stage companies working on innovative but not yet fully tested clean technologies. The risk profile of such investments is usually very high. The extent to which this segment of the financial industry can successfully support "deep" energy innovations is still debated (Gaddy et al., 2017). When cleantech start-ups develop hardware requiring a high upfront investment, support from the public sector seems necessary in order to attract further investments from large corporations and patient institutional investors.
- *Crowdfunding and alternative finance* are emerging as a channel to both finance small-scale clean energy projects as well as fund early stage innovative clean technologies (Cumming et al., 2017; Bento et al., 2019).

[END BOX 18.7 HERE]

18.4.2.3 Institutional capacity

Institutional capacity for system transitions refers to the capacity of structures and processes, rules, norms, and cultures to shape development expectations and actions aimed at durable improvements in human well-being. The AR5 highlighted the need for strong institutions to create enabling environments for adaptation and greenhouse gas mitigation action (Denton et al., 2014). Institutions stand within the social and political practices and broader systems of governance that ultimately drive adaptation and development processes and outcomes. They are thus produced by them and can become tools by which some actors constrain the actions of others (Gebreyes, 2018). As a consequence, they and can become a significant barrier to change, whether incremental or more transformational *(very high confidence*). The post-AR5 focus on transformational adaptation and resilience present in the literature suggests that institutions that enable system transitions toward CRD are secure enough to facilitate a wide range of voices, and legitimate enough to change goals or processes over time, without reducing confidence in their efficacy.

The limited literature on institutions and pathways relevant to system transitions and CRD suggests that institutions are most effective when taking a development-first approach to adaptation. This is consistent with the principles of CRD which emphasizes not simply reducing climate risk, but rather making development processes resilient to the changing climate. There is agreement in this literature that such an approach allows for the effective integration of climate challenges into existing policy and planning processes *(very high confidence*) (Pervin et al., 2013; Kim et al., 2017b; Mogelgaard et al., 2018). However, this approach generally rests on an incremental framing of institutional change (Mahoney and Thelen, 2009) based on two critical assumptions. The first is that existing processes and institutions are capable of bringing about system transitions that generate desired development outcomes and thus can be considered appropriate vehicles for the achievement of CRD. A large critical literature questions the efficacy of formal state and multilateral institutions. The evidence for the ability of local, informal institutions to achieve development goals remains uneven, with robust evidence of positive impacts on public service delivery, but more ambiguous evidence on behavior changes associated with strengthened institutions (Berkhout et al., 2018). The second is that the mainstreaming of adaptation will bring about changes to currently unsustainable development practices and pathways, instead of merely strengthening development-as-usual by subsuming adaptation to existing development pathways and allowing them to endure in the face of growing stresses (Eriksen et al., 2015; Godfrey-Wood and Otto Naess, 2016; Scoville-Simonds et al., 2020). There is evidence that countries with poor governance have limited adaptation planning or action at the national level, even when other determinants of adaptive capacity are present (Berrang-Ford et al., 2014). This suggests that, in these contexts, adaptation efforts are likely to be subsumed to existing government goals and actions, rather than having transformational impact.

18.4.2.4 Science, Technology & Innovation

Ongoing innovations in technology, finance, and policy have enabled more ambitious climate action over the past decade, including significant growth in renewable energy, electrical vehicles, and energy efficiency. However, access to, and the benefits of, that innovation have not been evenly distributed among global regions and communities and continued innovation is needed to facilitate climate action and sustainable development *(very high confidence*). Policymakers need useful science and information (Kirchhoff et al., 2013; Calkins, 2015; IPCC, 2019f) to make informed decisions about possible risks, and the benefits, costs, and trade-offs of available adaptation, mitigation, and sustainable development solutions (i.e., Article 4.1 of the Paris Agreement; UNFCCC, 2015). Moreover, recent literature has emphasized the need for deep technological, as well social, changes to avert the risks of conventional development trajectories (Gerst et al., 2013; IPCC, 2014a).

An effective and innovative technological regime is one that is integrated with local social entities across different modes of life, local governance processes (Pereira, 2018; Nightingale et al., 2020); and local knowledge(s), which increasingly support adaptation to socio-environmental drivers of vulnerability (Schipper et al., 2014; Nalau et al., 2018; IPCC, 2019f). These actors and their knowledge are often ignored in favor of knowledge held by experts and policymakers, exacerbating uneven power relations (Naess, 2013; Nightingale et al., 2020). For example, achieving sustainability and shifting towards a low carbon energy system (e.g., hydropower dams, wind farms) remains a contested space with divergent interests, values and prospects of future (Bradley and Hedrén, 2014; Avila, 2018; Mikulewicz, 2019), and potential impacts on human rights as embodied by the Paris Agreement (UNFCCC, 2015). A number of studies have emphasized the limits of relying upon technology innovation and deployment (e.g., expansion of renewable energy systems and/or carbon capture) as a solution to challenges of climate change and sustainable development (18.3.1.2). This is because such solutions may fail to consider the local historical contexts and barriers to participation of vulnerable communities, restricting their access to land, food, energy, and resources for their livelihoods.

18.4.2.5 Monitoring and Evaluation Frameworks

Enabling system transitions toward CRD is dependent in part on the ability to monitor and evaluate system transitions and broader development pathways to identify effective interventions and barriers to their implementation *(very high confidence*). However, the monitoring and evaluation of individual system transitions, much less CRD, remains highly challenging for multiple reasons (Persson, 2019). The highly contextual nature of resilience, adaptation and sustainable development means that, unlike climate mitigation, it is difficult to define universal metrics or targets for adaptation and resilience (Pringle and Leiter, 2018), (Brooks et al., 2014). This is demonstrated by the Paris Agreement's global goal for adaptation, The mismatch between timescales associated with resilience and adaptation interventions and those over which the results of such interventions are expected to become apparent tends to result in a focus on the measurement of spending, outputs, and short-term outcomes, rather than longer-term impacts (Brooks et al., 2014; Pringle and Leiter, 2018). The need to assess resilience and adaptation against a background of evolving climate hazards, and to link resilience and adaptation with development outcomes, present further methodological challenges *(very high confidence*) (Brooks et al., 2014).

Currently, the ability to monitor different components of CRD are in various stages of maturity *(very high confidence*). Monitoring of the sustainable development goals, for example, is a routine established practice at global and regional levels, and UNDP publishes annual updates on progress toward the SDGs (United Nations, 2021). For resilience, Brooks et al. (2014) identify three broad approaches to its measurement, each of which could offer potential mechanisms for monitoring progress toward CRD. One is a 'hazards' approach, in which resilience is described in terms of the magnitude of a particular hazard that can be accommodated by a system, useful in contexts where thresholds in climate and related parameters can be identified and linked with adverse impacts on human populations, infrastructure and other systems (Naylor et al., 2020). An 'impacts' approach is one in which resilience is measured in terms of actual or avoided impacts and is suited for tracking adaptation success in delivering CRD over longer timescales, for example at the national level (Brooks et al., 2014). Finally, a 'systems' approach is one where resilience is described in terms of the characteristics of a system using quantitative or qualitative indicators which are often associated with different 'dimensions' of resilience (Serfilippi and Ramnath, 2018; Saja et al., 2019). This allows measurement of key indicators that are proxies for resilience at regular intervals, even in the absence of significant climate hazards and associated disruptions (*very high confidence*) (Brooks et al., 2014) (see also Cross-Chapter Box ADAPT in Chapter 1). Similar criteria could be applied to evaluating adaptation options and their implementation as well as various interventions in pursuit of SDGs.

18.4.3 Arenas of Engagement

Much of the enabling conditions for system transitions discussed in 18.4.2 are inherently linked to actors and their agency in pursuing system change. Yet, a significant literature has developed since the AR5 exploring note only the role of different actors in pursuing adaptation, mitigation, and sustainable development options, but also how those actors interact with one another to drive outcomes. CRD pathways are determined by the interactions between societal actors and networks, including government, civil society and the private sector, as well as science and the media. The resultant social choices and cumulative private and public actions (and inactions) are institutionalized through both formal and informal institutions that evolve over time and seek to provide societal stability in the face of change. The degree to which the emergent pathways foster just and climate resilient development depends on how contending societal interests, values and worldviews are reconciled through these interactions. These interactions occur in many different arenas of engagement, i.e., the settings, places and spaces in which societal actors interact to influence the nature and course of development, including political, economic, socio-cultural, ecological, knowledge-technology and community arenas (Figures 18.1, 18.2).

For example, political arenas range from formalized election and voting procedures to more informal and less transparent practices, like special interest lobbying. Town squares and streets can become sites of political struggle and dissent, including protests against climate inaction. As a more specific case-in-point, the formal space for national, sub-national and international adaptation governance emerged at COP 16 (UNFCCC, 2010) when adaptation was recognized as having a similar level of priority as mitigation. The Paris Agreement (UNFCCC, 2015) built on this and the 2030 Sustainable Development Agenda (United Nations, 2015) to link adaptation to development and climate justice, widening the scope of adaptation governance beyond formal government institutions. It also highlighted the importance of multi-level adaptation governance, including non-state voices from civil society and the private sector. This implied the need for wider arenas and modes of engagement around adaptation (Chung Tiam Fook, 2017; Lesnikowski et al., 2017; IPCC, 2018a) that facilitate coordination and convergence among these diverse actors including individual citizens to collectively solve problems and unlock the synergies between adaptation and mitigation and sustainable development (IPCC, 2018a; Romero-Lankao et al., 2018).

There are many other visible and less visible arenas of engagement in the other interconnected spheres of societal interaction spanning scales from the local to international level. The metaphor of arenas derives from diverse social and political theory, with applications in studies of, among other things, governance transformation and transitions (Healey, 2006; Jørgensen, 2012; Jørgensen et al., 2017). It underscores that these arenas can be enduring or temporary in nature, are historically situated and often spatially bounded, and signifies the many different mechanisms by which societal actors interact in dynamic and emergent ways. Power and politics impact access and influence in these arenas of engagement – with varying levels of inclusion and exclusion shaping the nature and trajectory of development. In practice, some arenas of engagement are 'struggle arenas' as different societal actors strive to influence the trajectory of development, with inevitable winners and losers.

Institutional arrangements to foster CRD are at an early stage of development in most regions (*medium agreement, limited evidence*). They need to be further clarified and strengthened to enable a sharing of resources and responsibilities that facilitate climate actions embracing climate resilience, equity, justice, poverty alleviation and sustainable development (Wood et al., 2017; IPCC, 2018a; Reckien et al., 2018). These endeavours are strongly influenced by how contested and complementary worldviews about climate change and development are mobilised by societal actors to justify, direct, accelerate and deepen transformational climate action or entrench maladaptive business as usual practices (18.4.3.1).

18.4.3.1 Worldviews

Worldviews are overarching systems of meaning and meaning-making that inform how people interpret, enact, and co-create reality (De Witt et al., 2016). Worldviews shape the vision, beliefs, attitudes, values, emotions, actions, and even political and institutional arrangements. As such, they can promote holistic, egalitarian approaches to enable, accelerate and deepen climate action and environmental care (Ramkissoon and Smith, 2014; De Witt et al., 2016; Lacroix and Gifford, 2017; Sanganyado et al., 2018; Brink and Wamsler, 2019). Alternatively, they can also serve as significant barriers to system transitions and transformation, based on anthropocentric, mechanistic and materialistic, worldviews and the utilitarian, individualist or skeptical values and attitudes they often promote *(very high confidence*) (Beddoe et al., 2009; van Egmond and de Vries, 2011; Stevenson et al., 2014; Zummo et al., 2020).

Traditional, modern and postmodern worldviews have different, and in many ways, complementary potentials for integrative diverse approaches to climate action and sustainable development. They can also destabilize climate-sensitive societal values (van Egmond and de Vries, 2011; Van Opstal and Hugé, 2013; De Witt et al., 2016; Shaw, 2016) which are predictors of concern (Shi et al., 2015). Among the challenges of strongly different climate-related worldviews, is that they rarely co-exist. Some worldviews become incompatible or hostile to other worldviews, openly seeking to dominate, eliminate or segregate competing perspectives (*medium agreement, medium evidence*) (de Witt, 2015; Jackson, 2016; Nightingale, 2016; Xue et al., 2016; Goldman et al., 2018).

To address these difficult contests, climate- and global environmental change-related worldviews are often scientized. This can exclude other worldviews which ultimately narrows understanding of climate change and the solution space. Hence, the post-AR5 literature on worldviews focuses on the numerous meanings, associations, narratives and frames of climate change and how these shape perceptions, attitudes and values (Morton, 2013; Boulton, 2016; Hulme, 2018; Nightingale Böhler, 2019). The recognition of the diversity of interpretations and meanings has led to multidisciplinary and transdisciplinary research that incorporates the humanities and the arts (Murphy, 2011; Elliott and Cullis, 2017; Steelman et al., 2019; Tauginienė et al., 2020), feminist studies (MacGregor, 2003; Demeritt et al., 2011; Bell, 2013; Brink and Wamsler, 2019; Plesa, 2019) and religious studies (Sachdeva, 2016; McPhetres and Zuckerman, 2018) to examine diverse understandings of reality and knowledge possibilities around climate change. In addition, literature on cultural cognition, epistemological plurality and relational ontologies draws on non-Western worldviews and forms of knowledge (Goldman et al., 2018) (Jackson, 2016; Nightingale, 2016; Xue et al., 2016).

On the other hand, the tendence for certain worldviews to dominate the policy discourse has the potential to exacerbate social, economic and political inequities *(very high confidence*). ontological, epistemic and procedural injustices. Research aimed at exploring the existing political ontology and knowledge politics of exclusion that marginalize certain communities and actors originated in academic, or scientific perspectives. This includes institutions such as the IPCC and is subsequently replicated in social representations, including the media, public policy and the development agenda, narrowing possibilities for social transformation (Jackson, 2014; Luton, 2015; Escobar, 2016; Burman, 2017; Newman et al., 2018; Sanganyado et al., 2018; Wilson and Inkster, 2018).

[START CROSS-CHAPTER BOX INDIG HERE]

Cross-Chapter Box INDIG: The Role of Indigenous Knowledge and Local Knowledge in Understanding and Adapting to Climate Change

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Indigenous knowledge refers to the understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings (UNESCO, 2018; IPCC, 2019a). Local knowledge refers to the understandings and skills developed by individuals and populations, specific to the places where they live (UNESCO, 2018; IPCC, 2019a). Indigenous knowledge and local knowledge are inherently valuable but have only recently begun to be appreciated and in western scientific assessment processes in their own right (Ford et al., 2016). In the past these often endangered ways of knowing have been suppressed or attacked (Mustonen, 2014). Yet these knowledge systems represent a range of cultural practices, wisdom, traditions, and ways of knowing the world that provide accurate and useful climate change information, observations, and solutions (*very high confidence*) (Table Cross-Chapter Box INDIG.1). Rooted in their own contextual and relative embedded locations, some of these knowledges represent unbroken engagement with the earth, nature and weather for many tens of thousands of years, with an understanding of the ecosystem and climatic changes over longer-term timescales that is held both as knowledge by Indigenous Peoples and Local Peoples as well as in the archaeological record (Barnhardt and Angayuqaq, 2005; UNESCO, 2018).

Indigenous Peoples around the world often hold unique worldviews that link today's generations with past generations. In particular, many Indigenous Peoples consider concepts of responsibility through intergenerational equity, thereby honouring both past and future generations (Matsui, 2015; McGregor et al., 2020). This can often be in sharp contrast to environmental valuing and decision-making that occurs in Western societies (Barnhardt and Angayuqaq, 2005). Therefore, consideration of Indigenous knowledge and local knowledge needs to be a priority in the assessment of adaptation futures (Nakashima et al., 2012)(Ford et al., 2016) (Chapter 1), although adequate Indigenous cultural and intellectual property rights require legal and non-legal measures for recognition and protection (Janke, 2018).

Indigenous knowledge and local knowledge are crucial to address environmental impacts, such as climate change, where the uncertainty of outcome is high and a range of responses are required (Mackey and Claudie, 2015). However, working with this knowledge in an appropriate and ethically acceptable way can be challenging. For instance, questions of data 'validity' and the requirement to communicate such knowledge in the dominant language can lead to inaccurate portrayals of Indigenous knowledge as inferior to science. This may overlook the uniqueness of Indigenous knowledge and then lead to the overall devaluation of Indigenous political economies, cultural ecologies, languages, educational systems, and spiritual practices (Smith, 2013; Sillitoe, 2016; Naude, 2019; Barker and Pickerill, 2020). Furthermore, Indigenous knowledge is too often only sought superficially – focusing only on the 'what', rather than the 'how' of climate change adaptation and/or seen through the lenses of 'romantic glorification' leaving little room for the knowledge to be expressed as authored by the communities and knowledge holders themselves (Yunkaporta, 2019).

Multiple knowledge systems and frameworks

Indigenous knowledge systems include not only the specific narratives and practices to make sense of the world, but also profound sources of ethics and wisdom. They are networks of actors and institutions that organise the production, transfer and use of knowledge (Löfmarck and Lidskog, 2017). There is a pluralism of forms of knowledge that emerge from oral traditions, local engagement with multiple spaces, and Indigenous cultures (Peterson et al., 2018). Recognising such multiplicity of forms of knowledge has long been an important concern within sustainability science (Folke et al., 2016). Less dominant forms of knowledge should not be put aside because they are not comparable or complementary with scientific knowledge (Brattland and Mustonen, 2018; Mustonen, 2018; Ford et al., 2020; Ogar et al., 2020). Instead, Indigenous knowledge and local knowledge can shape how climate change risk is understood and experienced, the possibility of developing climate change solutions grounded in place-based experiences, and the development of governance systems that match the expectations of different Indigenous knowledge and local knowledge holders (*very high confidence*).

Different frameworks that enable the inclusion of Indigenous knowledge have emerged from efforts to utilise more than one knowledge system (*high evidence, high agreement*). For example, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has developed a 'nature's contribution to peoples' framework that provides a common conceptual vocabulary and structural analysis (Díaz et al., 2015; Tengö et al., 2017; Díaz et al., 2018; Peterson et al., 2018). The IPBES approach complements other efforts to study areas of intersection between scientific and Indigenous worldviews (Barnhardt and Angayuqaq, 2005; Huaman and Sriraman, 2015) or 'boundaries' that illustrate 'blind spots' in scientific knowledge (Cash et al., 2003; Clark et al., 2016; Brattland and Mustonen, 2018). These frameworks highlight areas of collaboration but provide less guidance in areas where sources of evidence conflict across different knowledge systems (Löfmarck and Lidskog, 2017). These experiences suggest that the inclusion of Indigenous knowledge and local knowledge in international assessments may transform the process of assessment of scientific, technical, and socio-economic evidence (*medium evidence, high agreement*). These knowledge systems also point to novel discoveries that may be still unknown to the scientific world but have been known by communities for millennia (Mustonen and Feodoroff, 2020).

The importance of free and prior-informed consent

Obtaining free and prior-informed consent is a necessary but not sufficient condition to engage in knowledge production with Indigenous Peoples (Sillitoe, 2016). Self-determination in climate change assessment, response, and governance is critical (Chakraborty and Sherpa, 2021), and Indigenous Peoples are actively contributing to respond to climate change (Etchart, 2017). Climate change assessment and adaptation should be self-determined and led by Indigenous Peoples, acknowledge the importance of developing genuine partnerships, respect Indigenous knowledge and ways of knowing, and acknowledge Indigenous Peoples as stewards of their environment (Country et al., 2016; Country et al., 2018; ITK, 2019; Barker and Pickerill, 2020; Chakraborty and Sherpa, 2021). Supporting Indigenous Peoples' leadership and rights in climate adaptation options at the local, regional, national and international levels is an effective way to ensure that such options are adapted to their living conditions and do not pose additional detrimental impacts to their lives (*very high confidence*). Chapter 18 shows that the transformations required to deliver climate resilient futures will create societal disruptions, with impacts that are most often unevenly experienced by groups with high exposure and sensitivity to climate change, including Indigenous Peoples and local communities (Schipper et al., 2020a). Climate-resilient futures depend on finding strategies to address the causes and drivers of deep inequities (Chapter 18). For example, climate resilient futures will depend on recognising the socio-economic, political and health inequities that often affect Indigenous Peoples (Mapfumo et al., 2016; Ludwig and Poliseli, 2018) (*very high confidence*).

International conventions to support and utilize Indigenous knowledge and local knowledge

Several tools within international conventions may support instruments to develop equitable processes that facilitate the inclusion Indigenous knowledge and leadership in climate change adaptation initiatives. The International Labour Convention 69 recognised Indigenous People's right to self-determination in 1989 (ILO, 1989). The United Nations' Declaration on the Rights of Indigenous Peoples (United Nations, 2007) includes articles on the right to development (Article 23), the right to maintain and strengthen their distinctive spiritual relationship and to uphold responsibilities to future generations (Article 25), and the right to the conservation and protection of the environment and the productive capacity of their territories (Article 29). Article 26 upholds the right to the lands, territories and resources, the right to own, use, develop and control the lands, and legal recognition and protection of these lands, territories, and resources. Indigenous Peoples are also recognized within the Sustainable Development Goals as a priority group (Carino and Tamayo, 2019). International events such as the 'Resilience in a time of uncertainty: Indigenous Peoples and Climate Change' Conference brought together Indigenous Peoples' representatives and government leaders from around the world to discuss the role of Indigenous Peoples in climate adaptation (UNESCO, 2015).

The value of Indigenous knowledge and local knowledge in climate adaptation planning

There have been increasing efforts to enable Indigenous knowledge holders to participate directly in IPCC assessment reports (Ford et al., 2012; Nakashima et al., 2012; Ford et al., 2016). Adaptation efforts have benefited from the inclusion of Indigenous knowledge and local knowledge (IPCC, 2019e) (*very high confidence*). Moreover, it has been recognized that including Indigenous knowledge and local knowledge in IPCC reports can contribute to overcoming the combined challenges of climate change, food security, biodiversity conservation, and combating desertification and land degradation (IPCC, 2019c) (*high confidence*). Limiting warming to 1.5°C necessitates building the capability of formal assessment processes to respect, include and utilize Indigenous knowledge and local knowledge (IPCC, 2018a) (*medium evidence, high agreement*).

However, these efforts have been accompanied by a recognition that 'integration' of Indigenous knowledge and local knowledge cannot mean that those knowledge systems are subsumed or required to be validated through typical scientific means (Gratani et al., 2011; Matsui, 2015). Such a critique of 'validity' can be inappropriate, unnecessary, can disrespect Indigenous Peoples' own identities and histories, limits the advancement and sharing of these perspectives in the formal literature, and overlooks the structural drivers of oppression and endangerment that are associated with Western civilization (Ford et al., 2016). Moreover, by underutilizing Indigenous knowledge and local knowledge systems, opportunities that could otherwise facilitate effective and feasible adaptation action can be overlooked. We should also reserve space for the understanding that each cultural knowledge system, building on linguistic-cultural endemicity, is unique and inherently valuable.

Indigenous Peoples have often constructed their ways of knowing using oral histories as one of the vehicles of mind and memory, observance, governance, and maintenance of customary law (Table Cross-Chapter Box INDIG.2). These ways of knowing can also incorporate the relationships between multiple factors simultaneously which adds particular value towards understanding complex systems that is in contrast to the dominant reductionist, Western approach- noting that non-reductionist approaches also exist (Ludwig et al., 2014; Hoagland, 2017).

For climate research, the role of oral histories as a part of Indigenous knowledge and local knowledge is extremely relevant. For example, ocean adaptation initiatives can be guided by oral historians and keepers of knowledge who can convey new knowledge and baselines of ecosystem change over long-time frames (Nunn and Reid, 2016). Oral histories can also convey cultural indicators and linguistic devices of species identification as a part of a local dialect matrix and changes in ecosystems and species using interlinkages not available to science (Mustonen, 2013; Frainer et al., 2020). Oral histories attached to maritime place names, especially underwater areas (Brattland and Nilsen, 2011), can position observations relevant for understanding climate change over long ecological timeframes (Nunn and Reid, 2016). Species abundances, well-being and locations are some of the examples present in the ever-evolving oral histories as living ways of knowing. Indigenous knowledge and oral histories may also have the potential to convey governance, moral, and ethical frameworks of sustainable livelihoods and cultures (Mustonen and Shadrin, 2020) rooted in the particular Indigenous or local contexts that are not otherwise available in written or published forms.

Climate change research involving Indigenous Peoples and local communities has shown that the generation, innovation, transmission, and preservation of Indigenous knowledge is threatened by climate change (Kermoal and Altamirano-Jiménez, 2016; Simonee et al., 2021). This is because Indigenous knowledge is taught, local knowledge is gained through experience, and relationships with the land are sustained through social engagement within and among families, communities, and other societies (Tobias J.K, 2014; Kermoal and Altamirano-Jiménez, 2016). The knowledge that has traditionally been passed on in support of identity, language and purpose has been disrupted at an intergenerational level (Lemke and Delormier, 2017). Many of these dynamics have affected local knowledge transfers equally (Mustonen, 2013). This scenario represents a tension for Indigenous Peoples, where Indigenous knowledge in the form of land-based life ways, languages, food security, intergenerational transmission and application are threatened by climate change, yet in parallel, these same practices can enable adaptation and resilience (McGregor et al., 2020).

Table Cross-Chapter Box INDIG.1: Examples of Indigenous knowledge and local knowledge about climate change used in this Assessment Report

Issue	**Examples of Indigenous Peoples' and local communities' action**	**Context, peoples, and location**	**Source**
Climate forecasting/early warning	Phenological cues to forecast and respond to climate change	Smallholder farmers, Delta State, Nigeria	Ch9
	Forecasting of weather and climate variation through observation of the natural environment (e.g. changes in insects, and wildlife).	Afar pastoralists, north-eastern Ethiopia	
	Observation of wind patterns to plan response to coastal erosion/flooding	Inupiat, Alaska, US	Ch14
	Sky and moon observation to determine the onset of rainy season	Maya, Guatemala	Ch12
Fire hazards	Prescribed burning	Indigenous nations in Venezuela, Brazil, Guyana, Canada, and US	Ch12 Ch14
Crop yield / food security	Water management, native seeds conservation and exchange, crop rotation, polyculture, and agroforestry	Mapuche, Chile	Ch12
	Crop association (milpa) agroforestry, land preparation and tillage practices, native seed selection and exchange, adjusting planting calendars,	Maya, Guatemala	Ch12
	Harvesting rain-water and the use of maize landraces by Indigenous farmers to adapt to climate impacts and promote food security in Mexico	Yucatán Peninsula, Mexico	Ch14
Livelihood and well-being	Cultural values ingrained in knowledge system: reciprocity, collectiveness, equilibrium, and solidarity	Quechua, Cusco, Peru	Ch12
Ecosystem degradation	Ecosystem restoration including rewilding	Sámi, Nenets, and Komi, Scandinavia and Siberia	Ch13
	Collaboration with researchers, foresters, and landowners to manage native black ash deciduous trees against emerald ash borer	Indigenous Nations in Canada and US	Ch14
	Selection and planting of native plants that reduce erosion Whole-of-island approaches that embed IK and LK in environmental governance	Small islands states (as defined by Chapter 15)	Ch15
Fisheries	Traditional climate-resilient fishing approaches	Indigenous nations across North America and the Arctic	Ch14 CCP6

Management of urban resources	Restoration of traditional network of water tanks	Traditional communities and activists in South Indian cities such as Bengaluru	Ch6

Table Cross-Chapter Box INDIG.2: Case Study Summary

Region	Summary
Africa	Many rural smallholder farmers in Africa use their ingrained Indigenous knowledge systems to navigate climatic changes as many do not have access to Western systems of weather forecasting. Instead, these farmers have been reported to use observations of clouds and thunderstorms, and migration of local birds to determine the start of the wet season, as well as create temporary walls by rivers to store water during droughts. Indigenous knowledge systems should be incorporated into strategic plans for climate change adaptation policies to help smallholder farmers cope with climate change (Mapfumo et al., 2016).
Arctic	For local Inuit hunters and others who travel across Arctic land, ice and sea, there is evidence that the most accurate approach to reduce risk and enable informed decision-making for safe travel, is to combine Indigenous knowledge and local observations of weather with official online weather and marine services information that is available nationally (Simonee et al., 2021). Combining Inuit and local knowledge of weather, water, ice, and climate information with official forecasts has provided local hunters with more accurate, locally relevant information, and has on several occasions helped to avoid major weather-related accidents.
Latin America	In Venezuela, Brazil, and Guyana, Indigenous knowledge systems have led to a lower incidence of wildfires, reducing the risk of rising temperatures and droughts (Mistry et al., 2016). The Mapuche Indigenous Peoples in Chile use various traditional and sustainable agricultural practices, including: native seed conservation and exchange (*trafkintu*), crop rotation, polyculture, and tree-crop association. They also give thanks to Mother Earth through rituals to nurture socioecological sustainability (Parraguez-Vergara et al., 2018). In rural Cusco Region of Peru, "cultures values known in Quechua as *ayni* (reciprocity), *ayllu* (collectiveness), *yanantin* (equilibrium) and *chanincha* (solidarity)" have led to successful adaptation to climate change (Walshe and Argumedo, 2016).
Māori (Aotearoa New Zealand)	The traditional calendar system (*maramataka*) used by the Māori in Aotearoa-New Zealand incorporates ecological, environmental and celestial Indigenous knowledge. Māori practitioners are collaborating with scientists through the Effect of Climate Change on Traditional Māori Calendars project (Harris et al., 2017) to examine if climatic changes are impacting the use of the *maramataka*, which can be used as a framework to identify and explain environmental changes. Observations are being documented across Aotearoa, New Zealand to improve understandings of environmental changes and explore the use of Indigenous Māori knowledge in climate change assessment and adaptation.
Skolt Sámi (Finland)	In 2011, the Skolt Sámi in Finland began the first co-governance initiative where collaborative management and Indigenous knowledge were utilized to effectively manage a river and Atlantic Salmon (*Salmo salar*). This species is culturally and spiritually significant to the Skolt Sámi and has been adversely impacted by rising water temperatures and habitat loss (Brattland and Mustonen, 2018; Feodoroff, 2020; Ogar et al., 2020) (see also CCP Polar). Using Indigenous knowledge, they mapped changes in catchment areas and used cultural indicators to determine the severity of changes. Through collaborative management efforts that utilized both Indigenous knowledge and science, spawning and juvenile habitat areas for trout and grayling were restored, demonstrating the autonomous community capacity (Huntington et al., 2017) of the Indigenous Skolt Sámi and the capacity of Indigenous knowledge to address climate change impacts and detection of very first microplastics pollution together with science (Pecl et al., 2017; Brattland and Mustonen, 2018; Mustonen and Feodoroff, 2020).

[END CROSS-CHAPTER BOX INDIG HERE]

18.4.3.2 Political and government arenas

Climate resilient development is embedded in social systems, in the political economy and its underlying ideologies, interests and institutions (see 18.4.1). The pursuit of CRD, and shifting development pathways away from prevailing trends, unfolds in an array of political arenas, from the offices of bureaucrats to parliament buildings, sidewalks and streets, to discursive arenas in which governance actors interact – from the village level to global forums (Jørgensen et al., 2017; Montoute et al., 2019; Sørensen and Torfing, 2019; Pasquini, 2020). Paradoxically, the post-AR5 literature suggests that political arenas are often used to shut down efforts to explore the solution space for climate change and sustainable development (*medium agreement, robust evidence*) (e.g., Kenis and Mathijs, 2012; Kenis and Mathijs, 2014; Beveridge and Koch, 2016; Kenis and Lievens, 2016; Driver et al., 2018; Meriluoto, 2018; Swyngedouw, 2018; Mocca and Osborne, 2019). Power relationships among different actors create opportunities for people to be included or excluded in collective action (Siméant-Germanos, 2019) (18.3.1.6, 18.4.3.5). Therefore, as evidenced by examples from the UK (MacGregor, 2019) and China (Huang and Sun, 2020) small-scale collective environmental action has transformative potential in part due to its ability to increase levels of cooperation among different actors (*medium agreement, limited evidence*) (Green et al., 2020; Blühdorn and Deflorian, 2021).

In addition to the 'arm's length' acts of voting, social mobilisation, protest, and dissent can be critical catalysts for transformative change (Porta, 2020). These are competitions for recognition, power, and authority (Nightingale, 2017) that take place in settings. This is evidenced by experiences from the energy sector in Bangladesh which became a contested national policy domain and where social movements eventually transformed the nation's energy politics (Faruque, 2017). Similarly, in Germany, the nation's energy transition led to marked changes in agency, legal frameworks, and energy markets drove the proliferation of so-called municipalizations of energy systems – a reversal of years of system privatization (Becker et al., 2016). Meanwhile, experience in Bolivia demonstrate that the transformative potential of political conflict depends on transcending narrow issues to form broad coalitions with a collective identity that challenge prevailing development objectives and trajectories (Andreucci, 2019). Such examples illustrate the power of the communities as a vanguard against environmentally destructive practices (Villamayor-Tomas and García-López, 2018). Social movements have been successful at countering fossil fuel extraction (Piggot, 2018) and open up political opportunities in the face of increasing efforts to capture natural resources (Tramel, 2018) and are bolstered by resistance from within some corporations and/or their shareholders (Fougère and Bond, 2016; Swaffield, 2017).

Coincident with these social movements targeting climate change and sustainability has been a rise of political conservatism and populism as well as growth in misinformation (*high agreement, medium evidence*) (Mahony and Hulme, 2016; Swyngedouw, 2019). This reflects efforts to maintain the status quo by actors in positions of power in the face of rising social inertia for climate action (Brulle and Norgaard, 2019). Political arenas of the future may even require a new body politic that includes non-humans and a new geo-spatial politics (Latour et al., 2018).

As introduced in the discussion of governance as an enabling condition (18.4.2.1), a wide range of actors are involved in successful adaptation, mitigation, and sustainability policy and practice including national, regional and local governments, communities, and international agencies (Lwasa, 2015). As of 2018, 197 countries had between them over 1,500 laws and policies addressing climate change as compared to 60 countries with such legislation in 1997 when the Kyoto Protocol was agreed upon (Nachmany et al., 2017; Nachmany and Setzer, 2018). In judicial branches, climate change litigation is increasingly becoming an important influence on policy and corporate behavior among investors, activists, and local and state governments (Setzer and Byrnes, 2019). There is enhanced action on climate change at both national and subnational levels, even in cases where national policies are inimical as in USA (Carmin et al., 2012; Hansen et al., 2013).

The strong role of governments in climate action has implications for the nature of democracy, the relationship between the local and the national state, and between citizens and the state (Dodman and Mitlin, 2015). More integration of government policy and interventions across scales, accompanied by capacity building to accelerate adaptation is needed *(very high confidence*). Key needs include enhanced funding, clear roles and responsibilities, increased institutional capability, strategic approaches, community engagement, judicial integrity (Lawrence et al., 2015). More resources, and more active involvement of the private sector and civil society can help maintain adaptation on the policy agenda. Multilevel adaptation approaches are also relevant in low-income countries where local governments have limited financial resources and human capabilities often leading to dependency on national governments and donor organizations (Donner et al., 2016; Adenle et al., 2017).

Unlike mitigation, adaptation has traditionally been viewed as a local process, involving local authorities, communities, and stakeholders (Preston et al., 2015). The literature on the governance of adaptation continues to emphasize that local governments have demonstrated leadership in implementation by collaborating with the private sector and academia. Local governments can also play a key role (Melica et al., 2018; Romero-Lankao et al., 2018) in converging mitigation and adaptation strategies, coordinating and develop effective local responses, enabling community engagement and more effective policies around exposure and vulnerability reduction (Fudge et al., 2016). Local authorities are well-positioned to involve the wider community in designing and implementing climate policies and adaptation implementation (Slee, 2015; Fudge et al., 2016). Local governments also help deliver basic services, and protect their integrity from climate impacts (Austin et al., 2015; Cloutier et al., 2015; Nalau et al., 2015; Araos et al., 2017). However, the resource limitations of local governments as well as their small geographic sphere of influence suggests the need for more funding for this from higher levels of government, particularly national governments, to address adaptation gaps *(very high confidence*) (Dekker, 2020). Local adaptation implementation gaps can be linked to limited political commitment at higher levels of government and weak cooperation between key stakeholders (Runhaar, 2018). Incongruities and conflicts can exist between adaptation agendas pursued by national governments and the spontaneous adaptation practices of communities. There may be grounds for re-evaluating current consultative processes integral to policy development, if narrow technical approaches emerge as the norm for adaptation (Smucker et al., 2015).

Therefore, the traditional view of adaptation as a local process has now widened to recognize it as a multi-actor process that transcends scales from the local and sub-national to national and even international *(very high confidence* (Mimura et al., 2014). Many of the impacts of climate change are both local and transboundary, so that local, bilateral and multilateral cooperation are needed (Nalau et al., 2015; Donner et al., 2016; Magnan and Ribera, 2016; Tilleard and Ford, 2016; Lesnikowski et al., 2017). National policies and transnational governance should be seen as complementary, especially where they favor transnational engagement with sub- and non-state actors (Andonova et al., 2017). National governments typically act as a pivot for adaptation coordination, planning, determining policy priorities, and distributing financial, institutional and sometimes knowledge resources. National governments are also accountable to the international community through international agreements. National governments have helped enhance adaptive capacity through building awareness of climate impacts, encouraging economic growth, providing incentives, establishing legislative frameworks conducive to adaptation, and communicating climate change information (Berrang-Ford et al., 2014; Massey et al., 2014; Austin et al., 2015; Huitema et al., 2016).

18.4.3.3 Economic and financial arenas

The performance of local, national, and the global economies is a priority consideration shaping perceptions of climate risk and the costs and benefits of different policy responses to climate change. The most commonly used indicator of performance is gross domestic product (GDP) (Hoekstra et al., 2017). Traditionally, national development efforts have sought to maximize the growth of GDP under the assumption that GDP growth equates not only to economic prosperity (including poverty reduction) but also to increased efficiency and reduced environmental externalities (Ota, 2017). Such assumptions often employ models such as the environmental Kuznets curve (EKC) that postulates that economic development initially increases environmental impacts, but these trends eventually reverse with continued economic growth. Wealthy nations of the global North, including for example the United States, Great Britain, Iceland, Japan, have had success over the past decade in reducing their greenhouse gas emissions while growing their economies *(very high confidence*). However, attempts to empirically test EKC in different national contexts has yielded mixed results. Case studies in Myanmar, China, and Singapore, for example, suggest that the impacts of GDP on environmental quality are contingent on the development context and the environmental impact under consideration (Aung et al., 2017; Lee and Thiel, 2017; Xu, 2018; Chen and Taylor, 2020). In addition, an extensive literature now argues that current patterns of development, and the economic systems underpinning that development, are unsustainable (Washington and Twomey, 2016), and thus economic growth may not necessarily continue indefinitely in the absence of more concerted effort to pursue sustainable development, including reducing the impacts of climate change.

Given such criticisms of the link between development and economic growth, a growing number of researchers argue for the need for alternatives to GDP to guide development and evaluate the costs and benefits of different policy interventions (Hilmi et al., 2015). For example, while GDP growth can drive growth in income, it can also drive growth in inequality which can undermine poverty reduction efforts *(very high confidence*) (Fosu, 2017). Hence, recent years have seen significant interest in the concept of well-being as a more robust measure for linking policy and the economy with sustainable development for a healthy Anthropocene era (Fioramonti et al., 2019).

Another mechanism for evaluating environmental performance is to include environmental data in the System of National Accounts (SNA) through the System of Environmental-Economic Accounting (SEEA) introduced by the UN. As the international statistical standard for environmental-economic accounting (Pirmana et al., 2019), SEEA includes natural capital resources in national accounting. A number of recent studies conclude that failure to account for natural capital in macroeconomic impact assessments results in overly optimistic outcomes (Pirmana et al., 2019; Jendrzejewski, 2020; Naspolini et al., 2020), (Banerjee et al., 2019; Kabir and Salim, 2019; Keith et al., 2019). For example, Jendrzejewski (2020) inserted natural capital into a computable general equilibrium model of the 2017 European windstorm on state-owned forests in Poland. This resulted in more negative assessment of impacts, suggesting excluding natural capital could lead to erroneous investments, strategies. or policies. Similarly, other studies rely on Quality of life (QOL) measurements as alternatives for GDP. Estoque et al. (2018) suggested a "QOL-Climate" assessment framework, designed to capture the social-ecological impacts of climate change and variability.

Another alternative to GDP is Green GDP which seeks to incorporate the environmental consequences of economic growth (Boyd, 2007; Stjepanović et al., 2017; Stjepanović et al., 2019). Green GDP is difficult to measure, because it is difficult to evaluate the environmental depletion and ecological damages of growth (Stjepanović et al., 2019). Although there is no consensus in measuring Green GDP, attempts have been made for select countries including the United States (Garcia and You, 2017), Europe (Stjepanović et al., 2019), China (Chi and Rauch, 2010; Yu et al., 2019; Wang et al., 2020), Ukraine and Thailand (Harnphatananusorn et al., 2019), and Malaysia (Vaghefi et al., 2015). Le (2016) illustrated the potential negative impacts of climate change vulnerability on green growth. Some studies have suggested that focusing on green growth as the only strategy to address climate change would be risky. Hickel and Kallis (2020) argue that green growth is likely to be a misguided goal due to the difficulties of separating economic growth from resource use and, therefore, carbon emissions (see also (Antal and van den Bergh, 2014). Therefore, alternative strategies are required (Hickel and Kallis, 2020). In addition, green growth should also be able to justly respond to social movements involving contestation, internal debates and tensions (Mathai et al., 2018).

The emphasis on Green GDP is mirrored by another concept, Blue Growth, that focuses on the pursuing sustainable development through the ecosystem services derived from ocean conservation (Mustafa et al., 2019). Synthesis studies suggest that more intensive use of ocean resources, such as scaling up seaweed aquaculture, can be used to enhance CO2eq sequestration, thereby contributing to greenhouse gas mitigation, while also achieving other economic goals (Lillebø et al., 2017; Froehlich et al., 2019). Similarly, Sarker et al. (2018) present a framework for linking Blue Growth and climate resilient development in Bangladesh, with Blue Growth representing an opportunity for adapting to climate change. Bethel et al. (2021) also links Blue Growth to resilience, noting that a Blue economy can help facilitate recovery from the COVID-19 pandemic. Nevertheless, consistent with earlier assessment of enabling conditions for system transitions (18.4.2.1), implementation of Blue Growth initiatives is contingent upon the successful achievement of social innovation as well as creating an inclusive and cooperative governance structure *(very high confidence*) (Larik et al., 2017; Soma et al., 2018).

A potential critique of the various alternative metrics and models for economic development is that they are all framed in the context of growth. Over the past decade, ecological economists and political scientists have proposed Degrowth (e.g., Kallis, 2011; Demaria et al., 2013) and managing without growth (e.g., Jackson, 2009) as a solution for achieving environmental sustainability and socio-economic progress. Such concepts are a deliberate response to concerns about ecological limits to growth and the compatibility between growth-oriented development and sustainability (Kallis et al., 2009). Sustainable degrowth is not the same as negative GDP growth which is typically referred to as a recession (Kallis, 2011). Degrowth goes beyond criticizing economic growth; it explores the intersection among environmental sustainability, social justice, and well-being (Demaria et al., 2013). Under current economic and fiscal policies (see Box 18.8), degrowth has been argued as an unstable development paradigm because declining consumer demand leads to rising unemployment, declining competitiveness, and a spiral of recession (Jackson, 2009: 46). More comprehensive modelling of socio-economic performance understands the segments of sufficient social transformation to guarantee maintenance and rise in wellbeing coupled with reduced 'footprints' (Raworth, 2017; Hickel, 2019; D'Alessandro et al., 2020).

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Box 18.8: Macroeconomic policies in support of Climate-Resilient Development

Climate change risk may differ from other economic and financial risks in a number of ways: climate change is global; involves long-term impact; and involves a great deal of uncertainty; and with the possibility of irreversible change (Hansen, 2021). The macroeconomic implications will differ across countries with less developed countries are likely to suffer more relative to more advanced ones (Batten, 2018). Hence, policymakers need to understand the impact of climate change on macroeconomic issues such as potential output growth, capital formation, productivity, and long run level of interest rates, in order to better design policy interventions, be it monetary or fiscal (Economides and Xepapadeas, 2018; Bank of England, 2019; Rudebusch, 2019). As discussed, below a range of fiscal tools can be leveraged to mitigate the effects of climate change (Krogstrup and Oman, 2019).

Monetary Policy

Changes in climate and subsequent policy responses could increase volatility of food and energy prices, resulting in higher headline inflation rates. Thus, Central Banks (CBs) have to pay careful attention to underlying inflationary factors in order to maintain their inflationary targets. In response, CBs can take a number of actions. For example, they could require that collateral comprises assets that support the move to low-carbon economy, or their refinancing operations and crisis facilities could incentivize borrowers' move to low-carbon activities, particularly in countries where CBs' mandate has been expanded to account for climate impact (Papoutsi et al., 2021). Other actions that CBs could take include adoption of sustainable and responsible investment principles (Rudebusch, 2019), require financial firms to disclose their climate related risks (ECB, 2020; Lee, 2020). Despite these opportunities, there is ongoing debate regarding whether CBs should actively use monetary policy to address climate change and its risks (Honohan, 2019).

Fiscal policy

The application of green fiscal policies to address climate change could lead to environmental benefits including environmental revenues that may be used for broader fiscal reforms (OECD, 2021). As the US aims at becoming carbon neutral by 2050, fiscal policies at the national, sectoral, and international level can help to achieve this goal, along with investment, regulatory, and technology policies (Parry, 2021). The effectiveness of green fiscal policies are through their fiscal potential, opportunities for efficiency gains, distributional and macroeconomic impacts, and their political economy implications (Metcalf, 2016). The International Monetary Fund argues public support for green policies may rise in response to the COVID-19 crisis (IMF, 2017). For example, Leibenluft (2020) argues that investments to combat climate change should be an important component of the efforts to rebuild the economy in the wake of COVID-19. Such action is justified not only on ecological and social welfare grounds, but from a long-term fiscal perspective. For example, climate change impacts and/or efforts to adapt to those impacts drive increased spending in areas such as public health and disaster mitigation or response. Preventive and corrective actions would strengthen resilience to shocks and alleviate the financial constraints they create, particularly for small countries (Catalano et al., 2020). For example, Mallucci (2020) found that natural disasters exacerbate fiscal vulnerabilities and trigger sovereign defaults in seven Caribbean countries. Ryota (2019) illustrates how to include natural disaster and climate change in a fiscal policy framework to developing countries.

Carbon pricing

Pricing of greenhouse gases, including carbon, is a crucial tool in any cost-effective climate change mitigation strategy, as it provides a mechanism for linking climate action to economic development (IMF/OECD, 2021). By 2019, 57 nations around the world had implemented or scheduled implementation of carbon pricing. These initiatives cover 11 gigatons of carbon dioxide or about 20% of greenhouse gases emissions. Carbon prices in existing initiatives range between $1 and $127 per ton of carbon dioxide, while 51% of the emissions that are covered are priced more than $10 per ton of carbon dioxide. Moreover, in 2018, Governments raised about $44 billion in carbon pricing revenues (World Bank, 2019). However, the carbon prices are lower than the levels required for attaining the ambitious goal of climate change mitigation, and therefore, prices would need to increase if pricing alone is going to be used to drive compliance with the Paris Agreement. Higher carbon prices would also be warranted if prices are based on the social cost of carbon, which represents the present value of the marginal damage to economic output caused by carbon emissions (Cai and Lontzek, 2018). This cost needs to be considered with the social benefits of reducing carbon emissions through cost-benefit analyses in order to make the intended regulation acceptable.

Taxes

Carbon taxes represent another financial mechanism for addressing climate (Metcalf, 2019), 2019b). For example, the implementation of a carbon tax and a value-added tax on transport fuel in Sweden resulted in a reduction of CO2 emissions from transport of about 11% in which the carbon tax had the largest share (Andersson, 2019). In the United States, for example, a carbon tax could increase fiscal flexibility by collecting new revenues that can be redeployed to finance reforms and help stimulate economic growth. However, U.S. tax-inclusive energy prices would have to be 273% higher than laissez faire levels in 2055 in order to meet international agreements (Casey, 2019). Similarly, limiting global warming to 2 degrees or less would likely require a carbon tax rate in the Asia/Pacific region to be significantly higher than $25 per ton (IMF, 2021). Therefore, using tax revenues to issue payments back to taxpayers that are disproportionately impacted or to redistribute capital among regions may be one of the most important features of carbon tax policies. Although the average effect of carbon tax on welfare would be positive, some regions (56%) will gain and some regions (44%) lose (Scobie, 2013). Therefore, large transfer payments are needed to compensate those losing from carbon tax (Krusell and Smith, 2018). IMF (2019) argues that, of the various mitigation strategies to reduce fossil fuel CO2 emissions, carbon taxes are the most powerful and efficient, because they allow firms and households to find the lowest-cost ways of reducing energy use and shifting toward cleaner alternatives.

Subsidies

The World Bank has been encouraging both developed and developing states, especially those with petroleum reserves, to use the removal of subsidies as a mechanism for promoting energy transitions away from fossil fuels. The transition has led to social unrest in some cases, especially where there is a culture of entitlement to low-cost energy because it is an indigenous resource. Such reforms have been more effective when governments have been able to clearly show how savings are applied to social and health programs that benefit human well-being. Nevertheless, policy makers should not underestimate the complexity of issues involved in the removal of subsidies that will increase the cost of carbon and hasten the transition to cleaner fuels (Scobie, 2017; Scobie et al., 2018; Chen et al., 2020a). A crucial issue to take into account is the harmful effects some subsidies have on biodiversity. Although governments agreed in 2010 to make progress on reducing subsidies in 2010, by 2020 few governments had identified specific incentives to remove or taken action toward their removal. Further investigation of the positive and negative effects of subsidy redirection or elimination on people and the environment (Dempsey et al., 2020).

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18.4.3.4 Knowledge-technology and ecological arenas

Knowledge-technology arenas comprise the interaction in knowledge spaces connected to technology transitions. The institutional and political architecture through which knowledge and technology interact is described in sustainability transitions literature (Fazey et al., 2018b; Sengers et al., 2019l Kanger, 2020 #3709). A common theme explored in that literature is the ability of actors to access and apply various forms of knowledge as a means of effecting change. Different forms of innovation are recognized as a core enabling condition for achieving system transitions for CRD (18.3.3; Cross-Chapter Box INDIG). However, while scientific and technology knowledge may be useful, in some cases, they remain subordinate to political agendas, or are controlled by actors in positions of power and thus not equitably distributed *(very high confidence*) (Mormina, 2019). Participatory decision-making, for example, assumes that multiple actors, with differing motivations, agency and influence, engage with climate decision making and co-produce actions. Yet, some actors may not participate in the process if the proposed actions do not align with their motivations or if they do not have adequate agency (Roelich and Giesekam, 2019). Hence, effectively using knowledge to inform policy is challenging for both scientists, policymakers, and civil society alike.

Science, technology, and innovation (STI) policies are expected to shape expectations of the potential for a better world based on clean technologies, higher labor productivity, economic growth and a healthier environment (Schot and Steinmueller, 2018; Mormina, 2019). STI policies are considered as 'social goods for development'. Hence, STI policies are often proposed or implemented as means of addressing environmental challenges such as climate change along with sustainable development goals such as the reduction of inequality, poverty, and environmental pollution (Mormina, 2019). Realizing the benefits of STI, however, may be contingent on building broader STI capacity and bolstering nations' systems of innovation (*very high confidence)* (Mormina, 2019). This could include building global research partnerships to address priority STI needs as well as long-standing gaps between the global North and South. Such an approach shifts the framing of STI as one focused on individual investigators to one comprised of building knowledge networks. It also creates opportunities for integration of disparate forms of knowledge and innovation, including local and indigenous knowledge, into global knowledge systems (Cross-Chapter Box INDIG).

Furthermore, an extensive literature increasingly incorporates natural and ecological systems as knowledge domains relevant to understanding opportunities for sustainability and CRD. For example, the literature on socioecological systems (SES) (Sterk et al., 2017; Holzer et al., 2018; Avriel-Avni and Dick, 2019; Martínez-Fernández et al., 2021) as well as social, ecological, and technological systems (SETS) (McPhearson and Wijsman, 2017; Webb et al., 2018; Ahlborg et al., 2019), explicitly integrate ecological knowledge into sustainability including concepts such as planetary boundaries (18.1.1), adaptation and nature-based solutions, natural resources management, rights and access to nature, and understanding of how humans govern society-nature interactions in the face of climate change (Benjaminsen and Kaarhus, 2018; Mikulewicz, 2019; Nightingale et al., 2020). Some of these interactions are explained in Cross-Chapter Box INDIG including conflict over which knowledges are recognized as valuable in understanding and responding to climate change and therefore shape the nature of climate actions. Actor engagement in stewardship, solidarity, inclusion of multiple knowledges and nature-society connectedness can highlight the intertwined nature of ecological change and knowledge relations thereby support shifts to sustainability (Pelling, 2010; Hulme, 2018; Ives et al., 2019; Nightingale et al., 2020) (see also Box 18.6).

The expanding definition of what constitutes credible, relevant, and legitimate knowledge is leading to the democratization of knowledge and efforts to address historical inequities in access to knowledge (Ott and Kiteme, 2016; Rowell and Feldman, 2019). This is reflected in the communication of science, which is increasingly focused on reducing the distance between internal scientific and public communication and more engagement in public science governance and knowledge production (Waldherr, 2012; Peters, 2013). One innovative approach in co-production of knowledge is mobilizing communities through citizen science (Heigl et al., 2019). This also presents additional opportunities to incorporate local knowledge with scientific research, and better match scientific capability to societal needs.

18.4.3.5 Community arenas

Societal choices and development trajectories emerge from decisions made in different arenas which intersect and interact across levels and scales, in diverse institutional settings - some formal with their associated instruments and interventions, while others are informal. Since AR5, both formal and informal setting are increasingly arenas of debate and contestation regarding development choices and pathways *(very high confidence*) (see 18.4.4, Chapters 1, 6, 8, 10 and 17). Community arenas exist from the local to the global scale and constitute the many interactions between governance actors, often transcending any one scale to reflect the emergent outcomes of interactions in political, economic, socio-cultural, knowledge-technology and ecological arenas of engagement. Actions within and between these five arenas hence come together in the community arena of engagement. While community engagement is often described at the level of villages and cities (Ziervogel et al., 2021) (Chapter 8), communities in terms of people interacting with each other sharing worldviews, values and behaviors, also exist at the regional and global levels. For example, civil society engagement in climate action reached a peak in 2019, notably through the global youth movement which led to large global mobilisation and street demonstrations on all continents and in many large cities (Bandura and Cherry, 2020; Han and Ahn, 2020; Martiskainen et al., 2020). Calling for enhanced climate action by governments and other societal actors, the youth movement was supported by many other societal groups and networks, including arenas of community interaction.

While the SR1.5 (de Coninck et al., 2018) for the first time comprehensively assessed behavioral dimensions of climate change adaptation, most literature still has a greater focus on what triggers mitigation behavior (Lorenzoni and Whitmarsh, 2014; Clayton et al., 2015). Meanwhile, with CRD still a relatively young concept, there is little literature focused on what motivates action in pursuit of CRD rather than its subcomponents of climate action and sustainable development. Nevertheless, a common motivation that is emerging in the literature is clinically significant levels of climate distress among individuals (Bodnar, 2008), which is experienced as a continuing distress over a changed landscape which no longer offers solace, also known as solastalgia (*high agreement, medium evidence*) (Albrecht et al., 2007). This is accompanied by a shift from blaming natural forces for disasters to attributing it to human negligence which is known to lead to more acute perceptions of risk as well as more prolonged PTSD than trauma arising from non-human causes. Improving social connections, acknowledging anxiety, reconnecting to nature, and finding creative ways to re-engage are identified as ways of managing this growing anxiety (Lertzman, 2010; Clayton et al., 2017). Climate action in communities at various scales could fulfil many of these needs.

18.4.4 Frontiers of Climate Action

After decades of limited government action and social inertia to reduce the risk of climate change, there is also increasing social dissent toward the current political, economic and environmental policies to address climate (Brulle and Norgaard, 2019; Carpenter et al., 2019). Social movements are demanding radical action as the only option to achieve the mobilization necessary for deep societal transformation *(very high confidence*) (Hallam, 2019; Berglund and Schmidt, 2020).

Prompted by SR1.5, new youth movements seek to use science-based policy to break with incremental reforms and demand radical climate action beyond emissions reductions (Hallam, 2019; Klein, 2020; Thackeray et al., 2020; Thew et al., 2020). Recent social movements and climate protests embrace new modalities of action related to political responsibility for climate injustice through disruptive collective political action (Young, 2003; Langlois, 2014). This is complemented by a regenerative culture and ethics of care (Westwell and Bunting, 2020). These new social movements are based on nonviolent methods of resistance, including actions classified as dutiful, disruptive and dangerous dissent (O'Brien, 2018).

The new climate movement mixes messages of fear and hope to propel urgency and the need to respond to a climate emergency (Gills and Morgan, 2020). While some consider the mix between fear and hope as beneficial to success depending on psychological factors (Salamon, 2019) or political geography (Kleres and Wettergren, 2017) others warn of the risks of a rhetoric of emergency and its political outcomes (Hulme and Apollo-University Of Cambridge Repository, 2019; Slaven and Heydon, 2020).

Research shows that new climate movements have increased public awareness, and also stimulated unprecedented public engagement with climate change *(very high confidence*) (Lee et al., 2020; Thackeray et al., 2020) and has helped rethink the role of science with society (Isgren et al., 2019). Such movements may represent new approaches to accelerate social transformation and have resulted in notable political successes, such as declarations of climate emergency at the national and local level, as well as in universities. Their methods have also proven effective to end fossil fuel sponsorship (Piggot, 2018). Social demands for radical action are likely to continue to grow, as there is growing discontent with political inertia and a rejection of reformist positions.

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Box 18.9: The Role of the Private Sector in Climate Resilient Development via Climate Finance, Investments and Innovation.

Climate finance broadly refers to resources that catalyze low-carbon and climate-resilient development. It covers the costs and risks of climate action, supports an enabling environment and capacity for adaptation and mitigation, and encourages R&D and deployment of new technologies. Climate finance can be mobilized through a range of instruments from a variety of sources, international and domestic, public and private (see Sections 18.4.2.2).

The private sector has particular competencies which can make significant contributions to adaptation, through innovative technology, design of resilient infrastructure, development and implementation of improved information systems and the management of major projects. The private sector can be seen as a "supplier of innovative goods and services" to meet the adaptation priorities of developing countries with expertise in technology and service delivery (Biagini and Miller, 2013).

Future investment opportunities in CRD are in water resources, agriculture and environmental services. Provision of clean water is another opportunity, requiring investment in water purification and treatment technologies such as desalination, and wastewater treatment. Weather and climate services are a possible area for private investment. (Hov et al., 2017; Hewitt et al., 2020).

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18.5 Sectoral and Regional Synthesis of Climate Resilient Development

Prior sections of this chapter assessed the literature relevant to CRD inclusive of climate risk management, systems transitions and transformation, and actors and the arenas in which they engage one another to enable or constrain CRD. Here, this knowledge is explored in different climatological and development contexts through a synthesis of CRD-relevant assessments within the WGII sectoral and regional chapters.

18.5.1 Regional Synthesis of Climate-Resilient Development

In synthesizing regional knowledge relevant to the pursuit of CRD, this section first considers geographic heterogeneity in regional responses of common climate variables to increases in globally averaged temperatures. Such heterogeneity is a key driver of climate risk in different global regions, as well as human and natural systems within those regions. This is followed by synthesis of various national development indicators, aggregated to the regional level, as well as various challenges, opportunities, and options supporting CRD reported within WGII regional chapters.

18.5.1.1 Climate Change Risk for Different Global Regions

Two important elements of understanding the opportunities and challenges associated with the pursuit of CRD in different regional contexts are a) the geographic variability in climate conditions that shape livelihoods, behaviors, and responses of human and natural systems; and b) how those conditions could shift in the future in response to climate change, which determines the additional burden that climate change could create for adaptation and sustainable development.

The climate analyses of WGI provide information on regional differences in temperature, rainfall, and sea-surface temperatures for different global regions and how they are projected to change in response to different levels of aggregate global warming (Table 18.4). Such data reveal that even when aggregated to broad geographic regions, significant variations exist for all of these parameters, which is a function of the baseline climatology of each region. For example, temperatures in Africa and Australia are, on average, warmer than in Europe or North America. Significant variations are also observed for rainfall variables. Such regional variation in climate conditions is part of the regional context that shapes current patterns of development of the past present and future. They influence biodiversity and natural resource availability as well as exposure to climatic extremes (tropical storms, heat waves, and drought) that contribute to disasters.

The WGI data also indicate that increases in globally averaged temperatures will have different consequences for regional climate change (Table 18.4), including variation in the magnitude and, for precipitation, even the direction of change (*very high confidence*). For example, although average temperatures, daily minimum temperature, and the number of days over a given thresholds are projected to increase in all regions except Antarctica, the magnitude of the change varies. Moreover, little change is projected for daily maximum temperatures across different regions. Nevertheless, the number of days over different temperature thresholds such as 35°C increases markedly in most regions, reflecting the disproportionate impact that global warming has on the tails of temperature distributions. Given outcomes in many systems including public health, agriculture, ecosystems and biodiversity, and infrastructure are often associated with biophysical thresholds (e.g., physiological or design thresholds), those regions where such thresholds are increasingly exceeded due to climate change may experience disproportionately higher impacts (*very high confidence*). Given such temperatures occur more frequently in regions such as Africa and Central and South America, this disproportionate exposure is exacerbated by disproportionate vulnerability, adaptation gaps, and development needs (*very high confidence*; 18.2.4; Table 18.4).

The regional response of precipitation to globally averaged temperatures increases is less clear than temperature, in part due to high intra-region variability. Average daily precipitation remains fairly stable in all global regions in response to higher magnitudes of global warming (Table 18.4). However, 5-day precipitation totals provide a clearer signal of increasing hydrologic activity in response to higher globally averaged temperatures (Table 18.4). Such data no not necessarily reflect changes in rainfall extremes that could occur with downstream consequences for hazards such as drought or flooding. Similarly, while SSTs are more uniform across global ocean basins, all basins are anticipated to warm in response to higher globally averaged temperatures (Table 18.5). Unlike temperature, however, SST increases are anticipated to be only a fraction of the globally averaged increase in temperature, due in large part to the heat capacity of the oceans. Nevertheless, such higher SSTs have implications not only for ocean ecosystems and the distribution of marine species, but also for weather patterns, such as formation and intensity of tropical cyclones (*very high confidence*).

The other aspect of the regional climate responses to global temperature increases that is important for CRD is the marked differences observed between changes in response to 1.5°C versus 4°C of warming. Higher levels of global warming are associated with higher regional changes, including changes in extremes of temperature. This in turn increases climate risk to exposed and vulnerable human and natural systems, thereby increasing demand for adaptation. If that demand is not met, then the adaptation gap will be larger with greater risk of loss and damage (*very high confidence)* (Schaeffer et al., 2015; Chen et al., 2016; United Nations Environment Programme, 2021). This is true not only for regions, but also at the sectoral level (18.5.2). Therefore, CRD pathways must balance the demands for emissions reductions to reduce exposure, adaptation to manage residual climate change risks, and sustainable development to address vulnerability and enhance capacity for sustainable development.

Table 18.4: Projected continental level result ranges for select temperature and precipitation climate change variables by global warming level. Ranges are 5th and 95th percentiles from SSP5-8.5 WGI CMIP6 ensemble results. There is little variation in the 5th and 95th percentile values by GWL across the SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 projections. Source: WGI AR6 Interactive Atlas (https://interactive-atlas.ipcc.ch/).

Climate variable	Global warming level	All Regions	North America	Europe	Asia	Centra-South America	Africa	Australia	Antarctica
Mean temperature (degrees C)	**4˚C**	12 to 15	8 to 11	5 to 9	12 to 14	24 to 27	26 to 29	24 to 27	-33 to -27
	3˚C	11 to 14	6 to 11	4 to 7	10 to 14	23 to 26	25 to 28	23 to 26	-35 to -26
	2˚C	10 to 13	5 to 9	3 to 6	8 to 12	22 to 25	24 to 27	22 to 25	-36 to -27
	1.5˚C	9 to 12	4 to 8	2 to 5	8 to 12	22 to 24	24 to 26	22 to 24	-36 to -27
Minimum of daily minimum temperatures (degrees C)	**4˚C**	-12 to -5	-25 to -15	-22 to -14	-18 to -9	11 to 15	10 to 14	5 to 10	-64 to -48
	3˚C	-13 to -6	-27 to -15	-24 to -15	-20 to -11	10 to 15	8 to 14	4 to 10	-64 to -50
	2˚C	-15 to -8	-30 to -18	-27 to -17	-22 to -13	9 to 14	7 to 13	3 to 9	-65 to -51
	1.5˚C	-16 to -9	-32 to -20	-28 to -19	-23 to -14	8 to 14	6 to 12	3 to 9	-66 to -51
Maximum of daily maximum temperatures (degrees C)	**4˚C**	32 to 37	32 to 38	28 to 33	35 to 40	36 to 43	40 to 47	41 to 49	-12 to -5
	3˚C	31 to 39	31 to 38	28 to 34	35 to 41	35 to 44	39 to 51	41 to 54	-12 to -3
	2˚C	30 to 37	30 to 36	26 to 33	33 to 39	34 to 43	38 to 50	39 to 53	-13 to -4
	1.5˚C	29 to 36	29 to 35	25 to 31	32 to 39	33 to 42	38 to 49	39 to 52	-14 to -5
Number of days with maximum temperature above 35˚C – bias adjusted	**4˚C**	81 to 106	36 to 50	11 to 22	57 to 77	138 to 194	153 to 210	140 to 168	0 to 0
	3˚C	66 to 87	27 to 40	6 to 15	44 to 59	100 to 153	131 to 183	124 to 147	0 to 0
	2˚C	52 to 68	19 to 29	4 to 8	33 to 45	61 to 106	116 to 151	102 to 124	0 to 0
	1.5˚C	45 to 58	16 to 24	2 to 5	30 to 39	43 to 85	107 to 133	94 to 115	0 to 0
Near-surface total precipitation (mm/day)	**4˚C**	2 to 3	2 to 3	2 to 2	2 to 3	4 to 5	2 to 3	1 to 2	1 to 1
	3˚C	2 to 3	2 to 3	2 to 2	2 to 3	3 to 5	2 to 3	1 to 2	1 to 1
	2˚C	2 to 3	2 to 3	2 to 2	2 to 3	3 to 5	2 to 3	1 to 2	1 to 1
	1.5˚C	2 to 3	2 to 3	2 to 2	2 to 3	3 to 5	2 to 3	1 to 2	1 to 1
Maximum 5-day precipitation amount (mm)	**4˚C**	79 to 99	75 to 93	53 to 71	81 to 105	118 to 168	68 to 113	81 to 124	20 to 29
	3˚C	66 to 99	68 to 87	48 to 68	70 to 101	97 to 165	60 to 118	76 to 129	19 to 27
	2˚C	64 to 93	65 to 84	47 to 65	66 to 95	93 to 162	55 to 107	73 to 122	18 to 26
	1.5˚C	63 to 91	63 to 83	46 to 64	64 to 93	92 to 160	52 to 105	74 to 119	18 to 25

Table 18.5: Projected sea surface temperature change ranges by global warming level and ocean biome (degrees Celsius). Ranges are 5th and 95th percentiles from SSP5-8.5 WGI CMIP6 ensemble results. There is little variation in the 5th and 95th percentile values by GWL across the SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 projections. Source: WGI AR6 Interactive Atlas (https://interactive-atlas.ipcc.ch/).

Global warming level	All ocean biomes	Northern Hemisphere - High Latitudes	Northern Hemisphere - Subtropics	Equatorial	Southern Hemisphere - Subtropics	Southern Hemisphere - High Latitudes	Gulf of Mexico	Eastern Boundaries	Amazon River	Arabian Sea	Indonesian Flowthrough
4°C	1.9 to 2.4	2.0 to 3.3	2.2 to 2.8	2.1 to 3.0	1.8 to 2.4	1.3 to 2.0	2.1 to 2.8	2.1 to 2.7	1.7 to 2.5	2.3 to 2.9	1.9 to 2.7
3°C	1.3 to 1.7	1.2 to 2.2	1.4 to 2.4	1.4 to 2.2	1.2 to 1.7	0.7 to 1.4	1.5 to 2.3	1.4 to 2.1	1.2 to 2.0	1.6 to 2.2	1.3 to 1.9
2°C	0.6 to 1.0	0.5 to 1.4	0.7 to 1.4	0.7 to 1.3	0.5 to 1	0.3 to 0.8	0.6 to 1.4	0.6 to 1.3	0.6 to 1.3	0.6 to 1.3	0.5 to 1.2
1.5°C	0.2 to 0.7	0.1 to 0.9	0.2 to 1.0	0.2 to 0.8	0.2 to 0.6	0.1 to 0.5	0.2 to 1.0	0.2 to 0.9	0.2 to 0.9	0.2 to 0.9	0.1 to 0.8

18.5.1.2 Regional Perspectives on Climate-Resilient Development

The various regional chapters within the AR6 WGII report each provide insights into progress toward CRD as well as the opportunities and challenges associated with future pursuit of different CRD pathways. Common indicators of development reflect the significant diversity that exists across different global regions with respect to their development context (*very high confidence)*. For example, the Human Development Index, recently adjusted to reflect the effect of planetary pressures (PPAHDI), illustrates the overall higher levels of development of North America and European countries of the global North as well as Australasia compared with Asia, Africa, Central and South America and small islands of the global South. Generally, this reflects the higher levels of vulnerability and greater need for both sustainable development to reduce poverty and support sustainable economies as well as climate action to address climate risk (Table 18.6).

However, even within a given region, there is significant variation in PPAHDI among nations. Such differences reflect fundamental differences in historical patterns of development, as well as current development needs and challenges, and they imply differences in what future development pathways would be consistent with CRD. In addition, nations and regions with lower PPAHDI values suggests greater capacity challenges for both greenhouse gas mitigation and climate adaptation. However, nations and regions with high PPAHDI values also tend to have higher per capita CO_2e emissions production, indicating that economic development based on fossil fuel use undermines both efforts on climate action as well as the SDGs (*very high confidence*) (Figure 18.6). Such challenges are also reflected by differential Gini coefficients and metrics of state fragility among regions, which reflect inequities in income distribution and broader vulnerability of nations and regions to shocks and stressors (Figure 18.6). In addition, high variation is observed in CO2 emissions production, even among comparatively wealthy nations, suggesting CO2e emissions of some nations are tightly coupled to development, while others have pursued more carbon neutral development trajectories. Even within regions such as Africa, Asia, Central and South America, and Europe, large within-region variations are observed in inequality and state fragility, suggesting high variability among nations. Given the emphasis in the sustainable development and CRD literature on equity and vulnerability, addressing such determinants of vulnerability is a core design principle for CRD pathways.

In addition to development indicators, the literature assessed in the WGII regional chapters indicates that different regions experience a range of development challenges and opportunities that affect the pursuit of CRD (*very high confidence*). These represent dimensions of governance, institutions, economic development, capacity, and social and cultural factors that shape decision-making, investment, and development trajectories. For example, significant challenges exist within regions with respect to managing debt and the ability to fund or finance climate action and sustainable development interventions (*very high confidence*). On the other hand, a broad range of opportunities exist to pursue CRD including challenges with debt and financing of adaptation competing policy objectives, social protection programs, economic diversification, investing in education and human capital development, and expanding disaster risk reduction efforts (*very high confidence*).

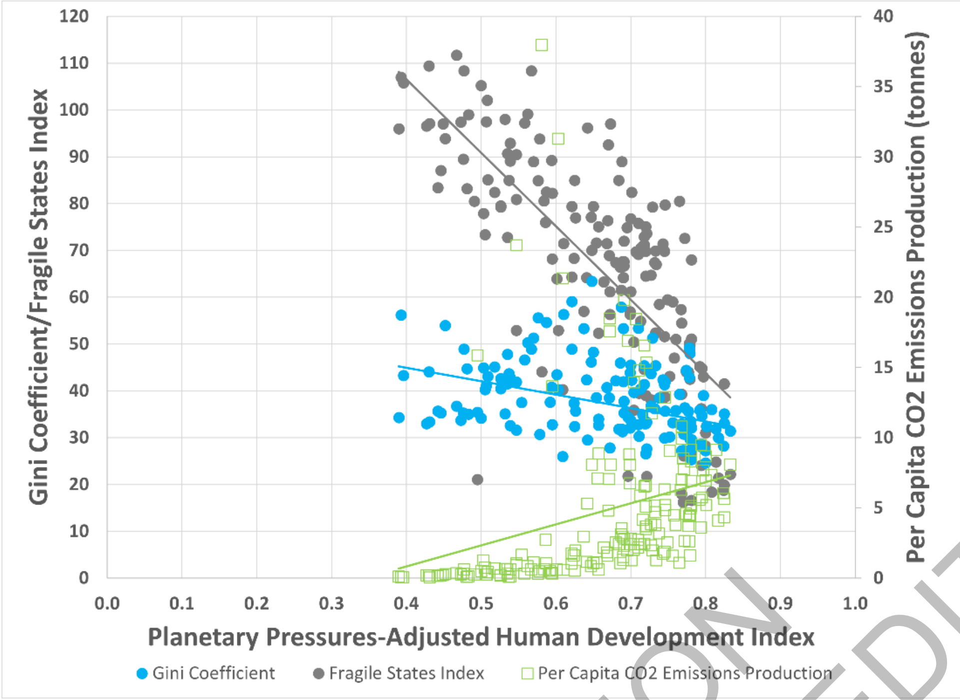

Figure 18.6: Relationship among development indicators relevant to climate-resilient development. National Gini coefficients (most recent year available; n=141; (World Bank, 2021)), the Fragile States Index (2021; n=163; (Fund for Peace, 2021)), and per capita CO2 emissions (2018; n=169; (Human Development Report Office, 2020)) are plotted against the Planetary Pressures-Adjusted Human Development Index (2020, n=163; (Human Development Report Office, 2020)

There are a wide variety of more focused options for climate action and sustainable development (*very high confidence*). Such options have potential for synergies and trade-offs including implications for greenhouse gas mitigation, land use change and conservation, food and water, or social equity. Despite variation in development context, regional assessments suggest CRD efforts will be associated with some common features. For example, in all regions, existing vulnerability and inequality exacerbate climate risk and therefore pose challenges to CRD (*very high confidence*). Furthermore, low prioritization of sustainability and climate action in government decision making, low perceptions of climate risk, and path dependence in governance systems and decision-making processes all pose barriers to system transitions, transformation, and CRD (*very high confidence*).

18.5.2 Sectoral Synthesis of Climate-Resilient Development

The sectoral chapters of the WGII report provide insights regarding how development processes interact with sectors to shape the potential for climate-resilient development. Similar to global regions, each sector is associated with various challenges, opportunities, and options that enable or constrain CRD (Table 18.7). A number of challenges are common across sectors and mirror those associated with different regions. For example, issues associated with natural resource dependency, access to information for decision-making, access to human and financial capital, and path dependence of institutions represent barriers that must be overcome if sectors are to support transitions that enable CRD. These challenges are more acute within vulnerable communities or nations where capacity to innovate and invest are constrained and social inequities reinforce the status quo (*very high confidence*). At the same time, a number of sector-specific opportunities for mitigation, adaptation, and sustainable development can be used to integrate sectors into CRD pathways. This could include policies and planning initiatives to enhance sector sustainability and resilience as well as capacity building and greater inclusion of different actors and groups in decision making including capitalizing on local and indigenous knowledge as a mechanism for more representative and equitable action.

In addition, the sectoral assessments identify a broad range of specific adaptation, mitigation, and sustainable development options that could play a role in facilitating CRD. Many of these options appear initially to be specific to a given sector. For example, options for the water sector (Chapter 4) are assessed independently from those for health and well-being (Chapter 7). In practice, however, evidence suggests the importance of thinking about sectoral options as cross-cutting, mutually supportive, and synergistic packages rather than singular options. First, each of the sectoral chapters has links to multiple SDGs (Table 18.7), implying each sector is important for achieving a range of sustainability goals that extend beyond sectoral boundaries. Moreover, progress across multiple sectors simultaneously creates opportunities for synergies for achieving the SDGs, but also enhances the risk of potential trade-offs (*very high confidence*). Second, a number of options are common to multiple sectors. For example, options associated with ecosystem-based adaptation and nature-based approaches to environmental management appear in multiple sectors (Table 18.7). Similarly, climate-smart agriculture and agroecological approaches to food systems create opportunities for food security, but those same options also benefit land-based ecosystems, water, poverty and livelihoods, and human well-being. Joint implementation

18.5.3 Feasibility and Efficacy of Options for Climate-Resilient Development

While both the sectoral and regional assessments indicate a rich toolkit of management options is available to decision-makers to facilitate CRD, two key uncertainties undermine efforts to implement those options. The first is the feasibility of implementation. Options that seem promising could nevertheless encounter implementation barriers due to cost, absence of necessary capacity, lack of public acceptance, or competition with alternative options. Progress in the literature since the AR5 and SR1.5 reports enables improved consideration for options feasibility for both mitigation (SR1.5 ref) and adaptation (Cross-Chapter Box FEASIB). This assessment allows the range of available options to be considered in a more critical light, particular when on is considering opportunities for implementation over the near-term. Meanwhile, the other challenge is that of option efficacy. Significant uncertainties remain regarding how well a given option will perform in a specific context and whether it is capable of adequately addressing risk (18.6.1). Such uncertainties can undermine the pursuit of CRD or at least efforts to accelerate system transitions that support CRD (*medium evidence, medium agreement)* (18.3). Accordingly, closer examination of option implementation in the real world, including within different sectoral and regional contexts, would enhance the knowledge available to decision-makers regarding which options will best fit the needs of a given CRD pathway.

Table 18.6: Regional synthesis of dimensions of climate-resilient development. For each region, quantitative information is provided on common development indicators including the planetary pressures-adjusted human development index (PPHDI, 2020, n=169; (Human Development Report Office, 2020)), Gini coefficients (GINI, most recent year available; n=156; (World Bank, 2021)), Fragile States Index (FRAGILITY; 2021; n=173; (Fund for Peace, 2021)), and per capita CO2 emissions production (CO2/PC, 2018; n=169; (Human Development Report Office, 2020)). Each indicator is associated with a mean value among nations within a specific region as well as the range (minimum to maximum) value. In addition, the table contains evidence of sustainable development challenges and opportunities as well as adaptation/sustainable development options and potential synergies and trade-offs associated with their implementation. Synergies and trade-offs are categorized as follows: (T) Trade-off among policies and practices; (S+) Synergy among policies and practices that enhances sustainability; (S-) Synergy among policies and practices that undermines sustainability.

Region	***Development Indicators mean (range)***		***Challenges***	***Opportunities***	***Options***	***Synergies and Trade-Offs***
Africa	PPAHDI	0.53 (0.39-0.72)	• institutional and financial challenges in programming and implementing activities to support concrete adaptation measures (9.14.5) • high debt levels exacerbate fiscal challenges and undermine economic resilience (9.14) • insufficient development and adaptation finance and accessibility of finance (9.14.5) • complexity of estimating the costs and benefits for adaptation measures in specific contexts (9.14.2) • exclusions of migrants and other vulnerable populations from social programs (9.9.4) • mismatch between the supply of, and demand for, climate services (9.5)	• climate change literacy can enable the mainstreaming of climate change into national and sub-national developmental agendas (9.4.2) • Adaptive responses can be used as an opportunity for comprehensive, transformative change (9.6.2) • Investments in human capital, can facilitate socioeconomic development and poverty reduction (9.9.1) • Strengthening the participation of women in decision-making as well as advance traditional and local knowledge can support climate action and sustainable livelihoods (9.9.3)	• strengthening climate services (9.4.2) • ecosystem based adaptation (9.11.4.2) • economic diversification (9.12.3) • intensive irrigation9.15.2 • agricultural and livelihood diversification (9.12.3) • drought resistant crop varieties (9.15.2) • soil and water conservation (9.15.2	• (T) competing uses for water such as hydropower generation, irrigation, and ecosystem requirements create trade-offs among different management objectives (9.7.3) • (T) migration in response to unfavorable environmental conditions provides opportunities for farmers but puts pressure on the provision of social services and reduces farm labor (9.15.2) • (T) intensive Irrigation contributes to the development of agriculture but has come at a cost to ecosystem integrity and human well-being (9.15.2)
	GINI	42.8 (27.6-63.4)				
	FRAGILITY	87.3 (57.0-110.9)				
	CO2/PC	1.1 (0.0-8.1)				
Asia	HPAHDI	0.65 (0.47-0.78)	• migration and displacement (Box 10.6) • uneven economic development (10.4.6) • rapid land use change (10.4.6)	• Investing in climate-resilient and sustainable infrastructure can be a source of green jobs as well as a means of reducing climate vulnerability (10.6.2)	• risk insurance 10.5.5 • climate-smart agriculture 10.4.5.5, (Table 10.6) • wetland protection and restoration (Table 10.6)	• (S+) nature-based adaptation solutions, wetland protection, and climate-smart agriculture enhance carbon sequestration (Table 10.6)
	GINI	34.9 (26.6-43.9)				
	FRAGILITY	73.6				

		(32.3-111.7)	• increasing inequality (10.4.6) • large, socially differentiated vulnerable populations (10.4.6)	• sustainable development pathways that connect climate change adaptation and disaster risk reduction efforts can reduce climate vulnerability and increase resilience (10.6.2) • social protection programs can develop risk management strategies to address loss and damage from climate change (10.5.6)	• aquifer storage and recovery (Table 10.6) • integrated smart water grids (Table 10.6) • disaster risk management (Table 10.6) • early warning systems (Table 10.6) • resettlement and migration (Table 10.6) • nature-based solutions in urban areas • coastal green infrastructure (Table 10.6)	• (S+) disaster risk reduction and capacity building has synergistic interactions with climate adaptation when the two are effectively integrated (10.6.2) • (S+) environmental sustainability has benefits for relieving poverty and promoting social equity (10.6.4) • (T) intensive irrigation and other forms of water consumption can have a negative effect on water quality and aquatic ecosystems (10.6.3)
	CO_2/PC	6.3 (0.3-38.0)				
Australasia	PPAHDI	0.75 (0.70-0.81)	• Underinvestment in adaptation, particularly in public health systems, given current and projected risks (11.3.6.3) • Underlying social and economic vulnerabilities exacerbate disadvantage among particular social groups (11.8.2) • Competing policy and planning objectives within governments (11.7.2) • Limits to adaptation across the region and among neighbors (11.7.2) • Fear of litigation and demands for compensation create disincentives for climate adaptation (11.7.2) • different climate change risk perceptions among different groups (11.7.2)	• implementation of national policies and guidance on climate adaptation and resilience (Box 11.5) • cooperation among individual farmers for adaptation and regional innovation (11.7.1) • enhancing understanding of Indigenous knowledge and practices (Table 11.11)	• climate adaptation services, planning and tools from government and private sector providers (11.7.1) • enhancing governance frameworks (Table 11.17) • building capacity for adaptation (Table 11.17) • community partnership and collaborative engagement(Table 11.17) • flexible decision-making (Table 11.17) • reducing systemic vulnerabilities (Table 11.17) • providing adaptation funding and compensation mechanisms (Table 11.17) • addressing social attitudes and engagement in adaptation and climate action (Table 11.17)	• (T) adapting to fire risk in peri-urban zones introduces potential trade-offs among ecological values and fuel reduction in treed landscapes (11.3.5)
	GINI	34.4 (34.4-34.4)				
	FRAGILITY	20.1 (18.4-21.8)				
	CO_2/PC	12.1 (7.3-16.9)				
	PPAHDI	0.71				

Central and South America		(0.62-0.78)	• vulnerability of informal settlements with chronic exposure to everyday, non-climate risks • limited political influence of poor and most vulnerable groups • poor market access of rural households • little consideration of the implications of NDCs for poverty and livelihoods • corruption, particularly in the construction and infrastructure sector • gender inequities in labor markets • limits to adaptation	• Address existing development deficits, particularly the needs of informal settlements and economies • Adopt collaborative approaches to decision-making that integrate civic groups and communities as well as the private sector • Enhance adoption of sustainable tourism and livelihood diversification	• upgrading of informal and vulnerable settlements • capacity building in national and city level government institutions • enhancing social protection programs • integrated land use planning and risk-sensitive zoning • infrastructure greening • disaster risk mitigation and management • emergency medical and public health preparedness • improving insurance mechanisms and climate financing • ecosystem conservation, protection, and restoration • appropriate use of climate information and development of climate services	• (S+) conservation and restoration of natural ecosystems have synergies with mitigation, adaptation and sustainable development (12.7.1)
	GINI	47.2 (38.6-57.9)				
	FRAGILITY	65.9 (35.9-92.6)				
	CO2/PC	2.2 (0.9-4.8)				
Europe	PPAHDI	0.76 (0.52-0.83)	• mitigation and adaptation remain siloed around sectoral approaches (Box 13.3) • institutional, policy, and behavioral lock-ins constrain the rate of system transitions (13.11.4) • legislative and decision-making process constraints on climate action (13.11.4) • high adaptation costs and concerns about effectiveness and feasibility (13.3.2, Table 13.A.5) • competition for land use among adaptation and other uses (13.3.2)	• engagement in climate change knowledge, policy, and practice networks (Box 13.3) • national policies can lead to more ambitious and integrated climate planning and action with associated co-benefits (Box 13.3) • system transformations towards more adaptive and climate resilient systems (13.11.4, Box 13.3)	• ecological restoration of habitats agroforestry and reforestation (13.8.2) • “smart farming” and knowledge training (13.5.2.1) • soil management practices (13.5.2.1) • changing sowing dates and changes in cultivars (13.5.2.1) • stricter enforcement of existing health regulations (13.7.2) • integrated coastal zone management and marine spatial planning (13.4.2) • nature-based solutions (13.4.2) • climate services 13.6.2.3	• (T) wind farms support greenhouse gas mitigation but have ecosystem implications and impacts (13.4.2) • (T) adapting and mitigating climate change through afforestation and forest management may be hampered by biophysical and land use trade-offs (13.3.2)
	GINI	31.9 (24.6-41.3)				
	FRAGILITY	41.1 (16.2-72.9)				
	CO2/PC	6.8 (1.3-21.3)				

			• perceptions of climate change as irrelevant or not urgent (13.3.2) • public budget and human capital limitations (13.3.2)		• tailored insurance products for specific physical climate risks13.6.2.5 • protection of world heritage sites (13.8.2)	
North America	PPAHDI	0.72 (0.72-0.73)	• lack of representation of all groups and communities in politics and decision-making (14.6.3) • economic and financial constraints on adaptation within communities 14.6.2 • persistent social vulnerability and inequities 14.6.3, 14.4.7.3 • adaptation actions that are maladaptive and exacerbate existing inequities (14.6.2.1) • constraints on capacity for data collection (Table 14.8) • limited organizational willingness implement new and untested solutions (Table 14.8)	• increased focus on building adaptive capacity in small towns and rural areas (14.6.3) • greater use of SDGs as a framework for equitable adaptation measures (14.6.3) • broader and deeper recognition of the role of Indigenous knowledge and local knowledge systems in adaptation (14.6.3) • greater emphasis on participatory governance and co-production of knowledge in adaptation decision-making (14.6.2.2) • enhanced use of risk-based decision analysis frameworks and flexible adaptation pathways (14.6.2.2) • coordination of policies to support transformational adaptation (14.6.2.2)	• indigenous knowledge-based land and resource management (Section 14.4.4) • adaptive co-management of agriculture and freshwater resources (Section 14.4.3) • ecosystem based management and nature based solutions (Box 14.3) Section 14.4.2, 14.4.3, 14.4.4) (Table 14.9). • increase efficiency and equity of water management and allocation (14.4.3.3) • energy conservation measures (14.6.1.3) • guidelines, codes, standards, and specifications for infrastructure (14.6.1.6) • modifying zoning and buying properties in floodplains (14.6.1.3) • web-based tools for visualizing and exploring climate information scenario planning and risk analyses (s14.6.1.6)	• (S+) Post-fire ecosystem recovery measures, restoration of habitat connectivity, and managing for carbon storage enhance adaptation potential and offers co-benefits with carbon mitigation (Box 14.1) • (T) REDD+ represents a trade-off between carbon mitigation and the ability of communities to improve their food security (14.4.7) • (T) New coastal and alpine developments generate economic activity but enhance local social inequalities (15.4.10)
	GINI	40.0 (33.3-45.4)				
	FRAGILITY	45.4 (21.7-69.9)				
	CO2/PC	11.9 (3.8-16.6)				
Small Islands	PPAHDI	0.68 (0.51-0.76)	• high dependence of economic activity on tourism (15.3.4.5) • Lack of coordination among government departments (15.6.1) • limited regional cooperation (15.6.1)	• increasing women's access to climate change funding and support from organizations (15.6.5)promoting agroecology, food sovereignty, and regenerative economies (15.7)	• raising dwellings and other infrastructure (15.5.2) • land reclamation (15.5.2) • migration and planned resettlement (15.5.2) • ecosystem-based adaptation including Indigenous and local knowledge (15.5.2)	• (S+) development decisions and outcomes are strengthened by consideration of climate and disaster risk (15.7) • (S-) impacts of invasive alien species on islands are projected to increase with
	GINI	40.2 (28.7-56.3)				
	FRAGILITY	64.6 (38.1-97.5)				

	CO2/PC	3.7 (0.3-31.3)	• absence of planning frameworks (15.6.1) • corruption and corrupt people in political and public life (15.6.1) • insufficient human capital (15.6.1) • competing development priorities (15.5.5) • lack of education and awareness around climate change (15.6.4) • failure of externally driven adaptation (15.6.5) • constraints on economic, legislative, and technical capacity of local governments (15.7)	• expanding sustainable tourism economies (15.7) • integrating climate change and disaster management with broader development planning and implementation (15.7) • using climate risk insurance as a way to support development and adaptation processes (15.7) • improving cross sectoral and cross agency coordination (15.7) • enhanced integration between development assistance, public financial management, and climate finance (15.5.7)	• protected areas (15.5.2) • ecosystem restoration and improved agroforestry practices (15.5.2 15.5.4) • community-based adaptation (15.5.5) • livelihood diversification and use of improved technologies and equipment (15.5.6) • diversifying cropping patterns, expanding or prioritizing other cash crops (15.5.6) • small-scale livestock husbandry (15.5.6) • irrigation technologies (15.5.6) • diversification away from coastal tourism • disaster risk management (DRM) (15.5.7) • early warning systems and climate services (15.5.7)	time due to synergies between climate change and other drivers (15.3.3) • (S-) synergies between changing climate and other natural and anthropogenic stressors could lead to disproportionate impacts on biodiversity (15.3.3)

Table 18.7: Sectoral synthesis of dimensions of climate-resilient development. For each sectoral chapter of the WGII report, this table identifies those SDGs that are discussed in the relevant chapter as being particularly relevant to the sector. In addition, the table contains evidence of sustainable development challenges and opportunities as well as adaptation/sustainable development options and potential synergies and trade-offs associated with their implementation. Synergies and trade-offs are categorized as follows: (T) Trade-off among policies and practices; (S+) Synergy among policies and practices that enhances sustainability; (S-) Synergy among policies and practices that undermines sustainability.

Sector	***Relevant SDGs***	***Challenges***	***Opportunities***	***Options***	***Trade-offs***
Terrestrial and freshwater ecosystems and their services	SDG 1, SDG 2, SDG 3, SDG 6, SDG 7, SDG 9, SDG 10, SDG 11,	• low capacity for dispersal limits range shifts to match climate (2.6.1) • constraints on the evolution of greater stress tolerance among species (2.4.2, 2.6.1) • altered peatland drainage and repeated disturbances pose	• nature based solutions offer the opportunity to address climate change and biodiversity problems in an integrated way (2.6) • adaptation can be integrated with the protection of biodiversity and land-based	• habitat restoration, connectivity, and creation of protected areas (Table 2.5) • integrated landscape management (Table Cross-Chapter Box NATURAL.1 in Chapter 2)	• (S+) ecosystem-based adaptation measures, such as restoration of forests and wetlands for flood and erosion control help maintain freshwater supply and quality (2.2.2) • (S-) over-grazing/stocking of pastures and grasslands can result

	SDG 12, SDG 13, SDG 15, SDG 17	barriers to restoration of tropical peatlands (2.4.3) • demonstrating the efficacy of natural flood management efforts poses challenges to its deployment (2.6.5) • uncertainties in climate and socioeconomic projections constrain adaptation planning and implementation (2.7)	climate change mitigation initiatives (2.6.2)	• community-based natural resource management (2.6.5.7) • maintain or restore natural species and structural diversity (Table Cross-Chapter Box NATURAL.1 in Chapter 2) • restoration of hydrological flows and catchment vegetation (Table Cross-Chapter Box NATURAL.1 in Chapter 2) • control of feral herbivores with (Table Cross-Chapter Box NATURAL.1 in Chapter 2) • reduce non-climatic stressors to land-based ecosystems (Table 2.6)	in soil erosion and the loss of biodiversity (Table Cross-Chapter BoxNATURAL1 in Chapter 2) • (T) planting non-native monocultures for mitigation can reduce biodiversity and resilience • (T) inappropriate hydrological restoration can result in increased methane emissions (Table Cross-Chapter Box NATURAL1 in Chapter 2) • (T) afforestation/reforestation and bioenergy initiatives can conflict with other land uses such as food and timber production (Table Cross-Chapter Box BECCS, 2.2.2, Box 2.2)
Ocean and coastal ecosystems and their services	SDG1, SDG2, SDG3, SDG5, SDG7, SDG8, SDG9, SDG10, SDG11, SDG12, SDG13, SDG14	• shifts in the distribution of fish species across exclusive economic zones present governance, ecological, and conservation challenges (3.4.3) • resource constraints impede the implementation of ecosystem-based and community-based adaptation for low- to middle-income nations (3.6.2) • governance in marine social-ecological systems is highly complex with poorly-defined legal frameworks (3.6.2) • "Coastal squeeze" challenges adaptation, creating tensions between coastal development and coastal habitat management (3.6.3)	• development assistance can help address resource constraints associated with marine ecosystem management (3.6.3) • improving coordination among actors and projects will contribute to achieving SDGs (3.6.3) • private finance can support restoration of blue-carbon systems (3.6.3) • joint implementation of coastal and marine management initiatives can address governance challenges across scales and sectors (3.6.3) • ocean-based renewable energy options can reduce reliance on imported fuel (3.6.3)	• maritime spatial planning and integrated coastal management (3.6.2; Figure 3.2.6) • adaptive and sustainable fisheries management (3.6.2) • habitat restoration (3.6.2) • fishery mobility (Figure 3.6.2) • assisted evolution (Figure 3.2.6) • increase participation in management and governance (Figure 3.2.6) • nature-based solutions (3.6.2) • hard and soft infrastructure (Figure 3.2.6) • livelihood diversification (Figure 3.6.2)	• (S+) adaptation in ocean and coastal systems can be designed in ways that substantially contribute to the SDGs and not only support but allow the attainment of social, environmental and economic targets (3.6.4) • (S+) blue/green economies can reduce emissions and finance adaptation pathways (3.6.3) • (T) built infrastructure conflicts with mitigation goals and can create potential ecological, social and cultural impacts that undermines ecosystem health (3.6.2)

				• disaster mitigation and response (Figure 3.2.6) • finance and market mechanisms (Figure 3.2.6)	
Water	SDG 1, SDG 2, SDG 3, SDG 6, SDG 7, SDG 10, SDG 11, SDG 13	• uncertainty in future water availability (Box 4.1, Box 4.4) • lack of sufficient data, information and knowledge in understanding the water energy food nexus (Box 4.6) • increasing urbanization is creating new and difficult demands for urban water management. (4.3.4) • barriers to adapting water-dependent livelihoods in rural communities (4.3.1) • mainstreaming water management across sectors and enhancing finance for adaptation (4.3.5) • path-dependency of institutions, and the speed at which these allow for changes in the decision-making process (4.5.3)	• a resilient circular economy delivers access to water, sanitation, wastewater, and ecological flows (Box 4.7) • adaptive sanitation systems and sustainable urban drainage contribute to a 'one health approach' which can prevent water and sanitation contamination risks during floods and droughts. (Box 4.7) • climate-proof infrastructure would reduce infection risks in flood-prone areas (Box 4.7) • governance can derive legitimacy from inclusion of multiple stakeholders, including women, indigenous communities and young people (4.6.6) • Indigenous and local knowledge can help ensure solutions align with the interests of communities (FAQ 4.5)	• changes in crop cultivars and agronomic practices (4.5) • changes in irrigation and water management practices (4.5) • water and soil conservation (4.5) • migration and off-farm livelihood diversification (4.5) • collective action, policies and institutions (4.5) • economic and financial incentives (4.5) • training and capacity building (4.5) • flood risk reduction measures (4.5) • urban water management (4.5) • water, sanitation, and hygiene adaptations (4.5) • agro-forestry and forestry responses (4.5) • livestock and fishery responses (4.5) • indigenous and local knowledge (4.5) • energy related adaptations (4.5)	• (S+) increasing the proportion of sewerage, treated wastewater, recycling and safe reuse would help reach climate and water targets (Box 4.7) • (S+) solar irrigation pumps provide for income diversification for small and marginal farmers while also generating renewable energy (Box 4.7) • (T) desalination of seawater or brackish inland water is energy-intensive, high salinity brine, and other contaminants (4.5.5) • (T) negative-emission technologies, such as direct air capture can result in a net increase in water consumption (4.5.5)
Food, fiber, and other ecosystem products	SDG1, SDG2, SDG3, SDG4, SDG5, SDG6,	• increased cost and management challenges of providing safe food (5.2.2) • warming-induced shifts of species create resource allocation	• integrated approaches to food, water, health, biodiversity and energy that involve vulnerable groups can help to address current and future food security challenges, reduce vulnerability	• livelihood diversification (5.4.4) • social protection policies and programs (5.4.4) • changes in crop management including irrigation,	• (S+) agricultural production systems that integrate crops, livestock, forestry, fisheries and aquaculture can increase food production per unit of land, reduce

	SDG7, SDG9, SDG9, SDG10, SDG11, SDG12, SDG13, SDG14, SDG15, SDG16	challenges among different fishing fleets (5.2.1) • challenges related to REDD+ implementation and forest use (5.6.3) • differences in perceptions about the validity of different forms of knowledge (5.8.4) • inequality in access to climate services (5.14.1) • lack of support, policies, and incentives for the adoption of agroecological approaches (BIOECO.1) • financial barriers limit implementation of adaptation options in agriculture, fisheries, aquaculture and forestry (5.14.3)	of Indigenous people, small-scale landholders and pastoralists, and promote resilient ecosystems. (5.12.3, 5.13.2; 5.14) • agroforestry delivers benefits for climate change mitigation, adaptation, desertification, land degradation, and food security and is considered to have broad adaptation and moderate mitigation potential (5.10.4) • partnerships between key stakeholders such as researchers, forest managers, and local actors can lead to a shared understanding of climate-related challenges and more effective decisions. (5.6.3)	fertilizers, planting schedules, and crop varieties (5.4.4.1) • adjusting water management for forage production (5.5.4) • rotational grazing of livestock (5.5.4) • fire management to control woody thickening of grass (5.5.4) • using more suitable livestock breeds or species (5.5.4) • migratory pastoralist activities (5.5.4) • monitor and manage the spread of pests, weeds, and diseases (5.5.4) • nature- or ecosystem-based strategies (5.12.5.2)	climatic risk, and reduce emissions (Chapter 5 ES) • (S+) integrated approaches to food, water, health, biodiversity and energy can help address current and future food security challenges, reduce vulnerability of Indigenous people, small-scale landholders and pastoralists, and promote resilient ecosystems. (5.12.3, 5.13.2; 5.14) • (T) growing biomass demand for producing sustainable bioproducts competes with food production with potential effects on food prices and knock-on effects related to civil unrest (BIOECO.1)
Cities, settlements and key infrastructure	SDG11, SDG13, SDG17	• poor municipal funding, data collection, and collaboration hinders sustainable development initiatives, capacity building, and climate action (6.1.5, 6.4.5, 6.4.9) • high urbanization rates pose challenges to areas that already have high levels of poverty, unemployment, informality, and housing and service backlogs (6.2.1) • Limited capacity for early-warning systems in low-income countries (6.3.2) • lack of administrative capacities, coordination across sectors and efforts, transparency and accountability slows sustainability transitions and disaster risk reduction (Case Study 6.4)	• urban ecological infrastructure including green, blue, turquoise and others can be a source of nature-based solutions that can improve both adaptation and mitigation in urban areas (6.1.2) • transition architecture movements can drive urban adaptation (6.4.1) • transformative capacities support adaptation efforts and systemic change processes (6.4.4) • incorporating Indigenous and local knowledge help generate more people-oriented and place-specific adaptation policies (6.4.7) • climate finance offers the opportunity to overcome structural impediments to climate action (Box 6.5)	• green infrastructure, sustainable land use and planning, and sustainable water management (6.1.2) • nature-based solutions (6.3.3) • insurance (6.3.2) • switching to air cooling for thermal power plants (6.3.4) • increasing the efficiency of hydro and thermoelectric power plants (6.3.4) • changing reservoir operation rules (6.3.4) • upgrading infrastructure and strengthening, or relocating (critical) assets (6.3.4) • including green, blue, turquoise and nature-based solutions (Cross-Chapter Box URBAN in Chapter 6)	• (S+) sustainable urban energy planning that includes opportunities to avoid and reduce the UHI effect can provide synergies for both climate mitigation and adaptation in urban areas (Cross-Chapter Box URBAN in Chapter 6) • (S+) natural ventilation and passive energy strategies can capture synergies between climate mitigation and adaptation (Cross-Chapter Box URBAN in Chapter 6) • (S+) community-based adaptation has potential to be better integrated to enhance well-being and create synergies with the Sustainable Development Goals • (T) urban mitigation efforts can create trade-offs with adaptation such as intensifying the Urban

			• urban ecological infrastructure can be a source of nature-based solutions that can improve both adaptation and mitigation in urban areas (Cross-Chapter Box URBAN in Chapter 6) • high density environments coupled with other design measures can provide mitigation and adaptation benefits (Cross-Chapter Box URBAN in Chapter 6)	• cooling networks (Cross-Chapter Box URBAN in Chapter 6) • early warning systems (Table 6.4) • resource demand and supply side management strategies (Table 6.4) • enhanced monitoring of air quality in rapidly developing cities (Table 6.4) • investment in air pollution controls (Table 6.4) • core and shell preservation, elevation and relocation for heritage buildings (6.3.2)	Heat Island (UHI) effect (Cross-Chapter Box URBAN in Chapter 6) • (T) efforts aimed at increasing adaptation may undermine mitigation objectives by increasing investment in hard infrastructure that increases emissions (Cross-Chapter Box URBAN in Chapter 6) • (T) lack of open and green spaces may induce long-distance leisure trips thereby increasing emissions and (Cross-Chapter Box URBAN in Chapter 6)
Health, wellbeing and the changing structure of communities	SDG3, SDG5, SDG8, SDG10, SDG13	• a lack of capacity for adaptation has resulted in only moderate or low levels of adaptation implementation across different countries (7.4.2) • transitioning to renewable energy sources presents opportunities for realizing health co-benefits (7.4.4) • shifting to healthier plant-rich diets can reduce GHG emissions and reduce land-use (Cross-Chapter Box HEALTH in Chapter 7) • future flows of migration within and between countries are likely to respond strongly to particular combinations of climatic hazards and may present challenges for future adaptation policies and programs • climate change disruptions to natural environments can be expected to disrupt livelihood practices, stimulate higher rates	• COVID-19 recovery investments offer an opportunity to contribute to climate resilient development through a green, resilient, healthy and inclusive recovery (Cross-Chapter Box COVID in Chapter 7) • investing in basic infrastructure for all can transform development opportunities, increase adaptive capacity and reduce climate risk (Cross-Chapter Box HEALTH in Chapter 7) • Integrated agroecological systems offer opportunities to increase dietary diversity while building local resilience to climate-related food insecurity (7.4.2) • Incorporating climate change and health considerations into disaster reduction and management strategies could	• improved building and urban design including use of passive cooling systems (Table 7.2) • better access to public health systems for the most vulnerable (Table 7.2) • deployment of renewable energy sources (Table 7.2) • improved water, sanitation and hygiene conditions (Table 7.2) • early-warning system of vector-borne diseases, insecticide treated bed nets, and indoor spraying of insecticide (Table 7.2) • targeted efforts to develop vaccines for infectious diseases exacerbated by climate change (Table 7.2) • improved personal drinking and eating habits (Table 7.2)	• (T) energy strategies for energy efficiency and GHG emissions reductions can generate health co-benefits through improved air quality but may slow poverty reduction efforts (7.4.2, 7.4.5) • (S+) investing in adaptation for health and community wellbeing has the potential to generate considerable co-benefits in terms of reducing impacts of non-climate health challenges • (S+) investments in mitigating greenhouse gas emissions will not only reduce risks associated with dangerous climate change, but will increase population health and wellbeing through a number of pathways. (7.4)

		of outmigration to urban centers, and in some instances necessitate planned or organized relocations of exposed settlements (Cross-Chapter Box MIGRATE in Chapter 7)	potentially improve funding opportunities (7.4.2) • adaptive urban design that provides access to healthy natural spaces can promote social cohesion and mitigate mental health challenges (7.4.2)	• improved food storage, food processing, and food preservation (Table 7.2) • emergency shelters for people to escape heat (Table 7.2) • improved funding and access to mental health care (Table 7.2) • improved education for girls and women (Table 7.2) • improved maternal and child health services (Table 7.2)	
Poverty, livelihoods and sustainable development	SDG1, SDG2, SDG3, SDG5, SDG10, SDG14	• use of political frameworks for decision-making that are unfavorable towards adaptation and system transitions (Table 8.4) • attitudes toward risk and other cultural values limit responses (Table 8.4) • psychological distress causes insecurity and behaviors that increase vulnerability (Table 8.4) • limited financial resources to support adaptation projects (8.2.2, Table 8.4) • small-holder farmers have poor access to markets and land tenure (8.6.1) • unsuitable infrastructure may increase exposure (Table 8.4) • lack of access to technologies that can support adaptation (Table 8.4) • gender-based inequalities constrain women's access to resources for adaptation (Table 8.7) • poverty constrains livelihood diversification, resilience or adaptive capacity (Table 8.7)	• polycentric governance, adaptive governance, multi-level governance, collaborative governance, or network governance are increasingly used to understand transitions towards climate-compatible development (8.6.2) • well-coordinated and integrated nexus approaches to adaptation offer opportunities to build resilient systems while harmonizing interventions, mitigating trade-offs and improving sustainability (8.6.2) • income from new livelihood activities can support recovery following disasters linked to climate variability and change (8.4.5) • improving industrial processes can contribute to the optimized use of energy, reuse of waste, reducing GHG emissions, use of biomass and more efficient equipment (Table 8.3) • industrialization and technological innovation in rural areas may assist vulnerable	• expanded private sector activity and public-private partnerships (8.6.1) • credit and insurance (8.6.1) • use of climate-smart agricultural practices and technologies (8.6.1) • crop insurance (8.6.1) • conservation agriculture (8.6.1) • changing farmers' perception and enhancing farmers' adaptive capacity (8.6.1) • REDD+ (8.6.1) • improving industrial processes (Table 8.3) • renewable energy and energy efficiency (Table 8.3) • smart electricity grids (8.6.1) • green buildings (8.6.1) • efficient fuels (8.6.1) • pollution control investments (8.6.1) • public transit and non-motorized transport with increased use of biofuels (8.6.1)	• (S+) agriculture technologies facilitate mitigation to climate change and adaptation such as saving water while maintaining grain yield (8.6.1) • (S+) sustainable pastoralism increases carbon sequestration but can also contribute to adaptation by changing grazing management, livestock breeds, pest management, and production structures (8.6.1) • (S+) REDD+ may provide adaptation benefits by enhancing households' economic resilience through positive livelihood impacts (8.6.1) • (S+) solar energy contributes to reducing GHG emissions and improving air quality (8.6.1) • (S+) hydropower contributes to mitigation and adaptation through water resource availability for irrigation and drinking water (8.6.1) • (S+) green roofed buildings contribute to cooler temperatures, thereby reducing energy use for air-conditioning (8.6.1)

		• indigenous peoples and other populations with strong attachments to place face barriers to adaptation (Table 8.7) • local institutions face ongoing challenges in gaining support from higher governance levels, particularly in developing countries. (8.5.2)	communities through provision of resources, enhanced forecast information, or reuse of biowaste (Table 8.3) • responses to climate change can create significant development opportunities including job creation and livelihood diversification (8.4.3)	• integrated natural resource management (Table 8.2) • disaster risk management (Table 8.2) • relocation of vulnerable communities (Table 8.2) • Education and communication (Table 8.2) • land use planning (Table 8.3)	• (T) mitigation measures such as bioenergy may result in trade-offs with efforts to achieve sustainable development, eradicate poverty and reduce inequalities (8.6.1) • (T) migration to urban centers can be a form of adaptation, but can increase the vulnerability of communities of origin or at destinations (8.2.2)

18.6 Conclusions and Research Needs

18.6.1 Knowledge Gaps

Research to improve the understanding of CRD currently exists in a nascent state, because, as noted in the AR5, "*integrating climate change mitigation, climate change adaptation, and sustainable development is a relatively new challenge*" (Denton et al., 2014). While a large volume of literature has emerged since the AR5 that spans the nexus of sustainable development, CRD, and climate action, the identified research gaps in AR5 (Denton et al., 2014) continue to be priorities for informing CRD. These include enhancing understanding of mainstreaming of climate change into institutional decision-making, managing risk under conditions of uncertainty, catalyzing system transitions and transformation, and processes for enhancing participation, equity, and accountability in sustainable development (*very high confidence*).

The more recent literature adds significant context to the concept of CRD, but also introduces broader perspectives regarding its significance in the arena of climate action. Hence, concepts that are both complementary to, and competitive with, CRD, such as climate safe', 'climate compatible' and 'climate smart' development (Huxham et al., 2015; Kim et al., 2017b; Ficklin et al., 2018; Mcleod et al., 2019) (18.1.1). These different framings of the intersection between sustainable development and climate action are used in different communities of research and practice, which complicates efforts to provide clear guidance to decision-makers regarding the goals of CRD and how best to achieve it. This is attributable in part to persistent conceptual confusion and disciplinary divides over more fundamental concepts such as resilience and sustainability (Rogers et al., 2020; Zaman, 2021), not to mention contested perspectives regarding development (Lo et al., 2020; Song et al., 2020a; Morton, 2021) (*medium agreement; medium evidence*).

Reconciling different perspectives on CRD is not simply a matter of academic debate. Climate action, resilience, and sustainable development are all active areas of policy and practice with significant economic, social, environmental, and political implications (18.1.3). Hence, enhancing the role of CRD as a practical framework for development and a guide for action may necessitate improving the science-policy discourse regarding CRD (Winterfeldt, 2013; Jones et al., 2014; Ryan and Bustos, 2019). This includes consideration for risk and science communication; decision analysis and decision support systems; and mechanisms for knowledge co-production between scientists and public policy actors (*very high confidence)*.

In addition, the AR6 WGII report highlights a number of elements of CRD that are associated with significant knowledge gaps and uncertainties. As a result, enhancing the value of CRD as a unifying concept in development would benefit from further conceptualization and socialization of the concept as well as efforts to address the following knowledge gaps:

- The challenges posed by different levels of global warming to achieving CRD and the magnitude and nature of the adaptation gap (and associated finance needs) that must be addressed to enable climate resilience.
- The efficacy of different adaptation, mitigation, and sustainable development interventions in reducing climate risk and/or enhancing opportunities for CRD in the short, medium and long term.
- How different CRD pathways can be designed such that they illustrate opportunities for the practical pursuit of CRD in a manner consistent with principles of inclusion, equity, and justice.
- How deliberative, participatory learning can be integrated into approaches to CRD in order to enhance the representation of diverse actors, forms of knowledge, governance regimes, economic systems, and models for decision-making in CRD.
- The synergies and trade-offs associated with the implementation of different policy packages and the design principles and development contexts that enhance the ability to successfully manage potential trade-offs.
- The limits of incremental system transitions to achieving CRD on a timeline that reflects the urgency associated with the Paris Agreement and the Sustainable Development Goals.
- The capacity of governments, social institutions, and individuals to drive large-scale social transformations that open up the solutions space for CRD.

- Best practices for avoiding maladaptation and ensuring that adaptation interventions are designed so they do not exacerbate vulnerability to climate change to support CRD.

18.6.2 Conclusions

The concept of CRD presents an ambitious agenda for actors at multiple scales – global to local, particularly in the manner in which it reframes climate action to integrate a broader set of objectives than simply reducing greenhouse gas emissions or adapting to the impacts of climate change. Specifically, recent literature extends policy goals for climate action beyond avoiding dangerous interference with the climate system to adopt normative goals of meeting basic human needs, eliminating poverty and enabling sustainable development in ways that are just and equitable. This creates a policy landscape for climate action that is not only richer, but also more complex in that it situates responses to climate change squarely within the development arena. Current policy goals associated with the Paris Agreement, Sendai Framework, and the SDGs imply aggressive timetables. Yet, as noted in the AR5 and supported by more recent literature (Section 18.2.1), the world is neither on track to achieve all of the SDGs nor fulfil the Paris Agreement's objective of limiting warming to well-below 2°C (Denton et al., 2014; IPCC, 2018a). This places aspirations for CRD in a precarious position. Transitions will be necessary across multiple systems (Section 18.1.3). While some may be already underway, the pace of those transitions must accelerate, and societal transformations may be necessary, to enable CRD (18.3, 18.4, Box 18.1)

Given the pace of climate change and the inherent challenge of sustainable development, particularly in the face of inevitable disruptions and setbacks such as the COVID-19 pandemic (Cross-Chapter Box COVID in Chapter 7), the feasibility of achieving CRD is an open question. Rapid changes will be required to shift public and private investments, strengthen institutions and orient them toward more sustainable policies and practices, expand the inclusiveness of governance and the equity of decision-making, and shift societal and consumer preferences to more climate-resilient lifestyles. Nevertheless, the collective body of recent literature on CRD, system transitions, and societal transformation, combined with the assessments within recent IPCC Special Reports (IPCC, 2018a; IPCC, 2019b; IPCC, 2019d) indicate that there are a broad range of opportunities for designing and implementing adaptation and mitigation options that enable the climate goals in the Paris Agreement to be achieved while enhancing resilience and meeting sustainable development objectives. However, options should be considered alongside the mechanisms by which societies can engage in order to create the conditions that can support the implementation of those options (Section 18.4). This includes formal policy mechanisms pursued by governments, the catalyzation of innovation by private firms and entrepreneurship, as well as informal, grassroots interventions by civil society. While there is no "one-size-fits-all" solution for CRD that will work for all actors at all scales, exploring different pathways by which actors can achieve their development and climate goals can make valuable contributions to developing effective strategies for CRD.

A fundamental challenge for achieving CRD globally is reconciling different perspectives on CRD. As noted in the AR5, "*as policy makers explore what pathways to pursue, they will increasingly face questions about managing discourses about what societal objectives to pursue*" (Denton et al., 2014: 1124). Since the AR5, such discourses have become prominent in policy debates over climate action and sustainable development due to different nations, communities, and subpopulations having different understandings of what constitutes CRD. Aggressive efforts to rapidly reduce greenhouse gas emissions or enhance resilience to climate change, for example, could have negative externalities for the development objectives of some actors. This potential for trade-offs complicates efforts to build consensus regarding what constitutes appropriate climate and development policies and practices and by whom. The CRD pathways preferred by one actor are likely to be contested by others. This means operationalizing concepts such as CRD in practice is likely to necessitate ongoing negotiation.

Ultimately, one of the critical developments within the literature is the emergence of procedural and distributive justice as key criteria for evaluating climate action and CRD more specifically. This trend not only recognizes the need to prevent vulnerable human and ecological systems from experiencing disproportionate harm from the changing climate, but also the need to prevent those same systems from being harmed by mitigation, adaptation, and sustainable development policies and practices. Failure to adequately engage with equity and justice when designing sustainability transitions could lead to maladaptation, aggravated poverty, reinforcement of existing inequalities, and entrenched gender bias and exclusion of Indigenous and marginalized communities (Jenkins et al., 2018; Fisher et al., 2019; Schipper et al., 2020b). These consequences could ultimately slow, rather than accelerate, CRD. Hence, developing programs and practices for prioritizing equity in effective transition risk management is an important dimension of enabling CRD.

As indicated by the literature assessed within this chapter, keeping windows of opportunity open for CRD will necessitate urgent action, even under diverse assumptions regarding how future mitigation and adaptation interventions evolve. If nations are to collectively limit warming to well-below 2°C, for example, unprecedented emissions reductions will be necessary over the next decade (IPCC, 2018a). These reductions would necessitate rapid progression of system transitions (18.3). If, despite the Paris Agreement, future emissions trajectories take the world beyond 2°C, a greater demand will be placed on adaptation as a means of enhancing the resilience of development. Given the long-lived nature of human systems, and the built environment in particular, significant adaptation investments would be needed over the near-term to meet this demand. Yet, it is important to note that even in the absence of consideration for climate change, substantial development needs exist for communities around the world at present. Hence, a robust strategy for the pursuit of CRDPs is a near-term focus on portfolios of policies and practices that promote of human and ecological well-being.

[START FAQ18.1 HERE]

FAQ18.1: What is a climate resilient development pathway?

Climate resilient development pathways (CRDPs) are continuous processes that strengthen sustainable development, efforts to eradicate poverty and reduce inequalities while promoting fair and cross-scalar capacities for adaptation to global warming and reduction of greenhouse gases in the atmosphere.

A pathway is defined in IPCC reports as a temporal evolution of natural and/or human systems towards a future state. These can range from sets of scenarios, narratives of potential futures to solution-oriented decision-making processes to achieve desirable societal goals.

When used in the context of climate resilient development (CRD), pathways refer to continuous processes that strengthen sustainable development, efforts to eradicate poverty, and reduce inequalities while promoting fair and cross-scalar adaptation and mitigation. As they imply deep societal changes and/or transformation, CRDPs raise questions of ethics, equity, and feasibility of options to drastically reduce emission of greenhouse gasses (mitigation) that limit global warming (e.g., to well below 2°C) and achieve desirable and livable futures and wellbeing for all.

There in no one true, correct pathway to pursue but multiple ways, modalities, depending on numerous factors, such as political, cultural and economic contexts. Pathways are not one single decision or action, nor is there an absolute, universal, fixed, final goal to be pursued, yet there are undesirable and non-CRDPs. Hence, a CRDP is a continuum of coherent, consistent decisions, actions and interventions within each country, and as a global community. While dependent on past development and its socio-ethical, political, economic, ecological and knowledge-technology outcomes at any point in time, transformation, ecological tipping points and shocks can create sudden shifts and unexpected non-linear development pathways. Actions taken today also foreclose some future potential pathways. The differentiated impacts of hurricanes and COVID-19 illustrate how the character of societal development such as equity and inclusion have enabled some societies to be more resilient than others.

[END FAQ18.1 HERE]

[START FAQ18.2 HERE]

FAQ18.2: What is climate resilient development and how can climate change adaptation (measures) contribute to achieving this?

The key purpose of CRD is to pursue sustainable development, engaging climate actions in ways that support human and planetary health and well-being, equity and justice. Climate resilient development combines adaptation and mitigation with underlying development choices and everyday actions, carried out by multiple actors within political, economic, ecological, socio-ethical and knowledge-technology arenas. The character of processes within these development arenas are intrinsic to how social choices are made, directing actions in a CRD or non-CRD direction. For example, inclusion, agency and social justice are qualities within the political arena that underpin actions that enable CRD.

CRD addresses the relationship between greenhouse gas emissions, levels of warming and related climate risks. However, CRD involves more than just achieving temperature targets. It considers the possible transitions that enable those targets to be achieved as well as the evaluation of different adaptation strategies and how the implementation of these strategies interact with broader sustainable development efforts and objectives. This interdependence between patterns of development, climate risk, and the demand for mitigation and adaptation action is fundamental to the concept of CRD. Therefore, climate change and sustainable development cannot be assessed or planned in isolation of one another.

Hence, CRD is defined as the development that deliberately adopts mitigation and adaptation measures to secure a safe climate on earth, meet basic needs for each human being, eliminate poverty and enable equitable, just and sustainable development. It halts practices causing dangerous levels of global warming. CRD may involve deep societal transformation to ensure well-being for all. CRD is now emerging as one of the guiding principles for climate policy, both at the international level, reflected in the Paris Agreement (UNFCCC, 2015) and within specific countries.

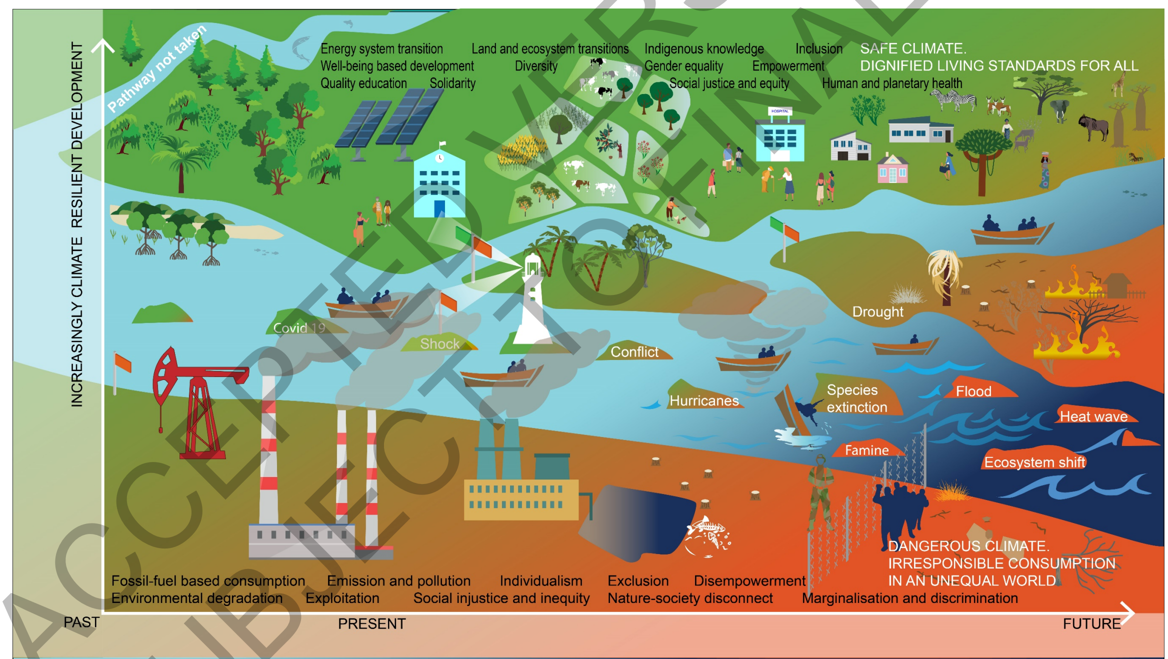

Figure FAQ18.2.1: Multiple intertwined climate resilient development pathways. Climate change adaptation is one of several climatic and non-climatic measures carried out through decision-making by multiple actors that may drive a pathway in a CRD or non-CRD direction. Adaptation, mitigation and sustainable development actions can push a society in a CRD direction, but only if these measures are just and equitable. There are multiple simultaneous pathways in the past, present and future. Societies (illustrated as boats) move on different pathways, towards CRD and non-CRD, with some pathways more dominant than others. The direction of pathways is emergent, taking place through contestations and social choices, through social transformation as well as through surprises and shocks (illustrated as rocks). Path dependency means it is possible but often turbulent to shift from a non-CRD to a CRD pathway. Such a shift becomes more difficult in as risks/shocks increase (more rocks) and non-CRD processes and outcomes progress, limiting future options. Low CRD processes and outcomes at the bottom are characterized by inequity, exclusion, polarization, environmental and social exploitation, entrenchment of business as usual, with increasing risks/shocks. High CRD processes and outcomes (at the top of the figure) are characterized by equity, solidarity, justice, human well-being, planetary health, stewardship/care and system transitions.

Climate change adaptation is one of several climatic and non-climatic measures carried out through decision-making by multiple actors that may drive a pathway in a CRD or non-CRD direction. Adaptation, mitigation and sustainable development actions can push a society in a CRD direction, but only if these measures are just and equitable. There are multiple simultaneous pathways in the past, present and future. Societies (illustrated as boats) move on different pathways, towards CRD and non-CRD, with some pathways more dominant than others. The direction of pathways is emergent, taking place through contestations and social choices, through social transformation as well as through surprises and shocks (illustrated as rocks). Path dependency means it is possible but often turbulent to shift from a non-CRD to a CRD pathway. Such a shift becomes more difficult in as risks/shocks increase (more rocks) and non-CRD processes and outcomes progress, limiting future options. Low CRD processes and outcomes at the bottom are characterized by inequity, exclusion, polarization, environmental and social exploitation, entrenchment of business as usual, with increasing risks/shocks. High CRD processes and outcomes (at the top of the figure) are characterized by equity, solidarity, justice, human well-being, planetary health, stewardship/care and system transitions.

[END FAQ18.2 HERE]

[START FAQ18.3 HERE]

FAQ18.3: How can different actors across society and levels of government be empowered to pursue climate resilient development?

CRD entails trade-offs between different policy objectives. Governments, political and economic elites may play a key role in defining the direction of development at a national and sub-national scale; but in practice, these pathways can be influenced and even resisted by local people, NGOs and civil society.

Contestation and debate are inherent in its construct and implementation. An active civil society and citizenship create the enabling conditions for deliberation, protest, dissent and pressure which are fundamental for an inclusive participatory process. These enable a multiplicity of actors to engage across multiple arenas, from decision-making and everyday actions Hence, decisions and actions may be influenced by uneven interactions between actors, including socio-political relations of domination, marginalization, contestation, compliance and resistance with diverse and often unpredictable outcomes.

In this way, recent social movements and climate protests show new modalities of action related to political responsibility for inaction based on contestation. The new climate movement led mostly by youngsters, markedly seek science-based policy and more importantly, demand to break with a reformist stance and social inertia through radical climate action. This is mostly done through collective disruptive action, and non-violent resistance to promote awareness, a regenerative culture and ethics of care. These movements have resulted in notable political successes, such as declarations of climate emergency at the national and local level, as well as in universities. Also, their methods have proven effective to end fossil fuel sponsorship.

The success and importance of recent climate movements also provide elements to rethink the role of science in society. In one hand, the new climate movements demanding political action were prompted by the findings of scientific reports, mainly the IPCC (2018a) and IPBES (2019) reports. On the other hand, these movements have increased public awareness, and also stimulated public engagement with climate change at unprecedented levels.

[END FAQ18.3 HERE]

[START FAQ18.4 HERE]

FAQ18.4: What role do transitions and transformations in energy, urban and infrastructure, industrial, land and ocean ecosystems, and in society, play in climate resilient development?

The IPCC 1.5 report identified transitions and transformations in key systems, such as energy, land, and ocean ecosystems, and urban and infrastructure, that are needed for a climate resilient development. A system transitions focus helps visualize the interdependence between each system as well as how sustainable development, mitigation, and adaptation interact. A societal transformation, in terms of values and worldviews that shape aspirations, lifestyles and consumption patterns, is a constraining/enabling condition for such transformations. This report however identifies societal transformation as one of the five major transformations currently underway. It delves into the implications of this on how we assess options, value different outcomes from the perspectives of ethics, equity, justice and inclusion.

[END FAQ18.4 HERE]

[START FAQ18.5 HERE]

FAQ18.5: What are success criteria in climate resilient development and how can actors satisfy those criteria?

Climate resilient development is not a predefined goal to be achieved at a certain point or stage in the future. It is a constant process of evaluating, valuing, acting and adjusting various options for mitigation, adaptation and sustainable development, shaped by societal values as well as contestations of these. Any achievement or success is always a work in progress, with continuous, directed, intentional actions. These actions will vary according to the priorities and needs of each population or system; therefore, specific indicators will vary according to each specific context, ensuring we prioritize people, planet, prosperity, peace, and partnership, per the broad goals of the Agenda 2030 on sustainable development.

If Climate Resilient Development is defined as the development that deliberately adopts mitigation and adaptation measures to secure a safe climate, meet basic needs, eliminate poverty and enable equitable, just and sustainable development, then, the 17 United Nations' Sustainable Development Goals (SDGs) provide a good (although limited) measure of progress. They aim at ending poverty and hunger globally and protect life on land and under water until the year 2030. Although there are proven synergies between the SDGs and mitigation, there remains to explore clear synergies between the SDGs and adaptation in terms of how adaptation relates to the fulfilment of the SDGs.

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[START CROSS-CHAPTER BOX FEASIB HERE]

Cross-Chapter Box FEASIB: Feasibility Assessment of Adaptation Options: An Update of the SR1.5

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Key Messages

The feasibility assessment presents a systematic work towards providing a suite of adaptation and mitigation options organised by system transitions. This Cross-Chapter Box assessed the feasibility over six
dimensions: geophysical, environmental-ecological, technological, economic, socio-cultural and institutional to identify factors within each dimension that present barriers to the achievement of the option. The results are presented

For energy systems transitions the options of infrastructure resilience, efficient water use and water management, and reliable power systems enable systems to work during disasters with reduced costs demonstrating the synergistic relationships of mitigation and adaptation (*high confidence*). There is high confidence in the high feasibility of infrastructure resilience and reliable power systems as they enable power systems to provide emergency services during disasters as well as for the continuance of these services during recovery periods. New evidence has focused on both options for peri-urban and rural areas through distributed generation and isolated renewable energy systems, which also provide multiple social co-benefits (medium confidence). For efficient water use and management, there is also high confidence on the synergistic potential with mitigation as it can make processes more efficient and cost effective. With regards to adaptation feasibility, efficient water use is especially useful in drought-stricken areas and provides a better water management for multiple uses (high confidence).

There are multiple options for land and other ecosystems. Forest- and biodiversity-based adaptation solutions are generally promoted on the basis of their positive impacts on adaptive and ecological capacities, increased provision of ecosystem services and goods, with a particularly strong contribution to carbon sequestration (high confidence). However, large afforestation projects and the introduction of non-native and fast-growing vegetation have been found to reduce water availability, impoverish habitats for wildlife, and reduce overall ecological resilience, threatening the achievement of some SDGs, and potentially leading to maladaptation (high confidence). In addition, over-reliance on forest-based solutions may increase the susceptibility to wildfires, with detrimental consequences both for mitigation and adaptation (medium confidence). Over the last decade, forest- and biodiversity-based solutions have gained considerable political traction and social acceptability (high confidence), but in countries with economies highly dependent on the export of agricultural commodities, opportunity costs continue to hinder the expansion of these alternatives, particularly against more profitable land uses (high confidence). In such cases, government support and innovative financial schemes, including payments for ecosystem services, are fundamental for broader adherence to forest- and biodiversity-based options.

Agroforestry solutions have strong ecological and adaptive co-benefits (high confidence), including improved provision of ecosystem services, synergies with the water-energy-land-food nexus, and positive outcomes in agricultural intensification, job diversification and household income. While broad inclusion of agroforestry schemes in countries' Nationally Determined Contributions reflect growing international interest in these strategies, insufficient financial support to small farmers continues to limit the expansion of agroforestry initiatives in developing and tropical countries.

Implementing environmentally and biodiversity-sensitive coastal defense options - often as part of Integrated Coastal Zone Management - is limited by economic, environmental, institutional and social barriers. Successful implementation requires a strong socio-economic framework and can offer diverse social, ecological and economic benefits, as well as sequestering carbon (high confidence). There is extensive experience with hard engineering coastal defense structures, which can be cost-effective in economic terms, depending on the location (*medium confidence*); however they are considered non-adaptive and unsustainable in some contexts (*medium confidence*) due to their lack of flexibility or robustness in response to a changing climate, as well as their carbon-intensiveness and potential ecological impacts (*medium confidence*).

There is *medium confidence* on the feasibility of sustainable aquaculture as adaptation measure. There are financial barriers to implementing sustainable aquaculture, even though it can improve employment opportunities, which would benefit local communities (*medium confidence*). Technical resource availability is still lacking and could represent a barrier to implementing sustainable aquaculture (*medium confidence*). Robust institutional and legal frameworks are needed to guarantee successful sustainable adaptation (*high confidence*). Social aspects, such as social acceptability, inclusiveness, and gender equity are relevant for the feasibility of sustainable aquaculture (*medium confidence*). Sustainable aquaculture is highly dependent on healthy and resilient ecosystems (*high confidence*). It can provide diverse ecosystem services and support efforts for coastal ecosystems restoration (*medium confidence*).

There are a range of strategies to improve livestock system efficiency including improved livestock diets, enhanced animal health, breeding and manure management, and grassland management. This suite of strategies has strong feasibility to build resilience while improving incomes (medium confidence) and providing mitigation co-benefits (high confidence). While technological and ecological feasibility is high, institutional, market-linked, and socio-political acceptability remain significant barriers (medium confidence).

Improving water use efficiency and water resource management under land and ecosystem transitions has high technological feasibility (high confidence) with positive resilience building and socio-economic co-benefits. However, economic and institutional barriers based on type, scale, and location of interventions
(medium confidence). Notably, inadequate institutional capacities to prepare for changing water availability, especially in the long term, unsustainable and unequal water use and sharing practices, and fragmented water resource management approaches remain critical barriers to feasibility (high confidence).

Improved cropland management includes agricultural adaptation strategies such as integrated soil management, no/reduced tillage, conservation agriculture, planting of stress-resistant or early maturing crop varieties, and mulching. These strategies have high economic and environmental feasibility (high confidence) and also have substantial mitigation co-benefits (medium confidence). However, costs, inadequate information and technical know-how, delays between actions and tangible benefits, lack of comprehensive policies, fragmentation across different sectors, inadequate access to credit, and unequal access to resources constrain technological, institutional and socio-cultural feasibility (medium confidence).

For urban and infrastructure system transitions, urban planning can support both adaptation and decarbonization by mainstreaming climate concerns, including effective land-use into urban policies, by promoting resilient and low-carbon infrastructure; and by protecting and integrating carbon-reducing biodiversity and ecosystem services into city planning (medium confidence). Urban green infrastructure and ecosystem services have high feasibility to support climate adaptation and mitigation efforts in cities, for example to reduce flood exposure and attenuate the urban heat island (high confidence). While green infrastructure options are cost-effective and provide co-benefits in terms of ecosystem services such as improved air quality or other health benefits (high confidence), there remains a need for systematically assessing co-benefits, particularly for flood risk management and sustainable material flow analysis. Governments across scales can support urban sustainable water management by undertaking projects to recycle wastewater and runoff through green infrastructure; greater coherence between urban water and riverine basin management; decentralization of water systems; supporting networks for sharing best practices in water supply and storm runoff treatment to scale sustainable management; and foregrounding equity and justice concerns, especially participation involving informal settlement residents (medium confidence).

Strong and equitable health systems can protect the health of populations in the face of known and unexpected stressors (medium confidence). Public health system adaptation is feasible where capacity is well-developed, and where options align with national priorities and engage local and international communities (medium confidence). Socio-cultural acceptability of public health adaptation is high and there is significant potential for risk-mitigation and social co-benefits where adaptation addresses the needs of vulnerable regions and populations (medium confidence). Microeconomic feasibility, and socio-economic vulnerability reduction potential are also high (high confidence), though macroeconomic feasibility may pose a significant challenge in low-income settings (medium confidence). However, inadequate institutional capacity and resource availability represent major barriers, particularly for health systems struggling to manage current health risks (high confidence).

There is strong evidence that disaster risk management (DRM) is highly feasible when supported by strong institutions, good governance, local engagement, and trust across actors (medium confidence). DRM are constrained by lack of capacity, inadequate institutions, limited coordination across levels of government (high confidence), lack of transparency and accountability and poor communication (medium confidence). There is a preference for top-down DRM processes, which can undermine local institutions and perpetuate uneven power relationships (medium confidence). However, local integration of worldviews, belief systems and Local and Indigenous Knowledge into DRM activities can facilitate successful, disability-inclusive and gender-focused DRM (medium confidence). Moves towards community-based and ecosystem-based DRM are promising but uneven and may increase vulnerability if they fail to address underlying and structural determinants of vulnerability (high confidence).

There is *high confidence* that climate services that are demand-driven and context-specific (e.g., to a particular crop or agricultural system) build adaptation capacity and enable short- and longer-term risk management decisions. Metrics to assess the economic outcomes of climate services remain insufficient to capture longer-term benefits of interventions (medium confidence). While technological capacity and political acceptance is high (medium confidence), institutional barriers, poor fit with user requirements, and inadequate regional coverage constrain the option's overall feasibility.

Risk insurance can be a feasible tool to adapt to climate risks and support sustainable development (*high confidence*). They can reduce both vulnerability and exposure, support post-disaster recovery, and reduce financial burden on governments, households, and business. Insurance mechanisms enjoy wide legal and regulatory acceptability among policy makers and are institutionally feasible (*high confidence*). However, socio-cultural and financial barriers have made insurance spatially and temporally challenging to implement (*high confidence*), even though it can improve the health and well-being of populations (*medium confidence*). The risk of generating maladaptive outcomes can further limit the uptake of insurance, as it can provide disincentives for reducing risk over the long term (*medium confidence*). Expanding the knowledge base on insurance is fundamental to successfully implement insurance among all relevant stakeholders, and ensuring an equitable access to and benefits from innovative financial products (e.g. loans) is also needed to guarantee successful uptake of insurance across all the population (*high confidence*).

Migration has been used by millions around the world to maintain and improve their wellbeing in the face of changed circumstances, often as part of labour or livelihood diversification (*very high confidence*). Properly supported and where levels of agency and assets are high, migration as an adaptation to climate change can reduce exposure and socioeconomic vulnerability (*medium confidence*). Households and communities in climate-exposed regions experience a range of intersecting stressors. These households can undertake distress migration, which results in negative adaptive and resilience outcomes (*high confidence*). Outcomes can be improved through a systematic examination of the political economy of local and regional sectors that employ precarious communities and by addressing vulnerabilities that pose barriers to *in situ* adaptation and livelihood strategies (*medium confidence*). Migrants and their sending and receiving communities can be supported through temporary labour migration schemes; improving discourses on migration; and meeting existing migration agreements and development objectives (*medium confidence*).

Planned relocation and resettlement have low feasibility as an adaptation option (*medium confidence*). Previous disaster- and development-related relocation has been expensive, contentious, posed multiple challenges for governments and amplified existing, and generated new, vulnerabilities for the people involved (*high confidence*). Planned relocation will be increasingly required as climate change undermines habitability, especially for coastal areas (*medium confidence*). Full participation of those affected, ensuring human rights-based approaches, preserving cultural, emotional and spiritual bonds to place, and dedicated governance structures and associated funding are associated with improved outcomes (*high confidence)*. Improving the feasibility of planned relocation and resettlement is a high priority for managing climate risks *(high confidence*).

CCB FEASIB.1 Scope

The Paris Climate Agreement marked a significant shift for the IPCC AR6 assessment towards a systematic exploration of climate solutions and a suite of linked adaptation and mitigation options (IPCC, 2018; IPCC, 2019). This shift was first evidenced in SR1.5, whose plenary-approved outline sought to define " Feasibility refers to the potential for a mitigation or adaptation option to be implemented. Factors influencing feasibility are context-dependent, temporally dynamic, and may vary between different groups and actors. Feasibility depends on geophysical, environmental-ecological, technological, economic, socio-cultural and institutional factors that enable or constrain the implementation of an option. The feasibility of options may change when different options are combined, and increase when enabling conditions are strengthened". Based on this mandate, SR1.5 identified (with *high confidence*) rapid and far-reaching transitions in four systems: energy, land and other ecosystems, urban and infrastructure (including transport and buildings) and industrial systems, necessary to enable pathways to limit average global warming to 1.5°C compared to pre-industrial temperatures (Bazaz et al., 2018; IPCC, 2018). This was deepened for terrestrial systems in SRCCL, while SROCC added additional evidence from ocean and cryosphere systems. The assessment includes the interactions between carbon dioxide removal and adaptation outcomes: compared to previous Assessment Reports, it is clear that the ambitious temperature targets agreed upon in Paris in 2015 will require at least some carbon dioxide removal (CDR), i.e. all 1.5°C pathways feature annual removals at Gigaton level (Rogelj et al., 2018). This necessitates assessing the interactions of CDR with adaptation.

This feasibility assessment of adaptation options is situated within four system transitions identified in SR1.5 (de Coninck et al., 2018). In this report, feasibility refers to the potential for a mitigation or adaptation option to be implemented. Factors influencing feasibility are context-dependent, temporally dynamic, and may vary between different groups and actors. Feasibility depends on geophysical, environmental-ecological, technological, economic, socio-cultural and institutional factors that enable or constrain the implementation of an option. The feasibility of options may change when different options are combined, and increase when enabling conditions are strengthened. Twenty-two key adaptation options have been identified in AR6, across these system transitions, and mapped against representative key risks at global scale (Chapter 16) (Figure 1).

This cross-chapter box first presents the methodology for the feasibility assessment of adaptation options (section 2); findings of the FA (section 3); presents S&Ts of adaptation for mitigation options and mitigation for adaptations (section 4); and knowledge gaps (section 5).

There has been growing research emphasis on synthesising adaptation literature through meta-reviews of adaptation research (Sietsma et al., 2021), adaptation readiness (Ford et al., 2015; Ford et al., 2017); adaptation progress (Araos et al., 2016a); adaptation barriers and enablers (Biesbroek et al., 2013; Eisenack et al., 2014; Barnett et al., 2015); and adaptation outcomes (Owen, 2020) [Cross-Chapter Box ADAPT in Chapter 1]. In particular, understanding which adaptation options are effective, to what risks, and under what conditions, is particularly challenging given the lack of a clearly defined, globally agreed upon adaptation goal and disagreement on the metrics to assess effectiveness (Berrang-Ford et al., 2019; Singh et al., 2021b) [Ch 17, Sec 17.5.2 on Successful adaptation]. Effectiveness studies often use metrics such as proportion of population amount of population exposure reduced or conduct cost-benefit analyses of specific options, which lend themselves well to infrastructural options (e.g. effectiveness of seawalls in reducing SLR exposure in coastal cities) but do not translate well to 'soft' adaptation options such as uptake of climate services or changing building codes.

Systems transitions RKRs	Energy Systems Transitions	Land and Ecosystems Transitions	Urband & Infrastructure Systems Transitions	Overarching Adapatation Options
Risk to coastal socio-ecological systems		• Coastal defence and hardening • Sustainable aquaculture		
Risk to terrestrial and ocean ecosystems		• Integrated coastal zone management including wetland, mangrove conservation • Sustainable forest management and conservation, reforestation and afforestation • Biodiversity management and ecosystem connectivity		• Social safety nets • Risk spreading and sharing • Risk spreading and sharing • Climate services, including EWS • Disaster risk management • Population health and health systems • Human migration and displacement • Planned relocation and resettlement
Risks associated with critical physical infrastructure, networks, and services	• Resilient power infrastructure • Improved power reliability		• Green infrastructure & ecosystem services • Sustainable land-use & urban planning	
Risk to living standards and equity		• Livelihood diversification		
Risk to human health				
Risk to food security		• Improved cropland management(including integrated soil management, conservation agriculture) • Efficient livestock systems (including improved grazing land management) Agroforestry		
Risk to water security	• Improve water use efficiency	• Water use efficiency and water resource management	• Sustainable urban water management	
Risk to peace and migration				

Figure Cross-Chapter Box FEASIB.1: Feasibility assessment option mapped against Representative Key Risks (RKRs)

CCB FEASIB.2 Methodology: feasibility assessment of adaptation options across key system transitions

Multi-dimensional feasibility of adaptation options is assessed across six dimensions. This multidimensional framework goes beyond technical or economic feasibility alone to capture how adaptation is mediated by the political environment, sociocultural norms (Evans et al., 2016), cognitive and motivational factors (van Valkengoed and Steg, 2019), economic incentives and benefits (Masud et al., 2017), and ecological conditions (Biesbroek et al., 2013).

The six feasibility dimensions are underpinned by a set of twenty indicators. Each adaptation option is scored as having high, medium or low evidence on barriers based on a review of literature published from 2018 onwards (pre-2018 literature is expected to be covered by SR1.5 but in some cases pre-2018 literature was added where relevant literature was found) that reports studies that are 1.5°C-relevant. Further details and motivations for this methodology can be found in (Singh et al., 2020c)."

The scoring process is undertaken by one author and reviewed by at least two more authors to ensure robustness and geographical coverage. While the literature does not support an assessment at different temperature levels or an assessment of how feasibility can change over time, some examples on these spatial and temporal aspects are detailed below.

CCB FEASIB.3 Findings: feasibility assessment of adaptation options across key system transitions

The following sections outline the findings of a 1.5ºC-relevant feasibility assessment of adaptation options by the four system transitions. A synoptic summary of the findings of the multi-dimensional feasibility is shown at the end of this section in Figure Cross-Chapter Box FEASIB.2. The full line of sight can be found in Supplementary Material (SM).

CCB FEASIB.3.1 Energy systems transitions

The adaptation options assessed for energy system transitions are resilient power infrastructure, water management, focused on water efficiency and cooling, for all types of generation source, and reliable power systems. Since SR1.5, there has not been significant change in the feasibility of the first two options as they continue to be implemented successfully, allowing for power generation to maintain or increase its reliability during extreme weather events (high confidence) (Zhang et al., 2018) (Ali and Kumar, 2016; DeNooyer et al., 2016). As in the case of SR1.5, these options are not sufficient for the far-reaching transformations required in the energy sector, which tend to focus on technological transitions from a fossil-based to a renewable energy regime (Erlinghagen and Markard, 2012; Muench et al., 2014; Brand and von Gleich, 2015; Monstadt and Wolff, 2015; Child and Breyer, 2017; Hermwille et al., 2017). The main difference from SR1.5 is that resilient power infrastructure now includes distributed generation utilities, such as microgrids, as there is increasing evidence of its role in reducing vulnerability, especially within underserved populations (high confidence).

The option for resilient power infrastructure is considered for all types of power generation sources, and transmission and distribution systems. There is robust evidence and high agreement for the high feasibility of the economic and technological dimensions as the technologies have been used and their cost effectiveness is high, although the latter is dependent upon the generation source and location of each specific generation plant. There is medium institutional feasibility (medium evidence, medium agreement) as there are insufficient policies for resilient infrastructure, although there is high acceptability for these options.

The option of efficient water use and management also has high feasibility for the economic, technological and environmental dimensions (robust evidence, high agreement), as this option also has proven that technology and efficient water use can make operations more efficient and cost effective as well as have positive effects on the environment, especially in drought-stricken regions. There is high political acceptability, existence of water use policies, regulations and supporting institutional frameworks to ensure compliance (Ali and Kumar, 2016; DeNooyer et al., 2016; Zhang et al., 2018). There is medium evidence and high agreement for the medium feasibility of the socio-cultural dimension, especially given the evidence of resilience in distributed generation systems and independent microgrids.

Since AR5, the reliability of power systems has gained interest due to the numerous service disruptions during extreme weather events. As with resilient power systems, there is increasing evidence of the feasibility of increased reliability for both existing power plants, independently of the generation source, and for rural landscapes. The option has high confidence (robust evidence, high agreement) for the high feasibility of the technological and social dimensions. As with previous options, the technological means exist to create redundancy in power generation, transmission and distribution systems and their implementation ensures the continuous functionality of emergency services, such as communications, health, and water pumping, amongst others, in urban, peri-urban and rural landscapes (high confidence). There is high feasibility for the economic, technical and socio-cultural dimensions (the latter more prominently for decentralized systems), and medium feasibility for institutional and geophysical dimensions.

For the three options, some of the indicators within the institutional, social and geophysical dimensions have limited evidence as they haven't been the focus of research. For example, when discussing the social co-benefits of energy reliable systems of efficient water use, literature doesn't focus on intergenerational or gender issues separately from the broad range of social co-benefits the options provide, but, for example, highlight the need for electricity for communications and health centers.

CCB FEASIB.3.2 Land and ecosystems

CCB FEASIB.3.2.1 Coastal defence & hardening

There is *medium agreement* and *robust evidence* regarding the feasibility of coastal defense and hardening as adaptation options in some circumstances, which here includes hard engineering solutions and grey coastal infrastructure. Economic and social factors potentially limit the feasibility of these options as they require large investments (both construction, maintenance and monitoring) (Hamin et al., 2018; Magnan and Duvat, 2018; Morris et al., 2018; Morris et al., 2019; Nicholls et al., 2019; Hanley et al., 2020b) (CCP2.3). While these costs present challenges for rural areas, coastal defense structures may still be cost-effective in some areas, such as those with larger economies (Aerts, 2018; Lincke and Hinkel, 2018; Tiggeloven et al., 2020; Vousdoukas et al., 2020; Lima and Coelho, 2021)). Strong yet transparent and inclusive governance is key, suggesting that these measures can occasionally fail to adequately balance competing stakeholder interests. Consequently, they may disproportionately benefit wealthier people and exacerbate existing vulnerability (Kind et al., 2017; O'Donnell, 2019; Ratter et al., 2019; Siders and Keenan, 2020; Siriwardane-de Zoysa, 2020). They are also potentially maladaptive in that they are not flexible or robust in response to a changing climate (Antunes do Carmo, 2018; Hamin et al., 2018; Morris et al., 2019; Baills et al., 2020; Foti et al., 2020; Hanley et al., 2020b) and can have negative impacts on the local environment, habitats, ecosystems and services, and communities (Mills et al., 2016; Morris et al., 2018; Morris et al., 2019; Foti et al., 2020; Hanley et al., 2020b).

Recent projects have focused on improving adaptability and increasing ecological and social sustainability, by combining both hard engineering and 'softer' nature-based solutions (Morris et al., 2019; Scheres and Schüttrumpf, 2019; Schoonees et al., 2019; Van Loon-Steensma and Vellinga, 2019; Du et al., 2020; Foti et al., 2020; Winters et al., 2020; Ghiasian et al., 2021; Joy and Gopinath, 2021; Tanaya et al., 2021; Waryszak et al., 2021). For example, coastal defense might involve a combination of 'stabilizing' ecosystems (e.g. seagrasses, mangroves, salt marsh) and hard human-made structures. Such coastal defense 'mixed' structures can be part of an Integrated Coastal Zone Management (ICZM) strategy, which is covered as a separate option below.

CCB FEASIB.3.2.2 Sustainable aquaculture

There is *medium evidence* with *medium agreement* on the feasibility of sustainable aquaculture as an adaptation measure. Sustainable aquaculture (e.g. Integrated Multi-Tropic Aquaculture, polyculture, aquaponics, mangrove-integrated culture) can have socio-economic benefits for vulnerable communities and small-scale fisheries (Ahmed, 2018; Blasiak et al., 2019; Mustafa et al., 2021; Thomas et al., 2021; Xuan et al., 2021). Nevertheless, caution is important to guarantee that access to fish supply of local and vulnerable communities is not affected (Chan et al., 2019; Galappaththi et al., 2020). Access to financial resources is often a barrier to implementation, although sustainable aquaculture can increase employment opportunities that are increasingly gender equitable (Alleway et al., 2018; Leakhena et al., 2018; Valenti et al., 2018; Gopal et al., 2020), as well as increasing the resilience of coastal livelihoods to climate change (Shaffril et al., 2017; Blasiak and Wabnitz, 2018). Technological, institutional and socio-cultural factors can form barriers to the feasibility of sustainability of aquaculture (e.g. (Ahmed et al., 2018; Blasiak et al., 2019; Galappaththi et al., 2019; Boyd et al., 2020; Osmundsen et al., 2020; Stentiford et al., 2020; Mustapha et al., 2021; Xuan et al., 2021).

Sustainable aquaculture depends on healthy ecosystems (Sampantamit et al., 2020; Stentiford et al., 2020; Qurani et al., 2021). At the same time, its implementation can increase or regenerate ecosystem services, enhance ecosystem's adaptive capacity (Shaffril et al., 2017; Freduah et al., 2018; Custódio et al., 2020; Bricknell et al., 2021; Mustafa et al., 2021) and protect nursery grounds and habitats for fish and other important organisms (i.e., many commercial species are associated with mangroves). It may also prevent ecosystem degradation such as deforestation, enhancing land-use potential (Ahmed et al., 2018; Stentiford et al., 2020; Turolla et al., 2020; Mustafa et al., 2021).

Environmental as well as economic aspects are key when assessing the sustainability of aquaculture practices (Ahmed et al., 2018; Aubin et al., 2019; Bohnes et al., 2019; Galappaththi et al., 2019; Boyd et al., 2020; Galappaththi et al., 2020; Osmundsen et al., 2020; Stentiford et al., 2020; Thomas et al., 2021). A global picture of where sustainable aquaculture is possible is clearly desirable (FAO, 2018; Galappaththi et al., 2019; Bricknell et al., 2021), yet there are few new references to physical feasibility. Adaptation options for existing sustainable aquaculture need to be developed, along with institutional arrangements such as education and technical exchange, focused on developing sustainable industries (Section 8.6.2.3). Sustainable agriculture is likely to receive strong support from many countries but may experience resistance for several reasons (e.g., competition with existing industries, debates over tolerance to aesthetic changes to coastlines). Literature on this area is growing and potential barriers at the government and political levels are significant (e.g. (Jayanthi et al., 2018; Blasiak et al., 2019; Hargan et al., 2020; Osmundsen et al., 2020; Stentiford et al., 2020; Mustafa et al., 2021; Qurani et al., 2021).

CCB FEASIB.3.2.3 Integrated coastal zone management

Salt marsh management, re-vegetation of shorelines, community-based coastal adaptation, and ecosystem-based adaptation, among other approaches implemented in coastal areas (which are considered to be part of ICZM, "soft measures") were considered in this assessment. There is robust evidence and high agreement that ICZM increases ecological and adaptive capacity to climate change (Villamizar et al., 2017; Antunes do Carmo, 2018; Hamin et al., 2018; Le Cornu et al., 2018; Propato et al., 2018; Romañach et al., 2018; Rosendo et al., 2018; Warnken and Mosadeghi, 2018; Morecroft et al., 2019; Morris et al., 2019; Alves et al., 2020; Donatti et al., 2020; Erftemeijer et al., 2020; Foti et al., 2020; Gómez Martín et al., 2020; Hanley et al., 2020b; Jones et al., 2020b; Krauss and Osland, 2020; O'Mahony et al., 2020; Perera-Valderrama et al., 2020; Cantasano et al., 2021).

Diverse socio-economic co-benefits have been identified, including integration of tourism activities, increased educational opportunities for the reduction in storm damage, maintenance of ecosystems and their services, increasing adaptive capacities of institutions (Romañach et al., 2018; Mestanza-Ramón et al., 2019; Morris et al., 2019; Donatti et al., 2020; Ellison et al., 2020; Erftemeijer et al., 2020; Gómez Martín et al., 2020; Hanley et al., 2020a; Jones et al., 2020b; Martuti et al., 2020; Perera-Valderrama et al., 2020; Telave and Chandankar, 2021); as well as environmental and geophysical co-benefits aspects, including mitigation potential and hazard risk reduction (Propato et al., 2018; Romañach et al., 2018; Ellison et al., 2020; Erftemeijer et al., 2020; Hanley et al., 2020a; Jones et al., 2020b; Martuti et al., 2020; Cantasano et al., 2021).

ICZM measures are generally more cost-effective or affordable than "hard-engineering" measures (Antunes do Carmo, 2018; Morecroft et al., 2019; Morris et al., 2019; Donatti et al., 2020; Erftemeijer et al., 2020; Hanley et al., 2020a; Jones et al., 2020b), but the costs for its implementation is a barrier, especially in low income countries (Lamari et al., 2016; Villamizar et al., 2017; Rosendo et al., 2018; Mestanza-Ramón et al., 2019; Barragán Muñoz, 2020; Botero and Zielinski, 2020; Caviedes et al., 2020; Martuti et al., 2020; Lin et al., 2021). The implementation of ICZM measures requires a strong institutional framework, where all relevant stakeholders (especially representatives of local communities) are part of the decision-making process (Pérez-Cayeiro and Chica-Ruiz, 2015; Lamari et al., 2016; Hassanali, 2017; Antunes do Carmo, 2018; Hamin et al., 2018; Phillips et al., 2018; Romañach et al., 2018; Rosendo et al., 2018; Warnken and Mosadeghi, 2018; Mestanza-Ramón et al., 2019; Morecroft et al., 2019; Morris et al., 2019; Walsh, 2019; Barragán Muñoz, 2020; Caviedes et al., 2020; Donatti et al., 2020; Ellison et al., 2020; Martuti et al., 2020; O'Mahony et al., 2020; Perera-Valderrama et al., 2020). This aspect is mentioned as a key challenge in developing countries (Pérez-Cayeiro and Chica-Ruiz, 2015; Villamizar et al., 2017; Rosendo et al., 2018; Alves et al., 2020). Similarly, incorporating gender issues explicitly into ICZM is generally recommended, also because women are key knowledge holders in coastal communities; however, this is rarely done in practice, which may lead to suboptimal or unequal outcomes (Nguyen Mai and Dang Hoang, 2018; Hoegh-Guldberg and al., 2019; Pearson et al., 2019; Barreto et al., 2020). The perception that building "hard" infrastructure (i.e. coastal defense and hardening) is a more efficient way of reducing coastal risk than the implementation of "soft" or NBS measures has been challenged in recent studies (Magnan and Duvat, 2018).

CCB FEASIB.3.2.4 Agroforestry

There is *robust evidence* and *high agreement* that agroforestry systems can increase ecological and adaptive capacity (Schoeneberger et al., 2012; Smith et al., 2013; Minang et al., 2014; Apuri et al., 2018; Kmoch et al., 2018; IPCC, 2019; Jordon et al., 2020). Benefits include preservation of ecosystems services, such as water provision and soil conservation, more efficient use of limited land, alleviation of land degradation, prevention of desertification and improved agricultural output. Agroforestry solutions also result in co-benefits in the water-energy-land-food nexus, with observed positive outcomes in soil management, crop diversification, water efficiency and alternative sources of energy (De Beenhouwer et al., 2013; Elagib and Al-Saidi, 2020). Further, they can have social and economic benefits and positive synergies between adaptation and mitigation (Section 8.6.2.2) (Coulibaly et al., 2017; Hernández-Morcillo et al., 2018; Tschora and Cherubini, 2020; Duffy et al., 2021).

When locally adapted to fine-scale ecological and social variation, agroforestry initiatives can improve household income, and provide regular employment and sustainable livelihood to local communities, thereby strengthening peoples' resilience to cope with adverse impacts of changing climate conditions (Coe et al., 2014; Ogada et al., 2020; Sharma et al., 2020; Sollen-Norrlin et al., 2020; Awazi et al., 2021). However, (Cechin et al., 2021) question the financial viability of agroforestry systems, especially in the case of smallholders in agrarian reform settlements, struggling with high upfront costs. Similarly, insufficient financial support was found to be a major constraint for the implementation of broader agroforestry initiatives in South East Asia and Africa (Sections 8.5.2 and 8.6.2.1) (Dhyani et al., 2021; Williams et al., 2021).

Over the last decade, agroforestry schemes have grown in acceptability and political support, most notably observed in their broad inclusion in countries' Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs). Governance and institutional arrangements, however, have not been conducive to broader implementation of agroforestry initiatives at the landscape level (Dhyani et al., 2021; Williams et al., 2021). *Medium evidence* with *medium agreement* suggests that economic and cultural barriers may explain difficulties with the implementation of agroforestry systems (Coe et al., 2014; Quandt et al., 2017; Cedamon et al., 2018; Hernández-Morcillo et al., 2018; Ghosh-Jerath et al., 2021). Also, unclear land tenure and ownership issues, together with inappropriate mapping and databases for monitoring vegetation, continue to hinder the adoption of broader agroforestry strategies, particularly in remote areas and tropical forests (Martin et al., 2020).
Notably, agroforestry practices are often part of indigenous and local knowledge (Santoro et al., 2020), and so far, most literature refers to the evaluation of existing agroforestry practices or autonomous adaptation, with few studies evaluating the effects of targeted interventions, especially in low and middle income countries (Miller, 2020; Castle et al., 2021).

CCB FEASIB.3.2.5 Sustainable forest management and conservation, reforestation and afforestation

There is *robust evidence* and *medium agreement* supporting the overall feasibility of forest-based adaptation options. Regarding its economic feasibility, some studies (Nabuurs et al., 2017; Chow et al., 2019; Seddon et al., 2020a) highlight that the net benefits of measures such as reforestation, sustainable forest management and ecosystem restoration outweigh the costs of implementation and maintenance. Yet, another strand of literature observes that limited access to financial resources is a major constraint to reforestation and adaptive management initiatives, especially in the face of upfront investment costs and alternative, more profitable land uses, like agriculture (Bustamante et al., 2019; Ota et al., 2020; Seddon et al., 2020b). In countries with extensive rural areas where forests provide for local communities, government support together with private investments and long-term assurances of maintenance, are considered fundamental for the long-term viability of forest conservation strategies (Bustamante et al., 2019; Seddon et al., 2020b). In rural areas, smallholders can diversify their livelihood and increase household income as a result of improved local forest governance (Bustamante et al., 2019; Fleischman et al., 2020; Ota et al., 2020) Similarly, ecosystem restoration has been found to reduce poverty and improve social inclusion and participation, given that ecosystems can be managed jointly and in traditional ways (Woroniecki et al., 2019). *Robust evidence* (*high agreement*) links forest-based adaptation to job creation, improved health and recreational benefits, most notably for indigenous, rural and remote communities (Muricho et al., 2019; Rahman et al., 2019; Ambrosino et al., 2020; Bhattarai, 2020; Ota et al., 2020; von Holle et al., 2020; Tagliari et al., 2021). However (Chausson et al., 2020), note that still today frameworks for assessing the cost-effectiveness of adaptation strategies continue to be tailored to conventional, engineered interventions, which fail to capture the broader array of material and non-material benefits that sustainable forest management might bring.

Forest-based solutions enjoy wide local, regional and international support (Lange et al., 2019; Chausson et al., 2020; Seddon et al., 2020b), and most countries have the basic regulatory framework for environmental protection. However, lack of institutional capacity, deficient inter-agency coordination, and insufficient staff and budget continue to limit broader implementation of forest-based adaptation measures. Limited technical capacity, insufficient production and supply of seeds and seedlings, long transport distances and immature supply chains have also been identified as significant barriers that hinder the expansion of forest-based initiatives (Bustamante et al., 2019; Nunes et al., 2020).

There is *robust evidence* and *medium agreement* that forest-based solutions support ecosystems' capacity to adapt to climate change, including better regulation of microclimate, increased groundwater recharge, improved quality of air and water, reduced soil erosion, improved and climate-adapted biodiversity habitats, expansion of biomass, as well as continuous provision of renewable wood products (Nabuurs et al., 2017; Chow et al., 2019; Lochhead et al., 2019; Shannon et al., 2019; Weng et al., 2019; von Holle et al., 2020; Dooley et al., 2021; Forster et al., 2021; Tagliari et al., 2021). In well designed systems, adaptation and mitigation can then go hand in hand, as in climate smart forestry. What is more, adaptive forest management is already being tested in climate smart forestry pilots in several temperate regions (Nabuurs et al., 2017). However, large afforestation and non-native monoculture plantations may negatively impact non-forest ecosystems, such as grasslands, shrublands, and peatlands, their water resources and biodiversity (Seddon et al., 2019; Seddon et al., 2020a; Seddon et al., 2020b). Similarly, the International Resource Panel (2019) warns that restoration may also imply trade-offs with other ecological and societal goals.

Regarding risk reduction potential, reforestation and afforestation strategies are found to protect in-land infrastructure from landslides and coastal infrastructure from storm surges (Seddon et al., 2020a; Seddon et al., 2020b), together with offering a cheaper solution than engineered grey solutions (Chausson et al., 2020). Land availability is a limiting factor for expanding forest-based solutions (Morecroft et al., 2019; Ontl et al., 2020). However, there is *high agreement* and *robust evidence* that reforestation, environmental conservation and nature-based solutions result in increased carbon sinks (Griscom et al., 2017; Nabuurs et al., 2017; de Coninck et al., 2018; Fuss et al., 2018; Favretto et al., 2020; Forster et al., 2021). Some authors argue that primary ecosystems and native forests contain larger stocks of carbon than tree plantations (Seddon et al., 2019; Fleischman et al., 2020; Seddon et al., 2020a), while another strain of literature finds that net sequestration rate is lower in mature primary forests than in younger managed forests with their associated wood value chains (Cowie et al., 2021; Forster et al., 2021; Gundersen et al., 2021). There is *robust evidence* and *high agreement* that reforestation and ecosystem-based strategies result in hazard risk reduction potential. Environmental restoration can be an effective climate change adaptation alternative, reducing susceptibility to extreme events, improving ecological capacities and increasing overall ecosystems' resilience (Chapter 8, Box 9.7) (Nunes et al., 2020). However, too much reliance on reforestation and green alternatives might increase water shortages and wildfires (Seddon et al., 2019; Fleischman et al., 2020).

CCB FEASIB.3.2.6 Biodiversity management and ecosystem connectivity

There is *robust evidence* and *medium agreement* supporting the overall feasibility of biodiversity management and ecosystem connectivity as adaptation options. With respect to its economic feasibility, financial constraints continue to hinder broader implementation of biodiversity-based solutions (Lausche et al., 2013; Chausson et al., 2020; Jones et al., 2020a).(Seddon et al., 2020a) highlights that only five percent of climate finance goes towards adaptation strategies, and only one percent is destined to disaster risk management including nature-based solutions and biodiversity management. Government support via subsidies and fiscal transfers is critical for broader biodiversity management interventions. In addition, REDD+ initiatives have been promoted as a profitable mechanism to advance biodiversity conservation strategies while reducing carbon emissions. As far as ecosystem connectivity is concerned, its feasibility will strongly depend on the existence of a regulatory framework that appropriately balances property rights, environmental regulations and monetary incentives to ensure landowners' willingness to participate and maintain ecosystem corridors (Jones et al., 2020b). The demands of commodity-based economies, favouring extractive land-uses, present serious barriers to upscaling biodiversity-based adaptation interventions (Seddon et al., 2020a). In addition, integrated assessments have shown how biodiversity-based solutions can deliver jobs from landscape restoration or income from wildlife tourism and how those benefits are fairly distributed (Chausson et al., 2020).

Legal and regulatory instruments are not perceived as major barriers to biodiversity management and ecosystem connectivity projects (Lausche et al., 2013; D'Aloia et al., 2019). A challenge that biodiversity-based measures still face is less acceptance among decision-makers because their efficiency and cost-benefit ratio are difficult to determine and most of the measures are only effective in the long-term (Lange et al., 2019). Methodologies to determine cost-effectiveness vary substantially between studies, in part because these analyses must be tailored to the social-ecological context in order to be meaningful for local governance. This makes it challenging to capture and synthesize the full economic benefits of biodiversity-based solutions in comparison to alternatives (Chausson et al., 2020). In all, biodiversity and nature-based solutions have gained considerable political traction, with the greatest emphasis on the role of ecosystems as carbon sinks (Lange et al., 2019; Chausson et al., 2020; Seddon et al., 2020a).

Several social co-benefits are found to follow from biodiversity management strategies, including improved community health, recreational activities, eco-tourism, in addition to educational, spiritual and scientific benefits (Lausche et al., 2013; Worboys et al., 2016; Seddon et al., 2020a). (Lavorel et al., 2020) show how the benefits of biodiversity management are co-produced by harnessing ecological and social capital to promote resilient ecosystems with high connectivity and functional diversity. Furthermore, (Chausson et al., 2020) note how properly implemented nature-based solutions, including biodiversity management, can strengthen social networks and foster a sense of place, supporting virtuous cycles of community engagement to sustain interventions over time.

There is *high agreement* and *robust evidence* supporting the ecological capacity enhancement of biodiversity-based and ecosystem connectivity strategies (Thompson et al., 2017; Lavorel et al., 2020). Forest management that favors mixed-species rather than non-native monocultures can promote the resilience of timber production and carbon storage while also benefiting biodiversity (Chausson et al., 2020). Similarly, monocultures have been found to impoverish biodiversity and hold less resilient carbon stocks than natural and semi-natural forests (Seddon et al., 2020a).

There is a *relatively high agreement* that ecosystem connectivity has the potential to improve the adaptive capacity of both ecological systems and humans. (Krosby et al., 2010), for example, found that planting trees in short distances could increase the probability of range shifts in species that depend on the habitat those trees provide. Likewise, connectivity conservation has benefits for climate change mitigation (Lausche et al., 2013), but empirical evidence of the adaptation benefits for humans is scant. More recently, it has been found that biodiversity conservation reduces the risk of zoonotic diseases when it provides additional habitats for species and reduces the potential contact between wildlife, livestock and humans (Van Langevelde et al., 2020). Ecosystem-based approaches have been promoted to address the risk of increased zoonotic diseases, including the conservation of wildlife corridors (Gibb et al., 2020).

Despite abundant literature on the necessity to implement ecosystem connectivity strategies, many policy recommendations are mostly discursive and not supported by evidence. There is a lack of specificity when referring to the actors that should intervene in the design, implementation and evaluation of policies. What is more, most of the literature comes from the natural sciences and is concerned with co-benefits to wildlife and nature, with very little elaboration on the socio-economic co-benefits for humans.

CCB FEASIB.3.2.7 Improved cropland management

Improved cropland management, which includes agricultural adaptation strategies such as integrated soil management, no/reduced tillage, conservation agriculture, planting of stress-resistant or early maturing crop varieties, and mulching, has high economic and environmental feasibility (*robust evidence, high agreement*) (AGEGNEHU and AMEDE, 2017; Lalani et al., 2017; Schulte et al., 2017; Thierfelder et al., 2017; Aryal et al., 2018a; Mayer et al., 2018; Prestele et al., 2018; Sova et al., 2018; Gonzalez-Sanchez et al., 2019; Lunduka et al., 2019; McFadden et al., 2019; Shah and Wu, 2019; TerAvest et al., 2019; Adams et al., 2020; Aryal et al., 2020a; Debie, 2020; Mutuku et al., 2020; Somasundaram et al., 2020; Du et al., 2021). Despite higher initial costs in some cases, the economic feasibility of improved cropland management is high through improved productivity, higher net-returns, reduced input costs (Aryal, 2020 #6850}(Mottaleb et al., 2017; Keil et al., 2019; Lunduka et al., 2019; McFadden et al., 2019; Parihar et al., 2020). Self-efficacy is shown to be the most important predictor in technical and non-technical adaptation behaviour (Zobeidi et al., 2021), while subsidies, extension services, training, commercial custom-hire services and strong social connections such as farmer networks are among the factors supporting adoption among farmers (Section 8.5.2.3) (Aryal et al., 2015a; Aryal et al., 2015b; Kannan and Ramappa, 2017; Bedeke et al., 2019; Acevedo et al., 2020). In some regions and for some practices, technological feasibility is constrained by cost, and inadequate information and technical know-how on particular practices and their benefits and tradeoffs, indicating medium feasibility (Khatri-Chhetri et al., 2016; Bhatta et al., 2017; Dougill et al., 2017; Kannan and Ramappa, 2017; Aryal et al., 2018a; Sova et al., 2018; Findlater et al., 2019). Delays between actions and tangible benefits can reduce public and private acceptability and uptake of improved cropland management practices (e.g. (Dougill et al., 2017) in Malawi).

There remain institutional and financial barriers to improved cropland management such as lack of comprehensive policies, inadequate mainstreaming into national policy priorities (e.g. (Amjath-Babu et al., 2019) and (Reddy et al., 2020) in South Asia), fragmentation across different sectors (Dougill et al., 2017) in Malawi), and inadequate access to credit (Aryal et al., 2018c) in India). Adoption of improved cropland management practices is often strongly mediated by gender: structural barriers such as unequal access to land, machinery, inputs, and extension and credit services, constrain adoption by female farmers (Aryal et al., 2018b; Aryal et al., 2018c). (Mponela et al., 2016; Van Hulst and Posthumus, 2016; Ntshangase et al., 2018; Aryal et al., 2020b; Somasundaram et al., 2020). Improved cropland management practices have social and ecological co-benefits in terms of better health, education and food security (Agarwal, 2017; Farnworth et al., 2017; Hörner and Wollni, 2020) and better soil health and ecosystem functioning (AGEGNEHU and AMEDE, 2017; Mottaleb et al., 2017; Thierfelder et al., 2017; Zomer et al., 2017; Sarkar et al., 2018; Gonzalez-Sanchez et al., 2019; Shah and Wu, 2019; Du et al., 2020; Mutuku et al., 2020; Somasundaram et al., 2020).

There is *robust evidence* (*medium agreement*) that improved cropland management can have mitigation co-benefits but the exact quantity of emissions reductions and increased removals depend on agro-ecosystem type, climatic factors and cropping practices (VandenBygaart, 2016; Han et al., 2018; Mayer et al., 2018; Prestele et al., 2018; Singh et al., 2018a; Sommer et al., 2018; Gonzalez-Sanchez et al., 2019; Ogle et al., 2019; Shah and Wu, 2019; Adams et al., 2020; Aryal et al., 2020a; Li et al., 2020; Wang et al., 2020; Shang et al., 2021).

CCB FEASIB.3.2.8 Efficient livestock systems

Enhancing the production efficiency of livestock systems, through for example, improved livestock diets, enhanced animal health, breeding and manure management, can contribute to adaptation and mitigation (Ericksen and Crane, 2018; Accatino et al., 2019; Paul et al., 2020)IPCC WGIII AR6 Section 7.4.3). While the technological and ecological feasibility of improving livestock production systems is high (i.e. measures are technically well established, with different options applicable to a range of livestock production systems and ecological conditions), there are multiple context-specific barriers to adoption. These include a lack of coordinated policy support or governance, potentially high implementation costs and limited access to finance, inadequate advisory, knowledge exchange or infrastructural capacity (Escarcha et al., 2018; Paul et al., 2020), the potential land requirements and associated ecological impacts of adjusting livestock management, lack of context specific research (Pardo and del Prado, 2020), and socio-cultural barriers limiting access by women or low-income groups to better breeds or feed varieties (Luqman et al., 2018; Salmon et al., 2018) as well as women losing influence in the household in some contexts when farms intensify (Tavenner and Crane, 2018). In dryland livestock systems in Ethiopia and Kenya, (Ericksen and Crane, 2018) find that low governance capacities to implement improved grazing regimes and prevent overgrazing constrain improved grassland management.

CCB FEASIB.3.2.9 Water use efficiency and water resource management

There is high technological feasibility (*robust evidence, high agreement*) to improve water use efficiency as well as manage water resources at basin and field scales. These approaches include rainwater harvesting, drip irrigation, laser land leveling, drainage management and stubble retention (Dasgupta and Roy, 2017; Khatri-Chhetri et al., 2017; Rahman et al., 2017; Adham et al., 2018; Darzi-Naftchali and Ritzema, 2018; Terêncio et al., 2018; Velasco-Muñoz et al., 2018; Sojka et al., 2019). There is *high evidence (medium agreement*) that such measures have socio-economic co-benefits and improve adaptive capacities through improved water supply (e.g. through rainwater harvesting , increased infiltration, or integrated watershed management),, and sustainable water demand management (e.g. reduction of evaporation loss). There is *medium evidence* (*high agreement*) of the option's economic feasibility due to water and energy cost savings enhanced by low-cost monitoring systems in some cases (Kodali and Sarjerao, 2017; Viani et al., 2017). Implementation costs vary widely, with landforming and irrigation infrastructure requiring substantial up-front investment, while mulches and cover crops are low cost practices. Water management and use efficiency is currently constrained by governance and institutional factors such as inadequate institutional capacities to prepare for changing water availability, especially in the long term, unsustainable and unequal water use and sharing practices, particularly across boundaries, and fragmented, and siloed resource management approaches (Lardizabal, 2015; Margerum and Robinson, 2015; Singh et al., 2020a).

CCB FEASIB.3.2.10 Livelihood diversification

Livelihood diversification is a key coping and adaptive strategy to climatic and non-climatic risks (Gautam and Andersen, 2016; Asfaw et al., 2018)Liu, 2015 #1681}(Goulden et al., 2013; Makate et al., 2016; Orchard et al., 2016; Nyantakyi-Frimpong, 2017; Schuhbauer et al., 2017; Kihila, 2018; Radel et al., 2018; Tian and Lemos, 2018; Buechler and Lutz-Ley, 2019; Salam and Bauer, 2020). There is high evidence (medium agreement) that diversifying livelihoods improves incomes and reduces socio-economic vulnerability, but depending on livelihood type, opportunities, and local context, feasibility changes (Section 8.5.1) (Barrett, 2013; Martin and Lorenzen, 2016; Sina et al., 2019). Livelihood diversification has positive and negative outcomes for adaptive capacity, especially in ecologically and resource-stressed regions (for e.g.(Anderson et al., 2017; Woodhouse and McCabe, 2018; Rosyida et al., 2019; Ojea et al., 2020), with diversification predominantly out of rural farm-based livelihoods on the rise (Rigg and Oven, 2015; Shackleton et al., 2015; Ober and Sakdapolrak, 2020). Key barriers to livelihood diversification include socio-cultural and institutional barriers (including social networks (Goulden et al., 2013) as well as inadequate resources and livelihood opportunities that hinder the full adaptive possibilities of existing livelihood diversification practices (Shackleton et al., 2015; Nightingale, 2017; Bhowmik et al., 2021; Rahut et al., 2021). Autonomous diversification in the absence of more equitable and harmonised efforts at regional and national scales to facilitate sustainable diversification can further skew development indicators at the subnational scale in favour of local elites, increased inequality, and environmental degradation (Ford et al., 2014; Wilson, 2014; Alobo Loison, 2015; Tanner et al., 2015; Gautam and Andersen, 2016; Baird and Hartter, 2017; Torell et al., 2017; Asfaw et al., 2018; Woodhouse and McCabe, 2018; Brown et al., 2019; Rosyida et al., 2019; Sani Ibrahim et al., 2019; Ojea et al., 2020; Salam and Bauer, 2020). Livelihood diversification can be facilitated in key technical areas (Shackleton et al., 2015; Brown et al., 2017; Schuhbauer et al., 2017) including regulatory frameworks (Butler et al., 2020) (limited but robust evidence), as well institutional support through funding and more localised research on interaction among and between enablers and barriers concerning specific local diversification options (Barrett, 2013; Herrero et al., 2016; Martin and Lorenzen, 2016; Sina et al., 2019) in the case of pastoral communities).

CCB FEASIB.3.3 Urban and infrastructure system transitions

CCB FEASIB.3.3.1 Sustainable land-use & urban planning

Urban planning is a medium feasibility option to support adaptation by prioritizing it in city plans, such as land-use planning, transportation (Liang et al., 2020), and health and social services (Carter et al., 2015; Araos et al., 2016b); by procuring the design and construction of resilient infrastructure; by promoting community-based adaptation through community-based design and implementation of adaptation activities (Archer, 2016); and by protecting and integrating biodiversity and ecosystem services into city planning. Research since SR 1.5 documents the challenging high costs of infrastructure (Georgeson et al., 2016; Woodruff et al., 2018); potential loss of municipal revenue in the case of managed retreat (Shi and Varuzzo, 2020; Siders and Keenan, 2020); and the fraught causal connection between planning and the reduction of socioeconomic vulnerability (Keenan et al., 2018; Anguelovski et al., 2019a; Elliott, 2019; Paganini, 2019; Shokry et al., 2020). However, adaptation benefits could potentially outweigh costs (Carey, 2020); the financial viability of green infrastructure (Meerow, 2019; Zhang et al., 2019; Van Oijstaeijen et al., 2020; Ossola and Lin, 2021); and availability of technical expertise, although the inequitable planning processes and distribution of those resources remains a significant concern (Serre and Heinzlef, 2018; Szewrański et al., 2018; Fitzgibbons and Mitchell, 2019; Hasan et al., 2019; Heikkinen et al., 2019; Colven, 2020; Goetz et al., 2020; Goh, 2020).

Structural disincentives and institutional arrangements create challenges for planning even where political willingness may be high (Di Gregorio et al., 2019; DuPuis and Greenberg, 2019; Shi, 2019; Zen et al., 2019; Rasmussen et al., 2020). Social resistance may significantly delay or block progress entirely, as vulnerable communities have responded negatively in cases adaptive urban and land-use planning leads to perceived "resilience gentrification" (Keenan et al., 2018; Anguelovski et al., 2019a), if residents do not perceive themselves as included in the crafting of plans (Araos, 2020; Rasmussen et al., 2020), if the options such as managed retreat are perceived as culturally unacceptable (Ajibade, 2019; Koslov, 2019; Siders, 2019), or if wealthier and advantaged residents benefit from planning at the expense of socially vulnerable groups (Chu and Michael, 2018; Chu et al., 2018; Fainstein, 2018; Rosenzweig et al., 2018; Pelling and Garschagen, 2019; Ranganathan and Bratman, 2021). Nonetheless, potential social co-benefits related to health and education are high (Raymond et al., 2017; Spaans and Waterhout, 2017; Klinenberg, 2018; Keeler et al., 2019; Meerow, 2019). Finally, the option is highly feasible in relation to ecological and geophysical characteristics, as urban and land-use planning's primary tool is to manipulate the built environment and natural spaces to protect and reduce the vulnerability of residents.

CCB FEASIB.3.3.2 Green infrastructure & ecosystem services

Urban green infrastructure and ecosystem services have high feasibility to support climate adaptation and mitigation efforts in cities, for example to reduce flood exposure and attenuate the urban heat island (Perrotti and Stremke, 2018; Belčáková et al., 2019; De la Sota et al., 2019; Stefanakis, 2019). While green infrastructure options are cost-effective and provide co-benefits in terms of ecosystem services such as improved air quality or other health benefits (Depietri and McPhearson, 2017; Morris et al., 2018; Reguero et al., 2018; Escobedo et al., 2019; Filazzola et al., 2019; Hewitt et al., 2020b; Venter et al., 2020; Nieuwenhuijsen, 2021) (*robust evidence, high agreement*), there remains a need for systematically assessing co-benefits, particularly for flood risk management (Alves, 2019 (Alves et al., 2019; Stefanakis, 2019) and sustainable material flow analysis (Perrotti and Stremke, 2018). Moreover, while once neglected, rapidly increasing attention has been paid to the equity and justice dimensions of planning and implementing green infrastructure initiatives, such as inclusion of citizens in decision-making or the allocation of benefits and impacts of projects (Anguelovski et al., 2019b; Buijs et al., 2019; Langemeyer et al., 2020; Venter et al., 2020)

Institutional barriers constrain the feasibility of urban green infrastructure (medium confidence), such as policy resistance to shift priorities from grey to green infrastructure (e.g. Johns 2019 in Canada) or siloed governance structures (Willems et al., 2021). Further social and political acceptability of green infrastructure is constrained by lack of confidence in efficacy (Thorne et al., 2018) or issues of accessibility (Biernacka and Kronenberg, 2018).

For flood management, a mix of green, blue and grey infrastructures are found effective with grey infrastructure reducing the risk of flooding and green infrastructure yielding multiple co-benefits (Alves et al., 2019; Gu et al., 2019; Webber et al., 2020) but catchment-wide solutions are advocated as the best performing strategy (Webber et al., 2020). Recognising and addressing a full range of ecosystem disturbances and disasters over a larger urban spatial scale (Vargas-Hernández and Zdunek-Wielgołaska, 2021) are crucial for planning green infrastructure based solutions. In some cases, low impact development interventions yield effective flood management outcomes but are adequate only for small flood peaks (Pour et al., 2020), with the major challenge being identifying best practices. Nature-based strategies (NBS) hold significant potential to achieve mitigation and adaptation goals in comparison to traditional approaches, but more research is necessary to understand their effectiveness, distribution, implementation at scale, cost-benefit and integration with spatial dimensions of planning (Davies et al., 2019; Dorst et al., 2019; Zwierzchowska et al., 2019; Hobbie and Grimm, 2020).

CCB FEASIB.3.3.3 Sustainable urban water management (blue infrastructure interventions e.g. lake/river restoration; rainwater harvesting)

Governments across scales can support urban sustainable water management with high feasibility by undertaking projects to recycle wastewater and runoff from worsening storms, with implications for decarbonization and adaptation. Green infrastructure, for example, has shown the high potential to reduce water use footprints and to save potable water for consumption (Liu and Jensen, 2018), and contributing to a "circular" water system in cities (Oral et al., 2020). Supportive governance can yield positive outcomes such as improved water security (Jensen and Nair, 2019); and there is *medium evidence* and *high agreement* that participation, such as involving informal settlement residents in water management can improve social inclusion (Pelling et al., 2018; Williams et al., 2018; Leigh and Lee, 2019; Sletto et al., 2019). Green infrastructure can support the planning of "sponge cities," such as in China, wherein large areas of green space, permeable surfaces, and sustainable water sourcing combine to purify urban runoff, attenuate peak runoff, and conserve water for consumption (Chan et al., 2018; Nguyen et al., 2019). Similar approaches in Dutch cities focus on designing and planning for the capturing, storing, and draining of storm water (Dai et al., 2018). Nonetheless, some interventions suffer from uncertainties in design, planning, and financing (Nguyen et al., 2019). As drought becomes more severe in some regions, physical barriers in the form of reduced availability of water may become pressing (Singh et al., 2021a)}.

Deployment of decentralised water management, through effective local governance frameworks, is an important water management strategy (Herslund and Mguni, 2019; Leigh and Lee, 2019) but in general, insufficient institutional learning and capacity is a critical barrier for the uptake of sustainable urban water management practices (Krueger et al., 2019; Adem Esmail and Suleiman, 2020). Transnational networks of cities for sharing best practices in water supply and storm runoff treatment also hold the potential to scale sustainable management (Feingold et al., 2018). In rapidly growing large urban areas, sustainable water management faces challenges of institutional heterogeneity (Chu et al., 2018), scalar mismatch; particularly between river basin and city scales (van den Brandeler et al., 2019) and equity and justice concerns (Chu et al., 2018; Pelling et al., 2018). Finally, assessing the vulnerability of urban water infrastructures at city-scale remains an important knowledge gap (Dong et al., 2020).

CCB FEASIB.3.4 Overarching adaptation options

CCB FEASIB.3.4.1 Social safety nets

Social safety nets meet development goals (e.g. poverty alleviation, accessible education and health services) and are increasingly being reconfigured to build adaptive capacities of the most vulnerable (Coirolo et al., 2013; Aleksandrova, 2020; Bowen et al., 2020; Fischer, 2020; Mueller et al., 2020). They include a range of policy and market-based instruments such as public works programmes and conditional or unconditional cash transfers, in-kind transfers; and insurance schemes (Centre, 2019; Aleksandrova, 2020). While there is *high evidence (medium agreement)* that social safety nets can build adaptive capacities, reduce socio-economic vulnerability, and reduce risk linked to hazards (Fischer, 2020; Mueller et al., 2020); macroeconomic, institutional, and regulatory barriers such as limited state resources, underdeveloped credit and insurance markets, and leakages constraint feasibility (Singh et al., 2018c; Hansen et al., 2019; Aleksandrova, 2020; Lykke Strøbech and Bordon Rosa, 2020). Social safety nets have strong co-benefits with development goals such as education, poverty alleviation, gender inclusion, and food security (Section 8.6) (Castells-Quintana et al., 2018; Ulrichs et al., 2019; Mueller et al., 2020) but these positive outcomes are constrained by inadequate regional inclusiveness (e.g. limited access in certain remote, rural areas - (Singh et al., 2018b; Aleksandrova, 2020; Lykke Strøbech and Bordon Rosa, 2020); or focus on rural areas overlooks urban vulnerable groups (Coirolo et al., 2013).

CCB FEASIB.3.4.2 Risk spreading and sharing

There is high confidence on risk spreading and sharing, most commonly arranged through insurance, as an adaptation option, but high to medium feasibility depending on context (e.g. developed vs. developing countries)Technological, economic, and institutional feasibility is high, as insurance can spread risk, provide a buffer against the impact of climate-hazards, support recovery and reduce the financial burden on governments, households, and businesses (Wolfrom and Yokoi-Arai, 2015; O'Hare et al., 2016; Glaas et al., 2017; Jenkins et al., 2017; Patel et al., 2017; Kousky et al., 2021). Insurance can shift the mobilization of financial resources away from ad hoc post-event payments, where funding is often unpredictable and delayed, towards more strategic approaches that are set up in advance of disastrous events (Surminski et al., 2016). By pricing risk, insurance can provide incentives for investments and behavior that reduce vulnerability and exposure (Linnerooth-Bayer and Hochrainer-Stigler, 2015; Shapiro, 2016; Jenkins et al., 2017). Socio-cultural barriers, such as social inclusiveness, socio-cultural acceptability and gender equity, constraints feasibility (Bageant and Barrett, 2017; Budhathoki et al., 2019). Insurance can provide disincentives for reducing risk through the transfer of the risk spatially and temporally; can distort incentives for adaptation strategies if the pricing is too low (moral hazard); is often unaffordable, poorly understood, and not widely utilized in developing nations even when subsidized; and can lead to maladaptation (García Romero and Molina, 2015; Joyette et al., 2015; Lashley and Warner, 2015; Jin et al., 2016; Müller et al., 2017; Tesselaar et al., 2020). Insurance can reinforce exposure and vulnerability through underwriting a return to the 'status-quo' rather than enabling adaptive behaviour (e.g. through 'no-betterment' principles) (Collier and Cox, 2021). (Surminski et al., 2016) raise concern that for low income nations and in the absence of global support, insurance shifts responsibility to those least responsible for climate change.

CCB FEASIB.3.4.3 Disaster risk management

There is robust evidence (high agreement) that DRM aids adaptation decision-making, particularly where it is demand-driven, context-specific and supported by strong institutions, good governance, strong local engagement, and trust across actors (Hasan et al., 2019; Kim and Marcouiller, 2020; Peng et al., 2020; Smucker et al., 2020; Uddin et al., 2020; Webb, 2020; Ali et al., 2021; Anderson and Renaud, 2021; Glantz and Pierce, 2021; Ji and Lee, 2021; Villeneuve, 2021). These conditions are rarely met, and therefore DRM is often constrained by institutional factors that may even increase vulnerability (Booth et al., 2020; Islam et

al., 2020a; Islam et al., 2020b; Marchezini, 2020; Goryushina, 2021; Mena and Hilhorst, 2021). The feasibility of DRM continues to be constrained by limited coordination across levels of government lack of transparency and accountability, poor communication, and a preference for top-down DRM processes that can undermine local institutions and perpetuate uneven power relationships (Atanga, 2020; Booth et al., 2020; Bordner et al., 2020; Bronen et al., 2020; Goryushina, 2021; Mena and Hilhorst, 2021; Son et al., 2021; Yumagulova et al., 2021). However, local integration of worldviews, belief systems and Local and Indigenous Knowledge into DRM activities improves feasibility (Bordner et al., 2020; Cuaton and Su, 2020; Hosen et al., 2020; Sharma and Sharma, 2021), including disability-inclusive and gender-focused DRM (Ruszczyk et al., 2020; Crawford et al., 2021). Data access and availability continues to challenge DRM despite advances in data analytics, especially in rapidly growing informal settlements, including population estimates and limited mobility data (Goniewicz and Burkle, 2019; Marchezini, 2020).
Moves towards community-based and ecosystem-based DRM are promising but uneven (Klein et al., 2019; Seebauer et al., 2019; Almutairi et al., 2020; Bordner et al., 2020; Hosen et al., 2020; Murti et al., 2020; Sharma and Sharma, 2021), and may increase vulnerability if they fail to address underlying, structural determinants of vulnerability, particularly among marginalised groups and by gender (Sections 8.4.4 and 8.4.5) (Seleka et al., 2017; Hossen et al., 2019; Ramalho, 2019; Atanga, 2020; Cuaton and Su, 2020; Gartrell et al., 2020; Kenney and Phibbs, 2020; Khalil et al., 2020; Ngin et al., 2020; Ruszczyk et al., 2020; Webb, 2020; Ali et al., 2021; Geekiyanage et al., 2021; Villeneuve, 2021).

CCB FEASIB.3.4.4 Climate services, including EWS

There is robust evidence (high agreement) that climate services aid adaptation decision-making and build adaptive capacity, particularly where they are demand-driven and context-specific (Vaughan et al., 2018; Bruno Soares and Buontempo, 2019; Daniels et al., 2020; Hewitt et al., 2020a; Findlater et al., 2021). Climate service interventions are constrained by low capacity, inadequate institutions, difficulties in maintaining systems beyond pilot project stage (Vincent et al., 2017; Tall et al., 2018; Bruno Soares and Buontempo, 2019), and poor mapping between climate services and existing user capacities and demands (Williams et al., 2020) (robust evidence, high agreement). Metrics to assess outcomes of climate services remain project-based and insufficiently capture longer-term economic and non-economic benefits of interventions (Tall et al., 2018; Parton et al., 2019; Perrels, 2020). The technical feasibility of climate services is relatively strong and growing (Vaughan et al., 2016; Kihila, 2017; Findlater et al., 2021) but they can be made more inclusive by focussing on addressing uneven uptake based on location or gender (Amegnaglo et al., 2017; Daly and Dessai, 2018; Tall et al., 2018; Alexander and Dessai, 2019; Vaughan et al., 2019; Gumucio et al., 2020) and a more balanced focus on uptake rather than data production alone (Dorward et al., 2021; Findlater et al., 2021) that values co-production and different knowledge systems (Daniels et al., 2020; Martínez-Barón et al., 2021).

CCB FEASIB.3.4.5 Population health and health systems

Climate change will exacerbate existing health challenges. Strong health systems can protect and promote the health of a population in the face of known and unexpected stressors and pressures (Watts et al., 2021), including climate change. The building blocks of strong health systems engender climate resilience, strong leadership and governance, and effective coordination across sectors, to prioritize the needs of the most vulnerable (Ebi et al., 2020). Options for enhancing current health services include providing access to safe water and sanitation, improving food security, enhancing access to essential services such as vaccinations, developing or strengthening integrated surveillance systems, and changing the timing and location of specific vector-control measures (WHO, 2015; Haines and Ebi, 2019). These measures can reduce the health system's vulnerability to climate change, especially if combined with iterative management that incorporates monitoring of (and resilience against) climate change impacts (Hanefeld et al., 2018; Haines and Ebi, 2019; Linares et al., 2020; Rudolph et al., 2020) (medium evidence, high agreement).

Health system can provide sufficient and high quality healthcare to all where capacity is well-developed, and where options are aligned with national priorities, engage local to international communities, and address the needs of particularly vulnerable regions and population groups (Hanefeld et al., 2018; Austin et al., 2019; Nuzzo et al., 2019; Sheehan and Fox, 2020). Microeconomic feasibility and socio-economic vulnerability reduction potential are high where a system's capacity is well-developed. Macroeconomic feasibility poses a significant challenge in low income settings, with many governments projected to require international climate finance for health systems which is not currently available (WHO, 2019; Watts et al., 2021), and where adequate household-level financial security is a cross-cutting barrier (Paudel and Pant, 2020). Risk mitigation potential is high where capacity is well developed, for example through technologies to monitor and alter environmental conditions (Lock-Wah-Hoon et al., 2020; Kouis et al., 2021; Ligsay et al., 2021). Social co-benefits of mainstreaming health and climate change are also present, such as the inclusion of environmental health in medical education curricula training programmes (Kligler et al., 2021). There is growing recognition that lack of institutional capacity and low availability of resources represent major barriers to health system adaptation options, particularly for health systems struggling to manage current health risks (Ebi et al., 2018; Brooke-Sumner et al., 2019; Chersich and Wright, 2019; Gilfillan, 2019; Negev et al., 2019; Hussey and Arku, 2020), for neglected populations (Hanefeld et al., 2018; Negev et al., 2019), and where there are conflicting mandates or poor coordination across ministries (Austin et al., 2019; Fox et al., 2019; Gilfillan, 2019; Kendrovski and Schmoll, 2019; Sheehan and Fox, 2020). Barriers to adapting health systems to climate change include lack of institutional funding, staff, and data access (Austin et al., 2019; Schramm et al., 2020; Opoku et al., 2021), inadequate resources for evaluation and management of adaptation (Pascal et al., 2021), competing stakeholder goals, and costly technology (Negev et al., 2021). Within the healthcare community, surveillance systems generally lack ways to integrate climate observation data, as well as expertise to critically evaluate these data, limiting their ability to plan and prepare for climate hazards and hospital-associated vulnerabilities (Runkle et al., 2018; Chersich and Wright, 2019; Liao et al., 2019). Although understanding on health vulnerability is growing (Berry et al., 2018), knowledge on the health effects of climate change among health practitioners remains limited (Ebi et al., 2018; Brooke-Sumner et al., 2019; Chersich and Wright, 2019; Fox et al., 2019; Liao et al., 2019; Albright et al., 2020). Mechanisms to ensure transparency and accountability of implementing, monitoring, and evaluating adaptation within the health sector are lacking, across scales and contexts (Gostin and Friedman, 2017; Huynh and Stringer, 2018; Parry et al., 2019).

CCB FEASIB.3.4.6 Human migration and displacement

Much climate-related migration is associated with labour migration. Rural-urban migrant networks are important channels for remittances and knowledge that help build resilience to hazards in sending areas (Bragg et al., 2018; Obokata and Veronis, 2018; Semenza and Ebi, 2019; Maharjan et al., 2020; Porst et al., 2020). Whether migration reduces vulnerability for migrants depends on levels of control over the migration decision and assets such as wealth education of the migrant household (Thober et al., 2018; Cattaneo, 2019; Hoffmann et al., 2020; Maharjan et al., 2020; Sedova and Kalkuhl, 2020). Individuals from households of all levels of wealth migrate. However, poorer households do so with lower levels of choice and often more likely under duress, and in these cases migration can undermine wellbeing (Suckall et al., 2016; Mallick et al., 2017; Nawrotzki and DeWaard, 2018; Natarajan et al., 2019). In some cases, migration can increase poverty in sending communities (Jacobson et al., 2019).Women in the sending community can experience an increase or decrease in the vulnerability depending on context (Banerjee et al., 2018; Banerjee et al., 2019; Goodrich et al., 2019; Maharjan et al., 2020; Rao et al., 2020; Singh and Basu, 2020; Singh et al., 2020b). Migration has been highly politicised, and climate-related immigration has been conceptualised in public and media discourse as a potential threat which limit adaptation feasibility (Telford, 2018; Honarmand Ebrahimi and Ossewaarde, 2019; McLeman, 2019; Wiegel et al., 2019; Hauer et al., 2020). Existing international agreements provide potential frameworks for climate-related migration to benefit adaptive capacity and sustainable development (Warner, 2018; Kälin, 2019). However, agreements to facilitate temporary or circular migration and remittances are often informal and limited in scope (Webber and Donner, 2017; Margaret and Matias, 2020) and migrant receiving areas, particularly urban areas, can be better assisted to prepare for population change (Deshpande et al., 2019; Adger et al., 2020; Hauer et al., 2020). Policies and planning are lacking that would ensure that positive migration outcomes for sending and receiving areas and the migrants themselves (Wrathall et al., 2019; Adger et al., 2020; de Salles Cavedon-Capdeville et al., 2020; Hughes, 2020).

Investing in building in situ adaptive capacity through climate resilient development is a precondition to supporting high agency migration (). Migration only tends to occur when adaptation in situ has been exhausted and thresholds for living with risk have been crossed (Sections 8.2.2.1, 8.4.4, 8.4.5) (McLeman, 2018; Adams and Kay, 2019; Semenza and Ebi, 2019). The financial, emotional and social costs of leaving are high (Adams and Kay, 2019; McNamara et al., 2021), there are environmental, health and wellbeing risks in destination areas (Schwerdtle et al., 2018; Schwerdtle et al., 2020) and existential threats to identity and citizenship (Oakes, 2019; Piguet, 2019; Desai et al., 2021). In receiving areas, without appropriate policies to ensure equitable provision of services, there can be socio-cultural barriers to in-migration where there is the perception of a loss caused by new arrivals, although outcomes are mixed (Koubi et al., 2018; Linke et al., 2018; Spilker et al., 2020; Petrova, 2021).

CCB FEASIB.3.4.7 Planned relocation and resettlement

Few climate-related planned resettlement and relocation initiatives have taken place. However, initial findings, and experience from past development and disaster-related resettlement programmes, show that when implemented in a top-down manner and without the full participation of those affected, resettlement increases vulnerability by undermining livelihoods, negatively impacting health, community cohesion and emotional and psychological wellbeing (Wilmsen and Webber, 2015; Dannenberg et al., 2019; Piggott-McKellar et al., 2019; Tabe, 2019; Ajibade et al., 2020; Henrique and Tschakert, 2020; Desai et al., 2021). Planned relocation could also redistribute vulnerability for those who do not move (Thomas and Benjamin, 2018; Mach et al., 2019; Piggott-McKellar et al., 2019; Johnson et al., 2021; Maldonado et al., 2021) and vulnerability generally is reproduced along existing social cleavages often worsening inequality (See and Wilmsen, 2020). Approaches that foreground participation; non-material and socio-cultural factors, livelihoods, and local power dynamics can be addressed and adjusted to prevent planned relocation from reproducing inequality (See and Wilmsen, 2020; Alverio et al., 2021).

There is inadequate institutional capacity to enable movement relocation with global and national policies identified as too abstract and lacking guidance on ensuring equity (Mortreux et al., 2018; Kelman et al., 2019; Ajibade et al., 2020; Hauer et al., 2020; Alverio et al., 2021). Lack of institutional capacity can lead to resettlements being stalled indefinitely. Climate-related resettlement can be facilitated by novel institutional structures that expand the definition of disaster to include slow onset events, adaptive management frameworks that facilitate a continuum of responses from supporting communities to community relocation and approaches that incorporate existing power dynamics (Bronen and Chapin, 2013; See and Wilmsen, 2020). In 2018, the Fiji Government provided a framework for climate change related relocation and equipped communities with rights in the planned relocation process (McMichael and Katonivualiku, 2020). However, even with guidelines in place, local socio-cultural dynamics complicate planning, and relocation should take place only after cost-benefit analysis of all available adaptation options (Jolliffe, 2016).(Bronen and Chapin, 2013; Albert et al., 2017; Mortreux et al., 2018). At a local level, issues around land tenure, a lack of financial support, dedicated governance frameworks and complex planning processes delay action (Albert et al., 2017). Funding for climate-related resettlement is currently not readily available, exacerbated by a lack of appropriate mechanisms through which to deliver that funding (Boston et al., 2021). For example, planned relocation projects cannot access disaster relief funds in the US because of the slow onset nature of the impacts (Bronen and Chapin, 2013).

Without consultation relocated people can experience significant financial and emotional distress as cultural and spiritual bonds to place and livelihoods are disrupted (Neef et al., 2018; Roy et al., 2018; Piggott-McKellar et al., 2019; Bertana, 2020; McMichael and Katonivualiku, 2020; McMichael et al., 2021) - However, in some places, where climate risks are acute, political acceptance for planned relocation is high (e.g. (McNamara, 2015; Roy et al., 2018) in Kiribati). Socio-cultural feasibility can be improved by participatory approaches, and where possible, moving within ancestral lands (McNamara, 2015). In this case, voluntary planned relocation can represent the assertion of people living in an area to preserve land and community-based social, cultural and spiritual ties.

A summary of feasible options to enable four 1.5C-relevant system transitions is presented in Figure Cross-Chapter Box FEASIB.2.

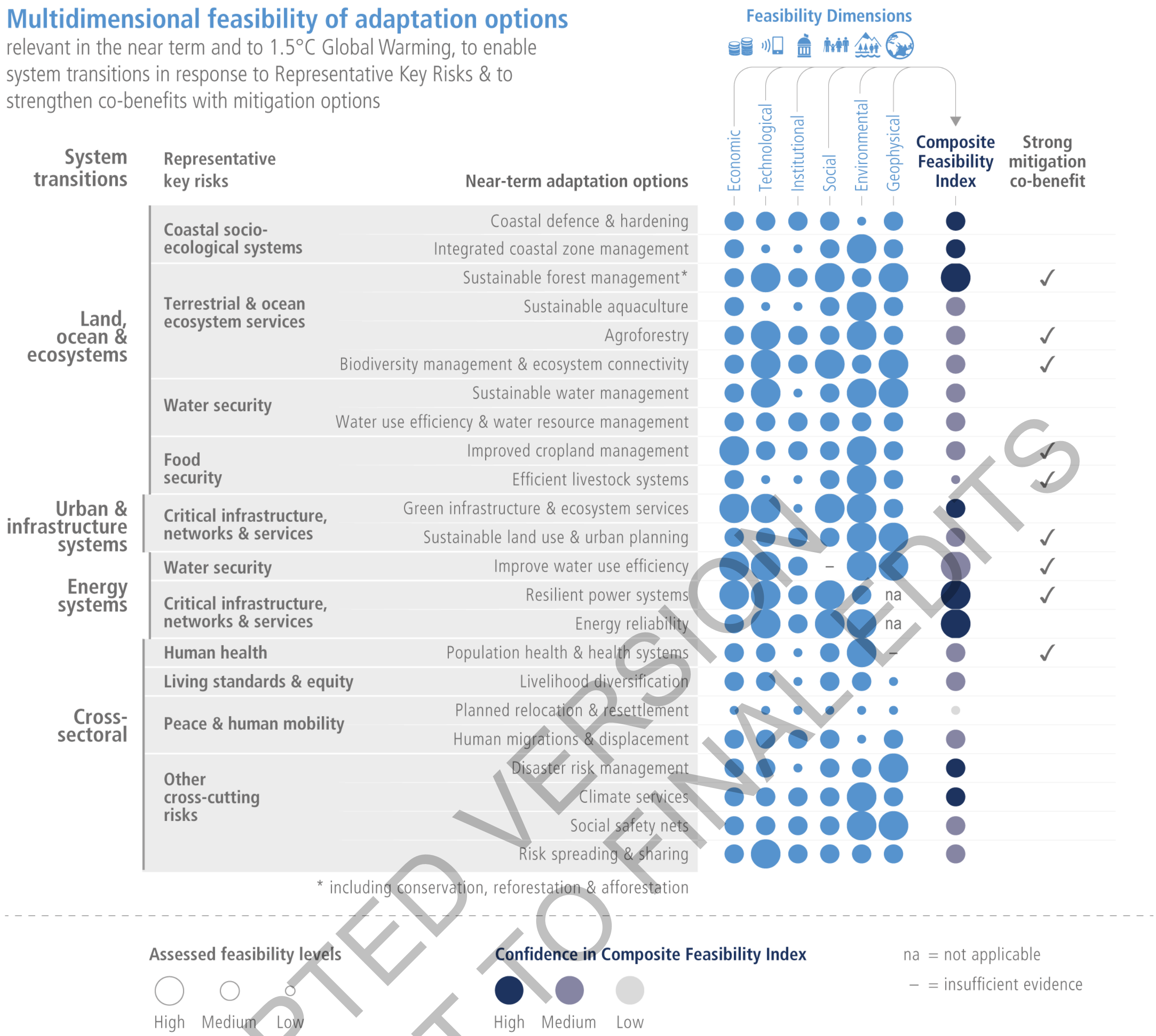
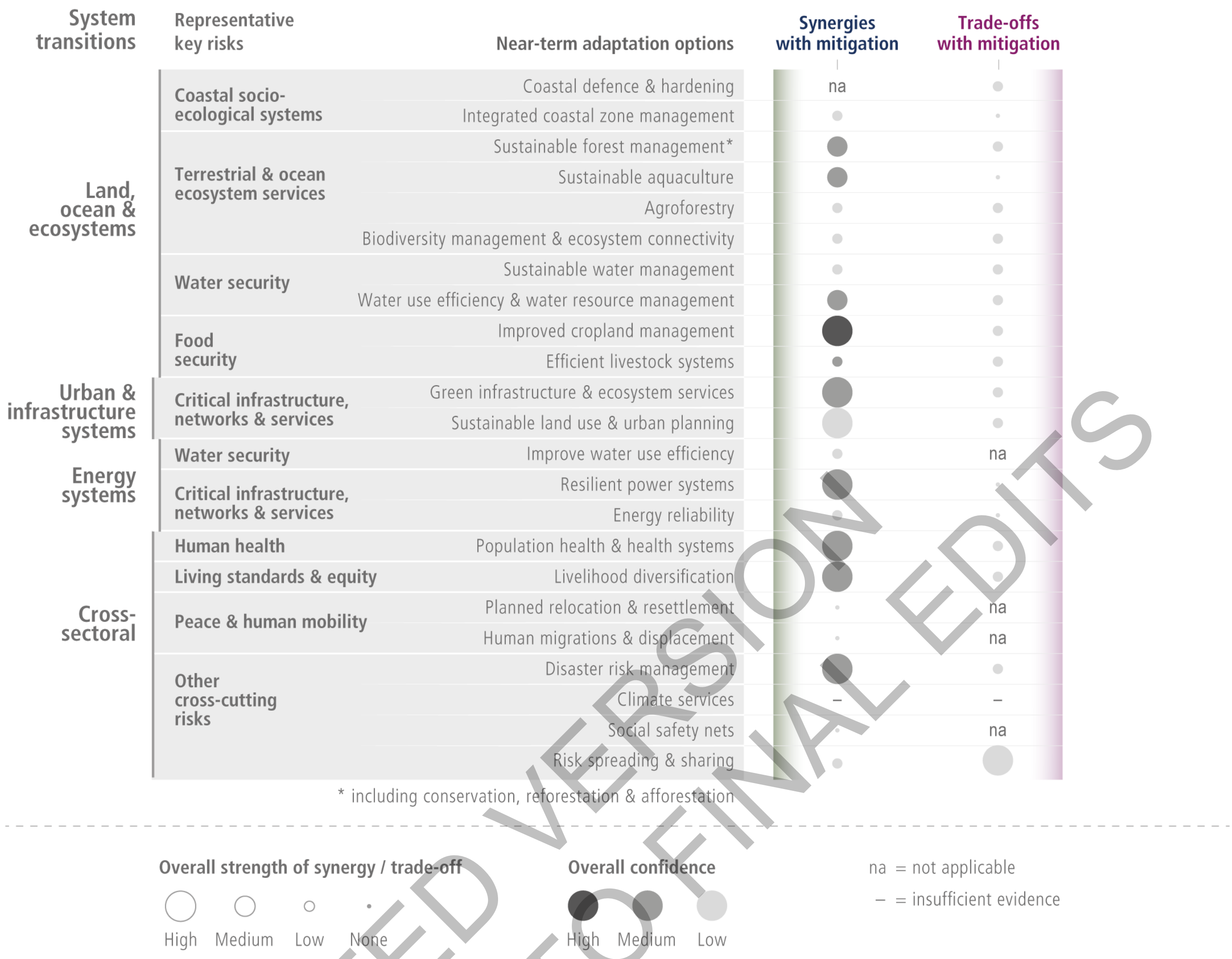


Figure Cross-Chapter Box FEASIB.2: Multi-dimensional feasibility.

CCB FEASIB.4 Synergies and Trade-offs

The feasibility assessment focuses on individual options. However, systems transitions necessitate assessing how mitigation and adaptation options *interact* to mediate overall feasibility. To capture these linkages, this section reports synergies and trade-offs of a) adaptation options for mitigation, and b) mitigation options for adaptation (following (de Coninck et al., 2018) as outcome of an iterative assessment between WG2 and WG3 authors. Also assessed are synergies and tradeoffs of adaptation with the SDGs following (Roy et al., 2018) (which was done for mitigation alone).

(a) Adaptation options & their implications for mitigation



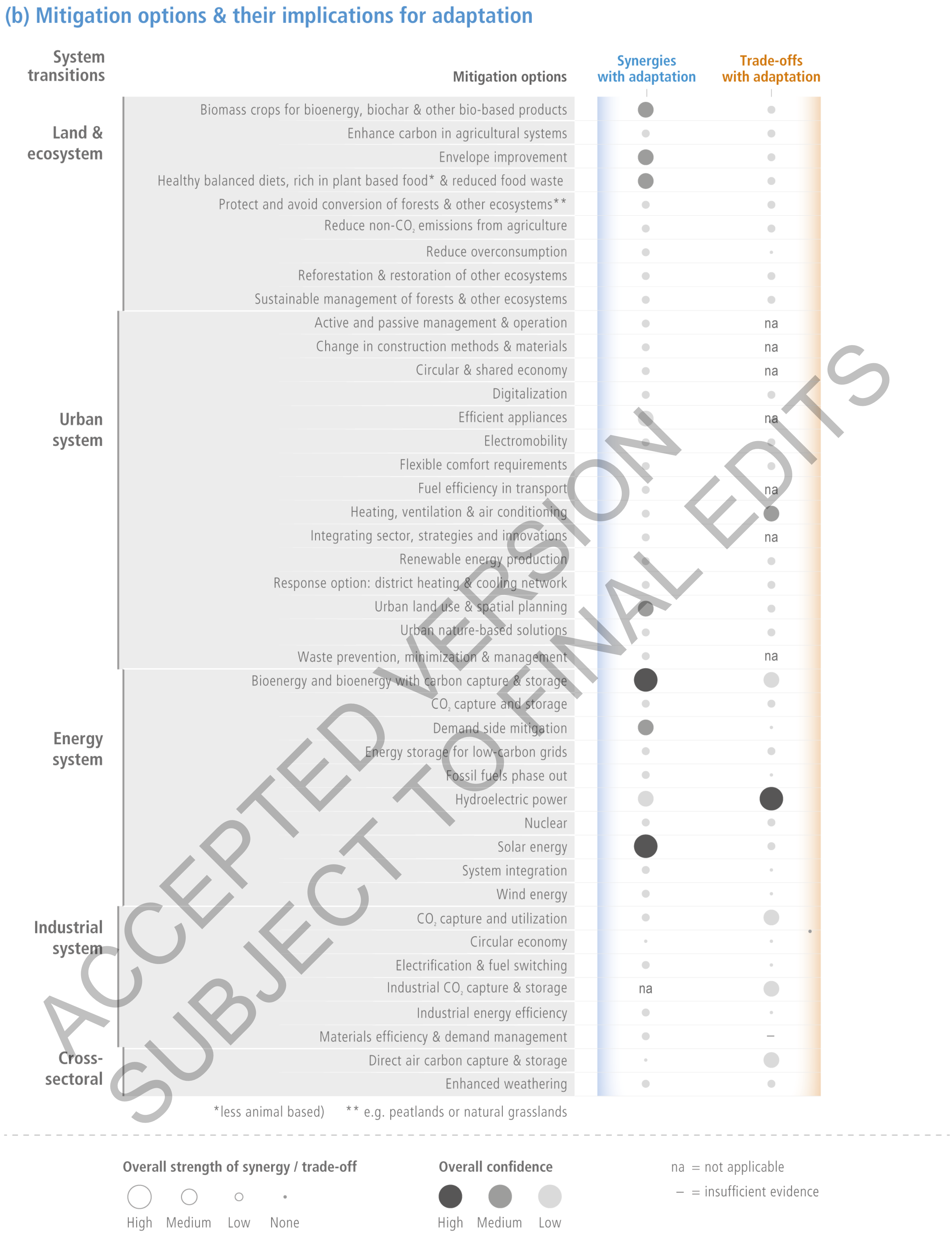


Figure Cross-Chapter Box FEASIB.3: Synergies and trade-offs. This figure shows a) adaptation options synergies and trade-offs with mitigation and b) mitigation options synergies and trade-offs with adaptation. The size of the circle denotes the strength of the synergy or trade-offs with big circles meaning strong synergy or trade-off and small circles denoting a weak synergy or trade-off.

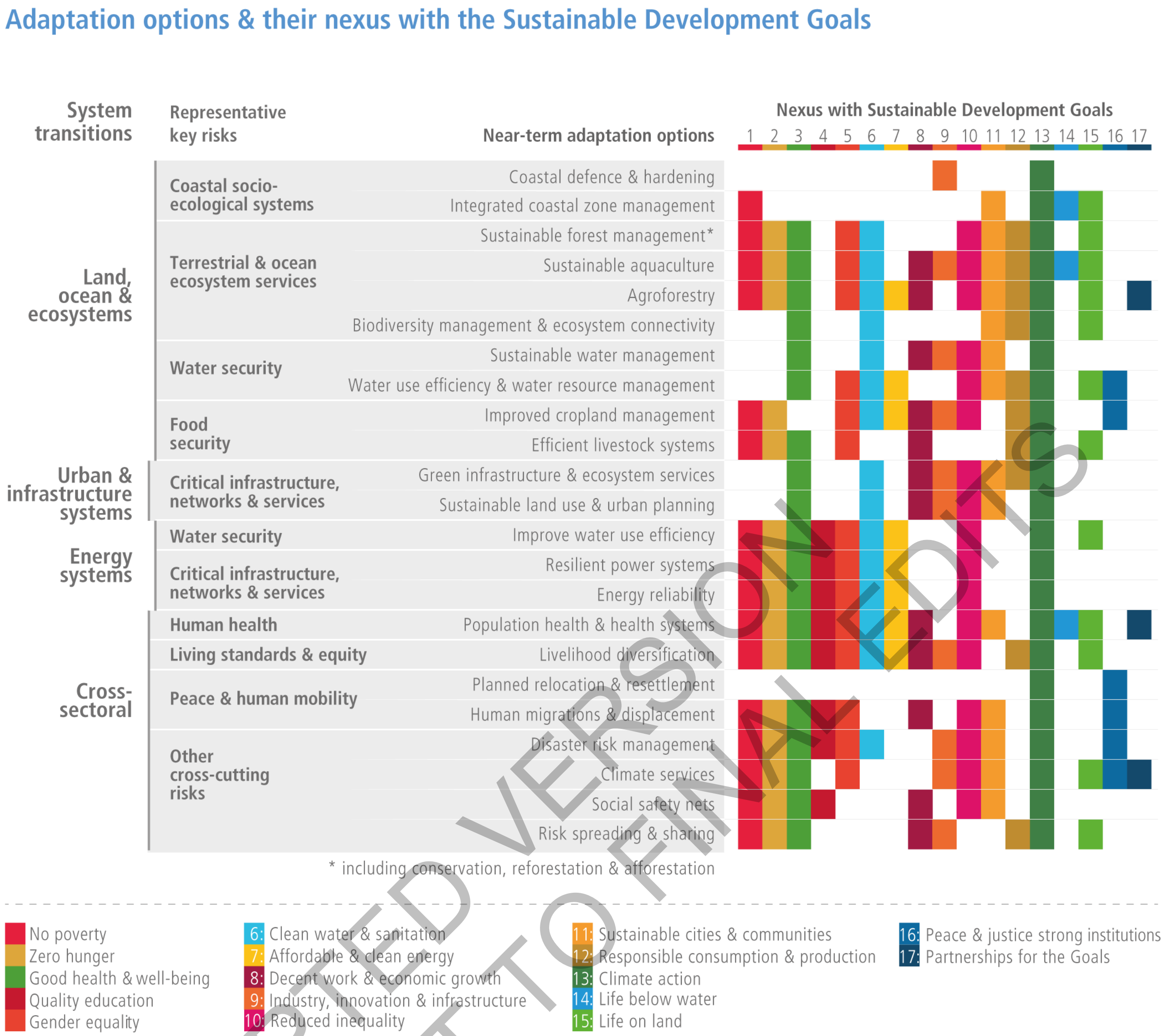


Figure Cross-Chapter Box FEASIB.4: Adaptation options and their nexus with the Sustainable Development Goals.

CCB FEASIB.5 Knowledge Gaps

Despite the progress in new evidence since the SR1.5, there remain several knowledge gaps for the assessment of adaptation and mitigation options. They are found within the Figure Cross-Chapter Box FEASIB.2 through the NE (no evidence) or LE (low evidence).

Within energy system transitions, resilient power infrastructure has knowledge gaps on indicators of transparency and accountability potential, socio-cultural acceptability, social and regional inclusiveness and intergenerational equity.

Under land and ecosystem system transitions, gaps include limited evidence for some of the institutional and socio-cultural feasibility dimensions indicators of Integrated Coastal Zone Management. Specifically, there is lack of evidence for transparency and accountability potential and for gender and intergenerational equity. For coastal defense and hardening, there is no or limited evidence on the indicators of employment and productivity enhancement, legal and regulatory acceptability, transparency and accountability potential, social and regional inclusiveness, benefits for gender equity, intergenerational equity and land use change enhancement potential. Sustainable aquaculture has knowledge gaps for the indicators of macroeconomic viability, legal and regulatory acceptability, transparency and accountability potential, social and regional inclusiveness, intergenerational equity and land use change enhancement potential. The geographical feasibility for migration and relocation is still an emerging area of research, however, there is limited evidence to assess this specific dimension.

The option of reforestation, afforestation, protection of forests and wild areas and their resources, biodiversity management and conservation has knowledge gaps for the indicators of risk mitigation potential, legal and regulatory feasibility and social and regional inclusiveness. The option of improved cropland management has no or limited evidence for the indicators of legal and regulatory feasibility, transparency and accountability potential and hazard risk reduction potential. Efficient livestock systems has no evidence for political acceptability and legal and regulatory feasibility and limited evidence for overall institutional feasibility. Agroforestry has knowledge gaps for employment and productivity enhancement, transparency and accountability potential and intergenerational equity. There is also limited evidence for the economic and technical feasibility dimensions for ecosystem connectivity.

For urban and infrastructure systems, the option of green infrastructure and ecosystem services has limited evidence for macroeconomic viability, employment and productivity enhancement and political acceptability. Sustainable water management has gaps for macroeconomic viability, employment and productivity enhancement, and transparency and accountability potential.

For overarching options, the main knowledge gaps identified are socio-cultural acceptability for social safety nets. While the evidence on resettlement, relocation and migration is large and growing, there is disagreement on several indicators, marking the need for more evidence synthesis. Geophysical feasibility for resettlement, relocation and migration has limited evidence, but is an emerging area of research.

In general, throughout most of the options, there is significantly less literature from the regions of Central and South America and West and Central Asia, as compared to other world regions.

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