Chapter 18: Climate Resilient Development Pathways

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Executive Summary

Climate resilient development is 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. It halts practices that contribute to dangerous levels of global warming and maladaptation. Climate resilient development may necessitate deep societal transformation to ensure wellbeing for all. Climate resilient development is an elusive conceptual and aspirational construct, that is subjective and depends on the values and priorities of different actors. {18.1.2}

Climate resilient development pathways are processes that strengthen sustainable development and efforts to eradicate poverty and reduce inequalities while promoting fair and cross-scalar adaptation and mitigation. They raise the ethics, equity, and feasibility aspects of the deep societal transformation needed to drastically reduce emissions to limit global warming (e.g., to well below 2°C) and achieve desirable and liveable futures and wellbeing for all. Climate resilient development pathways reflect fundamentally moral and ethical choices. {18.1.2}

Recent literature affirms that climate action and sustainable development are interdependent and need to be pursued in an integrated manner in order to enhance human and ecological well-being. For example, investments in healthcare systems, or universal water and energy access, would make populations less vulnerable and more resilient to climate impacts while also improving well-being and reducing poverty. Sustainable development is fundamental to building capacity for climate action, including achieving reductions in greenhouse gas emissions in a manner consistent with the Paris Climate Agreement as well as enhancing social and ecological resilience to climate change. Meanwhile, aggressive climate action is key to enabling the international community to successfully achieve the Sustainable Development Goals and subsequent sustainable development objectives. {18.2}

Observed changes in energy systems are primarily attributable to sustainable development priorities, with some climate mitigation and adaptation benefits, and weather and extreme events affecting systems but attribution to non-climate factors important in changes in climate risk (*high confidence*). Factors such as energy access, energy security, air pollution, and economic growth continue to be the dominant influence on energy system. Development has increased energy system exposure to natural hazards, but improvements related to income, poverty, health, and education have reduced vulnerability while system resiliency improvements have sustainable development benefits. To date, there is limited evidence on the effectiveness of adaptation responses in reducing vulnerability. {18.3}

Current patterns of development overall are inconsistent with principles of climate-resilient development. While demonstrable progress has been made on a number of the Sustainable Development Goals, significant gains across a range of dimensions are still necessary. Various global trends including rising income inequality, continued growth in greenhouse gas emissions, land use change, human displacement, and reversals of long-term trends toward increased life expectancy run counter to the Sustainable Development Goals as well as efforts to reduce greenhouse gas emissions and adapt to a changing climate. {18.2}

Additional climate change is expected over the next decade with key climate risks found to be potentially greatest in developing and transition economies, which is also where the least-cost emissions reductions are shown to be (*high confidence*). Additional climate change relative to today is expected from even the most ambitious global mitigation scenarios, with developing and transitional economies shown to be most at risk due to both climate change and development, and these same economies estimated to represent the lowest-cost mitigation opportunities globally. How adaptation and mitigation effort and cost would be facilitated and distributed respectively is a policy question. {18.4}

There are no known development pathways that achieve all the Sustainable Development Goals and the goals of the Paris Climate Agreement. This is because there are trade-offs, as well as synergies between them. The priorities of different decision-makers determine what trade-offs are mitigated and what synergies are harnessed. Climate resilient development involves choices that reflect real-world power dynamics and dictate who wins and who loses in a given situation. A synergistic pathway may still create trade-offs for some groups over others. With unavoidable climate change, and the challenges of implementing mitigation to meet the below 2˚C temperature elevation goal, climate risk management through adaptation is an inevitable part of key societal priorities in the future. {18.2}

Five simultaneous system transitions are necessary to enable the transformation towards climate resilient development: energy systems; land, ocean and ecosystems; urban and infrastructural systems; industrial systems and societal systems. These system transitions can widen the solution space, accelerate and deepen the implementation of sustainable development, adaptation and mitigation actions. They can do so across regions and scales, when supported by appropriate enabling conditions and plural knowledges, that a multiplicity of actors can bring to bear in key arenas for engagement. {18.3, 18.5}

Pursuing sustainable development in the future is shown to have synergies and trade-offs in its relationships with every element of climate risk; however, evidence suggests that trade-offs are unavoidable and managing trade-offs and synergies will be important as will be potential shifts in the distribution of trade-offs from managing them (*high confidence*). Sustainable development can affect the emissions and mitigation determining the climate hazard, the size, location, and composition of development determining exposure; and the adaptive capacity determining vulnerability. Global projections with characteristics more closely aligned with sustainable development type priorities have been found to imply lower emissions and projected climates, lower mitigation costs for ambitious climate goals, lower climate exposure due in large part to the size of society, and greater adaptative capacity. However, limitations impact their use in climate risk management planning, including limited understanding of the cost and feasibility of sustainable development transformations and the role of individual development characteristics, as well as stylized policy representations. There are opportunities to promote synergies between sustainable development, adaptation, and mitigation, but trade-offs are potentially unavoidable, and management of trade-offs does not eliminate them, but redistribute them. For instance, none of the 1.5˚C and 2˚C pathways assessed achieved all of the UN's Sustainable Develop Goals (SDGs). Furthermore, precluding the use of some mitigation options due to sustainable development concerns can have significant implications for the cost of pursuing ambitious climate goals, and potentially the attainability of those goals. {18.4}

There are many possible pathways for climate-resilient development, and the current literature does not suggest that climate-resilient development is associated with a specific climate outcome, like limiting global average warming 1.5˚C or 2˚C (*high confidence*). Climate-resilient development is potentially possible with different climate futures and pathways, with synergies, trade-offs, and sustainable development priorities varying by climate level. The literature suggests that different mixes of adaptation and mitigation strategies, and sustainable development and trade-off management priorities, measures, and reallocations, will be appropriate for different expected climates and locations; 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. {18.4}

Pursuing climate resilient development in a manner consistent with both the Sustainable Development Goals and the Paris Agreement will necessitate fundamental transformations in core societal systems, balancing of priorities, and management of mitigation trade-offs in particular. Globally, low climate change projections imply greater mitigation, lower climate risks, and less adaptation, which implies greater mitigation trade-offs in terms overall economic development, food crop prices, energy prices, and overall household consumption, but lower climate risk with lower adaptation trade-offs. Limiting the global temperature increase to less than 2°C, adapting to committed climate change, and securing long-term sustainable and equitable development requires unprecedented changes in governance and institutions, economic and financial systems, technology and innovation, and human behaviour and preferences. Implementing transformational change has the potential to pose risks to human and ecological well-being, and the types of transformations preferred by different actors may be contested. {18.4}

There is emerging evidence that enhancing equity and agency may be an integral part of the societal transitions required to achieve more climate resilient development. However, all such transitions are not necessarily ethical or desirable to all actors. {18.3, 18.5}

Climate-resilient development risks and opportunities vary by location with uncertainty about global mitigation effort and future climates relevant to local planning (*high confidence*). There is significant regional heterogeneity in climate change, exposure, and vulnerability, as well as mitigation, adaptation, and sustainable development opportunities, synergies, and trade-offs. 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. Furthermore, local decision makers are confronted with uncertainty about global mitigation effort, thus sustainable development planning needs to manage for the possibility of higher climates by further facilitating adaptation and managing adaptation trade-offs. {18.4}

Diverse actors are the agents of societal changes and transformations that enable climate-resilient development. While much of the literature on climate action has traditionally focused on the role of technology or policy as the factors that drive change, recent literature has focused on the role of specific actors – citizens, civil society, knowledge institutions, media, governments or businesses. In particular, differences in the power 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. Greater attention to which actors benefit, fail to benefit, or are harmed by particular interventions, could significantly advance efforts to pursue climate-resilient development. {18.5}

There are a range of policies, practices, and enabling conditions that can be implemented to accelerate efforts to pursue climate-resilient development. Enhancing capacity of institutions to manage climate risk in tandem with sustainable development can create enabling political environments. Investing in technology innovation, deployment, and transfer can speed the rate at which new technologies are delivered and used to transform industrial and other societal systems. Rethinking processes of urbanisation and the use of land for agriculture to decouple growth from resource consumption can enable land to play an important role in achieving more sustainable futures. {18.4}

The diversity of opportunities for achieving climate resilient development are anticipated to decline as the risks of climate change escalate. Delays in the pursuit of climate resilient development or failures to capitalise on policy windows and enabling conditions when they arise reduces the set of mitigation, adaptation, and sustainable development options available to actors. This limits the development pathways that are climate resilient or reduces the feasibility of successfully navigating those pathways. {18.4, 18.5}

Specific interventions to achieve climate action and sustainable development are highly complementary with strong synergies. There is also the potential for significant trade-offs depending on the nature of the interventions and the conditions under which they are implemented. As an example, aggressive greenhouse gas mitigation can generate social and ecological benefits in the form of reduced climate change impacts, but it can also affect energy prices, financial investment, and economic growth. These externalities of mitigation could have adverse consequences for human and ecological well-being, particularly for the most vulnerable. Similarly, interventions designed to reduce vulnerability to climate change and act to reinforce long-standing inequalities or create path dependence and lock-in. Both of these phenomena ultimately act to enhance, rather than reduce, vulnerability. {18.4}

Socio-technical transitions toward climate-resilient development pose potential risks to particular sectors and regions. Hence, managing transition risk is a critical element of transforming society. This includes managing climate risk in the event that greenhouse has mitigation efforts over- or under-perform. In addition, decision-makers should be aware of the financial risks associated with stranded assets, technology risks such as the use of geoengineering, and the risks to social equity or ecosystem health. By acknowledging, assessing, and managing such risks, actors will have a greater likelihood of achieving success in making development climate resilient. {18.4}

Dominant and prevailing ideologies, worldviews, institutions and socio-political relations open- up or close-down opportunities to shift practices and development trajectories in the direction of climate resilient development, by framing climate narratives and action. The interplay between worldviews and ethics, socio-political relations and institutions, and actions define the dynamics of multiple arenas of engagement, from the individual to the collective and will be pivotal to deepen to accelerate and widen the movement towards climate resilient development. {18.5}

18.1 Ways Forward for Climate Resilient Development

The links between climate change and development have been long recognised and extensively studied (Nagoda, 2015; Winkler et al., 2015; Webber, 2016; Carr, 2019) and assessed extensively in every AR report since AR3, especially in Working Group II (Smit et al., 2001; Yohe et al., 2007; Denton et al., 2014). AR5 described climate resilient pathways as being characterized by mitigation and adaptation actions to reduce climate change impacts, and the integration of effective risk management institutions, strategies and choices in development. Identifying and implementing appropriate technical and governance options for mitigation and adaptation as well as development strategies and choices that contribute to climate resilience were seen as being at the centre of such strategies. It also recognized that transformation of current development pathways in terms of wider political, economic and social systems may be necessary (Denton et al., 2014).

Development processes not only influence exposure and vulnerability to climate hazards, but also the rates and magnitude of current and future consumption, energy and carbon intensity and therefore climate change impacts (Winkler and Dubash, 2016; IPCC, 2018a). People and regions who already face high levels of poverty and vulnerability to climate hazards will be the most affected by 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 fall in growth by 1.2% (Acevedo et al., 2018). Countries whose economies are projected to be hard hit by an increase in temperature accounted for only about 20% of global Gross Domestic Product (GDP) in 2016. But they are home to nearly 60% of the global population, and this is expected to rise to more than 75% by the end of the century.

Current rates of global greenhouse gas emissions are a function of current patterns of development. These patterns are drivers of current and future climate risk to specific sectors and regions (Byers et al., 2018), and therefore the subsequent demand for both mitigation and adaptation action, to prevent climate change undermining sustainable development goals and targets. While progress is being made toward a number of the Sustainable Development Goals (SDGs), comprehensive achievement of all SDGs by 2030, across all global regions remains uncertain. 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. These characteristics, when combined with other 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).

This section lays out the context for and defines climate resilient development (CRD) and its related pathways. It describes the key elements and concepts that are part of the assessment in this chapter and introduces the systems transitions that are critical for achieving CRD.

18.1.1 Context of Climate Resilient Development

As reflected in Chapter 1 of this 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., 2017; Vincent and Colenbrander, 2018; Yalew, 2020). This framing of development encompasses the risks posed by climate change to development objectives (see also Chapter 16); synergies and trade-offs between mitigation, adaptation, and sustainable development; 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 (see Section 18.1.3). Nevertheless, the concept of resilience generally, and climate resilient development specifically, has come under increasing criticism in recent years (Joakim et al., 2015; Schlosberg et al., 2017; Mikulewicz, 2018; Mikulewicz, 2019).

Since the AR5, the volume of research at the nexus of climate action and sustainable development has changed markedly (*robust evidence*, *high agreement*). 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; Werners et al., submitted).

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. The SDGs, for example, explicitly identify climate action (SDG 13) among the goals needed to achieve sustainable development. 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 recognises 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.

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 enables significant reduction in greenhouse gas emissions and significant gains in human and natural system resilience (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 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 climate-resilient development (Fankhauser and McDermott, 2016). Therefore, climate change and sustainable development cannot be assessed or planned in isolation of one another.

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 an AR5 focus on decision points where actions to manage (or fail to manage) climate risk form pathways towards a range of possible futures (see WGII AR5, IPCC, 2014c, Figure SPM.9), to describe arenas of development and engagement within which societal processes towards (or away from) sustainable development takes place. CRD actions are those everyday formal and informal decisions, actions, and adaptation or mitigation policy interventions that support systems 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, sustainability is a process that provides a compass for the direction that these multiple actions should take (Anders, 2016).

18.1.2 Assessment of Climate Resilient Development

This chapter considers the broad scope of literature related to CRD and its many related terms, since the body of work exclusively mentioning CRD and climate resilient development pathways (CRDPs) is limited (see Section 18.1.2.1.1).

18.1.2.1 Outcomes expressed in the literature

Over time, the concept of climate resilient development has emerged to refer broadly development that accounts for climate change, but the term itself is frequently left undefined. CRD appeared in scholarly literature as well as project and programme documents well over a decade ago (Kamal Uddin et al., 2006; Garg and Halsnæs, 2007) and was used in past IPCC reports (e.g., Denton et al., 2014; Roy et al., 2018). Earlier IPCC Assessment Reports addressed the links between climate change, adaptation, and sustainable development (Smit et al., 2001; Klein et al., 2007; Yohe et al., 2007). Similarly, the use of the term climate resilient development pathways dates to 2009 (Ayers and Huq, 2009), but it accelerated after being used by the UNFCCC with the launch of the Green Climate Fund (UNFCCC, 2011).

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 climate resilient development found in the literature describe development that seeks to achieve poverty reduction and adaptation to climate change simultaneously without explicit mention of mitigation (e.g., USAID, 2014; Werners et al., submitted), 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., 2017; 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). In this spirit, AR5 specifically referred to climate-resilient development as "development trajectories that combine adaptation and mitigation to realise the goal of sustainable development" (Denton et al., 2014). Yet evidence suggests that finding a balance between these three in practice is challenging (Antwi-Agyei et al., 2017; Kalafatis, 2017).

This chapter defines CRD as *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. It halts practices causing dangerous levels of global warming. CRD may involve deep societal transformation to ensure well-being for all.*

Achieving CRD involves a process driven by diverse actors, at different scales based on environmental, developmental, socio-economic, cultural, and political context, as typified in the SDG and the Paris Climate Agreement negotiations (Kamau et al., 2018). The contingent nature of such CRD pathways 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, there may be a multitude of potential pathways, that need to be negotiated and traversed by a combined set of sustainable development, disaster risk reduction and climate actions (Schipper et al., 2016; Islam et al., 2020; Wamsler and Johannessen, 2020).

CRDPs can be interpreted as intersecting conduits influenced by opportunities, constraints, and trade-offs, associated with a diversity of development choices, which are both conscious and unconscious. We update the SR1.5 definition of CRDPs as *processes that strengthen sustainable development and efforts to eradicate poverty and reduce inequalities while promoting fair and cross-scalar adaptation and mitigation. They are shaped by the ethics, equity, and feasibility aspects of the deep societal transformation needed to drastically reduce emissions to limit global warming (e.g., to well below 2°C) and achieve desirable and liveable futures and well-being for all.*

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' (UN, 2015). 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 (Raworth, 2017; Faist, 2018). Frequently, considerations of social difference and equity are side-lined in evaluating different development choices. The assumption that a growing economy lifts opportunity for all, could for example, further marginalise those who are the most vulnerable to climate change (Matin et al., 2018; Diffenbaugh and Burke, 2019).

18.1.2.1.1 Thematic review of climate resilient development pathway literature since AR5

This section reviews the topics that are covered in the literature on CRDPs since AR5. Conceptual development since AR5 is found in the domains of climate resilience (Douxchamps et al., 2017; Wenger, 2017), development (Lo et al., 2020) and pathways (Scoones et al., 2020; Werners et al., 2020), however these three strands are yet to be brought together systematically (Werners et al., submitted). This includes such issues as understanding pathways as planning approach under ambiguity and uncertainty.

Werners et al. (submitted) find that literature since AR5 on CRDPs shows four non-exclusive clusters of approaches: (a) climate-action oriented (e.g., Mulugetta and Castán Broto, 2018), (b) mainstreaming oriented (e.g., Tanner et al., 2019; Dovie et al., 2020; Ferreira Costa, 2020), (c) social-learning and co-creation oriented (e.g., Moss et al., 2019; Scholz and Methner, 2020), and (d) transformation oriented (e.g., Abel et al., 2016; Schipper et al., 2020a). These approaches broadly correspond to four desired outcomes of CRDPs: (i) undertaking specific climate actions for meeting short and long-term sustainable development goals, (ii) mainstreaming climate action and development, including synergies/co-benefits and trade-offs, (iii) promoting collaborative learning, adaptive decision-making and adaptive capacity, (iv) accounting for multiple drivers (such as root causes of vulnerability, injustice and poverty), path dependency and long-term change, including a potential need for transformation towards long-term sustainable development.

18.1.2.2 Justice and Equity and their link to human and ecosystem well-being

This chapter considers transitions and transformation as two related terms that are part of CRD as well as lead to CRD (see Figure 1.2). Both just transitions and just transformation are central to climate resilient development in that they bring forth the notion of equity not just in discussions on low-carbon development and energy transitions, but also in adaptation pathways. These notions are found throughout the report [line of sight to come] and across the assessment [line of sight to come]. Human and ecosystem well-being and planetary health are concepts that probe the entangled relationships between society and environment and how these relationships determine disruption in and stewardship of socionatural systems, possibilities for human health and living well, as well as expanded understandings of human and ecological flourishing (Steffen et al., 2018; Nightingale Böhler, 2019).

An expanding literature on sustainability, adaptation, resilience and transformation documents the importance of equity not just as an aspirational outcome, but also as a quality of development *processes* required to build resilience at individual and collective levels (Ensor, 2016; Matin et al., 2018; Pelling, 2020). Past climate extremes as well as the current COVID-19 pandemic show that inequitable societies are much less resilient in the face of the pandemic than equitable and just societies, both in terms of collective resilience and in terms of further exacerbating social inequalities (Klassen and Murphy, 2020; Marmot, 2020; Marmot and Allen, 2020; Summers et al., 2020). Poor health and well-being levels are closely interconnected to social inequity at national and local scales (*high confidence*) (e.g., Di Martino and Prilleltensky, 2020; Marmot, 2020). Various forms of discrimination, such as structural racism and uneven power relations such as skewed gender relations are key causes of inequality and deprivation (Gill and Benatar, 2020; Marmot and Allen, 2020). Equity and justice are integrative means to achieve more resilient food, social and economic systems (Klassen and Murphy, 2020).

Just transitions is a term emerging from the need to anchor socio-technical transitions in politics and justice (Newell and Mulvaney, 2013). It emphasises that policy changes to protect the environment can have negative consequences for people’s livelihoods, and that these must therefore be implemented in a fair and equitable way (Newell and Mulvaney, 2013). The civil society movement on just transitions emerges from advocacy for employees of industries affected by environmental regulations (Stevis and Felli, 2015). The notion has gained traction in climate policy over the last decade (Newell and Mulvaney, 2013; Heffron and McCauley, 2018; Jenkins et al., 2018; Winkler, 2020) and introduces equity and justice directly into conversations around systems transitions for climate change (Bennett et al., 2019; Stevis and Felli, 2020 see also WGIII Section 1.5.3, Section 4.5, Chapter 6 and 17). The notion of just transitions emphasises that technical feasibility to achieve SDGs, climate change and other goals should be complimented by a process of deliberate inclusivity underpinned by plural visions of change (Beck and Forsyth, 2020).

Just transitions have been used extensively in discussions related to shifts in energy systems, with particular reference to loss of employment by coal miners upon mine closure, or as demand for coal is reduced through policy or behavioural changes (Stevis and Felli, 2015; Caldecott et al., 2017). Recent scholarship calls for these local experiences to be examined from a more global perspective (Forsyth, 2013; Agyeman, 2014; Heffron and McCauley, 2018). Yet just transitions are particularly challenged by the need for the transition away from fossil fuels to be rapid, as achieving justice requires a deliberate, and therefore slow, process (Heffron and McCauley, 2018). Questions still remain about how to ensure that low-carbon transitions can be just and equitable (Robins and Rydge, 2019; Green and Gambhir, 2020).

The concept has recently been applied to talk about 'just transformation' as well (Bennett et al., 2019; Wijsman and Feagan, 2019). Differences between transitions and transformation are critical in this context since transitions are associated with incremental change, while transformation is understood as challenging dominant socio-political systems and institutions to get at the underlying causes of injustice (2014; Webber, 2016; Few et al., 2017; O'Brien, 2018; Bennett et al., 2019; Mikulewicz, 2019; Eriksen et al., submitted). At the same time, transformation is often associated with sudden, profound shifts (Schipper et al., 2020a). However, long-lasting changes can also be considered transformation (Matin et al., 2018). As such, transformation can also be considered as a spectrum of gradual, incremental, 'evolutionary' changes (Magnan et al., in press).

18.1.2.3 Key risks

The key risks assessment in Chapter 16 is an important input into discussions of climate resilient development, with climate risk implications for development and development implications for climate risks, as well as climate risk management options (adaptation and mitigation). Chapter 16 provides a variety of useful resources and insights for Chapter 18's focus on near-term and location-specific development opportunities. Among other things, Chapter 16 collects and summarizes key risk information from the WGII sector and regional chapters, develops Representative Key Risk (RKR) indicators based on sets of key risks, characterizes potential variations in RKRs based on warming, development, and adaption levels, and provides illustrative projections of potential future changes in RKRs. The Chapter 16 RKRs include risks to coastal systems, terrestrial and ocean systems, critical infrastructure, networks and services, living standards and equity, human health, food security, water security, and peace and migration. Chapter 16 also maps the RKRs into an updated "Reasons For Concern" (RFC) framing, and provides a high-level characterisation of RKR and RFC relationships with SDGs. Chapter 16's assessment is particularly relevant to Section 18.4.2 (Climate Resilient Development & Managing Key Risks); however, it also informs Section 18.3.1.1.2 (Observed climate risks, adaptation, and sustainable development) on observed risks, attribution, and adaptation effectiveness.

18.1.2.4. Role of Options and Decision Making

Actors and institutions play a key part of climate resilient development and in the movement along and between different pathways. Chapter 18 picks up where Chapter 17 ends by assessing different adaptation options, in terms of processes, enablers, what is needed to measure progress, and how to take account of uncertainties along the way. Chapter 17 highlights three critical dimensions for responding to climate change, namely policies and processes, resources and the effects of climate change. The decision-making spaces explored by Chapter 17 underpin the arenas of engagement presented in this chapter (Section 18.5). These are defined in 17.6 as resulting in three sets of indicators for assessing progress and success of action: capabilities, responses, and outcomes.

Chapters 16 and 17 show that resultant climate impacts on people, sectors and the environment are and will be unequally distributed, and that those that are currently stressed are more likely to be reactive to the climate change impacts rather than being pro-active.

18.1.2.5 Enabling Conditions

Climate resilient development pathways emerge from the intersection of opportunities, visions and priorities for development, which are created by certain conditions. The qualities that describe sustainable development type processes (e.g., social justice, alternative development models, equity and solidarity etc as described above and in Figure 18.5) lead to outcomes and conditions such as measured by SDGs in the short term that in an iterative fashion enable further CRD processes (e.g., not reaching Paris goals and poor SDG achievement are outcomes that undermine the possibility of future SD quality processes). Such qualities and outcomes in the political, economic, ecological, socio-ethical and knowledge-technology arenas of development hence pervade enabling conditions and deepen understanding of enabling conditions, as discussed in Sections 18.5.2 to 18.5.6.

Due to its importance for charting the course of development, governance is the first of these enablers, implemented through both institutions and policy (Section 18.5.2.2). Institutions focus on the structural dimension of governance that encompasses collectively sanctioned formal and informal norms and rules that offer reliability and stability in socio-economic interactions. Policy focuses on how action is framed and undertaken, and political solutions crafted through governance interactions, instruments and interventions (Section 18.5.2.3). Economics and sustainable finance is the second of these enablers, since funding is critical for supporting systems transitions and transformations (Section 18.5.2.4). A third enabler is institutional capacity, which includes structures, processes, rules, norms, and cultures that shape development pathways, particularly by affecting the choices available to remain on or switch to a preferred pathway (Section 18.5.2.5). To be effective, these also account for gender and intersectional dimensions (see Cross-Chapter Box GENDER). Science, technology and innovation play a critical role as the fourth enabler, including through raising awareness of the interlinked nature of technological developments and access to knowledge and questions of equity and justice (Section 18.5.2.6). This is also reflected in the importance of indigenous and traditional knowledge (see Cross-Chapter Box INDIG). Finally, monitoring frameworks to allow for the assessment of progress toward climate resilient development (Section 18.5.2.7).

18.1.3 System Transitions and Transformation

CRD is dependent on transitions in key systems, which will take place through processes of transformation. This section sets out the different systems transitions discussed in this chapter, describes transformation and highlights the links between transition and transformation (Box 18.1).

18.1.3.1 System transitions in past reports

There has been an evolution of the conceptualisation of climate change-related systems, since IPCC AR5. This has led to a clearer understanding of key system transitions that could accelerate the transformations needed to implement the Paris Climate Agreement and the SDGs (IPCC, 2018a).

AR5 used three high-level and intersecting definitions of systems as frames of reference to assess climate impacts and adaptive responses. First, climate, natural and human systems; also presented as physical, biological, and human and managed systems. Second, a sectoral view of energy, AFOLU and food, industry, human settlements and infrastructure, buildings, transport, health and livelihood systems. Third, a spatial and regional view of urban, rural, coastal, mountain and polar systems (IPCC, 2014a; IPCC, 2014b).

The AR6 cycle saw a significant shift in this systems framing in its three Special Reports. This started with SR1.5, whose plenary approved outline sought to define “the potential for development and deployment of adaptation and mitigation responses to accelerate transitions within and across scales and systems (e.g., food production, cities).” A major post-Paris Agreement shift of the AR6 assessment focus was towards solution spaces largely situated in human systems, linked to ecosystems services and to climate systems via emissions and their impacts (IPCC, 2018a; IPCC, 2019a; IPCC, 2019c).

SR1.5 identified (with *high confidence*) rapid and far-reaching transitions in four systems: energy, land and terrestrial ecosystems, urban and infrastructure (including transport and buildings) and industrial systems, as necessary to enable pathways to limit global warming to 1.5°C (IPCC, 2018a; IPCC, 2018b). This was deepened for terrestrial systems in SRCCL, while SROCC added additional evidence from ocean and cryosphere systems.

[START BOX 18.1 HERE]

Box 18.1: Transformations in Support of Climate Resilient Development Pathways

Although there is widespread understanding that transformations are needed across all sectors and scales to reduce climate risk and vulnerability and meet the SDGs, there is less agreement on the means and manner of realising transformations to sustainability. The pursuit of sustainable CRDPs and trajectories involves both qualitative and quantitative dimensions as well as complex interactions between individual, collective, and systems change. Recognising this, the SR1.5 (IPCC, 2018a: 599) included a broad 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 behaviours, and a fairer balance of political, cultural, and institutional power in society."

In recent years, a growing body of literature has drawn attention to equity and power dynamics in transformations, raising questions such as who decides, who has agency, and who gains or losses (Blythe et al., 2018; Bennett et al., 2019). Critical approaches to transformation challenge neoliberal responses and assumptions about the universally beneficial and apolitical nature of sustainability transformations (Wilhite, 2016; Barkin and Sánchez, 2020; Brand et al., 2020; Feola, 2020; Schmid and Smith, 2020). Similar to vulnerability and resilience, transformation is recognised as multifaceted and context-specific (O'Brien, 2018). Research points out that transformation is not a neutral process, and a need to balance urgency with adequate deliberation about the implications for social justice and the long-term ecological consequences of proposed solutions (e.g., biofuels, nuclear power, geoengineering, see Blythe et al., 2018).

Although there are diverse theories, frameworks and approaches to transformation processes, consensus on how to rapidly and equitably generate transformations at a global scale has remained elusive. This has led to a growing literature on both leverage points and social tipping points, including how small interventions may accelerate transformations to sustainability (Abson et al., 2017; Centola et al., 2018; David Tàbara et al., 2018; Milkoreit et al., 2018; Chan et al., 2020; Lenton, 2020; Otto et al., 2020a). Many authors point to the high potential of deeper leverage points, including mindsets and paradigms (Göpel, 2016; Abson et al., 2017; Wamsler and Brink, 2018; Fischer and Riechers, 2019; Horcea-Milcu et al., 2019; Wamsler, 2019). Acknowledging the role of mindsets and paradigms in systems change has drawn attention to the role of agency in shifting norms, institutions and systems towards sustainable pathways (Westley et al., 2013; Sharpe et al., 2016; O'Brien, 2018; Otto et al., 2020b). Figure Box 18.1.1 shows how deep leverage points such as shifting the goals of a system (from growth to justice, dignity and equity) or altering the mindset or paradigm from which system arises (from individualism and human-nature alienation to solidarity, human well-being and climate justice) are more powerful in leveraging change than material, practical or technical shifts, feedbacks and parameters. Shifting the character of development processes in order to enable CRDPs may require a mix of incremental and transformational actions, including transformative adaptation. Transformative actions in the context of CRD specifically concerns identifying the levers through which the character of development within the five arenas can be shifted. Within the political and science-technology spheres, altering dominant worldviews and knowledges can shift unjust and unsustainable socio-political and nature-society relations (Görg et al., 2017; Brand et al., 2020). Responses to climate change can imply radically rethinking and rebuilding social, ecological and economic relations' (Gillard et al., 2016; Few et al., 2017) including reconnecting inner with external world dimensions and actions through solidarity and compassion (Horlings, 2015; Woiwode, 2020).

FIGURE 1 Schematic illustration of four realms of leverage (Abson et al., 2017) showing a gradient from shallow leverage points to deep leverage points (see Table 1 for details and examples); and the position of those realms of leverage regarding their explanation of system change in terms of causality or teleology. Round arrows indicate stylized interaction that may occur between any combination of leverage points. (Figure is adapted with permission from an earlier version by D.J. Abson.)

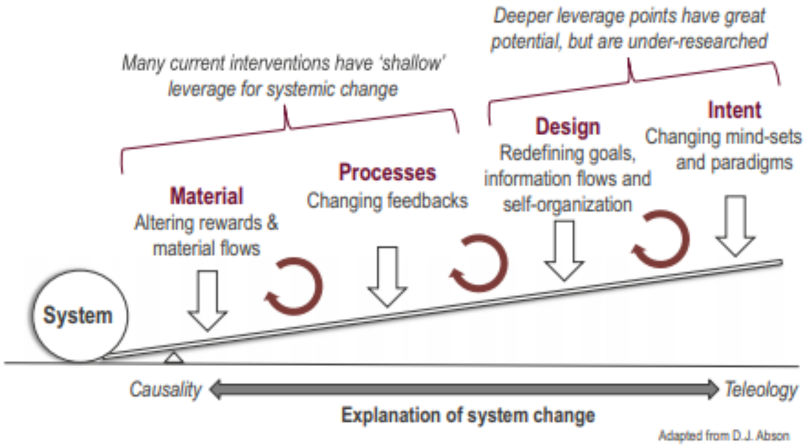

Figure Box 18.1.1: Deep and shallow leverage points for transformation. Source: (Fischer and Riechers, 2019: 117)

Transformation emerges as a result of collective actions, therefore, activating conscious human agency is a powerful way to change norms and institutions (Sharpe et al., 2016; O'Brien, 2018). This requires recognition of the role of human agency and learning capacity, and the potential of individuals and groups to become agents of change (see Section 18.5.3.2), as well as the importance of institutional drivers, which often operate within hidden networks (O'Brien and Sygna, 2013; Fazey et al., 2018b). It also requires exploring who has the power of resisting change (Sharpe et al., 2016).

The distinction between transitions and transformations is not always clear and depends on varying definitions of the two. The SR1.5 identified transformative change (in addition to some incremental change) as leading to transition, i.e., transition being an outcome of transformation. Much of the transitions literature focuses on how societal change occurs within existing political and economic systems, and has been linked theories of ecological modernisation (Warner, 2010; Bailey et al., 2011; Geels, 2011; Geels et al., 2016; Geels, 2019). In contrast, Pelling (2010) interprets transformation as involving more radical changes than transitions, including changes to existing structures and power relationships. Here transition implies incremental social change and the exercise of existing rights whereas transformation demands for new rights and changes in political regimes (Pelling, 2010). Others also consider transformations to involve deeper process than transitions, including shifts in beliefs, values, worldviews, and paradigms (Göpel, 2016; O'Brien, 2016; Kuenkel, 2019; Waddock, 2019). This perspective contrasts with a tendency to approach the issue of sustainability as if it were merely a technical problem that can be solved by applying existing and improved knowledge, know-how or expertise to develop new technologies and instigate behavioural change (O'Brien and Selboe, 2015). Yet, some socio-technological transitions and sustainability transitions literature will emphasise many of the same features as the transformations literature, such as the way that different actors interact to make decisions, and how just transitions take place. However, transformations can also be negative for some groups or sustainability concerns, and can also be oppressive when implemented in a top-down fashion privileging dominant economic, social or political interests or a narrow set of understandings (Blythe et al., 2018).

[END BOX 18.1 HERE]

18.1.3.3 Energy Systems

Energy is a key resource to economic activity and human well-being, with energy supply, distribution, and energy use technologies supporting a diverse set of household, industrial, transportation, agricultural, and commercial service demands for society. Global energy consumption has increased more than five-fold since 1950, with service levels growing even faster due to improvements in the efficiency of energy use, and these trends are expected to continue. Meanwhile, there have also been shifts in the composition of energy supply resulting in declining greenhouse gas emissions intensity but increases in emissions overall. Regional energy systems have evolved with economic markets, technological development, and societal priorities.

Various energy supply and demand physical, economic, environmental, and sustainable development elements have been used to describe energy systems and their changes over time (e.g., IPCC, 2007; Bruckner et al., 2014; Rogelj et al., 2018). Physical elements include descriptive metrics related to energy system size, growth, physical relationships (e.g., energy intensity), flows, composition (fuels, energy carriers, technologies), and services (e.g., vehicle miles, lightening, heating/cooling days, disruptions). Economic elements include market prices (inputs and outputs), production costs, social welfare, and distributional metrics. Environmental elements include resource use and environmental quality metrics. Sustainable development elements include metrics related to development, economic, environmental, and social priorities, such as indicators related to service levels, energy security, environmental quality, water use and quality, human health, and equity.

The literature since AR5 has evolved to provide more multi-dimensional insights covering a broader array of elements that provide better integrated perspectives and facilitate greater discussion of synergies and trade-offs associated with potential energy system transitions for mitigation and adaptation, with both more aggregate global and location specific research (e.g., de Coninck et al., 2018; McCollum et al., 2018a; Rogelj et al., 2018). Nonetheless, analysis tends to be stylized and there are challenges for using and communicating the diverse set of information (e.g., Roy et al., 2018).

18.1.3.4 Urban and infrastructure systems

Cities as system are studied for more than half a century but there is a growing literature using a systems approach for cities to understand climate change transition and transformation. The SR1.5 mentions four systems that urgently need to change in fundamental and transformative ways (IPCC, 2018a), including urban and infrastructure. The SRCCL identifies cities as spatial units for land-based mitigation and adaptation options but also places for managing demand for natural resources including food, fibre and water (IPCC, 2019a). Similarly, the evidence adduced in the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) report that cities straddle the biodiversity sphere in the sense that they present spatial units of ecosystem fragmentation and degradation but are at the same time spatial units where the concentration of biodiversity compares favourably with some landscapes (IPBES, 2019). In 2018, approximately 55 percent of the global population of 7.8 billion reside in urban areas (UNDESA, 2019). It is predicted that 68 percent of the world population will live in urban areas by 2050 (WGIII AR6 Chapter 8).

To avoid carbon lock-in, informal urban areas and cities mainly in developing countries can consider immediate transition actions with long-term impact on emissions and adaptation through alternative non networked infrastructure and energy systems. These actions have economic, health, adaptation co-benefits that can deliver on inclusiveness and resilience (WGIII AR6 Chapter 8). Adaptation to climate change may be incremental or transformational in nature. Cities can choose to combine both approaches, depending on their needs and circumstances (Parry, 2017). Urban climate adaptation provides opportunities for both incremental and transformative development (Revi et al., 2014). Other scholars have called for a focus on social transformation at the local level, specifically cities (Romero-Lankao et al., 2018) and local government (Amundsen et al., 2018).

18.1.3.5 Land, Oceans, and Ecosystems

The SR1.5 assessed the feasibility of mitigation and adaptation options related to land use and ecosystems, grouping land transitions around agriculture and food, ecosystems and forests, and coastal systems. The SR Land addressed GHG fluxes in land-based ecosystems, land use and sustainable land management in relation to climate change adaptation and mitigation, desertification, land degradation and food security. This takes into account the thematic assessment of the IPBES on Land Degradation and Restoration, the IPBES Global Assessment Report on Biodiversity and Ecosystem Services, and the Global Land Outlook of the UNCCD. The SROCC has examined from the highest mountains and remote polar regions to the deepest oceans. It finds that in these places, the transition due to the human-caused climate change has been evident for decades. It highlights the urgency of timely, ambitious, coordinated, and enduring action.

A key issue that links adaptation and land and ecosystems transition is land degradation. Even with the implementation of measures intended to avoid, reduce or reverse land degradation, there are limits to adaptation, which are dynamic, site-specific and are determined through the interaction of biophysical changes with social and institutional conditions. In some situations, exceeding the limits of adaptation can trigger escalating losses or result in undesirable transformational changes such as forced migration, conflicts or poverty. Examples include coastal erosion exacerbated by sea level rise where land disappears, thawing of permafrost affecting infrastructure and livelihoods, and extreme soil erosion causing loss of productive capacity (IPCC, 2019c, B.5.5).

A key issue that links mitigation and land transition is food production. Transitions towards low-GHG emission diets, for example, may be influenced by local production practices, technical and financial barriers and associated livelihoods and cultural habits (IPCC, 2019c, B.6.2).

Key issues related to oceans and ecosystems transition are the transition between the grounded part of an ice sheet and a floating ice shelf, called the grounding line and the transition from frozen water to liquid water at around 0ºC that can lead to rapid acceleration of ice-melt or permafrost thaw, the acidification and rising ocean temperatures (IPCC, 2019b: 79-81). Such thresholds often act as tipping points, as they are associated with rapid and abrupt changes even when the underlying forcing changes gradually. Tipping elements include, for example, the collapse of the ocean's large-scale overturning circulation in the Atlantic or the collapse of the West Antarctic Ice Sheet, a process called marine ice sheet instability. Potential Ocean and cryosphere tipping elements form part of the scientific case for efforts to limit climate warming to well below 2°C (IPCC, 2019b). Changes in the ocean and cryosphere, the ecosystem services that they provide, the drivers of those changes, and the risks to marine, coastal, polar and mountain ecosystems, occur on spatial and temporal scales that may not align within existing governance structures and practices. There are requirements for transformative governance, international and transboundary cooperation, and greater empowerment of local communities in the governance of the ocean, coasts, and cryosphere in a changing climate. (IPCC, 2019d).

Another important topic involving land, ocean and ecosystems transitions is the psychological implications across diverse communities and social and political contexts in the context of a just transition of both emissions reduction and adaptation. Impacts of climate change on natural and human environments (ex: extreme weather) or human-caused modifications to the environment (ex: adaptation) will raise further psychological challenges. This includes psychological impacts to the emotional well-being of people adversely affected (IPCC, 2019b).

18.1.3.6 Industrial systems transitions

The SR1.5 presents industrial system transitions as involving carbon dioxide capture utilisation and storage (CCUS), energy efficiency, bio-based and circularity, shifting to low- or zero-emission power generation, such as renewables and hydrogen, electrifying transport and developing green infrastructure, and improving energy efficiency by smart urban planning (de Coninck et al., 2018). This chapter deepens the conceptualisation of the transition of the industrial system.

Reducing the consequent impacts of emissions requires a wide range of mitigation and adaptation interventions. However, knowledge about the ability of adaptation options to reduce emissions is limited (Fischedick et al., 2014). The adaptation literature for companies and industries deals with adaptation to socio-political and economic changes, although there are few studies per se on adaptation to climate change (Linnenluecke et al., 2013). The literature on the transition of the industrial system is dominated by mitigation actions.

Decarbonisation and dematerialisation strategies have been proposed as key drivers for the transition of an industrial system (Fischedick et al., 2014; Worrell et al., 2016). The former involves limiting carbon emissions in energy-intensive industries through energy efficiency, electrification and fuel switching, and innovations in energy sources (CDR techniques, the role of hydrogen in industry, etc.) (IEA, 2017; Hildingsson et al., 2019). The latter involves material efficiency, circular economy, raw material demand management, environmentally friendly product and process innovations, and environmentally friendly supply chain management (Worrell et al., 2016; Petrides et al., 2018).

Sustainability transitions involve multiple elements that evolve together, including technologies, markets, infrastructures, policies, industrial structures, and supply and distribution chains (Köhler et al., 2019), which are organized in stable regimes that are often understood as technologies, institutions and actors. Therefore, the role of governance, policies and regulation is extremely important. Governments have increasingly regulated the use of materials and their disposal around the world (Rankin, 2013). Furthermore, policy drive is needed in terms of technological transition to induce materials efficiency (Allwood et al., 2013; Rankin, 2013; Allwood et al., 2019), circular economy (Garmulewicz et al., 2018) and demand management for raw materials. Similarly, a market pull is likely in terms of high and growing consumer demand for materials efficiency (Rizos et al., 2016) and raw material management (Olatunji et al., 2019) to induce manufacturers to invest in decarbonisation. Market pull, driven by end customers, will encourage the adoption of new technologies, energy source developments (Allwood et al., 2019) and energy efficiency (Kang and Lee, 2016) when there is a direct correlation with higher revenues. Additionally, carbon pricing is a vital tool for low-cost, low-carbon mitigation strategies (Ryan et al., 2011).

Systemic corporate strategies such as conscious and regenerative capitalism, market transformation, collaborative and constructive lobbying, and a new conception of transparency are shaping the next phase of corporate sustainability (Hoffman, 2018). However, greenwashing often has profound adverse effects on consumer and investor confidence and works against business sustainability (Delmas and Burbano, 2011; Newell et al., 2015; De Jong et al., 2017).

18.1.3.7 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 behaviour, 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. Furthermore, the understanding of development toward progress as linear has been challenged as being a Western concept by scholars of colonialisation (Sultana et al., 2019).

One strand of work on social transitions has come under the banner of sustainability transitions. Sustainability transitions involve fundamental social changes, and hence, they are shaped by active transition politics, including the roles of multiple actors driving or hindering the transition (Avelino and Wittmayer, 2016). In particular, states play a key role in fostering transitions and may also slow them (Johnstone and Newell, 2018). However, analyses of sustainability transitions rarely question capitalism as producing climate change-related emissions and vulnerability drivers. Furthermore, the literature on sustainability transitions has had a limited engagement with adaptation questions. The focus 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 reductions of carbon emissions, such as transport and energy. However, more recently, interest in adaptation has started to pick up, especially as several scholars of transitions 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). This analysis highlights the integrated character of sustainability transitions thought, which see adaptive transitions as a component of a whole sustainability transition.

Thus, this chapter attempts to characterise transitions evident in society including through the research done around emergent concepts such as 'solastalgia' (Albrecht et al., 2007; Askland and Bunn, 2018; Cunsolo and Ellis, 2018; Hayes et al., 2018; Galway et al., 2019), understood as a depression caused by increasing environmental degradation, 'eco-anxiety' (Clayton et al., 2017; Pihkala, 2018), and climate, green or 'apocalyptic fatigue' (Stoknes, 2014), where the bombardment of information creates lethargy and indifference.

18.1.3.8 System transitions characteristics

System transitions were seen as simultaneously accelerating change that was often underway, to provide impetus to limit global warming to 1.5°C. They were assessed to be unprecedented in scale but not in speed, and to be effective, needed deeper investments in implementing a wide portfolio of mitigation and adaptation options (IPCC, 2018b).

This framing of system transitions enabled synergies between mitigation and adaptation action, by bringing together two epistemic traditions of transformative change i.e., socio-technical transitions for mitigation and social-ecological transitions for adaptation. SR1.5 claimed that "transitional adaptation pathways would need to respond to low-emission energy and economic systems, and socio-technical transitions for mitigation involve removing barriers in social and institutional processes that could also benefit adaptation" (Pant et al., 2015; Geels et al., 2017).

SR1.5 also assessed with *high confidence* that, with the implementation of sustainable development, global system transitions could help facilitate the pursuit of climate-resilient development i.e., ambitious mitigation and adaptation, along with poverty eradication and reduction of inequalities (IPCC, 2018b).

Enabling conditions for system transitions include finance, technological innovation, strengthening policy instruments, institutional capacity, multilevel governance, and changes in human behaviour and lifestyles. They also include inclusive processes, attention to power asymmetries and unequal opportunities for development and reconsideration of values. (IPCC, 2018b). Synergies between mitigation and adaptation are enhanced by considering enabling conditions, while trade-offs are amplified when enabling conditions are not considered (Scott et al., 2015).

18.1.4 Key Questions and Chapter Roadmap

This chapter engages with understanding CRD and the pathways to achieving it, building on the regional and sectoral assessments in the early part of this report. Notably, this chapter takes off where Chapters 16 and 17 end: recognising the decision making context to address the representative key risks, among others. This chapter therefore highlights how choices around the way climate change is framed in connection to development and divergent visions of the future influence subsequent options and enabling conditions for solutions. The chapter in particular focuses on achieving CRD through systems transitions, discussing these in relation to societal transformation as introduced above.

In assessing the opportunities and constraints associated with the pursuit of sustainable development, this chapter proceeds in Section 18.2 to assesses development, sustainable development and SDGs in relation to climate adaptation and greenhouse gas mitigation. Then, in Section 18.3, the chapter assesses evidence of existing CRD and CRDPs from the thematic and regional chapters, seen through the five systems transitions presented in Section 18.1.3, to identify the conditions that enable CRD. Looking ahead into the future, Section 18.4 assesses what is necessary to accelerate systems transitions toward CRD, looking at this both from the perspective of manging key risks as well as implementing adaptation options. This section also includes the synergies and trade-offs between adaptation, and sustainable development policies and objectives, and adaptation and mitigation. Section 18.5 then goes into greater depth about the enabling conditions, the emerging actors, arenas and modes of engagement that facilitate CRD, as well as what creates barriers to climate resilient development and where the frontiers for climate action lie. 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.

This chapter hosts two Cross-Chapter Boxes, which have their natural home here. The Cross-chapter Box on Gender, Justice and Transformative Pathways (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 (INDIG) highlights that achieving CRD requires confronting the uncertainty of a climate change future. There are many perspectives both 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). This emphasises that there are no formulas for achieving CRD, as all countries need to find their context-specific pathways, but there are factors that can facilitate its achievement – these include taking account multiple worldviews and recognising their respective contributions by all groups.

18.2 Development Conditions and Trends and the Search for Climate Resilient Development

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 the imperative of addressing climate change in order to ensure sustainable development. For example, that climate change impacts 'undermine the ability of all countries to achieve sustainable development' (UN, 2015) and can reverse or erase improvements in living conditions and decades of development (Hallegatte and Rozenberg, 2017). However, recent analysis shows that actions needed to achieve the SDGs can also contribute to worsening climate change (Fuso Nerini et al., 2018). The negotiation of priorities and subsequent trade-offs between them depends on the goal, which is itself determined by normative framings of climate resilience and development.

This section examines understandings of development and sustainable development and their roles in shaping CRD through adaptation and mitigation.

18.2.1 Development Frameworks and Pathways

A framing of climate resilient development requires an explicit definition of development, its goals, dynamics, and timeframes. Prior IPCC reports employed development as a typological framing of the current state of a given country or population (i.e., IPCC, 2014a, Section 1.1.4). Such framings frequently rest upon measures of economic activity, using them as proxies for the wider opportunity and well-being of the population measured. For example, the gross domestic product (GDP) is often treated as synonymous with 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 has been decades of policies, programmes, and projects aimed at improving various aspects of the human condition by boosting economic growth at scales from the household to regional and global. One recurrent approach to development has been "the big push", a notion that to achieve economic growth (and therefore development), countries require a massive infusion of resources across sectors to jump-start economic transformation, which in turn will both bring about and sustain material and social changes, such as longer lifespans and greater gender equity (e.g., Rostow, 1959; Sachs and McArthur, 2005).

Thus far, these approaches have shown limited ability to bring about durable improvements in human well-being (Carr, 2008; Clemens and Demombynes, 2011; Michelson and Tully, 2018), prompting an array of ancillary efforts, ranging from forced restructuring of the economy to qualify for big push investments (such as in structural adjustment) to the downscaling of this approach to the village level (Cabral et al., 2006; Sanchez-Azofeifa et al., 2007).

Critiques of this approach to development can be classified into two categories: one questioning what is measured when discussing development; and the other questioning what the goal of development is. The first of these approaches is represented by literature seeking to expand the notion of what constitutes, and should be measured to understand, development.

By the 1960s, the use of Gross Domestic Product (GDP)-based measures to evaluate economic welfare was already being questioned. Several alternatives, focused on including environmental costs in the calculation of well-being, emerged. 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) and the Adjusted Net Saving Index or the Genuine Savings Index (GSI). All consider human, ecological and economic dimensions to measure net annual national wealth variation.

A second set of alternative framings broaden the approach to the measurement of human well-being. The Human Development Index (HDI), launched in 1990 by the United Nations Development Programme (UNDP, 2016b) provided a metric that enabled an assessment of quality of life (longevity, health, access to knowledge, decent standard of living) as an alternate measure of development to economic growth-oriented ones of the previous decades. Several indices emerged from adaptations to the HDI such as the Inequality-adjusted Human Development Index (UNDP, 2016a), the Gender Development Index, the Gender Inequality Index, and the Multidimensional Poverty Index. There are also efforts to fundamentally rework the measures and indicators of development, as embodied in 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, 2019), and the Happy Planet Index (NEF, 2016). Finally, a multitude of indices have emerged to assess ecological aspects of sustainability, such as the Ecological Footprint indicator (GFN, 2017), the Environmental Sustainability Index (Esty et al., 2005) (later updated as the Environmental Performance Index) and the Wellbeing Assessment (Prescott-Allen, 2001).

Such efforts have been accompanied by programmes and projects that are best defined as 'development alternatives' in that they offer broader framings of development and its goals than seen in growth-centred approaches, but do not fundamentally question the idea that development exists on an absolute scale that can be measured in a comparative way across contexts. A second body of critique fundamentally questions the unspoken premise that development is universal and comparable across contexts. This literature notes that the use of terms such as underdeveloped, or typologies that frame countries and people on a continuum from low human development to high human development, creates an implicit understanding of development as a movement from a state of lack to one of completeness or fulfilment (Esteva, 1992; Escobar, 1995), a process fuelled by economic growth. Such framings implicitly or explicitly place the wealthiest, most secure countries and people at the top of a hierarchy toward which all other people are moving. This critique has taken on force as observations of both the global environment and economy make it clear that the pathways taken by currently wealthy populations and countries rely on technologies, resources, and conditions that either no longer exist, or which would threaten their own well-being and that of others. Thus, the literature has begun to offer alternative framings of development framed around diversity and heterogeneity, not only in contemporary practices, but also pathways of change over time (Gibson-Graham, 2005; Gibson-Graham, 2006). This literature also critiques the linear paradigm of development as 'progress' (Sultana et al., 2019).

[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 industrialising, 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 realise 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 organisation, 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 decentralisation, 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 militarisation 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 recognised 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 centres, 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 behaviour 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]

18.2.2 The Quest for Sustainable Development

Since AR5, sustainable development has been inserted into understandings of climate resilient pathways through the SDGs (UN, 2015) and the SR1.5 term climate resilient *development* pathways. This section assesses the implications of expanding the focus of climate action to encompass social equity goals and the role of climate action in the broader societal process of development.

The key purpose of CRD is to pursue sustainable development, engaging climate actions in ways that support human and planetary health and well-being. SR1.5 identified social justice and equity as core aspects of climate resilient development pathways to achieve sustainable development and limit warming to 1.5C (Roy et al., 2018). Sustainable development hence frames the end goal of CRD as well as the character of actions and societal processes through which it is achieved.

Ideas of environmental decline as associated with human activities trace back to ancient philosophy (Nightingale Böhler, 2019). Framings of humanity's relationship with nature are contested, in particular whether the relationship between nature and society can be seen as dual or non-dual, the importance of material versus intangible values of nature, and the emphasis on inner embodied or outer physical aspects of our relationship to other human and non-human species (Horlings, 2015; Kenter et al., 2015; Jolly, 2019; Ives et al., 2020). Key debates dating back decades have been brought to the forefront by climate change, such as whether economic growth and rising consumption is compatible with sustainable development (see chapter 1), and increasingly, whether or not sustainable development can be achieved through technical, managerial and behavioural change, or whether more fundamental societal transformations are required (Lovins and Cohen, 2011; Abson et al., 2017; Holden et al., 2017; Fazey et al., 2018a; Nightingale Böhler, 2019, Box 18.1). For example, some framings attribute environmental degradation to moral decline, such as selfishness and lack of respect in our relationship to the socio-natural environment (Nightingale Böhler, 2019). However, when the UN Conference on the Human Environment placed sustainable development on the international agenda in 1972, the term sustainability emphasised how environmental problems could be solved while promoting progress and growth. While moral imperatives were introduced with the World Commission on Environment and Development definition (Brundtland, 1987) "meeting the needs of the present without compromising the ability of future generations to meet their own needs" both this and the UN Conference on Environment and Development and subsequent Rio Convention has been criticized for retaining a dual understanding of society and nature underpinning neoliberal economic growth narratives – an instrumental value understanding of nature justifying exploitation of natural resources to maximise human utility (Pelling, 2010; Adelman, 2018).

The 2030 Agenda for Sustainable Development (2015) and its 17 Sustainable Development Goals links the well-being of people and the planet, with equity, poverty eradication, and healthy environments as pervading all goals, aiming at achieving peaceful, just and inclusive societies. Leaving no one behind, human well-being and planetary health are underlying motivations of the SDGs, shifting notions of development towards social justice and qualities like dignity, human rights and fulfilment of human potential. The SDGs potentially represent a shift in development paradigm, for example by defining development not as economic growth but satisfying human needs, ensuring social justice, and respecting environmental limits (Holden et al., 2017). They also represent a potential leverage for transformation by calling for transformative actions to 'shift the world onto a sustainable and resilient path'. At the same time, the 2030 Agenda is also criticized for representing a nature-society dualism and aiming at sustainable economic growth, subsumed in a neoliberal agenda and business as usual development (Scheyvens et al., 2016; Adelman, 2018; Gay-Antaki and Liverman, 2018; Sultana et al., 2019). The SDGs are useful in foregrounding equity and power, providing a normative framework for what sustainable outcomes look like and can be measured. However, climate actions are poorly defined and a critical question is *how* sustainable development takes place and what transformative actions come about.

There is *robust evidence* and *high agreement* that equity contributes to resilience at a community level (Rodina et al., 2017). Health and education, as well as political, social and cultural capital, have been emphasised as pathways for social equity (Islam et al., 2017; Cafer et al., 2019). Equity issues are, however, insufficiently addressed in most climate change policies and interventions (Anguelovski et al., 2016; Meerow et al., 2019). Failure to incorporate social equity into efforts to support community resilience have been found to hamper long term resilience and achievement of sustainable development, improvements in well-being, and outcomes that 'leave no one behind', as observed for the case of Vanuatu and Solomon Islands (Trundle, 2020), Malawi (Wood et al., 2017) and Sri Lanka (Hewawasam and Matsui, 2020). Yet, as highlighted by McOmber (2019), paying attention to equity issues in the technical design and implementation of project activities is not enough – social norms and power relations within households and communities that produce inequity also needs to be recognized and addressed. Climate interventions such as climate smart agriculture that do not explicitly target underlying causes of inequity, such as within local decision-making and land access, have reduced smallholder resilience (Clay et al., 2018) negatively impacting *distributive equity* by transferring the burden of responsibility for mitigation to marginalized farmers, undermining *procedural equity* by failing to confront entrenched power relations that constrain pro-poor forms of adaptation, and hindering *recognition*, negatively impacting the bargaining power of the most vulnerable groups (Karlsson et al., 2020). Where interventions require a certain degree of pre-existing resources, skills and knowledges to gain access to project benefits, they risk perpetuating inequities in the community (Hewawasam and Matsui, 2020). This is clearly exemplified by a case of a climate compatible development project in Malawi where people were required to build corrals first to demonstrate their capability of keeping livestock in order to be considered eligible for support (Wood et al., 2017). The poorest people did not, have resources to do this at all, or to do it well, and were therefore left out of the project (Wood, 2017).

Inclusion – and recognition of the uneven power relations through which exclusion and socio-political inequity is produced – are highlighted as important in building social equity and reducing vulnerability (Forsyth, 2018; Mikulewicz and Taylor, 2020; Eriksen et al., submitted). Hazards have differential impacts on various assets and segments of community populations, hence acknowledging and including nondominant voices, recognising and incorporating alternative knowledges and re-organising institutionalized systems that disenfranchise non-dominant groups are important in order to build resilience (Cafer et al., 2019: 201). Inclusive development is fundamental to the 2030 Agenda, as recognized for example in SDG 1 (End poverty in all its forms everywhere) and SDG 5 (Achieve gender equality and empower all women and girls). A key issue for inclusion is the extent to which it gives authority to make decisions regarding development, rather than mere increased responsibility for implementing development designed by others (Bradshaw, 2019; Eriksen et al., 2019). Particular knowledges lead to particular types of actions, and determine who is included and who is excluded (Brooks et al., 2014; Morchain et al., 2015; Termeer et al., 2017)(Kaika 2017)(Nagoda and Nightingale, 2017; Nightingale et al., 2020; Omukuti, 2020).

Both development and CRDPs emerge from the interplay between cognitive-rational knowledges/techno-managerial decisions and evolving choices, strategies, and actions at scales from the individual to the society as well as multiple and contested knowledges (Ireland, 2012; Ludi et al., 2014; 2014)(Karlsson et al, 2017)(Hulme, 2018; Heinrichs, 2020; Nightingale et al., 2020). Inclusion forefronts questions of what types of resilience, for whom, and the role of power asymmetries (Szaboova et al., 2018; Taylor and Bhasme, 2020). Resilience can be a goal towards which socio-ecologies are managed by powerful actors, thus rendering inequitable and unsustainable systems durable in the face of challenges and pressures (Carr, 2019).

Sustainability science and political economy increasingly highlight the ethics underpinning development logics and sustainability actions. The ethical underpinnings of capitalist development pathways have been characterized as contradictory in its severe and inequitable impacts on the planet and human well-being 'as capital transforms life-worlds according to a commodity logic reaching into micro-practices of everyday existence' (Gill and Benatar, 2020: 168). In order to generate just and resilient societies in the face of the urgent and complex crises of today, solidarity and compassion are critical components of strategic action based on individual and collective wisdom, rather than techno-rational knowledge (Woiwode, 2020). Framings of the intrinsic and relational value of nature see human and planetary health and well-being are intrinsically linked (West et al., 2018; Stålhammar and Thorén, 2019). Relational ways of being, knowing and acting in relation to other human and non-human beings have been found to inspire stewardship, empathy, and care underpinning sustainability actions (Brown et al., 2019; Walsh et al., 2020). An ethics of planetary care is seen by some as in contradiction with the ethic of individualism underpinning neoliberalism, and valuing 'being' over 'having' and well-being over consumption as an alternative development paradigm (Fernandez and Ahmed, 2019).

Individual and collective values and behaviours and a fairer balance of power - i.e., individual and collective ethics as well as social equity and justice – can be seen as pervasive to enabling conditions for CRD. These qualities are located within several arenas of engagement and development including the socio-ethical (from inequity and alienation to solidarity and equity), political (from inclusion to exclusion and domination), ecological (from planetary health to warming and degradation), economic (from fossil fuel based growth to alternative development models like de-growth or blue-green growth, or well-being based development), knowledge-technology (from singular and human-nature dual understandings to plural knowledges and socio-ecology) (Section 18.5).

The CRD quest to pursue sustainable development involves development pathways towards particular aspirational outcomes. The SDGs signify short-term development goals (2030), but also serve as a globally agreed normative direction for longer term sustainable development in 2100 and beyond.

18.2.2.1 Gaps in the framing and implementation of Sustainable Development

While the broad and inclusive nature of sustainable development provides opportunities for dialogue and stakeholder engagement in policy making and implementation, it also poses several challenges for implementation (Redclift, 2005; Jordan, 2008). Some of these challenges emerge from the ways in which sustainable development has been framed. For example, while most approaches to sustainable development consider issues of intergenerational equity, fewer have taken up the Brundtland Report's concern for intragenerational equity on the way to sustainability goals. This gap is particularly critical at a time when trends are toward increasing inequality within countries and only a very limited convergence in incomes and other markers of human well-being among countries (Bangura, 2019). Further, sustainable development continues to be framed around economic growth as the central means to the improvement of human well-being (as noted in 18.2.2). Increasingly, current models of economic growth are seen not only as sources of sustainability challenges, but also as sources of the very development challenges that sustainable development is meant to address (Adelman, 2018). Efforts to understand and approach improvements in human well-being beyond measures of income, whether individual or in terms of the national economy, open pathways to the wider construction of economic costs and benefits of actions and impacts.

While the SDGs represent an effort to link approaches to human well-being and planetary health in a single framework, building on several of the approaches described above, policymakers and practitioners can adopt any of these broad approaches to framing and measurement as a basis for action and label it sustainable development. However, not all of the approaches described above are commensurable. This creates significant challenges for sustainable development, as often structural, socio-economic and political processes collide with an array of interests mobilising aspects of this conceptual flexibility in the contested domain of policymaking. However, from these challenges might come opportunities. Some argue that the ambiguity of sustainable development can strengthen planning, as ambiguity leaves space for deliberation as a shared territory (Evans and Jones, 2008). Others see the quest to define sustainable development as a struggle to learn more, to learn better, and to learn in a more contextualized fashion as part of our lived experience (Holden, 2006).

The framing of sustainable development shapes how it is measured, and therefore measurement of progress toward goals will not, by itself, resolve the conceptual contradictions outlined above. Further, the complexity associated with the rigorous measurement and attribution of change to SD actions complicates our understanding of progress toward sustainable development. While an SDG Index and Dashboards was developed by the Bertelsmann Stiftung and the Sustainable Development Solutions Network in July 2016 to assist countries in measuring their SDG baselines and future progress, issues such as persistent and growing inequality (Alvaredo et al., 2017; Chen et al., 2018; Haider et al., 2018; Chakravarty, 2019) within and across regions, which has been a feature of development in the last century, complicate the attribution of success or failure. The rapid changes in economic, ecological and social contexts at the sub-national levels, now further compounded by the differential impacts of COVID-19, add further complexity to the measurement of progress towards the SDGs. Further, the assessment and reporting on progress from a national government perspective, and that from a local, household or community perspective could be very different, raising questions about how different stakeholders' perspectives are balanced (Diaz-Sarachaga et al., 2018). The inter-linkages between the different framings of sustainability and different means of measurement inhibit the development of shared theories of change that might achieve specific goals, limiting coherent progress reports on SDGs.

18.2.2.2 The Sustainable Development Goals-Climate Resilient Development relationship

The SDGs present a 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., 2018; Roy et al., 2018; P.R. Shukla E. Calvo Buendia, 2019). However, achieving these goals requires negotiating synergies and trade-offs between socioeconomic development and responses to climate change (Altieri et al., 2016; Santika et al., 2019).

The interdependence of development patterns, climate risk, and demand for mitigation and adaptation actions is fundamental to the concept of climate-resilient development (Fankhauser and McDermott, 2016). The achievement of sustainable development requires CRD actions, as the impacts of climate change will exacerbate existing development challenges in regions where people face high levels of poverty and vulnerability to climate hazards (IPCC, 2014a; Hallegatte et al., 2019).

Addressing development and sustainability challenges through CRD requires negotiating trade-offs. Both the SR1.5 report and other literature have identified trade-offs between aggressive mitigation and the SDGs, suggesting the need to balance climate action and sustainable development. The arenas of negotiation, however, tend to reproduce processes that lead to the same problems that were to be addressed in the first place. For example, improving (i) the science-policy interface, (ii) the policy-legal interface, and (iii) institutional linkages (Yamineva and Liu, 2019) are often mentioned as solutions that can contribute to better governance and institutional capacities (de Coninck et al., 2018), thus addressing the impacts of climate change, climate justice and climate governance. However, under the current development paradigm, the workings of these arenas of engagement yield technical interventions that reproduce problematic framings of the relationship between nature and society (including economic activities) that are at the heart of the challenges to human well-being and planetary health that sustainable development is meant to address (Nightingale Böhler, 2019). Such interventions obscure complex realities that challenge established forms of governance and social structures and might open alternative framings of paths to sustainable development. A polycentric approach to climate governance could provide the best opportunity to accelerate progress towards global climate stabilisation by providing more frequent and varied opportunities for major sending parties to engage in face-to-face communications on a bilateral and multilateral basis (Cole, 2015; Jordan et al., 2015; Carlisle and Gruby, 2019).

SDGs represent many aspects of CRD outcomes in the short term within the socio-ethical, political, economic, ecological and knowledge-technology arenas, and indicate some important qualities of development processes within these arenas, such as through gender equality, responsible consumption, poverty eradication etc. Hence, SDG achievement is important to shifting pathways towards CRD, not least because SDG achievement by 2030 requires transformative action quickly, but are not sufficient to ensure that key qualities of development processes within the socio-ethical, political, ecological, economic and knowledge-technology arenas are shifted in the long term (for example towards actions characterized by equity, solidarity, human well-being, social justice, inclusion, planetary health, plural knowledges and alternative development discourses).

18.2.3 The Adaptation-Sustainable Development Nexus

Past IPCC reports have highlighted the close link between adaptation and sustainable development (Smit et al., 2001; Denton et al., 2014; Adger et al., 2017; Roy et al., 2018). Building on 18.2.2, this section presents understandings of sustainable development, the SDGs and adaptation with specific reference to CRD.

18.2.3.1 Alignment of Climate Adaptation and Climate Resilient Development

The SR1.5 says that climate resilient development pathways require system transitions and transformations, in addition to adaptation, mitigation and resilience measures. Adaptation, resilience and transformation are all related concepts with overlapping definitions in the literature (see Chapter 1). Adaptation can include incremental approaches that maintain the essence and integrity of a system or process at a given scale, or transformational adaptation, that changes the fundamental attributes of a socio-ecological system in anticipation of climate change and its impacts (AR6 Glossary). Adaptation represents one form of a suite of actions required to pursue climate resilient development, with actors involved in adaptation interacting with other actors through uneven relations, contestations, negotiation and resistance to shape development directions (Taylor, 2014; Mosberg et al., 2017; Harris et al., 2018; Schipper et al., 2020a). A key question is the extent to which, and how, adaptation can support CRD, in particular shift current development pathways towards achieving system transitions, social justice and equity, and hence help pursue sustainable development outcomes in the short and long term.

There is increasing global funding being channelled into formal climate change adaptation efforts. At the same time, adaptation forms part of everyday actions and processes to manage climate and other socio-environmental changes by multiple actors (see Chapter 17). Thus, adaptation actions and processes are nested in broader socio-political processes of societal development (Nightingale, 2017; Paprocki, 2018). Of particular relevance to CRD is the ways in which adaptation interacts with other formal and informal actions and activities to shape the quality of development processes within the socio-ethical, political, ecological, economic and knowledge-technology arenas (see Section 18.5). Growing evidence suggests that many adaptation-labelled strategies may exacerbate existing poverty and vulnerability or introduce new inequalities, e.g., by affecting certain disadvantaged groups more than others, even to the point of protecting the wealthy elite at the expense of the most vulnerable, thereby compounding the problems they sought to alleviate (Sovacool et al., 2015; Mikulewicz, 2019; Nightingale Böhler, 2019; Work et al., 2019; Eriksen et al., submitted).

Climate adaptation can form part of CRD actions and processes, but has also been found to undermine CRD (see Section 18.4.4.1). The ability of adaptation to support CRD depends on the quality of engagement within the five arenas noted above, such as how adaptation actions engage personal and collective ethics critical to sustainable development processes. Such engagement steers actions from polarisation to solidarity, exclusion to justice, empathy walls to care, rational-instrumental efficiency/consumption to compassion (Ziervogel et al., 2017; Matin et al., 2018; Brown et al., 2019; Thomas and Warner, 2019; Bond and Barth, 2020). Some climate change studies treat adaptive capacity and resilience as idiosyncratic qualities of particular places or communities. A political economy or ecology approach sees resilience as produced by uneven relations of production and development (e.g., Carr, 2019; Carr, 2020). In this case, CRD is a societal quality enacted through collective and cross-scalar processes rather than a set of identified 'good' discrete adaptation choices and actions (Atteridge and Remling, 2018; Mikulewicz, 2019; Werners et al., submitted).

Several studies question evidence-based policymaking as a framing of development and climate responses, in particular due to its lack of ethical underpinnings and a persistent ignoring of the uneven power relations and turbulent non-linear transformation (Nightingale et al., 2020; Schipper et al., 2020a). A paradigm shift may be required from the knowledge production and development discourses that the IPCC forms part (see Cross-Chapter Box INDIG).

[PLACEHOLDER FOR FINAL DRAFT: This chapter synthesizes and assess content still being developed in WGI, WGII, and WGIII. The content here will evolve with their content and coordination discussions with our chapter on our assessment insights to ensure consistency. This includes tables and figures that will be developed with the next iteration of cross-WG data. For now, placeholders are included that describe planned content.]

Table 18.1: CRD processes, outcomes, actions and risks [PLACEHOLDER FOR FINAL DRAFT: to be updated based on information from chapters]

Arena of engagement/ development	**Key qualities of CRD processes**	**CRD outcomes and conditions**	**Risks to CRD processes and outcomes**	**Forms of action and engagement (from Sections 18.4, 18.5 and AR6 WGII chapters)**	**Leverage points for transformation (from Sections 18.2, 18.3 and WGII AR6 chapters)**
Political Social justice, agency	Socially just access to health care and education, resource rights, empowerment in development decisions, Agency (Chapter 7)	Socio-political equality (e.g., gender, ethnicity), governance systems, poverty reduction (Chapter 7, Chapter 17, WGIII AR6 Chapters 13 & 14, SDG3, SDG5, SDG16)	Inequities reinforced by climate impacts and adaptation and mitigation actions. Discrimination, resource and land dispossession. Authoritarianism and polarisation, conflict	Public deliberation, inclusive adaptation and mitigation processes, integration of rights (e.g., health care, education, rights of people with disabilities), improved governance	Shift power relations and rules of the system: Give space for civil society mobilisation, e.g., give grassroots the power to meaningfully influence global negotiations. Foster dialogue across social divides to aid reconciliation and justice
Socio-ethical Well-being, equity, solidarity	Connectivity to self, others and nature, self-efficacy, solidarity, promoting health (Chapter 7)	Co-benefits for health and well-being of reduced pollution and system transitions (Chapter 7, WGIII AR6 Chapters 2 & 5, SDG1, SDG2, SDG3, SDG10, SDG12, SDG13)	Climate change impacts on health, exacerbating social inequalities Loss of ecosystems, sense of belonging, identity and well-being (Chapter 7) Loss of access to education due to climate and other shocks (e.g., COVID-19), increasing long term social inequalities	Increase public health expenditure, especially for deprived groups Strengthen rights to health services Evaluate practices and systems to reduce climate change emissions in public sectors, such as infrastructure, health sector (Chapter 7, WGIII AR6 Chapters 2 & 5)	Shift mindsets and power relations: Define CRD from the perspective of the most vulnerable. Give self-organized associations at the local level, e.g., agricultural or fishermen’s organisations, decision-making authority to design transformative pathways
Ecological Planetary health	Low emission, environmental stewardship	Paris Agreement target reached, ecosystem integrity, Water (Chapter 2, Chapter 4, SDG6), Oceans (Chapter 3, SDG14), Industry (WGIII AR6 Chapter 11, SDG9) Agri, forestry and land use (Chapter 2, Chapter 5, WGIII AR6 Chapter 7, SDG2, SDG16)	Impacts on socio-environmental systems of economic development, climate change, ecological tipping points	Civil society mobilisation and dissent, community and city level actions, environmental regulations, youth activism, shift in food systems	Shifting mindsets: Build climate action on ethics such as compassion and stewardship, emphasise relational and intrinsic (rather than instrumental) values of nature
Knowledge-technology Plural knowledges, nature-society connectivity	Innovation, creativity, recognition of multiple forms of knowing and inner world dimensions, shifts in paradigms and mindsets	SDG4, SDG9, Energy (Chapter 6, SDG7)	Domination of techno-managerial approaches reinforcing unsustainable development, loss of local knowledge due to climate change and societal change	Socio-physical spaces for sustainability cultures, participatory forms of planning, art, sustainability education, self-reflection	Shifting mindsets and paradigms: Redefining our place in humanity, and human-nature relations as entangled, socio-nature
Economic De-growth, alternative development models	Shift to well-being based and inclusive development models and metrics	Sustainable consumption, economic equality, reduced poverty Economy (WGIII AR6 Chapter 15, SDG1, SDG8	Effects of climate change on livelihoods. Resistance from dominant economic interests	Community and city level alternative development models, (Chapter 6, WGIII AR6 Chapters 8 & 9, SDG11)	Shifting goals of the system: Redefining national development metrics from GDP to justice, equity, dignity and well-being

18.2.3.2 Synergies and Trade-offs between Development and Adaptation: implications for CRD

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 (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 (Roy et al., 2018; Van Vuuren et al., 2019), particularly if longer time-horizons are used. These pathways require progress on multiple social, economic, technological, and governance aspects of development including building human capacity, managing consumption behaviour, decarbonisation of the global economy, improving food and water security, modernising cities and infrastructure, and innovations in science and technology (Van Vuuren et al., 2019). In addition, Olsson et al, (Olsson et al., 2014) and Roy et al, (Roy et al., 2018) emphasise 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 praxis and a lack of conceptual clarity about adaptation pose a conundrum for critical scholars (e.g., Bassett and Fogelman, 2013; Webber, 2016), who raise concerns that this leads to trade-offs (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 captured in an effort to use one of the SSPs to project progress on SDGs by 2030 (Moyer and Bohl, 2019), 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.). 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; Magnan et al., 2016)(Juhola et al, 2015)(Antwi-Agyei et al., 2017; Schipper et al., 2020a). 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.).

18.3 Evidence of Climate Resilient Development

[PLACEHOLDER FOR FINAL DRAFT: This section synthesizes and assess content still being developed in WGI, WGII, and WGIII. As such, the content here will evolve with their content and coordination discussions with our chapter on our assessment insights to ensure consistency. This includes tables and figures that will be developed with the next iteration of cross-WG data. For now, placeholders are included that describe the planned content.]

This section presents evidence on CRD from post-AR5 literature, starting with the AR6 Special Reports and key chapters of the AR6 assessment. It does this via a system transitions framing drawing on evidence from sectoral and regional chapters (Chapters 2 to 15) [PLACEHOLDER FOR FINAL DRAFT: to be completed after all relevant chapters are available], an understanding of ways forward for CRD (Section 18.1) and development-mitigation-adaptation nexus that helps define possible future directions (Section 18.2).

18.3.1 System Transitions

In 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" (Section 1.5), drawing on a common definition shared with the Special Reports (IPCC, 2018a; IPCC, 2019a). In the climate action solution space, system transitions provide a link between mitigation and adaptation options and actions, that often function simultaneously with synergies and trade-offs, to constrain, accelerate and deepen these transitions.

This is linked to system transformation defined as "a change in the fundamental attributes of a system including altered goals or values" (Section 1.5; (IPCC, 2018a) that could progress along a range of potential pathways, depending on whether: current climate goals are achievable within the current solution space; residual risk is tolerable; or deliberate transformational adaptation is necessary (Figure 18.5). As indicated in Box 18.1, there is a nexus between transitions and transformation (Hölscher et al., 2018). 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.' System transitions are therefore necessary conditions for climate and sustainable-development transformations to take place (Section 1.5).

SR1.5C identified rapid and far-reaching transitions in four systems: energy, land and terrestrial ecosystems, urban and infrastructure and industrial systems, as necessary to enable pathways to limit global warming to 1.5°C (Sections 1.5.1 and 18.1; (IPCC, 2018a; IPCC, 2018b). The was deepened for terrestrial systems in SRCCL, while SROCC added additional evidence from ocean and cryosphere systems.

This section assesses five main system transitions: energy; urban and infrastructure; land, oceans, and ecosystems; industrial and societal. Evidence on this comes from AR6 regional and sectoral chapters that focus on already occurring transitions and transformations that need to happen. Chapter 2 on terrestrial and freshwater ecosystems assesses land use transitions and risks with impacts that span energy, land and urban systems, and interactions with mitigation (BECCS and bioenergy) with the goal to achieve food security. Chapter 3 assesses ocean ecosystems with impacts on energy systems through ocean and wave energy generation. Chapter 5 deals with food system transitions focussed on production system transitions in agriculture and livelihoods and agroforestry.

Chapter 6 describes transformative changes in urban and infrastructural systems, and the potential of going from strengthening adaptive capacity to building transformative capacity. This chapter explores the alignment between urban systems and their transitions, and the impact of disruptions in one on others, which can assist in better defining climate resilient development pathways for cities and urban areas (Section 6.4.3.1.4). Chapter 7 calls for a transformation in health systems and in society, based on representative key risks.

Within the regional chapters, Chapters 10 (Asia) and 11 (Australasia) group adaptation needs and options by systems transitions while Chapter 12 (Central and South America) does so by sectors and risk. Chapter 13 (Europe), 14 (North America) and 15 (Small islands) analyse risks and adaptation needs by system transformation type. Chapters which use RKR's as an organising frame, largely undertake an assessment of urban and infrastructure transitions; and land, oceans, and ecosystems system transitions; and to a lesser degree the energy and societal transitions.

18.3.1.1 Energy Systems

Recent observed changes in energy systems include global growth in energy demand, led by increased demand for electricity by industry and buildings and increased demand for products and services (WGIII AR6 Chapter 2). Improvements in energy efficiency reported in industry, buildings, and transportation moderated energy demand growth. 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. 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.

Sustainable development factors such as energy access, energy security, air pollution, and economic growth continue to be the dominant influence on energy system decision making and the energy system's evolution (WGIII AR6 Chapter 6). Climate policy to date has been less influential, but many sustainable development priorities have climate mitigation benefits, 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 (de Coninck et al., 2018). Alternatively, sustainable development projects can 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 natural gas.

In addition to sustainable development objectives shaping observed changes in energy systems, observed energy system trends have implications for sustainable development, environmentally and socially (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, there has been significant growth in natural gas as they shift away from fuel oil and before implementing large scale renewable energy systems. Similarly, for energy access in developing countries, renewable energy or hybrid distributed generation systems are increasingly prioritised due to difficulty in access, costs and environmental concerns.

Historically, energy systems (supply and demand) are regularly exposed to changing weather and extremes and these factors are incorporated to some extent 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 changes in climate or anthropogenic climate change (WGI AR6; (USGCRP, 2017). Similarly, most observed energy system changes have been demonstrated to be correlated with weather events but have not been attributed with confidence to longer-term changes in climate or to anthropogenic climate change (Chapter 16). Nonetheless, changes in weather and extremes have had energy service and economic implications. The exposure of people and assets to these hazards has generally increased, especially due to population, economic, and energy demand growth, although with significant differences between locations and systems (Chapter 16 and WGII AR6 sector and region chapters).

Overall, there is limited historical evidence on the efficacy of adaptation responses in reducing vulnerability of energy systems. 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.

It is difficult to identify the impacts of past climate-related mitigation policies on sustainable development in a specific region or sector as literature is limited (WGIII AR6 Chapter 2). Nonetheless, the available literature agrees that emissions reductions have taken place in response to policy, and policies with stronger incentives 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, as noted above, sustainable development factors continue to be the dominant influence in recent energy system changes (WGIII AR6 Chapter 6).

18.3.1.2 Urban and infrastructure systems

Using a social-ecological resilience framework to assess climate risks is well suited to addressing the dynamic needs of urban areas. This may complement engineering resilience needed for the physical, infrastructural elements (Davidson et al., 2019).

Buildings are increasingly exposed to higher climate stresses and more frequent co-occurrences of climate shocks. Climate-smart design tools to address this can provide long-term strategic benefit to cities. Urban heat island (UHI) effects, can be limited through spatial planning, including the strategic use of green space. Architectural protocols and district-planning paradigms encourage patterns of resource use and community dynamics that increase resilience to the impacts of climate change (Venema and Temmer, 2017b).

A warming and more variable climate stresses electricity grids by increasing cooling demand requirements and by its exposure to climate shocks such as droughts, hurricanes and cyclones and tornados. Renewable energy generation and storage technologies are modular, distributed, and provide resilience to climate impact (Venema and Temmer, 2017a).

ICT, is modular and aids decentralisation that enables high climate resilience. Redundant landlines, Internet service provider diversity, emergency roaming and cell phone micro-charging backup systems increase ICT climate resilience. (Venema and Temmer, 2017a)

Building and maintaining urban water systems that are resilient to climate shocks requires "multiple barriers, that strengthen all infrastructure components. 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 provide greater resilience than most centralized systems (Parry, 2017). Water conservation and green infrastructure options for stormwater management are proven approaches for reducing climate risks (Venema and Temmer, 2017c) Green infrastructure can have adaptation and mitigation co-benefits. 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).

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); WGIII AR6 Chapter 8).

Ecosystems and green infrastructure provide human health benefits and critical environmental, social and economic services, and protect against climate shock and enhance the implementation of the SDGs. Healthy and well-managed ecosystems are economic assets that enhance a city's resilience to natural disturbances and extreme weather events. 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). Cities are often cases of ecosystem fragmentation and degradation, but can concentrate biodiversity more favourably than other landscapes (IPBES, 2019); WGIII AR6 Chapter 8).

Urban agriculture, enables citizens to fulfil some of their food needs, improving urban resilience to food shortages and increasing coping capacity during disasters (Demuzere et al., 2014);WGIII AR6 Chapter 8). Strengthening local food systems increases resilience to supply shocks from climate change impacts. Small-scale food production and processing can bolster food security and provide employment, strengthening local food systems and community cohesion (Temmer, 2017a).

Strategic investments in disaster risk reduction, including climate-resilient green infrastructure and updated building codes, provide significant long-term cost savings and social benefits. Continuous outreach and engagement processes can ensure that citizens prepare for and can respond to climate-related disasters (Temmer, 2017b).

18.3.1.3 Land, Oceans, and Ecosystems

Land, oceans, and terrestrial ecosystems are in transition across the globe. Anthropogenic factors have been a major driving force behind land use and land cover changes. Climate change has impacted marine ecosystems and caused changes in provisioning, regulating and supportive ecosystem services. Seventy-five per cent of the land surface is 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 ecosystem services assessed have improved functioning: agricultural production, fish harvest, bioenergy production and material harvests. The other 14 ecosystem services, mostly regulating and non-material, have declined (IPBES, 2019), making the imperative for land, oceans and ecosystems transitions in multiple reasons clear.

Yet, there are a few recorded initiatives that have successfully promoted and improved natural climate resilience. There is still limited evidence of planned adaptation contributing to CRD for terrestrial, ocean and coastal ecosystems. Some pilot projects with the potential to build climate resilience have been initiated, but it is necessary scale and monitor them before further inferences can be drawn. 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 to 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.

A number of regional examples are reported, where the use of land to produce biofuels could increase the resilience of production systems and address mitigation needs. Nevertheless, the potential of BECCS to induce maladaptation needs deeper analysis (Hoegh-Guldberg et al., 2019). Climate Smart Forestry 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).

Effective, land-based solutions that can combat desertification are site and regional specific: water harvesting and micro-irrigation, restoring degraded lands using drought-resilient ecologically appropriate plants, agroforestry, and other agroecological and ecosystem-based adaptation practices (IPCC, 2019c, B.4.1), 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, 2019c, B.4.2).

Diversification of food systems can enable a transition to 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.

Appropriate design of policies, institutions and governance systems at all scales can contribute to land-related adaptation and mitigation while facilitating the pursuit of climate-adaptive development pathways. 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, 2019c, C.1).

A range of nature-based solutions are assisting in protecting existing terrestrial and freshwater ecosystems, restoring degraded ones and building resilience. Indigenous and local community knowledge is important to enable this. Terrestrial ecosystem-based adaptation (EbA) e.g., using natural flood management, and restoring natural fire regimes, and local vegetation-based cooling show potential to enable adaptation support to CRD (Mainali et al., 2020).

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)

Many frameworks for climate resilient coastal adaptation have been developed since 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, 2019d). 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, that 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, 2019d).

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, 2019d).

The Global Commission on Adaptation (GCA, 2019b) estimates that investing US$ 1.8 trillion between 2020 to 2030 in five areas: early warning systems, climate-resilient infrastructure, dryland agriculture crop production, global mangrove conservation and making water resources more resilient can generate net benefits of US$ 7.1 trillion, i.e., a benefit-cost ratio of over 3.9 (GCA, 2019a) pointing towards potential CRDPs.

Ongoing initiatives to promote and improve observed terrestrial, ocean and coastal ecosystems transitions, need deeper analysis. There is limited current concrete evidence of these adaptation initiatives contributing to CRD. Some pilot projects have potential to support CRD, but need further monitoring and scale-up.

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) (*high confidence*). 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 the trend (ibid). This requires an effective transition of the industrial system.

Recent modellings suggest that per capita material stocks stabilise in developed countries and decouple from GDP (*high confidence*, *medium evidence*). For instance, Bleischwitz (Bleischwitz et al., 2018) confirmed the occurrence of a saturation effect for materials in four energy-intensive sectors (steel, cement, aluminium 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.

Technologies exist to bring all sectors to very low or zero emissions, but they require 5 to 15 years of innovation, commercialisation, and intensive policies to ensure uptake (Åhman et al., 2017) (*high confidence*, *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 hlsarna process (Quader et al., 2016).

A combined measures of i) dematerialisation and ii) decarbonisation measures; iii) governance, policies and regulations (transnational governance, technology push, market attraction, carbon price and carbon market, and technology transfer from developed to developing countries); and iv) systemic corporate strategies (regenerative and conscious capitalism, and market transformation strategy) are required for the effective transition of the industrial system (Singh and Chudasama, submitted) (Figure 18.1).

Although sustainable consumption at the consumer level can play a very important role in sustainable production (Allwood et al., 2013; Allwood et al., 2019), even sustainable production could lead to sustainable consumption, as promotional campaigns play a crucial role in the modification of consumer behaviour (Singh and Chudasama, submitted).

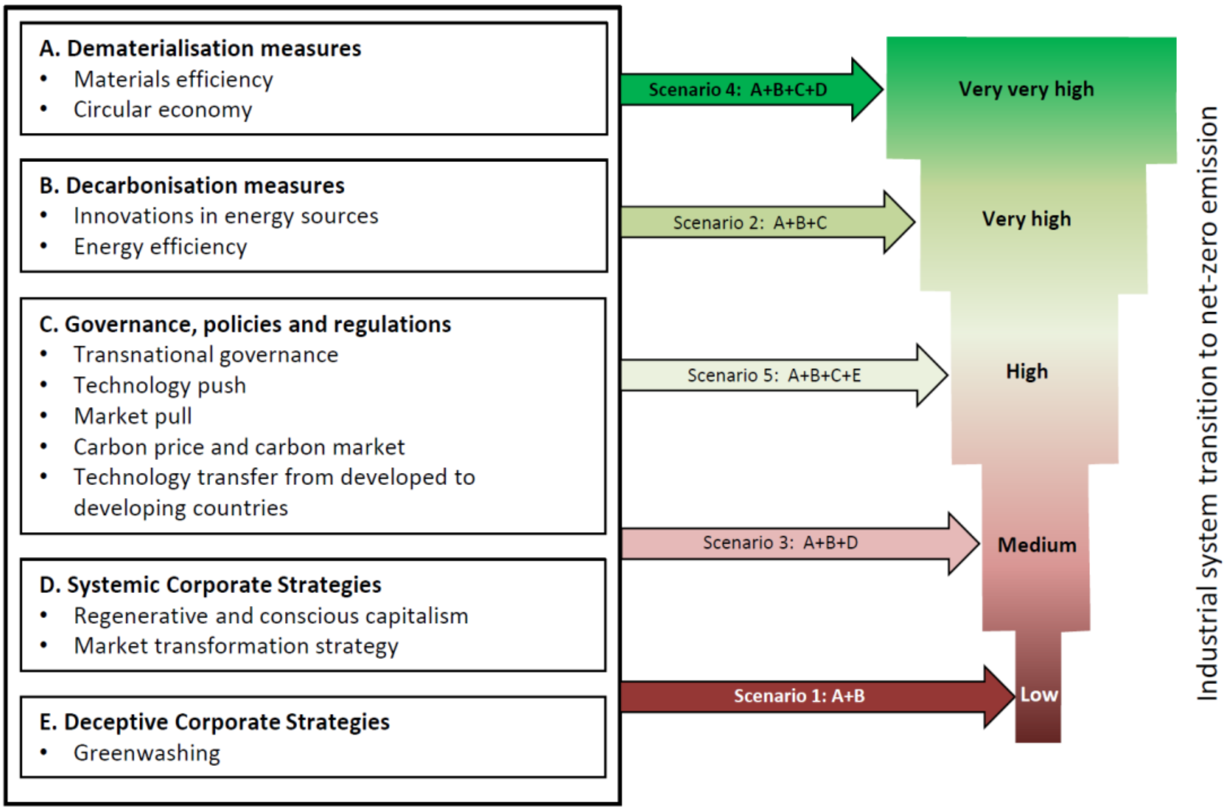

Figure 18.1: Pathways for industrial system transition to net-zero emission. Source: Adapted from Singh and Chudasama, in review (Singh and Chudasama, submitted)

18.3.1.5 Societal systems

Societal transitions, understood broadly as the collection of shifts in attitudes, values, consciousness and behaviour required to move toward climate resilient development (Section 18.1.3.7) appears explicitly in Chapter 3 on Ocean and Coastal Ecosystems and their Services, Chapter 4 on Water, and in Chapter 6 on

Cities, Settlements and Key Infrastructure [[PLACEHOLDER FOR FINAL DRAFT: based on First Order Drafts and early versions of Second Order Drafts as available; to be updated].

Chapter 3 (Section 3.6.2) refers to how changes in climate risks influence timescales for planning, emphasising that assessments that can address changes over longer time scales are critical for planning societal transitions. They draw on fisheries as an example, where observational and modelling capacities are needed to plan both in the short and long-term and note the need for societal and political will to ensure that ecosystem-based management principles are adopted. They also underscore the importance of polycentric governance to facilitate a participatory interface between scientists, policymakers and practitioners to support transitions toward more climate resilient fisheries.

Chapter 4 (Section 4.3.2.2) discusses changes in water supply and temperature, and how this will adversely impact the potential of hydropower as a low-carbon energy solution. In the transition toward low-carbon energy, grid insecurity can create obstacles for the societal acceptability of hydropower. As for all energy-related transitions, the extent to which these shifts are equitable is a critical and uncertain dimension. Yet energy security, which is both gendered and inequitable, is a component of societies willingness to transition and transform toward climate resilience.

Chapter 6 (Section 6.1.5) discusses societal transitions and transformation in a number of aspects of urbanisation, which highlight the complexity of urbanisation itself. It points to emerging civil society movements on climate justice as enablers of transitions and transformation in settlements.

[START CROSS-CHAPTER BOX GENDER HERE]

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

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Headline Statements

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

Long-term policy measures and investments, and equitable social rules are essential to address structural inequities and create an enabling environment for marginalised groups to effectively adapt to climate change (*very high confidence*)

Climate adaptation actions are more locally grounded so understanding links with SDG 5 becomes more important to make sure that adaptive actions are not worsening the already prevalent inequity in gender empowerment within the society. (e.g., leading to maladaptation practices) (*high confidence*). The assessment concluded with *high confidence* that any adaptation actions do not generate gender positive impacts automatically. They can have both positive and negative impacts unless the actions are designed to be sensitive to achieving adaptation and gender equity targets simultaneously.

There are few examples of successful integration of gender in climate policies that concurrently address climate change vulnerabilities and gender-based inequalities (*medium confidence*).

CCB GENDER.1 Gender, climate justice and climate change

A gender perspective does not centre only on women or men but examines structures and relationships of power between and among groups of men and women and also how being a man or woman intersects with other dimensions of power such as race, class, nationality, education. A gender and especially a feminist approach aim to shift and transform structural inequalities. Attention to gender is thus central to questions of climate justice that aims for a radically different future, encompassing a just and flourishing world (Bhavnani et al., 2019: 2). As a normative concept highlighting the unequal distribution of climate change impacts and opportunities for adaptation and mitigation, climate justice 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, 2019).

Evidence on gender and climate change demonstrates that gender relations mediate experiences of climate change, whether in relation to water (Köhler et al., 2019, Section 16.5.2.3.8), forests; (Arora, 2019), agriculture (Carr and Thompson, 2014), marine systems (Mcleod et al., 2018) or urban environments (Reckien et al., 2018). Women represent 43% of the agricultural labour force globally, but only 15% of agricultural landholders (OECD, 2019). Such inequities exist in relation to non-land assets, financial services (ibid.) and especially in the global South, often due to inadequate social protection and local institutions that do not create space for a fair access to production resources to all social groups (Collins et al., 2019b). Participation in environmental decision-making tends to favour certain social groups of men, whether in local environmental committees (Arora-Jonsson, 2011), international climate negotiations (Gay-Antaki and Liverman, 2018) or the IPCC (Nhamo and Nhamo, 2018). Climate change has direct negative impacts on women's livelihoods due to unequal access to resources and because they are often the ones with the least formal protection (Eastin, 2018). These impacts can lead to irreversible losses and damages from climate change across vulnerability hotspots (Section 8.3).

This Cross-Chapter Box sheds light on the intersecting issues of gender, climate justice and transformative pathways and provides a synthesis of key issues, concerns, and a discussion of what appears to work in efforts towards sustainability and climate justice.

CCB GENDER.2 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. 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 and 4.6.3). Climate change is reducing the quantity and quality of safe water available around the world and increasing domestic water management responsibilities (*high confidence*) (Ana Paula Aguiar Avit Bhowmik et al., 2019). It is forcing, primarily women and girls, to walk longer distances to access water, and in turn 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 has resulted in psychosocial distress, gender-based violence, 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 4.6.3) (*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 in prevention of mother to child transmission regimens for HIV positive pregnant women (UNDRR, 2019, Section 7.2).

In food systems (Section 16.5.2.3.7), extreme events impact food prices, especially affecting vulnerable groups, including low-income urban consumers, wage labourers, and low-income rural households who are net food buyers, reducing food availability and quality (Green et al., 2013; FAO, 2016) (Section 16.5.2.3.7).

Low-income women, ethnic minorities and Indigenous communities, are often more vulnerable to food insecurity and malnutrition from climate change impacts, intersecting with other factors such as poverty, discrimination and marginalisation (Vinyeta et al., 2016; Clay et al., 2018) (Section 5.12). Increased domestic responsibilities of women and youth, especially with men-migration worsens their vulnerability (O'Neil et al., 2017) (Section 16.5.2.3.9) (*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. Climate programs in the global South such as REDD+ have led to greater tensions in gender relations, as the conservation of the forests have led to men losing their livelihoods with more pressure on women to contribute to household incomes through their work on agricultural plots (Arora-Jonsson, 2011). In countries in the global North, reduced harvestable wood and revenues have led to employment restructuring that has important gendered effects and negatively affect communities' possibilities to transition (Reed et al, 2014).

CCB GENDER.3 Integrating gender in climate policy and practice

Climate policies: Climate change policies and programs across regions reveal wide variation in the degree and approach to addressing gender inequity (see Table CCB GENDER.1).

Table CCB GENDER.1: Gender integration in regional climate change policies. Climate policies span from the gender-blind (implicitly male-biased, excluding women) to gender-transformative/ redistributive (interventions that intend to transform existing distribution of resources and responsibilities to create more equitable gender relations). Along this continuum, policies can also take varied approaches such as gender-neutral (leave existing distribution of resources/ responsibility unchanged or unquestioned), gender-specific (targeting needs of women/men, but within existing distribution of resources/responsibilities), and gender-sensitive (focusing on identifying and reconfiguring processes which shape gender relations).

Countries	**How is gender considered in climate policy?**	**Illustrative examples**	**Barriers to gender integration**
Central and South America			
Regional assessment of Central & South America	Gender-sensitive; gender-specific (varies by policy)	NDCs (Argentina, Brazil, Chile, Costa Rica, Paraguay and Uruguay) (Tramutola, 2019) National Plans and Programs of the IUCN and GGCA, (2011-2012) in Costa Rica and Panamá; MINAM y MIMP (2015), Perú PIAL y UICN, (2014), Cuba. International and Ibero-American Foundation of Administration and Public Policies (FIIAPP): Regional approach promoting learning and exchange of experiences between local actors and decision-makers in the 3 countries. Intersectoral coordination initiative Gender and Climate Change Action Plans (PAGcc), adopted in some Latin American and Caribbean countries (Casas Varez, 2017).	Insufficient commitment and capacities of actors involved; few relevant tools in both the design and implementation phases; scarce specialists, resources, disaggregated data, documented cases in the region added to the difficulty in generating significant indicators (Tramutola, 2019). Vulnerability and resilience of women are dependent on household income diversification (Andersen et al., 2017) and household type.
Nicaragua	Gender-specific	Nicaragua maintains gender parity in ministerial positions and has one of the world's highest shares of women in parliament (WEF, 2018)	The policy tends to instrumentalise women by appealing to their care work for the environment while power differentials remain (Ojha et al., submitted).
Cuba. Guatemala Ecuador Perú, Costa Rica, Panamá Colombia	Gender-specific	(Cuba) Gender-based research in an integrated coastal zone management program (Montero et al., 2015).	(Cuba) Gender inequality in the integrated coastal zone management program.
		(Guatemala) Gender environmental policy mainly linked to climate change adaptation. (Bárcenas et al, 2020.)	

		(Ecuador) *Sumak Kawsay* or Buen Vivir is a concept included in the Constitution of Ecuador in 2008 (Cáceres-Arteaga, et al, 2020). Food Security and Gender Considerations (FORECCSA) policy uses a bottom-up approach, managed through community-based adaptation (Bárcenas et al, 2020).	(Ecuador) Indigenous women remain invisible in land tenure discussions (Radcliffe, 2014)
		(Perú, Cuba, Costa Rica, Panamá) Intersectoral coordination initiative Gender and Climate Change Action Plans (PAGcc)	
Colombia, Ecuador, Perú Chile	Gender-sensitive	(Colombia, Ecuador, Perú) International and Ibero-American Foundation of Administration and Public Policies (FIIAPP): Regional Approach promoting learning and exchange of experiences between local actors and decision-makers in the 3 countries.	(Colombia, Ecuador, Perú) In some practical activities (home gardens, management of inorganic trash) there is an internal weakness of the organisational part when it comes to include other women. (Columbia and Chile) Discrimination in land tenure (Tafur et al., 2015).
North America			
USA	Gender-specific	Declaration for Climate, Justice and Peace, proposed by a movement Earth Democracy and a non-profit organisation Women's International League for Peace and Freedom (Price (Price, 2014).	Differentiated economic interest conflict with addressing climate change and gender gap (Tranter and Booth, 2015). Policies often have a homogenized cultural vision that erases Indigenous people's autonomy (Gay-Antaki, 2020) and fails to address intersection of race, ethnicity, and gender for vulnerability to climate change (Vinyeta et al., 2016).
Canada, Mexico	Gender-sensitive	(Canada) New Feminist International Assistance Policy aims to incorporate the empowerment of women and girls, including policies addressing climate change (WEDO, 2018) Relevance of gendered climate adaptation emphasising traditional food systems (WEDO, 2018; (Burch et al., 2014; Williams, 2018). (Mexico) Mexican Nationally Determined Contribution (NDC) states gender equality and human rights as cross-cutting principles both for mitigation and adaptation. Legal reforms on water management (Silva Rodríguez de San Miguel, 2018).	(Canada) Research to support gender sensitive policies (Natcher et al., 2020). Policies often have a homogenized cultural vision that erases Indigenous people's autonomy (Gay-Antaki, 2020) (Mexico) Discrimination in land tenure; gender division of labor; salary gap and barriers to job placement (Griffin, 2014), and the unequal distribution of benefits (Vázquez García, 2015).
Africa			
Africa regional assessment	Gender-specific/ gender-sensitive	Gender lens is rarely applied in national policies or programmes (e.g., Ethiopia's Climate Resilience Green Economy policy - (Mersha and van Laerhoven, 2019), beyond the initial consultation stage (Holvoet and Inberg, 2014). Some gender and climate change action strategies and/or plans in several countries, including Liberia, Mozambique, Tanzania and Zambia (Republic of Mozambique and IUCN, 2014; Republic of Zambia and IUCN, 2017).	Practical constrains such as lack of staff capacity on gender, and lack of funding to support gender integration in policy (Kristjanson et al., 2017); other forms of resistance which lead to inaction (Acosta et al, 2019); poor integration of women in decision-making processes. In Many African context, local institutions do not value a fair access to production resources, such as land and financial capital, which increase the vulnerability of marginalized groups, especially women under climate change conditions (Van Wijk et al., 2018; Edward, 2020)
Europe			

European Union Norway Russian Federation	Gender-neutral	There are no examples from National adaptation plans and strategies. The European Parliament Resolution of 20 April 2012 on Women and Climate Change did not result in specific policy measures. The gender-blind documents, produced mainly by the Commission and the Council, construct climate change as a problem of energy security, competitiveness or security threats (Gill, 2014)	European climate change adaptation strategies and national policies are generally weak on gender, LGBTQI, and other social equity issues (Allwood, 2017). The issue has not yet been considered as a high priority in Europe.
Asia			
India	Gender-sensitive	Recognition of gendered vulnerability and need for targeting women in NAPCC (Roy et al., 2018) gendered vulnerability is recognised across national and state climate action planning (Singh et al., submitted); Jafry, 2016). Skill enhancement programs in agriculture and fisheries to increase and diversify livelihood opportunities (Pillai et al., 2015; Stacey et al., 2019)	Underlying structural inequalities around workforce participation, inadequate diverse gender representation in decision-making bodies and processes. Women are less represented in local decision-making committees in almost all Asian countries. Organised community collectives such as women self-help groups have had a mixed experience in gaining rights and benefits for women with positive impacts such as improved incomes (Salas et al., 2017) and somewhat negative impacts on women's participation in local adaptation decisions (Singh, 2019).
Malaysia	Gender -specific	Engagement of civil society, especially youth, in the development of the 2050 National Transformation Plan, a policy planning document outlining economic, social and environmental targets (Susskind et al., 2020). NGO advocacy for climate change actions studied impacts on sexual and reproductive health and rights among indigenous communities (Penita & Arrow, 2015). The National Policy on Climate Change includes specific mention of women, children, youth, indigenous peoples and their communities, as "Major Groups" and "Stakeholders" in addressing climate change, with focus on effective participation (MNRE, 2010).	Despite national initiatives to increase women's participation in the workforce to provide them with social support (Lim, 2019) and to empower them (Baqutqyan, 2020), gender mainstreaming, in general, is hampered by lack of full comprehension of gender issues (Ismail & Zakuan, 2014).
Nepal	Gender sensitive	The NAPA and the CCADRMA recognise the gender differentiated impacts of climate change in agriculture (Khatri-Chhetri et l., 2019) Localised action for climate change adaptation and disaster risk reduction (Viz et al, 2018; Bhattarai et al, 2015; Ojha et al. 2016)	Continuing failure of development policy and practices to address structural inequalities such as land ownership and access to gender-sensitive agrobiodiversity management services and technologies and forests (Bhattarai et al. 2015, Khadka et al, 2014)
Small Island States			

Pacific Island Countries (eg: Fiji & Vanuatu)	Gender considerations included in National Climate Change and Disaster Risk Reduction policies and frameworks (Sawer, 2020 & Secretariat of the Pacific Community, 2015).	The inclusion of gender considerations strengthens national planning (International Federation of Red Cross and Red Crescent Societies, 2020 & Secretariat of the Pacific Community, 2015). Pacific island countries are beginning to integrate gender into their climate change initiatives using a toolkit designed to support climate change practitioners in the region to integrate gender into their programmes and projects. (South Pacific Regional Environment Program 2014).	Barriers include financing to implement gender considerations in national policies (Mcleod et al., 2018; Kleiber et al., 2019)
Australasia			
Australia	Across all levels of government, there is minimal consideration of gender in climate change policy that may increase vulnerability and social exclusion and affect adaptive capacity and resilience (Alston 2017). Scant attention to gender in policies for emergency management and disaster response.	National gender and emergency management guidelines were drafted in 2017 in Australia (Parkinson et al., 2017), but these have not been endorsed or adopted by any Australian government The only literature located on climate and gender in Australia examined the different effects of drought on rural men and women (Pearce et al., 2018).	Lack of consideration of gender may be partially due to lack of diverse gender representation in decision-making processes (Parkinson et al., 2017)
Aotearoa-New Zealand	Recent Government-commissioned climate change risk assessments explicitly identifies gender as one of the limiting factors for equitable resources in response to climate-related risks, including housing, employment, childcare and safety (MoE,2020).	New Zealand-based Pacific Islander women have already demonstrated leadership roles in mobilising to respond to climate-related disasters and collaborations on their ancestral islands, demonstrating their abilities and networks of use in climate change adaptation and planning (Masaki, 2015)	No action is yet released by the Government that details how vulnerability will be reduced (MoE, 2020). A lack of gender-responsive design and implementation overlooks the growing evidence of the gendered experience of the impacts and projected risks of climate change and disasters, as well as the gendered nature of emergency management, in Australasia. This research identified gendered impacts on physical and mental health (eg. (Zara et al., 2016), as well as gender-based violence (eg. (e.g., Parkinson et al., 2017); Rees and Wells 2020) and discrimination (eg. (e.g., Dominey-Howes et al., 2016; Gorman-Murray et al., 2017)

CCB GENDER.3.1 Potential for Change and Solutions

Social movements, researchers and feminist economists in particular have shown how, due to the sexual division of labour, care work carried out primarily by women subsidizes the global economy (e.g., Hirway, 2015), negatively affecting their lives but also the ability to work towards sustainable environmental governance and aspirations in the SDGs (e.g., Arora, 2019). The assessment has indicated that attention to the following has the potential to bring about change:

- Increased access to reproductive health and family planning services have significant health and well-being benefits for women and their children, including increased education, empowerment and economic status, which contributes to climate change resilience and to socio-economic development (Onarheim et al. 2016; Starbird et al. 2016; Hardee et al. 2018; Lopez-Carr and Ervin 2017) (Sections 7.4, 4.6.3 and 4.3.3.3) (*high confidence*).
- Women's self-help groups hold potential to enable better participation in local adaptation decision-making, especially when combined with strong leadership, community acceptance, and long-term economic sustainability (Chu, 2018; Mersha and van Laerhoven, 2019; Singh, 2019, Section 4.6.3; Walch, 2019).

- Alternate water supplies, storage techniques and climate-proofed WASH infrastructure are key adaptation strategies that reduce both burdens and impacts on women and girls (Alam et al., 2011)(Woroniecki 2019) (Sections 4.3.3 and 4.6.3).
- Gender-sensitive early warning system design and vulnerability assessment can play a role in reducing vulnerabilities, prioritising effective adaptation pathways to women and marginalized groups (Mustafa et al., 2019; Tanner et al., 2019; Werners et al., submitted).
- Effective social protection, both cash and food transfers, such as the universal public distribution system (PDS) for cereals in India, or pensions and social grants in Namibia, can contribute to relieving immediate pressures on survival and support processes at the community level (Kattumuri et al., 2017; Lindoso et al., 2018; Rao, 2019). Such provision of services and a certain level of security have been shown to provide opportunities to deal with climate effects for women in innovative ways (Carr, 2020).
- Integrated approaches to adaptation, that include social protection measures, disaster risk management, and ecosystem-based climate change adaptation, are effective at strengthening adaptive capacity and resilience (*high confidence*). Agroecological approaches that include training with a feminist focus and nutrition-sensitive education are needed. It includes strengthening adaptive capacities and enabling 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 included, health, education, nutrition, family planning among others.

CCB GENDER.4 Climate change adaptation and SDG 5

Participation in climate action increases if the latter becomes inclusive and fair. Roy et al. (2018) assessed links among various SDGs and mitigation options. But information on link with SDG 5 (Gender equity) was sparse. Adaptation actions are more locally grounded so understanding links with SDG 5 becomes more important to make sure that adaptive actions are not worsening the already prevalent inequity in gender empowerment within the society. The current SDG 13 climate action targets do not specifically mention gender as a component for action. This makes it even more imperative to adaptive actions under SDG 13 to link SDG 5 to ensure that adaptation projects are synergistic with SDG 5 targets.
Do implementation of climate change adaptation options advance or hinder gender equality and equity? Are the targets under SDG 5 sufficient to track the gender sensitivity of adaptive actions? This assessment is based on scientific publications published on adaptation actions in 9 sectors from 2014 to 2020 and how they integrate gender perspective and how that impacted gender empowerment. Gender impact is classified by various targets under SDG 5. Given the time and scope the assessment was based on a rapid review methodology (McCartney et al., 2017; Liem et al., 2020). Following the approach taken in Roy et al. (2018) and Hoegh-Guldberg et al. (2019), the linkages were further classified into synergies (positive impacts or co-benefits) and trade-offs (negative impacts) based on the evidence obtained from the literature review which are finally used to develop net impact (positive or negative) scores.

The assessment concludes with *high confidence* that any adaptation actions do not generate automatically gender positive impacts. They can have both positive and negative impacts unless the actions are designed to be sensitive to achieving simultaneously gender equity targets. Not all adaptive actions are implemented with gender sensitivity and are thus leading to widening gaps in local contexts. At the aggregate level, 6 out of 9 sectors show net positive impacts while 3 are showing net negative impacts (summary results are listed in Table GENDERCCB2 while the detailed table is in supplementary material).

Various actions proved to be enabling in advancement of gender equity. Ecotourism related adaptive actions where women are innovating homestay programmes are enabling positive impacts. In cities urban agriculture, well designed transit actions, ICT programmes are integrating security, access and wellbeing of women. Post disaster programmes exclusively focusing on violence against women, maternal education, village savings, micro credits with special focus on women, engaging men and boys in addressing gender inequity through educational methods proved to be effective. Hygiene and sanitation transformation approach, where the participatory programmes included men, women, and girls increased trust and respect for women, helped in reducing school dropouts and advanced education attainments. Infrastructure that is developed to respond to natural disasters sensitive to gender specific needs, involve women in the design stage providing security for women. Women bring in unique knowledge in storage practices to manage water resources; this includes storing water in cool, dark areas, using plastic containers or rooftop and underground tanks. Also, fog harvesting is an innovative water storage technique that alleviates the physical and social burden of water collection on women and girls. Women's participation in intrahousehold adaptation decision-making is significantly correlated with their livelihood diversification through non-farm income-earnings, agroecological training, access to ICT, well organised water collection system helps women participation. In mountain regions women are pushed to new roles to address domestic water scarcity by conserving and recycling water are strengthening women's role in the community. Women are engaged and recognized for preparatory measures in advance of floods to stock up on essential items such as grains, oil, and kerosene, as well as drying fish and vegetables for future use. Investment in education systems, programmes on women empowerment, pro-poor policies on access to affordable credit facilities, social protection schemes for the vulnerable and access to markets especially for livestock are likely to enhance both men and women adaptation. Women led community based natural resource management programmes are sensitive to women's participation.

Existing structural discrimination are constraining women's participation. Specific health issues, low resource households, systems insensitive to unpaid work, excluding women from paid work in post disaster relief work, informality of workplaces, childcare roles are constraining participation in the absence of specially designed policies and options. In houses poorly adapted to heat, women experience higher impacts of extreme heat because culturally, women have limited mobility outside home. Many micro watershed development programmes remain insensitive to risk of accidents to women and children. Less familiarity with mobile telephone of women keeps them away from the climate information system. Marine Protected Areas tend to reproduce existing gender disparities in relation to leadership and power in multiple countries. In many areas culturally better paying mangrove restoration projects women were kept outside focus group discussions and low paying jobs were kept for women. REDD+ programmes which do not allow traditional practices constrain women's participation but, in some cases, they helped in enhancing family and social status of women.

Formalising women's land registration both in developed and developing country contexts, adopting equitable business models and policies help in addressing structural social inequalities and gendered power relations during disaster recovery. Design and delivery of climate information services need to be both relevant to the specific context and gender sensitive in content. Institutional practices, mechanisms and policies remain patriarchal. Female headed households lack finance, access to all modern information flows. Aquaculture provides opportunities of income diversification for both women and men. When women are not directly involved in commercial activities then almost all those involved in subsistence aquaculture are female due to the perceived lack of immediate economic gains. Introduction of technology needs monitoring to avoid enhancing gender gaps.

Some positive impacts of adaptive actions that are acting as enablers in advancing the gender goal through co-benefits are also observed. These adaptations are found to have consciously designed actions sensitive to the issue of gender. There is a need for research communities especially action research communities to focus on gender equity as an integral part of the climate change adaptation actions to generate positive gender-sensitive actions to avoid magnification of the structural injustice. The current SDG5 targets falls short of addressing many gender dimensions of adaptive actions which highlights the need for expanding the targets set to truly reflect gender sensitivity of climate actions.

Table CCB GENDER.2: Interrelations between SDG5 (gender equality) and adaptation initiatives in 9 major sectors

Sector	SDG 5 (net impact)	Main messages

Terrestrial	+ (enabling)	+ Community-based natural resource management increases participation of women, most likely if they are organised into women groups. + National forest conservation/reforestation programs (e.g through CDM and REDD+) and forest sequestration programs can improve the family and social status of women and creation of women's group in forest conservation programs can create more income for women and new connections which increases women's leadership and power in the local context. – However, too restricted rules of REDD+ that do not include traditional uses from local communities can hamper women and girls' traditional activities. – Payment for ecosystem services in the 'forest protection' category based on property size reduce women income as compared to men because women tend to have smaller size of property ± Engagement in aquaculture has the potential to bring respect and popularity to women, if they succeed which depends on gendered approach in introducing any technology otherwise the gender gap can increase, despite the many potential benefits of such technology.
Ocean	– (counteracting)	– Marine Protected Areas tend to reproduce existing gender disparities in relation to leadership and power. Research on MPAs in Kenya, Tanzania, Madagascar, Indonesia and the Philippines has concluded that women are less likely to participate in MPA governance and activities because MPAs restrict fishing and women have to find other sources of income to support their families. – Decision-making in relation to a mangrove restoration project women participation is very less as they are not informed of focus group discussion. Also, in some places, men were culturally deterred from participating in mangrove restoration activities due to the low associated pay which was felt to be more suitable for women. + Workshops conducted in the Pacific highlighted the ways in which women are taking the lead in a range of local scale adaptation actions that innovate as well as build on traditional knowledge. ± In Sustainable aquaculture practices, gender roles are clearly defined. Women are not directly involved in commercial activities and almost all those involved in subsistence aquaculture are female due to the perceived lack of immediate economic gains. However, aquaculture provides opportunities of income diversification for both women and men
Mountain	+ (enabling)	+ Being pushed into new roles, domains and spaces, women's skills and capacities have increased. Strategies adopted to address domestic water scarcity by conserving and recycling water are strengthening women's role in the community. + Women are engaged and recognized for such preparatory measures in advance of floods to stock up on essential items such as grains, oil and kerosene, as well as drying fish and vegetables for future use + Investment in education systems, programmes on women empowerment, pro– poor policies on access to affordable credit facilities, social protection schemes for the vulnerable and access to markets especially for livestock are likely to enhance both men and women adaptation. – Changes in gender roles to respond to climatic and socioeconomic stressors is not supported by institutional practices, mechanisms and policies that still remain patriarchal. – Adaptation strategies adopted do not change or exacerbate the incidences of violence against women and children, which remain as root cause of increased vulnerabilities. – Female-headed households are more vulnerable as they are less likely to adopt technologies because female heads have less access to information and other resources (including financial) due to traditional barriers.
Food	+ (enabling)	+ Women's power to participate in intrahousehold adaptation decision-making is significantly correlated with their livelihood diversification through non-farm income-earnings. + Women have reported that by implementing Best Management Practices (BMPs), changes were experienced in multiple domains, such as financial and physical capital, better nutrition (more food available to eat) and improved health care, as well as gaining more social and human capital. + Agroecological training in farming communities seems to increase gender-related sensitivity increasing girls schooling opportunities. + Access to ICT facilities enhances the resilience of women households by connecting them to new opportunities by increasing agricultural production incomes. + With well-organized water collection management, women and marginalized groups have equitable access to water springs, which was timesaving for them. – But the water infrastructure (micro-watershed) did not take the safety aspect for women and children into account to minimise accident risk. – Mobile phones is critical for access to Climate Information System but women perceive limited impact as they face some challenges that prevent them in accessing to mobile phones like low-income levels, lack of training, inability to interpret climate information and convert it into actions, limited access to mobile phones (mostly by women), and inability to afford calling credits. Therefore, the design and delivery of climate information services need to be both relevant to the specific context and gender sensitive in content

Water	+ (enabling)	+ Women experienced enhanced respect and trust through a hygiene and sanitation transformation approach, where the participatory programmes included men, women, and girls. + Improved water and sanitation facilities have shown to increase enrolment as well as reduce repetition and dropout rates for girls in school and higher education of women is shown to be correlated with reduced incidence of diarrhoea. + Infrastructure that is developed to respond to natural disasters and take into account gender-specific needs, such as sanitation facilities, can create security and safety for women and girls and provide a place to gather for support and foster empowerment + In developing countries, women are responding to water scarcity through collection adaptations, such as small rainwater harvesting systems and storage tanks, greywater recycling systems, fog water collection. These adaptation measures reduce physical burden and time commitment spent on collecting water, therefore increasing time to be spent on other activities such as school + Women play a significant role in response to natural disasters and when they are involved in pre-disaster planning, space is created to address women's-specific needs, such as building sanitation facilities above the flood line + In adapting to climate variability, women use unique storage practices to manage water resources; this includes storing water in cool, dark areas, using plastic containers or rooftop and underground tanks. Also, fog harvesting is also an innovative water storage technique that alleviates the physical and social burden of water collection on women and girls – When women travel further distances to collect water it puts their safety at risk including exposure to violence and sexual assault. – Lack of access to adequate hygiene and sanitation facilities often restricts women and girls from fully participating in the job place or regularly attending school
Poverty	– (constraining)	+ Women are experimenting and driving innovative adaptation options such as homestay-based ecotourism and fruit farming present promising adaptation strategies that are being taken up by others in the community – But patriarchal institutions and structural discriminations result in less access to services, economic resources as compared to men, including less control over income, fewer productive assets, lack of property rights, less access to credit and less access to irrigation, climate information, seeds and lead to devaluation of women's farm-related adaptation options. – Continued exclusion of women's ideas and views from policy processes will inhibit adaptation and may lead to discriminatory outcomes – Female care workers from the global south entering global care chains, they leave a care gap in the places they are migrating from, adding additional care burdens to those [women and girls] who remain behind – A feminist political economy view of disaster recovery across four empirical case studies (United States, Thailand, Philippines, and New Zealand) shows that processes of enclosure, exclusion, encroachment, and entrenchment can distort disaster-relief supports and safety nets, to preserve or exacerbate gender, class, and ethnic disparities Formalising women's land registration and adopting equitable business models and policies are needed. Prompt attention is needed to address structural social inequalities and gendered power relations during disaster recovery.
Cities	+ (enabling)	+ Urban agriculture has positively impacted women's participation by improving their wellbeing, food security, and income by increasing their social capital and also allows women to more efficiently and successfully perform their gender roles and responsibilities, and gain social and economic empowerment + Well-designed transit-oriented development have positive impacts on gender equality including women's freedom of movement and security + ICT programs that explicitly target women, address their specific vulnerabilities have shown to have positive impacts on women's livelihoods and wellbeing, expanding their socio-economic, physical and political space – In houses poorly adapted to heat, women experience higher impacts of extreme heat because culturally, women have limited mobility outside home and effective techniques to reduce indoor temperatures are not available (except air-conditioning at night and low-cost techniques at day time for some people) – Current urban policies around climate resilience do not recognise address structural barriers to gender participation such as inadequate recognition of women's unpaid work, inadequate participation and leadership in decision-making – Relocation can also force women into lowly paid jobs or informal economy, creating a vicious circle where women's time poverty further reduces their social capital and opportunities for self-development in terms of education or formal employment
Industry	– (constraining)	– Male workers had a significant increase in overall claims during moderate-severity heatwaves, while no significant change was observed for female workers. – Women find it difficult to carry out strenuous physical activity during menstruation and unequal wages distribution creates additional threats to cope with their health problems. ± There should be a separate neat and clean toilet for the women workers in workplaces. Wherever possible the eligible women workers should be given maternity benefit in

		industrial and organised sectors. Exhaustive and comprehensive legislation is urgently needed for regulating working conditions, wage structure, welfare measures of the women workers. Communication through self-help-groups of women and NGOs is needed for the receptivity among workers and employers. ± There are a large number of women groups and NGOs which work with migrant populations in the unorganised sector. Empowering these groups with the relevant latest IEC materials would enable them to fight the heat wave
Health	+ (enabling)	+ Village savings and loans and other microcredit programs that focus on women can increase their access to credit, income, social networks, adaptive capacity and improve women's overall well-being. + Some climate change adaptation policies explicitly address violence against women and girls that can increase during disasters or drought + Maternal education can significantly reduce the risk of child malnutrition in a post-flooding event or post-drought. + Climate change policies which address mitigation and adaptation can improve women's well-being and mental health, through mechanisms such as increased access to green spaces, reduced air pollution, increased use of bicycles and walking as transport. + Engaging men and boys in addressing gender inequity through educational methods can be effective and help build household and community cohesion and adaptive capacity. – During recovery efforts from hurricanes, floods and other extreme climate events, expecting women to participate in rebuilding can be hard for them due to competing child care and other household responsibilities, and communal living during the recovery period can create additional dangers for sexual and physical violence for women and girls' post-recovery. – In low-resource settings women have reduced agency to make healthcare decisions, the impacts of disease and disability are likely to be further magnified. – Some indigenous cultural beliefs affect women and girls, compelling them to eat less food as a form of intra-household adaptation to climate change. – Some disaster risk management programs exclude women from income-generating activities, or leadership roles in the program, and only consider their caregiving role. – Women often have less access to credit for climate change adaptation practices, including post-disaster relief, for example to deal with salinisation of water or flooding impacts – Some ecosystem-based adaptation initiatives do not take gender inequities into account and can reinforce gender and other social inequities in terms of discrimination. Development and climate programmes have to be redesigned to accommodate more context-specific policies instead of one-size-fits-all packages that will effectively address women's (and men's) differential needs and unequal relations and circumstances. Limited research and policy initiatives which consider climate change impacts on women's health and child care and nutrition, particularly for vulnerable groups.

CCB GENDER.5 Towards climate-resilient, gender-responsive transformative pathways

Climate change adaptation and gender literature calls 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., 2018) as well as for the importance of 'mainstreaming' gender in climate/development policy (Rochette, 2016; Mcleod et al., 2018). Women's organisations at the global level have argued both for including safeguards in relation to climate interventions and for including the question of women's unpaid labour, care and wellbeing in climate projects through the possibility of getting credits not only for carbon sequestration but also for questions relating to women's empowerment (Westholm and Arora-Jonsson, 2018).

Many calls have been made to consider gender in policy and practice, (e.g., Ford et al., 2015; Jost et al., 2016; Rochette, 2016; Thompson-Hall et al., 2016; Kristjanson et al., 2017; Mcleod et al., 2018; Westholm and Arora-Jonsson, 2018). Rather than merely emphasising the inclusion of women in patriarchal systems, transforming systems that perpetuate inequity can help address the structural causes of inequality, including gender but also other race, ethnicity and citizenship (Djoudi et al., 2016; Pearse, 2017). To date, such transformational change is rare although there is some evidence of incremental changes (e.g., increasing female 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 (e.g., Mersha and van Laerhoven, 2019); and mere inclusion of women and men in planning does not necessarily translate to substantial gender transformative action in National Adaptation Programmes of Action across sub-Saharan Africa (Holvoet and Inberg, 2014) and national and sub-national climate action plans in India (Singh and Chudasama). Importantly, there is frequently 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, 2019).

Gender and climate justice will be achieved when global macro and structural issues are addressed at their root causes, 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 decision-making processes. A transformative pathway for deliberation in a new manner needs to include the voice of the disenfranchised (MacGregor, 2020); Schipper (2020a) which are overshadowed by the way predominant political and economic interests shape in a fractal logic questions of science, knowledge and decision making (Harcourt, 2016).

[END CROSS-CHAPTER BOX GENDER HERE]

18.3.2 Enabling Conditions

A range of enabling factors for adaptation were identified in the AR5 synthesis report, along with the importance of governance as a means of strengthening adaptation and mitigation and advancing sustainable development (Fleurbaey et al., 2014). They included "effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods and behavioural and lifestyle choices" (IPCC, 2014c, Section 4.1). It went further to define that quality of a national enabling environment to include: institutional and regulatory effectiveness, policy credibility and security of property rights, and affirmed that in an appropriate enabling environment, both the public and private sector can play an important role in climate finance (IPCC, 2014c, Section 4.4.4). Gaps in adaptation finance, and the need for better assessment of global adaptation costs, funding and investment, were also identified. A limited range of economic and financial policy instruments were articulated: taxes, tradeable allowances, subsidies, regulatory approaches, information, government provision of public goods and services (IPCC, 2014c: Table 4.7). The Working Group II SPM, however, was marked by a significant lack of discussion on enabling conditions, and their linkages to policy or implementation.

With the articulation of the need to accelerate and deepen system transitions, the AR6 Special Reports identified, with *high confidence* enabling conditions that enhance the feasibility of mitigation and adaptation options, that underpin the necessary societal and systems transformations (Roy et al., 2018). Building on AR5 and recent literature, these seven enabling conditions are: strengthened multilevel governance, institutional capacity and policy instruments; technological innovation and transfer, mobilisation of finance, changes in human behaviour and lifestyles, and international cooperation (IPCC, 2018b): D2.3, D7). This is further affirmed in AR6 as: governance arrangements, building human and institutional capacity, legal and policy instruments, finance, climate services and information to support adaptation and risk management [to be updated from Section 17.5]

These are also linked to particular system transitions and the SDGs. For example, increased investment in physical and social infrastructure, which underpin the urban and infrastructure transition, is a *high confidence* enabler of enhance resilience and adaptive capacity (IPCC, 2018b): D3.1).

High confidence enablers of sustainable land management and poverty reduction include: expanding access to agricultural and climate services, strengthening land tenure security and access to land, empowering women farmers, improved access to markets, and facilitating payments for ecosystem services (IPCC, 2019c): C2.1). Policies that enable healthy and sustainable diets, have co-benefits in terms of public health, mitigation and adaptation (IPCC, 2019c): C2). Enhancing multi-level governance by supporting local management of natural resources and strengthening cooperation between institutions and actors, can enhance the adaptation potential of land restoration and rehabilitation. (IPCC, 2019c): C2.1)

High confidence enablers of ocean and cryosphere transitions include: funding, and institutional support, monitoring and forecasting, education and climate literacy and social learning and participation (IPCC, 2019c): C4). Enabling conditions to respond to sea-level rise include: enhancing governance and institutional capacity to address complex risks, improved coordination of responses, addressing social vulnerability to enable just climate transitions and sustainable development, creating safe community settings for meaningful public deliberation and conflict resolution, improving public awareness and social learning, and building on local, indigenous and scientific knowledge (IPCC, 2019c): C4.5).

The emerging literature suggests seven overarching governance strategies to enable the transition of the industrial system: a) policies to promote material efficiency and high-quality circularity; b) supply drives R&D and early commercialisation, as well as demand, pull lead/niche markets to help emerging technologies cross to the valley of death; c) carbon pricing or regulations with provisions on competitiveness to drive innovation and systemic carbon efficiency; d) low-cost, long-term financing mechanisms to enable investment and reduce risk; e) better planning of transport infrastructure; f) institutional support (e.g., labour market training and transition support; g) electricity market reform) (Åhman et al., 2017; Bataille et al., 2018; Material, 2019) (*high confidence*, *medium evidence*). Besides the policy mix should also focus on regulations – standards and labelling (Tanaka, 2011; Schwarz et al., 2020), material efficiency (Ciwmb, 2003), a ban on using new materials (Romero Mosquera, 2019) mandating technologies and targets (Tanaka, 2011); economic instruments—green taxes and carbon pricing (Ryan et al., 2011; Boyce, 2018), preferential loans and subsidies (Taylor, 2008); voluntary action agreements (UNEP, 2018), expanded producer responsibilities (Kaza et al., 2018); information programs: monitoring, evaluation (Söderholm and Tilton, 2012), partnerships, and research and development (Bataille et al., 2018); and government provisioning of services—government procurements (Ghisetti et al., 2017), technology push and market-pull (Taylor, 2008; Fischedick et al., 2014; Hansen and Lema, 2019).

Societal transitions are characterised by local to global action and a core commitment to social justice, solidarity and cooperation (Patterson et al., 2018; Robinson and Shine, 2018).

This can be enabled by a range of enabling conditions that help enhance well-being, reduce inequality with and between countries (Klinsky and Winkler, 2018) and pay attention to questions of power and inequality (Roy et al., 2018, Section 5.5.3). These include: inclusive governance (Fazey et al., 2018b; O'Brien, 2018; Patterson et al., 2018), empowerment of excluded stakeholders, especially women and youth (MRFCJ, 2015; Dumont et al., 2019), transforming economies (Popescu et al., 2017; David Tàbara et al., 2018), finance and technology aligned with local needs (de Coninck and Sagar, 2015; IEA, 2015; Parikh et al., 2018), overcoming uneven consumption and production patterns (Dearing et al., 2014; Häyhä et al., 2016; Raworth, 2017), allowing people to live a life in dignity and enhancing their capabilities (Klinsky and Winkler, 2018), involving local governments, enterprises and civil society organisations across different scales (Hajer et al., 2015; Labriet et al., 2015; Hale, 2016; Pelling et al., 2016; Kalafatis, 2017; Lyon, 2018), reconceptualising development around well-being rather than economic growth (Gupta and Pouw, 2017), rethinking, prevailing values, ethics and behaviour (Holden et al., 2017), improving decision-making processes that incorporate diverse values and world views (Cundill et al., 2014; Butler et al., 2016; Ensor, 2016; Fazey et al., 2016; Gorddard et al., 2016; Aipira et al., 2017; Chung Tiam Fook, 2017; Maor et al., 2017), creating space for negotiating diverse interests and preferences (*robust evidence*, *high agreement*) (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)

Climate adaptation is enhanced by a range of cross-cutting options that work across all five system transitions. The following table from SR1.5C outlines the range of specific enabling conditions of key cross-cutting adaptation options (Rogelj et al., 2018: Table 4.4).

- *Disaster Risk Management:* Enhanced governance and institutional capacity supports post-disaster recovery and reconstruction (Kull, 2016)
- *Risk sharing & spreading:* Institutional capacity and finance buffers climate risk (Wolfrom and Yokoi-Arai, 2015; O'Hare et al., 2016; Glaas et al., 2017; Jenkins et al., 2017; Patel et al., 2017).
- *Social safety nets:* Institutional capacity and finance builds generic adaptive capacity and reduces social vulnerability (Eakin et al., 2014; Lemos et al., 2016; Schwan and Yu, 2017).
- *Education and learning:* Behavioural change and institutional capacity enables social learning and strengthens adaptation (Clemens et al., 2015; Ensor and Harvey, 2015; Henly-Shepard et al., 2015)
- *Enabling Indigenous knowledge:* Institutional capacity and behavioural change is enhanced by knowledge of environmental conditions that helps communities detect and monitor change (Johnson et al., 2015; Mistry et al., 2016; Williams et al., 2017).

- *Climate services:* Technological innovation enables rapid technical development that improves the quality of climate information (Gasc et al., 2014; WMO, 2015; Roudier et al., 2016; Rogelj et al., 2018: Table 4.4)

The linkage between enabling conditions and context-specific adaptation options, that have positive sustainable development and poverty reduction outcomes, was established with *high confidence*, even though trade-offs are possible. (IPCC, 2018b): D3). Coherence between these enabling conditions was found to be important to enhance climate resilient development (IPCC, 2018b): Section 4.4). Characteristics of this coherence include: better alignment across governance scales (Geels et al., 2017), enabling multilevel governance (Cheshmehzangi, 2016; Revi, 2017; Tait and Euston-Brown, 2017) and nested institutions (Abbott, 2012).

18.3.3 Integration and Convergence between Transitions

In the current draft of AR6, a broad range of approaches to system transitions and transformations have been taken, in line with diverse understandings summarised in Box 18.1 A few chapters use a system transitions framing, others have used transformations, whilst yet others have only carried out sectoral and risks analyses. For policy relevance, a consistent and harmonised frame of assessment may be useful, if supported by the literature, to flow through the sectoral and regional chapters.

The Chapter 18 assessment shows that there is limited historical evidence on the efficacy of adaptation responses in reducing vulnerability of energy systems. Nevertheless, emissions reductions have taken place in response to mitigation policy and sustainable development factors have a dominant influence in recent energy system changes.

There is some evidence of elements of the urban and infrastructure transition contributing towards climate resilient development, via initiatives around buildings, urban water systems and related green infrastructure, greater resilience of electricity and ICT networks, urban agriculture and strengthening local food systems and disaster risk reduction.

On the terrestrial, freshwater and ocean ecosystems front there are some recorded initiatives that have successfully promoted and improved natural climate resilience. Yet, there is still limited evidence of planned adaptation contributing to CRD for terrestrial, ocean, polar and coastal ecosystems. Some pilot projects have potential to support CRD, but need further monitoring and scale-up. [PLACEHOLDER FOR THE FINAL DRAFT: to be deepened].

Reducing the impact of GHG emissions in industries requires a wide range of mitigation and adaptation options, and involves multiple elements that evolve together, including markets, infrastructures, policies, technologies, industrial structures and supply and distribution chains. Yet, the industrial system transition literature is dominated by mitigation actions, while knowledge of industrial adaptation options is limited.

There is very limited evidence of Societal transitions contributing to CRD at the current point in time. [PLACEHOLDER FOR THE FINAL DRAFT: to be deepened]. There is a rapidly growing literature on enabling conditions for CRD. Since the convergence between the five system transitions is at an early stage and coordinated adaptation actions at scale, still nascent, literature on the potential of these enabling conditions, assisting in the acceleration and deepening of these system transitions is weak and needs to be built out.

18.4 Strategies for Climate Resilient Development: Characterising the Future Actions Space

[PLACEHOLDER FOR FINAL DRAFT: This section synthesizes and assess content still being developed in WGI, WGII, and WGIII. As such, the content here will evolve with their content and coordination discussions with our chapter on our assessment insights to ensure consistency. This includes tables and figures that will be developed with the next iteration of cross-WG data. For now, placeholders are included that describe the planned content.]

The stated objectives of CRD imply not only rapid progress toward the SDGs but also climate action that limits warming to well below 2°C while also enhancing the resilience of social and ecological systems (Section 18.1.1). Achieving such objectives requires not only the implementation of individual adaptation, mitigation, and sustainable development initiatives, but their careful coordination and integration. This section assesses the literature on CRD in the context of key climate change risks (Chapter 16); potential synergies and trade-offs among mitigation, adaptation and sustainable development; and the mechanisms for managing those trade-offs. In addition, this section discusses the literature on approaches for accelerating the system transitions needed to enable CRD.

18.4.1 Climate Resilient Development & Managing Key Risks

CRD is an elusive conceptual and aspirational construct, that is highly subjective, depending on decision-makers and priorities (Roy et al., 2018, Section 18.2). At its core, however, is sustainable development, in particular equity and well-being, and choosing mitigation and adaptation with sustainable development priorities in mind. Mitigation and adaptation have indirect and direct relationships with sustainable development: indirect in managing climate risks and direct in how mitigation and adaptation options themselves may impact economic, environmental, and social outcomes. Chapter 16 and individual chapters of this report have identified key risks and assessed how these risks can change with climate, development, and adaptation. Similarly, WGIII has assessed potential mitigation pathways and strategies for different future climates (WGIII AR6 Chapter 3 and Chapter 4). This section synthesizes insights to assess mitigation and adaptation choices in support of sustainable development in the near-term (next decade) and mid-term (next few decades), including considering effort, types, and deployment levels of mitigation and adaptation, as well as sustainable development goals, metrics, and priorities. This section summarizes assessment of future climates and key risks before discussing options for managing key risks in light of sustainable development and key risk management combinations and CRD. Discussions regarding decision-makers differences, priorities, and decision processes are considered in Section 18.5 of this chapter.

18.4.1.1 Future climates and key risks

Over the next decade, additional climate change is expected regardless of mitigation efforts (WGI AR6). Across the global scenarios analysed in AR6, global average temperature changes relative to the reference period 1995-2014 range from 0.4˚C to 1.1˚C for the period 2021–2040 and 0.4˚C to 2.1˚C for the period 2041-2060 (WGI AR6 Chapter 4). However, emissions pathway feasibility issues affect the plausibility of the associated climate projections, potentially lowering the upper end of these ranges (WGIII AR6 Chapter 3). There is significant overlap between climate scenario ensemble ranges from different emissions scenarios through 2050, more so than through 2100 (WGI AR6 Chapter 4). There is also overlap between emissions scenario ensembles consistent with the different temperature outcomes, but less so than with the climate scenario ensembles (WGIII AR6 Chapter 3). Emissions pathway ranges represent uncertainties for policy-makers and organisations to consider and manage regarding, among other things, economic growth and structure, available technologies, markets, behavioural dynamics, policies, and non-CO2 climate forcings (WGIII AR6 Chapter 3), while climate pathway ranges represent bio-physical climate system and carbon cycle uncertainties (WGI AR6 Chapter 4). For all climate projections and variables, there is significant regional heterogeneity and uncertainty in projected climate change (WGI AR6). See Figure 18.2 for an example for average temperature change and extreme precipitation, and Table 18.2 for ensemble ranges for aggregate regions. Similarly, for all emissions projections, there is significant regional, sectoral, and local heterogeneity and uncertainty regarding potential pathways (WGIII AR6 Chapter 3 and Chapter 4). Not all uncertainties are represented in projected emissions pathway ensembles (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. 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 (WGIII AR6 Chapter 3). See Figure 18.2 for an example of key risk geographic heterogeneity, and Table 18.2 for assessed ranges for aggregate regions.

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 development and adaptation levels, as well as warming levels, with the relationships and scientific understanding varying significantly by risk type. Together, these three dimensions define risk – with projected climate changes defining the hazard, development defining the exposure, and development and adaptation defining vulnerability. For human systems, in general, the poor and disadvantaged 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 and some level of adaptation should also be expected.

Climate risks are also found to have implications for sustainable development, with links to a variety of potential sustainable development priorities—e.g., hunger, poverty, equity, economic growth, energy security, health, cities and communities, water quality (Chapter 16, WGII AR6 sectoral and regional chapters; (Roy et al., 2018; IPCC, 2019b; IPCC, 2019a). 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).

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Figure 18.2: Regional average temperature change and extreme precipitation maps, and key risk heterogeneity map(s) for near-term climate based on WGII AR6 common climate dimensions. [PLACEHOLDER FOR FINAL DRAFT: figure will be added based on revised WGI and WGII results]

Table 18.2: Regional climate and key risk ranges for near-term climate based on WGII AR6 common climate dimensions. [PLACEHOLDER FOR FINAL DRAFT table will be added based on revised WGI and WGII results] [

[PLACEHOLDER FOR FINAL DRAFT]

18.4.1.2 Options for managing future climate key risks

18.4.1.2.1 Adaptation

As shown elsewhere in this report, adaptation is a key mechanism for managing climate risks (Chapter 16). The lower estimates in Table 18.2 are associated with higher levels of adaptation and more conducive development conditions. Furthermore, additional adaptation 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, current understanding of adaptation types, options (individual to system), and implementation for the range of possible climate futures, and their potential and 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. 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.

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 prioritise 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). There are also opportunities for managing the trade-offs, in particular distributional effects—by recognising that there are trade-offs and considering alternatives and complementary strategies to offset the trade-offs (Section 18.4.4.2).

[PLACEHOLDER FOR FINAL DRAFT: Table being considered for here or elsewhere in WGII based on an assessment that is still in progress; possible table on adaptation options feasibility re-assessment table (updating what was done for SR1.5)]

18.4.1.2.2 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 related to human and natural systems. Limiting global average warming has been found to reduce climate risks (e.g., IPCC, 2014a; IPCC, 2018a; IPCC, 2019a), 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, and system dynamics uncertainties (Rose and Scott, 2018; Rose and Scott, 2020). Pathways consistent with limiting warming to 2˚C and below have been found to represent significant deployment of mitigation and substantial economic, energy, land use, policy, and societal transformation (WGIII AR6 Chapter 3 and Chapter 4), and the emissions pathways shown to be challenging deviations from current trends with attainability issues associated with pathway characteristics, assumptions, and model infeasibilities that are relevant to pathway likelihood, and even 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). See Table 18.3 for a high-level summary of pathway characteristics based on the WGIII AR6 assessment. Global pathways find large regional differences in mitigation potential, as well as the degree of regional non-linearity in cost increases 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.

Past assessment has evaluated representative mitigation options in terms of economic, technological, institutional, socio-cultural, environmental/ecological, and geophysical feasibility, as well as relationships to sustainable development goals (de Coninck et al., 2018). The feasibility analysis has been updated for AR6. 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 characterisations. 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 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 here as well, that accounts for the relevant geographic context and interactions between options, systems, and implications.

Pathway and system feasibility and sustainable development relationships are also important to consider in developing mitigation strategies. Pathway feasibility in terms of evaluating pathway characteristics as noted above, but also system operational feasibility that considers choosing a portfolio of mitigation options to ensure service reliability (e.g., WGIII AR6 Chapter 6).

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 or pricing the emissions future society can produce, which affects markets, resource allocation, economic structure, income distribution, consumers, and the environment (besides climate). 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, like that associated with global or regional emissions scenarios and energy systems. Figure 18.3, derived from WGIII scenarios data, illustrates estimated relationships between mitigation and various sustainable development proxy variables. In the figure, we observe synergies and trade-offs with mitigation—synergies in air pollutants black carbon, NO_x, and SO_2, and irrigation water use; 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).

Results like those in Figure 18.3 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 prioritisation. 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.

[PLACEHOLDER FOR FINAL DRAFT]

Table 18.3: Emissions pathway characteristics from WGIII scenarios database for pathways associated with different warming levels, e.g., 1.5˚C, 2˚C, 2.5˚C, and 3˚C. [PLACEHOLDER FOR FINAL DRAFT: table will be added based on revised WGIII Chapter 3 Second Order Draft scenario data]

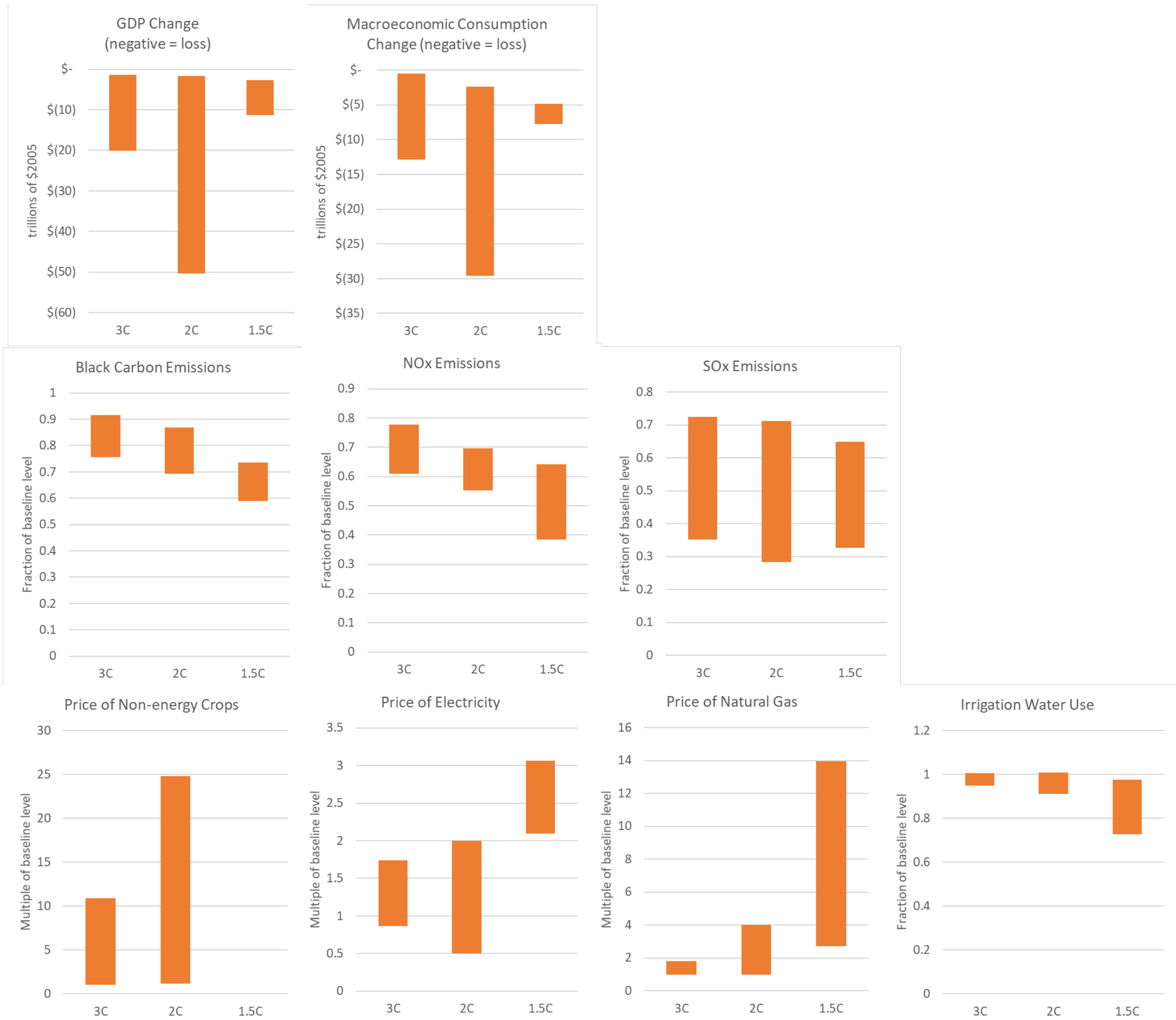

Figure 18.3: Implications of mitigation for different global mean temperature outcomes on various development and sustainable development proxy variables. Example of 2050 global implications of mitigation for different global mean temperature outcomes on various development and sustainable development 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. [PLACEHOLDER FOR FINAL DRAFT: figure will be updated with additional data from the WGIII scenarios database. The figure will also be extended for additional proxy variables and regional results as possible and practical.]

18.4.1.2.3 Sustainable development

Sustainable development represents specific development priorities that can affect climate risk and therefore represents a potential climate risk management option. Development in general can affect climate risk hazard, exposure, and vulnerability. The literature has shown for decades that altering the socio-economic future implies different projected emissions and future climate hazard (Nakicenovic and Swart, 2000; Metz et al., 2001; Fisher et al., 2007; Clarke et al., 2014); WGIII AR6 Chapter 3). This same literature has also illustrated how different socio-economic conditions affect mitigation options and costs. Similarly, development has also been found to impact climate risk exposure, defining the size, location, and composition of society and ecosystems, and climate risk vulnerability, defining the adaptive capacity in terms of resiliency, adaption options, and costs (IPCC, 2014a; IPCC, 2018a; IPCC, 2019a); WGII AR6).

Sustainable development represents a particular set of societal priorities, such as related to health, poverty, hunger, equity, environment, and well-being. Sustainable development can shape climate risks directly, by affecting exposure and vulnerability, or indirectly by affecting emissions pathways and the future potential climate hazard; mitigation options, strategies, and outcomes; and/or adaptation options, strategies, and outcomes. 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.

In aggregate, projections like the Shared Socioeconomic Pathways (SSPs)(O'Neill et al., 2017), represent sets of global societal assumptions. Projections with characteristics more closely aligned with sustainable development type priorities have been found to imply lower emissions and projected climates (WGIII AR6 Chapter 3), lower mitigation costs for ambitious climate goals (WGIII AR6 Chapter 3), lower climate exposure due in large part to the size of society (Chapter 16), and greater adaptive capacity (Chapter 16; (Roy et al., 2018). Development characteristics such as population and economy size, income distribution, consumption preferences and distribution, input and production productivity, and environmental quality policies have been noted as key features influencing these results. At the same time, this literature has also found sustainable development trade-offs and noted that none of the projections achieved all the sustainable development goals (Roy et al., 2018). Case studies reinforce this aggregate insight, for instance, illustrating poverty alleviation 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).

This literature is useful for characterising the potential climate risk implications of different global societies; however, important limitations impact their use in climate risk management planning. In particular, we have little understanding of the cost and what is required to transform from today into each socioeconomic future without climate policy, or the opportunity to shift from one pathway to another. 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, the 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.

Table 18.2, developed from the WGII report, illustrates the importance of development conditions, with the key risk ranges a function of development and adaptation, where both are influenced by development over time. Locally, pursuing sustainable development priorities can reduce climate risk by reducing magnifying factors, e.g., improving air quality, forest health, equity, and poverty reduction. Chapter 16 also provides projections of representative key risks for illustrative pathways, showing how the representative key risks depend on the socioeconomic conditions which impact hazard, exposure, and vulnerability.

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. 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). With trade-offs found throughout, the literature suggests that sustainable development trade-offs are inevitable. Managing the trade-offs, as well as capitalising on the synergies, will be important. However, managing the trade-offs will have distributional implications. See 18.4.1.2.1 and 18.4.1.2.2 for discussions related to mitigation and adaptation synergies and trade-offs with sustainable development.

18.4.1.3 Climate key risk management combinations and climate-resilient development

This section builds off the discussions of future climate change and key risks (Section 18.4.2.1) and options for managing future key risks—adaptation, mitigation, and sustainable development (Section 18.4.2.2). Specifically, this section assesses knowledge regarding climate risk management combinations and CRD.

18.4.1.3.1 Overview of relevant literature

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, e.g., 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 optimal global pathway below 2˚C. In addition, this work highlights the importance of characterising uncertainties and considering and managing them. 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 18.4.2.2, there are synergies and trade-offs between adaptation and sustainable development, as well as between mitigation and sustainable development. For instance, the global cost-effectiveness mitigation pathways literature provides insights regarding aggregate synergies and trade-offs between mitigation and sustainable development (e.g., Figure 18.4). 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). 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. Some of this is evident in results like those shown in Figure 18.4 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 (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 risk management combinations. 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.

18.4.1.3.2 Risk management combinations with lower to higher climate change

The different strands of literature discussed above can be put together to help us think about risk management combinations. 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 (Roy et al., 2018).

Sustainable development considerations could be used to prioritise 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 solve, and those that can adopt strong assumptions about global policy development and socioeconomic changes. Sustainable development might also affect the design of policies by prioritising 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, prioritising air quality has climate co-benefits but does not ensure the lowest cost climate strategy (Arneth et al., 2009; Kandlikar et al., 2009). Similarly, prioritising land protection has a variety of co-benefits but could increase food prices significantly, as well as the overall cost of climate mitigation (IPCC, 2019a). 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. Among other things, this impacts the future climate change possibilities. 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. Prioritising 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 (Wiebe et al., 2015; Hallegatte and Rozenberg, 2017). Uncertainty about global actions also implies uncertainty about markets, which will impact sustainable development strategies.

With the climate system slow to respond, climate change is a long-run issue, and near-term mitigation, adaptation, and sustainable development decisions will have long-run implications. Decisions today represent long-run trade-offs in terms of the opportunity cost of investments and climate risks. For instance, a low climate path entails greater reallocation of resources today towards mitigation and away from alternative productive uses, but lower climate risks in future decades. Thus, risk management combinations need to balance near-term mitigation resource reallocation, longer-run adaptation, and sustainable development priorities.

CRD represents choosing mitigation and adaptation to support sustainable development priorities; in particular, equity and well-being. The literature suggests that pursuing CRD in different climate futures entails different combinations of mitigation, adaptation, and sustainable development, including different strategies for managing the trade-offs and reallocating the costs. Higher climates imply a greater need for supporting adaptation capacity and managing adaptation trade-offs and distributional implications, while lower climates imply a greater need for managing mitigation trade-offs and distributional implications. In all contexts there are trade-offs, as well as synergies.

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 (e.g., David Tàbara et al., 2018; O'Brien, 2018). Instead, the current literature suggests that different mixes of adaptation and mitigation strategies, and sustainable development and trade-off management priorities, measures, and reallocations (Section 18.4.4.2), will be appropriate for different expected climates and locations; 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).

18.4.2 Implementing Adaptation Options

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 (Zinsstag et al., 2018) (*high confidence*). 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 (Few et al., 2017; Vermeulen et al., 2018; Fedele et al., 2019) (*medium confidence*).

Since AR5, the scientific community has deepened its understanding of the relationship between adaptation and sustainable development, 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). However, in the post-AR5 literature there is disagreement as to where such participation is most effective. Some of the literature points to the need to build participatory adaptation processes to avoid subsuming adaptation goals to development-as-usual (Eriksen et al., 2015) while literature drawn from the practice of linking adaptation to development argues that this work is most effective when it is focused on development efforts and considers how climate change will challenge the goals of those efforts (Kim et al., 2017). 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 (Eriksen et al., 2015; Mikulewicz, 2019; Nightingale Böhler, 2019; Eriksen et al., submitted). 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 (Few et al., 2017; Schipper et al., 2020b).

The critical literature on socio-ecological resilience, which has grown substantially since the last AR, 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 (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 organisations tend to exclude local experiences and sources of risk, and thus foreclose the need for transformative pathways to achieve development goals. 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.

18.4.3 Managing Synergies and Trade-offs

Sections 18.4.2.2.1 through 18.4.2.2.3 illustrate that there are synergies and trade-offs between sustainable development, mitigation, and adaptation. A key message from these discussions is that trade-offs are inevitable. Trade-offs occur in all cases and, therefore, decision-makers will need to balance social priorities and consider opportunities for both promoting synergies and managing trade-offs. Consideration of synergies and trade-offs can assist in jointly pursuing multiple climate risk management and sustainable development goals. Not doing so, can mean missed opportunities and unintended consequences, while doing so, can mean additional expense and different trade-offs. For instance, rural electrification typically emphasizes mitigation, and adaptation benefits are overlooked, and there are financing challenges in pursuing synergies because they imply incremental costs.

Synergies between adaptation, mitigation and sustainable development might be promoted by prioritising strategies with synergies (Roy et al., 2018; Karlsson et al., 2020), such as 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), or renewable energy systems that improve water management and preservation of river ecological integrity (e.g., Berga, 2016; Rasul and Sharma, 2016), or internalising 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 prioritising strategies, such as disqualifying mitigation options thought to have negative social implications (Section 18.4.2.2.2), internalising 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 (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.

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 optimisation of multiple priorities, evaluating alternative mechanisms and shifts in trade-offs, and evaluating redistribution implications with transfers.

This section explores overlaps between policy objectives that are relevant for CRD, namely adaptation as an extension of CRD and SDGs, and adaptation and mitigation both as part of CRD. The link between adaptation and SDGs is explored through two examples: good health and well-being (SDG3), and peace, justice and strong institutions (SDG16).

18.4.3.1 Adaptation and SDGs

SDG achievement signifies positive sustainability outcomes in the short term 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 (Section 18.2.3.2). 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.

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, and real participation and leadership by target populations (Remling and Veitayaki, 2016; Buckwell et al., 2020; McNamara et al., 2020; Owen, 2020). However, the objectives, actions and assessment methods of interventions have often been narrow, failing to address social justice directly and disregarding indirect negative effects on other populations or socio-environmental processes, including how adaptation actions sometimes exacerbate social vulnerability, inequity and uneven power relations (Antwi-Agyei et al., 2018; Atteridge and Remling, 2018; Mikulewicz and Taylor, 2020; Satyal et al., 2020; Scoville-Simonds et al., 2020) or reinforce inequitable development models (Paprocki, 2018).

18.4.3.1.1 Good health and well-being (SDG3)
The health sector is an important area for adaptation to counteract current and future climate change impacts. Several adaptation actions exist that respond to specific climate risks to health and well-being, such as an increase in malaria prevalence (Chapter 7). Addressing health inequities, such as through investment in public health care and access, is effective in building social justice and resilient societies (Marmot and Allen,

2020; Mullins and White, 2020). At the same time, social justice issues such as discrimination, disempowerment and deprivation impact directly on both individual and collective physical health and broader well-being indicators (Di Martino and Prilleltensky, 2020). Yet, relatively little adaptation spending has been directed towards health (Watts et al., 2019). There is less evidence regarding the effect of adaptation on broader sustainable development aspects such as SDG achievement. Increasing health adaptation efforts and in particular addressing social health inequalities may therefore help achieve the SDGs and enhance social justice and equity aspects of societal development that enable CRD in the longer term. However, broader societal measures are required to addressing the underlying causes of inequities that drive poor health and well-being in the Capitalocene, including cuts in public spending, and neoliberalisation and commodification of healthcare (Hall, 2020; Walsh and Dillard-Wright, 2020). There is little evidence regarding the ability of adaptation to promote health (Lindström and Eriksson, 2005) as opposed to reducing health risks, nor how it can ensure health related rights, such as the Convention on the Rights of People with Disabilities, even though people with disabilities are often among the most vulnerable to climate change, and climate related disasters also lead to disability (the effect of an event on physical and mental health; (Kosanic et al., 2019); Chapter 7).

Several development processes consistent with the SDGs not only enable CRD but also directly enhance health and well-being. For example, that solidarity and doing things for the common good are associated with good health (physical, mental and social well-being) (*medium evidence*, *medium agreement*). Adaptation measures that leverage solidarity, equity, well-being, nature connectedness, and other qualities in the socio-ethical and ecological arenas, contribute both to sustainability outcomes such as physical and psychological health, a flourishing and meaningful life and well-being, and to enabling climate action (Gambrel and Cafaro, 2009; Capaldi et al., 2015; Soga and Gaston, 2016; Ives et al., 2017; Markevych et al., 2017; Woiwode, 2020). A shift in discourse to CRD comprising planetary and human well-being implies going beyond goals (SDGs) that can be reached in a technocratic manner through decision points to what constitutes well-being and equity at a deeper ethical and political level. These ethical and political dimensions include our place in humanity and in relation to non-human species, and in relation to self. For example, alienation from nature as well as social disenfranchisement forms part of a high-consumption led, inequitable model of 'development' that contrasts with health and well-being needs for social cohesion, identity, dignity, and nature connectedness (Restall and Conrad, 2015; Frumkin et al., 2017). Well-being can be seen as not only an end point of climate change impacts, but also as a starting point for understanding the deeper and qualitative dimensions of CRDPs and how engagement to generate them can be fostered. Within this enlarged solution space, we would find experiments such as the co-creation by the public 'urban spaces of possibility', a socio-material space where social interactions and processes are supported that empower people in shaping their local urban surroundings in a way that also leads to a re-imagining of sustainability and people's place in nature (Kagan et al., 2018).

18.4.3.1.2 Peace, justice and strong institutions (SDG16)

So far there is a lack of academic peer-reviewed empirical findings about the relationship between CRD and peace, justice and strong institutions framed explicitly within the context of the SDGs. A vast body of literature about related topics may contribute to shed light on the prospects of climate resilient, peaceful, just and inclusive development pathways. Conflict, injustice, weak institutions, discrimination and exclusion are significant drivers of differential vulnerability to climate change (Thomas et al., 2019). The achievement of SDG16 targets including, peace, justice, human rights, inclusiveness, non-discrimination, good governance, rule of law, transparency and accountability, are crucial aspects of longer-term vulnerability reduction and hence adaptation to reduce negative impacts of climate change on livelihoods and well-being. At the same time, climate change may put additional pressure on already fragile institutions and socio-political contexts, and could potentially act as a 'threat multiplier' (Buhaug, 2016; Hope Sr., 2020). This might challenge the achievement of objectives under SDG16, as well as several of the other goals.

Little evidence exists so far of adaptation projects that have focused on conflict resolution specifically; however, the potential for adaptation projects to support livelihoods incomes and resource management, and thereby reduce tensions and the risk of conflicts is often an explicit or implicit motivation for interventions.

Climate change adaptation and mitigation measures in themselves might also have an impact on conflict dynamics, justice provision, human rights, inclusion, and governance structures (Buhaug, 2016; Gilmore, 2017; Work et al., 2019). There is evidence that adaptation measures affect broader socio-environmental processes, resource governance and conflict dynamics (Babcicky, 2013; Abrahams and Carr, 2017; Work, 2019). There is *medium confidence* (*high agreement*, *low evidence*) that climate change adaptation policies and projects have the potential to exacerbate or shift conflict dynamics between or within different social groups. Few empirical studies explore these dynamics thus far, but studies from Bangladesh, Cambodia and Nepal found that climate change adaptation-related policies and projects were in many cases an underlying cause of natural resource-based (violent and non-violent) conflicts, as well as contributing to land dispossession and exclusion, entrenchment of dependency relations, elite capture, and inequity that take place through violent acts and which can intensify further conflict and violence as well as undermine local livelihoods (Sovacool, 2018; Sultana et al., 2019). So-called autonomous adaptation carried out by local populations as part of livelihood activities and daily decision-making can also contribute to social conflicts and contestations as shifts in behavior or livelihood patterns, such as in mobility and resource use, also affect others (Antwi-Agyei et al., 2018; Napogbong et al., 2020).

This recognition has fostered a call for conflict-sensitive adaptation approaches characterized by a deep commitment to the ethical principle of 'do no harm' (Babcicky, 2013). Studies of environmental peacebuilding and climate resilient peace emphasise that rather than triggering conflict, climate change can also foster people coming together for collective solutions, i.e., the potential for building more peaceful social and political relations through collaborative climate action, environmental cooperation, natural resource governance and disaster risk management (Matthew, 2014; Barnett, 2018; Dresse et al., 2018; Ide, 2020). Ide (2020) cautions that environmental peacebuilding also has its potential downsides, and it is crucial to avoid the six D's: depoliticisation, displacement, discrimination, deterioration into conflict, delegitimisation of the state, and degradation of the environment. The formulation of adaptation policies and action plans at sub-national levels are suggested as a means of strengthening community participation and equity. Limited evidence of such policy processes raise a concern that the opposite can at times also take place, with adaptation projects reinforcing top-down knowledge and decision-making processes, asymmetric power relations and elite capture of adaptation resources (Nightingale, 2017; Eriksen et al., submitted), undermining enablers of CRD in the political and knowledge-technology arenas.

18.4.3.2 Adaptation and Mitigation

Newer analysis proposes the possibility of managing mitigation trade-offs through offsetting compensation transfer payments (e.g., McCollum et al., 2018a). However, there are other factors to consider; in particular, compensation payments represent a reallocation of the mitigation costs borne by society. Society still bears the costs overall, but the compensation payments represent a re-distribution of the costs, shifting the trade-offs to other parts of society and implying an alternative set of priorities. Similarly, externality controls could cause unintended shifts in trade-offs. For instance, land protection or pricing land related emissions to manage land conversion associated with biomass for energy could imply even greater price changes for non-energy crops (e.g., Humpenöder et al., 2018), while controls for cross-border emission leakage could result in higher energy costs and lower net emissions reductions (e.g., Bistline and Rose, 2018). In addition, prioritising strategies has also been shown to shift trade-offs, with, for instance, constraints on mitigation options resulting in higher mitigation costs and potentially trade-offs in terms of losing the option to pursue climate goals (WGIII AR6 Chapter 3). All these effects are currently not well evaluated or fully understood.

18.4.4 Accelerating Transitions

Successfully implementing climate actions and managing trade-offs between mitigation, adaptation and sustainable development has important time considerations. 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 (*robust evidence*, *high agreement*).

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 18.5.3). 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 behavioural 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. Policies that seek to promote social justice and equity, for example, could ultimately catalyse 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 18.5.3.7). Ehnert et al. (2018) describe local organisations 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 organisations to appeal to local identities in order to mobilise 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 behaviours and process. 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). For example, Valta (2020) describes the role of innovation ecosystems – partnerships among companies, investors, governments, and academics – in accelerating innovation (see also World Economic, 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 organisation (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.

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., 2020a). 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 behaviours (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., 2020).

18.5 Enabling Climate Resilient Development

This section examines three themes that are critical to the transition to climate resilient: the political economy, a set of enabling conditions, actors who will engage with each other is a set of expanding arenas of engagement to enable the implementation of CRD.

18.5.1 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) on CRD are virtually non-existent. But there is extensive post-AR5 scholarship on the political economy of: climate change and development (Naess et al., 2015); vulnerability (Barnett, 2020); adaptation (Sovacool et al., 2015; Sovacool et al., 2017); and climate risk (Gotham, 2016); as well as energy (Kuzemko et al., 2019; Newell, 2019); decarbonisation, degrowth and low-carbon economies (Perkins, 2019; Newell and Lane, 2020); Negative Emissions Technologies (Honegger and Reiner, 2018; Markusson et al., 2018; Carton, 2019); solar radiation management (Ott, 2018); planetary health (Gill and Benatar, 2020) and sustainability transitions and transformation (Kohler et al., 2019). Four key insights are on the nexus of political economy and CRD are highlighted below.

First, the political economy drives coupled development-climate change trajectories and creates vulnerability – 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, adaptation agenda is depoliticized, and market-based panaceas advocated (Barnett, 2020).

Second, 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): 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., submitted).

Third, a long-held view is that mitigation is global and adaptation is local. A political economy perspective 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), 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., 2020a).

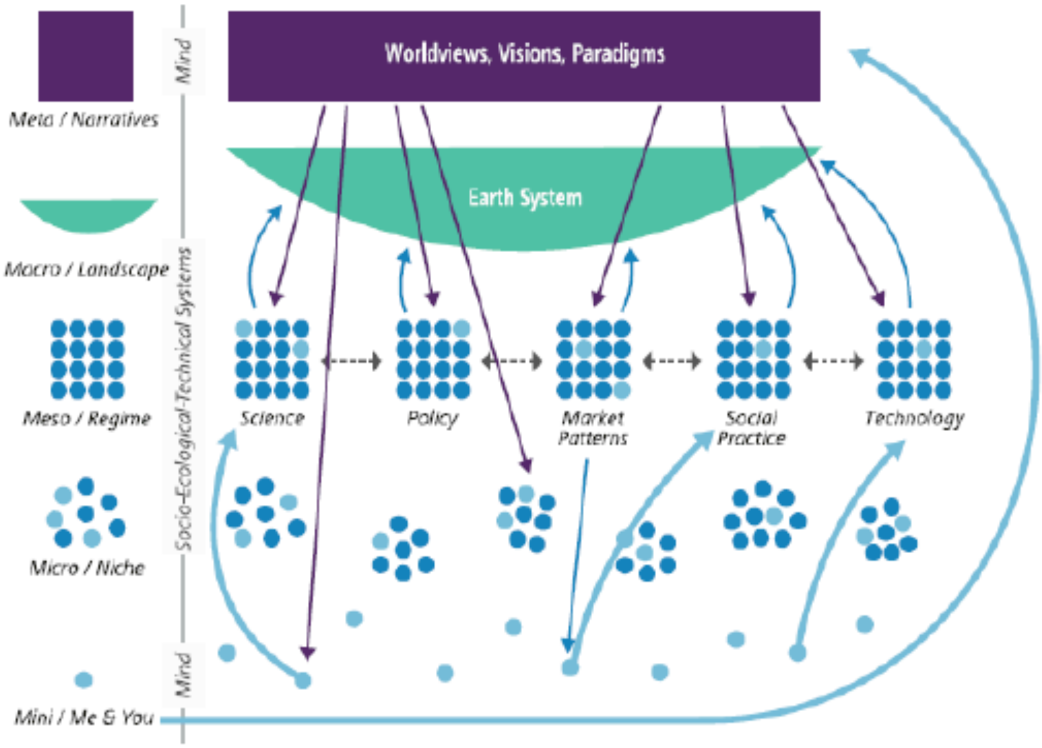

Figure 18.4: Mitigation for different global mean temperature outcomes on various development and sustainable development proxy variables. Example of 2050 global implications of mitigation for different global mean temperature outcomes on various development and sustainable development proxy variables. Figure note: 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.

The goal of CRD is to enable sustainable development to simultaneously ensure planetary health and human well-being. CRD describes the state of both natural and human systems at a particular juncture in space and time. It can be measured by progress against SD indicators, of which one example is the SDGs that run till 2030 i.e., the short-run in climate terms.

CRD is also the vector sum of complex multi-dimensional processes consisting of large numbers of actions and social choices made by multiple actors e.g., from government, industry, media, civil society and science. These actions and social choices are determined by the available solution space and options, along with a range of enabling conditions (Section 18.3) including governance (e.g., politics, institutions and practice), that are largely bounded by individual and collective worldviews, and related ethics and values. They are also influenced by key risks and vulnerabilities. Hence, CRD is not easily amenable to linear and simplified frames of analysis e.g., optimisation or cost-benefit analysis (Chapter 1).

These CRD-related processes are typically acted out in multiple levels (individual to the international) and arenas of engagement (political, economic, ecological, socio-cultural, knowledge, technological and community) that are explored in the section ahead (Figure 18.5). CRD outcomes (and normatively set goals) can help accelerate sustainable development and related CRD processes, such that limiting warming to 1.5°C via just transitions (see Section 18.2.2.2) and other sustainable development pathways.

CRDPs could, for example, aspire to achieve the goals of the Paris Climate Agreement as part of enabling planetary health, along with enabling human well-being, solidarity and social justice, and other political, economic and social sustainable development outcomes. CRDPs are typically dynamic and could be non-linear. Hence, they are not easily amenable to description via a linear aggregation of discrete decisions that mechanistically lead to pre-determined pathways.

This is in consonance with sustainable development being both an enacted and emergent *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 (Goldman et al., 2018; Heinrichs, 2020; Nightingale et al., 2020; Schipper et al., 2020a).

The ethical and political quality of sustainable development processes are instrumental in guiding CRD (Section 18.2.2) to address questions of intra- and intra-generational equity, identity and our place in humanity and in relationship to other species. In doing so, they would align with the core principles of the 2030 Sustainable Development Agenda (people, planet, peace, prosperity and partnership) that ideally pervade all five arenas of engagement, explored below (UN, 2015).

Outcomes, enablers and features of the development process can be characterised along five continuums, that align more strongly towards CRD towards the top of Fig 18.6.

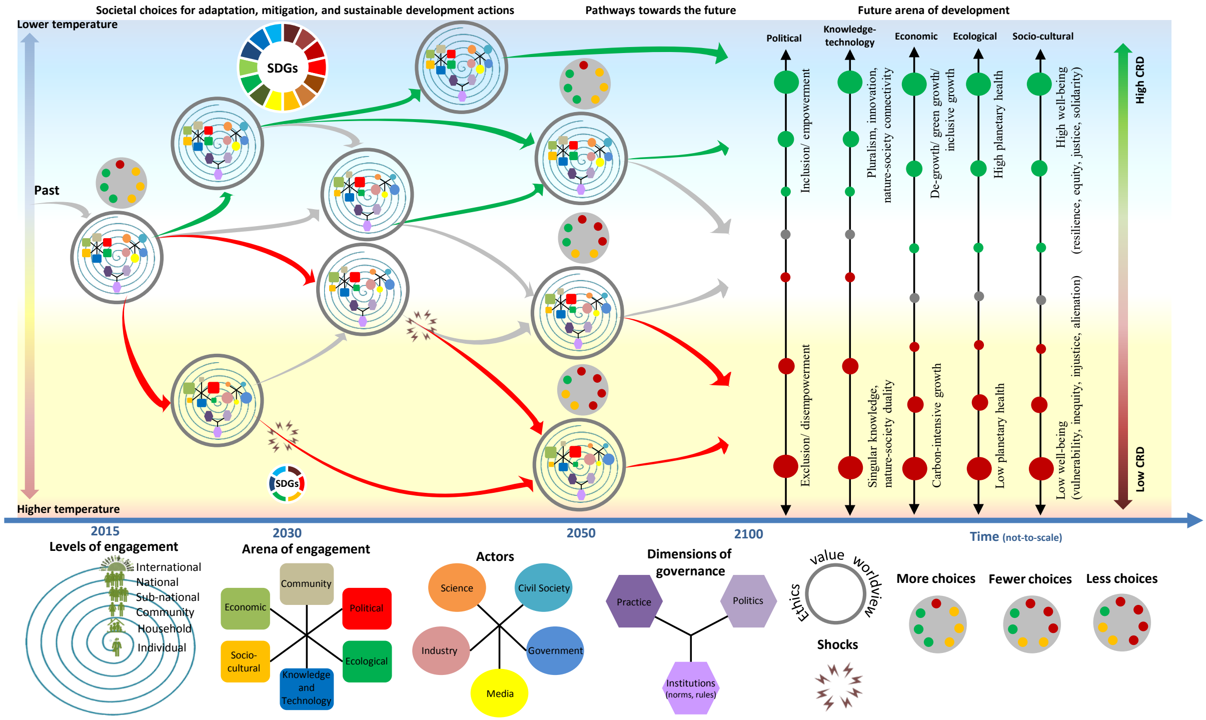

Figure 18.5: Climate Resilient Development Pathways

Pathways are the vector product of complex interactions between various enabling conditions and elements of governance that are bounded by worldviews, ethics and values. These five qualities pervade all sustainable development, adaptation and mitigation actions across key systems, regions, sectors and institutional types, including informal institutions. The extent to which sustainable development pathways align towards CRD depends on the depth and breadth of these features and synergies and trade-offs with and between them, in the system and/or region under consideration.

18.5.2 Enabling Conditions

The following section examines the role of key enabling condition (Section 18.3.2) of governance, policy, economics and sustainable finance, institutional capacity, science, technology and innovation, and monitoring frameworks on CRD.

18.5.2.2 Enabling Conditions of Governance for CRD

Translating enabling conditions of governance for CRD into practice depends on four actions: First, thwarting 'development solutions' and 'empty promises' that worsen climate risk, inequity, injustice and unsustainable development (Mikulewicz, 2018; Mikulewicz and Taylor, 2020) – from development aid

(Scoville-Simonds et al., 2020) and large-scale projects (e.g., biofuel project in Ethiopia, (Tufa et al., 2018) to urban growth management in Vietnam (DiGregorio, 2015). Second, recognising that power is not limited to resource access and influence but includes relational, productive, contingent and situated dimensions that are key to charting CRDPs (Ahlborg, 2017) (e.g., 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, developing enabling interactions between governments, the private sector and civil society, including providing 'safe arenas' for social actors to mobilise transitional and transformative change (Haukkala, 2018; Törnberg, 2018; Strazds; Ferragina et al., 2020; Koch, 2020). Fourth, operationalising inter-generational boundary spanning governance interventions to address the socially embedded, cumulative and synergistic interactions between development, climate change, equity and justice, and planetary health (Harvey et al., 2019; Hölscher et al., 2019), underscored by COVID-19 pandemic response and escalating disaster risk (Walch, 2019; Cohen, 2020; Schipper et al., 2020a; Wells et al., 2020).

18.5.2.3 Policy

The Paris Agreement 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): Art 7.1). The Nationally Determined Contributions (NDCs) are the core mechanism for increasing climate ambitions. SDG-relevant activities are increasingly incorporated in 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) reflecting the potential of the NDCs as policy instruments for CRD (McCollum et al., 2018b).

The mainstreaming of climate change concerns into development policies is also 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 depoliticising 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 SDGs and climate goals is nonetheless crucial for ensuring that the attainment of one does not come at the expense of others (Stafford-Smith et al., 2017).

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).

18.5.2.4 Economics and Sustainable Finance

18.5.2.4.1 Economics

Integrating climate resilience into growth and sustainable development planning is vital to reduce the costs of current climate variability, while preparing for the future effects of climate change. Climate change will affect many different economic sectors both directly and indirectly (Stern, 2007; IPCC, 2014a; Hilmi et al.), and the characteristics of economic systems will play an important role in determining their resilience. 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). 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) discussed some of the 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, to consider in the planning and application of adaptation measures that improve sustainability. Addressing climate impacts in isolation is unlikely to achieve equitable, efficient or effective outcomes. 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).

The focus of policies to affect private sector behaviour is largely 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. 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. The objective of these measures is to redirect investment from high to low carbon technologies (Komendantova et al., 2016).

Policies encouraging eco-innovation 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 (Costantini et al., 2018). 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). 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.

For a transition from dirty (more advanced) technology to clean (less advanced) one, carbon taxes and research subsidies need to be considered together, and an optimal policy makes heavy use of both of them (Acemoglu et al., 2016). 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 sector and would not generally lead to sustainable growth.

18.5.2.4.2 Climate finance

Recent evidence sheds light on the magnitude and pervasiveness of climate risks 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. However, when indirect exposures via financial counterparties are factored as well (Battiston et al., 2017), the share of assets subject to climate risks is much larger (40-54%). Hence, the magnitude of climate-change-related risks is substantial, and similar to the ones that started the 2008 financial crisis.

Besides measuring climate risks and acting on them (adaptation), the global financial system will be crucial in channelling capitals towards new green assets (mitigation) especially for clean power generation (OECD, 2017). By greening their investments portfolios, investors could, therefore, jointly reduce vulnerability to the consequences of climate change and contribute to the reduction of pollutant emissions.

Financial actors increasingly recognise that the generation of long-term, sustainable financial returns is dependent on a stable, well-functioning and well-governed social, environmental and economic systems (Shiller, 2012; Schoenmaker and Schramade, 2020). Institutional approaches to a variety of environmental domains (Krueger et al., 2019), which may not be exclusively based on a green strategy but also for financial gains, include: negative and positive screening, active ownership, targeted investments in green assets (e.g., green bonds, clean energy public equity) and specialized funds/vehicles such as renewable energy infrastructure (e.g., via project finance), cleantech venture capital and alternative finance (Gianfrate and Peri, 2019).

Sustainable finance can mitigate climate change and help adaptation strategies in several ways. In terms of mitigation, finance can contribute to the reduction of GHG emissions 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. At the same time, there is a growing need to spur greater public and private capital into climate adaptation and resilience.

On the other hand, the green mandates across the investment chain and investment definitions of some of the asset classes are still too ambiguous and poorly defined. The EU taxonomy for sustainable activities a promising step in the right direction. 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 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). Stable and predictable carbon-pricing regimes would significantly contribute to fostering financial innovation that can help further accelerating the de-carbonisation of the global economy even in jurisdictions which are more lenient in implementing climate mitigation actions (Baranzini et al, 2017).

A growing number of financial regulators are intensifying efforts to enhance climate-related disclosure of financial actors. Central banks are considering the possibility of steering or tilting the allocation of their assets to favour 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.

18.5.2.5 Institutional capacity

Institutional capacity for CRD 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. AR5 focused on the need for strong institutions that could create or facilitate enabling environments for adaptation and mitigation action (Denton et al., 2014). Institutions stand within the social and political practices that determine adaptation and development outcomes. They are thus produced by them and thus can become tools by which some actors constrain the actions of others (Gebreyes, 2018), and can become a significant barrier to transformational change. The post-AR5 focus on transformational adaptation and resilience suggests that institutions that enable 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 to CRD suggests that institutions are most effective when taking a development-first approach to adaptation. There is agreement in this literature that such an approach allows for the effective integration of climate challenges into existing policy and planning processes (Pervin et al., 2013; Kim et al., 2017; Mogelgaard et al., 2018). 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 desired development outcomes, and are therefore 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* for positive impacts on public service delivery, but more ambiguous evidence on behaviour 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.

18.5.2.6 Science, Technology & Innovation

The challenges to CRD increase as climate change impacts become increasingly significant (Stern, 2007; Goldstein, 2015; GCF, 2019). Policymakers need useful science (Kirchhoff et al., 2013; Calkins, 2015; IPCC, 2019c) to make informed decisions about possible risks, and best available adaptation and mitigation solutions (i.e., Article 4.1 of the Paris Agreement; UNFCCC, 2015). Deep social and technological changes are required to avert the social-ecological risks of conventional development trajectories (Gerst et al., 2013; IPCC, 2014a). One issue for CRD is to identify and implement appropriate policy mixes of adaptation and mitigation options that reduce net carbon emissions and support sustainable socio-economic development (IPCC, 2018a). An effective and innovative technological regime is one that links up 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, 2019c). These are often ignored in favour 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). This is because they 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.

18.5.2.7 Monitoring Frameworks

The monitoring and evaluation of CRD remains highly challenging for multiple reasons. The highly contextual nature of resilience and adaptation means that, unlike climate mitigation, it is difficult to impossible to define universal metrics or targets for adaptation and resilience (Pringle and Leiter, 2018), (Brooks et al., 2014). 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 on 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 (Brooks et al., 2014).

Brooks et al. (Barrett et al., 2020) identify three broad approaches to the measurement of resilience. 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 in which resilience is measured in terms of actual or avoided impacts, suited for tracking adaptation success in delivering CRD over longer timescales, for example at the national level (Brooks et al., 2014). A ‘systems’ approach, in which 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 (Brooks et al., 2014). See also Cross-Chapter Box ADAPT in Chapter 1.

18.5.3 Climate Resilient Development: Actors, Arenas & Modes of Engagement

The formal space for national, sub-national and international adaptation governance emerged at COP 16 (UNFCCC, 2010) when adaptation was recognised as a similar level of priority as mitigation. The Paris Agreement (UNFCCC, 2015) built on this and the 2030 Sustainable Development Agenda (UN, 2015) to link adaptation to development and climate justice, widening the ambit of adaptation governance beyond formal government institutions. It also highlighted the importance of multi-level adaptation governance, including new non-state voices and climate actors. This implied the need for wider arenas and modes of engagement around adaptation (Chung Tiam Fook, 2017; Lesnikowski et al., 2017; IPCC, 2018a).

Addressing climate change and sustainable development requires coordination and convergence between various levels of political authority and government (national, regional and local); integrating formal institutions (e.g., firms and civil society organisations), other actors (e.g., networks, informal institutions and communities) and citizens; into a common space to collectively solve problems, implement and scale-up solutions (IPCC, 2018a; Romero-Lankao et al., 2018).

These new institutional and informal arrangements are at an early stage of development in most regions. They need to be further clarified and strengthened to enable a sharing of resources and responsibilities to enable climate action to embrace equity, justice, poverty alleviation and sustainable 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.

18.5.3.1 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, that 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). They can also serve as significant barriers to transformational adaptation, based on anthropocentric, mechanistic and materialistic, worldviews and the utilitarian, individualist or sceptical values and attitudes they often promote (Beddoe et al., 2009; van Egmond and de Vries, 2011; Stevenson et al., 2014; Zummo et al.).

Traditional, modern and postmodern worldviews have different, and in many ways, complementary potentials for integrative approaches. They can also destabilise 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 have a competing ‘will to truth’ or belief in being the sole possessor of the truth. They can therefore, become incompatible or hostile to other worldviews, openly seeking to dominate, eliminate or segregate competing perspectives (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 in the understanding of reality, narrowing possibilities of understanding climate change and the solution space. Hence, 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 multiplicity of interpretations, meanings has led to multidisciplinary, transdisciplinary research and integral approaches to incorporate the humanities and the arts in general (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 domination exercise by certain worldviews exacerbates ontological, epistemic and procedural injustices. Research focuses aim at exploring the existing political ontology and knowledge politics of exclusion originated in academic, or scientific perspectives, including IPCC reports, 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 and local knowledge are inherently valuable (Mustonen, 2014) and often critically endangered ways of knowing that have, in the past, been suppressed, attacked, mocked, and only recently begun to be appreciated and valued on their own. These knowledge systems represent a range of cultural practices, wisdom, traditions, and ways of knowing the world that provide climate change information, observations, and solutions (*very high confidence*) (Table CCB INDIG.1). Indigenous knowledge refers to the understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings (UNESCO, 2018) IPCC, in press-b). Rooted in their own contextual and relative embedded locations, some of these knowledges represent unbroken engagement with the Earth, nature and weather for thousands of years, with an understanding of the ecosystem and climatic changes over longer-term timescales (Barnhardt and Angayuqaq, 2005; UNESCO, 2018). Indigenous Peoples around the world often hold unique worldviews that link today's generations with past generations. Local knowledge refers to the understandings and skills developed by individuals and populations, specific to the places where they live (UNESCO, 2018); IPCC, in press-b). The consideration of Indigenous knowledge and local knowledge is a priority in the assessment of adaptation futures (Chapter 1).

Indigenous knowledge and local knowledge are crucial to address 'post-normal' 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 overlooks the uniqueness of Indigenous knowledge and leads 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 utilisation of Indigenous knowledge have emerged from efforts to combine knowledge systems (*robust 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 the novel discoveries that may be still unknown to the scientific world but have been known by communities for centuries (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. That is, climate change assessment and adaptation for Indigenous Peoples should be 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; Barker and Pickerill, 2020). 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 will likely be shouldered 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 and poverty that often affect Indigenous Peoples (*very high confidence*).

International conventions to support and utilise Indigenous knowledge and local knowledge

Several tools in International Conventions may support instruments to develop equitable processes that facilitate the inclusion Indigenous knowledge and leadership in climate change adaptation initiatives. The United Nations' Declaration on the Rights of Indigenous Peoples (UN, 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, in press-c) (*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, in press-a) (*high confidence*). Limiting warming to 1.5°C necessitates building the capability of formal assessment processes to respect, include and utilise Indigenous knowledge and local knowledge (IPCC, 2018a) (*medium evidence*, *high agreement*). However, this has 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 scientific means (Gratani et al., 2011; Matsui, 2015). Such 'validation' is inappropriate, not necessary, can disrespect Indigenous Peoples' own identities and histories, and overlooks the structural drivers of oppression and endangerment that are associated with western civilisation (Ford et al., 2016).

Moreover, by underutilising Indigenous knowledge and local knowledge systems, opportunities that could otherwise facilitate adaptation action can be overlooked.

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 INDIG2). 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 example 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 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 (*robust evidence*, *high agreement*). Indigenous knowledge is taught, 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 knowledges 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 CCB INDIG.1: Examples of Indigenous knowledge and local knowledge about climate change used in this Assessment Report

Issue	Examples of Indigenous Peoples' action	Context, peoples, and location	Source
Climate forecasting/early warning	Phenological cues to forecast and respond to climate change	Smallholder farmers, Delta State, Nigeria	Chapter 9
	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	Chapter 14
	Sky and moon observation to determine the onset of rainy season	Maya, Guatemala	Chapter 12
Fire hazards	Prescribed burning	Indigenous nations in Venezuela, Brazil, and Guyana	Chapter 12
Crop yield / food security	Water management, native seeds conservation and exchange, crop rotation, polyculture, and agroforestry	Mapuche, Chile	Chapter 12
	Crop association (milpa) agroforestry, land preparation and tillage practices, native seed selection and exchange, adjusting planting calendars	Maya, Guatemala	Chapter 12

	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	Chapter 14
Livelihood and well-being	Cultural values ingrained in knowledge system: reciprocity, collectiveness, equilibrium, and solidarity	Quechua, Cusco, Peru	Chapter 12
Ecosystem degradation	Ecosystem restoration including rewilding	Sámi, Nenets, and Komi	Chapter 13
	Collaboration with researchers, foresters, and landowners to manage native black ash deciduous trees against emerald ash borer	Wabanaki Nations, Maine	Chapter 14
	Selection and planting of native plants that reduce erosion Whole-of-island approaches that embed IK and LK in environmental governance	Small Islands	Chapter 15
Fisheries	Traditional climate-resilient fishing approaches	Indigenous populations across North	Chapter 14
Managing of urban resources	Restoration of traditional network of water tanks	Traditional communities and activists in South Indian cities such as Bengaluru	Chapter 6

Table CCB 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 weather forecasts. 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).
Australia	In Australia, Indigenous Peoples have many practices rooted in Indigenous knowledge relating to climate change. Oral stories by the coastlines describe the process of the sea level rising with accurate details about previous land limits and depth of the ocean (Nunn and Reid, 2016). In Northern Australia, local knowledge of seasonal change indicates the flowering of trees and emergence of other food sources (Lyons et al., 2019). In the rural East Kimberley region, locally specific knowledge of ecological change can inform climatic models. The Miriwoong people of the East Kimberley, for example, "use a specific type of heavy rain 'that flattens the spear grass' as an indicator of the end to the wet season. In recent years such rain has not occurred, indicating a subtle shift in climatic patterns" (Leonard et al., 2013).
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 (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 and Clarke, 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); Cross-Chapter Paper 6; (Feodoroff, 2020; Ogar et al., 2020). 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 (Pecl et al., 2017; Brattland and Mustonen, 2018; Mustonen and Shadrin, 2020).

[END CROSS-CHAPTER BOX INDIG HERE]

18.5.3.2 Actors as critical agents of change

Since AR5, evidence on diverse forms of engagement by 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, art-based interventions, civil participation and partnerships with business (Ziervogel et al., 2016; 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 requires close attention to institutional and power dynamics and multidimensional operational approaches on the ground (Buggy and McNamara, 2016; Camargo and Ojeda, 2017; Silva Rodríguez de San Miguel, 2018). Equity and justice as explicit adaptation concerns also imply the need to include a wider range of actors in decision-making (Atteridge and Remling, 2018).

Actors are not only agents of behavioural change such as via change in their consumption patterns, but can also generate change within organisations, fields of practice and the political landscape of governance (Ojha et al., submitted). Such agency is rooted in ethics, commitment to social justice, and the inner world of worldviews, beliefs, values and consciousness (Woiwode, 2020; Ojha et al., submitted), highlighting the importance of rehumanising climate interventions and engagement (Mikulewicz, 2019). Agency is simultaneously personal and political, legitimacy and the space to act produced through socio-political relations, including the way formal policy processes recognise the voices, knowledges and rights of particular actors over others (Harris and Clarke, 2017; Nightingale, 2017; Bond and Barth, 2020; Muok et al.).

Engagement can take the form of entrepreneurship and creativity, civil mobilisation and disobedience, various forms of dissent and youth activism, as well as acts of everyday resistance within the workplace (O'Brien et al., 2018; Walsh and Dillard-Wright, 2020), 2019; (Hall, 2020). Not all engagement supports sustainable development outcomes, however. Some actors both at community and global scales actively seek to entrench existing inequities and patterns of pollution, highlighting how the resilience of unsustainable development may be the objective for some actors, and the importance of questioning the resilience of what and for whom (Carr, 2019; Meerow and Newell, 2019; Gill and Benatar, 2020).

18.5.3.3 Government arenas, actors and modes

A wide range of actors are involved in successful adaptation policy and practice, ranging from national, regional and local governments, communities and international agencies (Lwasa, 2015). This 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, with supporting practice architecture to accelerate adaptation is needed. Key enablers are enhanced funding, clear roles and responsibilities, increased institutional capability, strategic approaches, community engagement and 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 organisations. (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). This view has now widened with the recognition that adaptation is a multi-actor process that transcends scales from the local and sub-national to national and international (Mimura et al., 2014). 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. Yet, 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 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)(Massey and Huitema, 2016). National policies and transnational governance should be seen as complementary, especially where they favour transnational engagement with sub- and non-state actors (Andonova et al., 2017).

Local governments have demonstrated leadership in implementation by collaborating with the private sector and academia. But they need more funding for this from national government (Dekker, 2020). Local governments can 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).

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 adaption 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).

18.5.3.4 Economic arenas, actors and modes

18.5.3.4.1 Measuring the economic effects of climate change?

The way our economy works now is unsustainable (Washington and Twomey, 2016). Endless growth is not possible on a planet with finite resources. GDP is the most used indicator of economic growth. Hoekstra (2017) explains why GDP is the superstar of indicators and why going beyond GDP is challenging. Some economists argue that the focus of the new post–gross domestic product economy should be well-being with material output no longer a priority and they propose alternative indicators to GDP (Hilmi et al., 2015). Accordingly, what is needed to measure well-being as prosperity is the "missing link" that connects evolving policy and the economy with sustainable development for a healthy Anthropocene era (Fioramonti et al., 2019).

Another way to include environmental data in the System of National Accounts (SNA) is 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 and resolves the erroneous calculation of macroeconomic estimates (Jendrzejewski, 2020). The most recent studies using this method are: (Pirmana et al., 2019; Jendrzejewski, 2020; Naspolini et al., 2020), (Banerjee et al., 2019; Kabir and Salim, 2019; Keith et al., 2019).

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.

One alternative indicator of GDP and economic growth is called Green GDP which includes the environmental consequences of unending economic growth (Boyd, 2007; Stjepanović et al., 2017; Stjepanović et al., 2019). The problem is that Green GDP is hard to measure because it is very difficult to evaluate the environmental depletion and ecological damages of growth (Stjepanović et al., 2019). There is no consensus in measuring Green GDP; however, studies have attempted to evaluate it for some countries including the US (Garcia & You, 2017), Europe (Stjepanović et al., 2019), China (Chi and Rauch, 2010; Yu et al., 2019; Wang et al., 2020), Ukraine, Thailand (Harnphatananusorn et al., 2019), and Malaysia (Vaghefi et al., 2015). Le (2016) showed a negative impact of climate change vulnerability on green growth. However, focusing on green growth as the only strategy to address climate change would be risky due to various barriers to the fast decoupling of GHG emissions from economic output (Antal and van den Bergh, 2014).

Ocean conservation is important for climate change mitigation in the path of Blue Growth (Mustafa et al., 2019). Synthesized data has been used to investigate the role of blue growth in climate change mitigation (Froehlich et al., 2019). Lillebø et al. (2017) discuss how ecosystem services (ES) can support Blue Growth. Sarker et al. (2018) discussed the link between Blue Growth and achieving Sustainable Development Goals (SDGs) for Bangladesh. Soma et al. (2018) suggested social innovation as a strategy to achieve Blue Growth in the EU. Larik et al. (2017) discussed policies for creating an inclusive and cooperative governance structure for the Indian Ocean to achieve blue growth and go through sustainable development.

A different approach proposed by ecological economists is Degrowth (e.g., Kallis, 2011; Demaria et al., 2013) and managing without growth (e.g., Jackson, 2009) for rich countries as a solution for achieving environmental sustainability and socio-economic progress. It is a response to ecological limits to growth (Kallis et al., 2009). Sustainable degrowth is not the same as negative GDP growth which has the nickname "recession" (Kallis, 2011). Degrowth goes beyond criticising economic growth; it is looking for achieving environmental sustainability, social justice, and well-being (Demaria et al., 2013).

Under current conditions de-growth is unstable because declining consumer demand leads to rising unemployment, falling competitiveness and a spiral of recession (Jackson, 2009: 46).

18.5.3.4.2 Inserting climate change into Macroeconomic policies

The link between economic growth and CO2 emissions is being increasingly questioned (Hilmi et al., 2015). The European Central Bank decided to green its monetary policy. And some oil-exporting countries find advantages in transforming their economies (Hilmi et al., 2020).

In 2018, governments raised about $44 billion in carbon pricing revenues (World Bank, 2019). Yet, current carbon prices are lower than the levels required to attaining ambitious climate change mitigation and will need to increase. This will be possible through increasing public acceptability of carbon pricing by the appropriate uses of its revenues under different economic and political circumstances (Klenert et al., 2018).

The social cost of carbon as an important index of interaction between climate and the economy, and is affected by both climate and economic risks (Cai and Lontzek, 2018).

Greenhouse gases emissions are growing and current policies seem unable reduce them. Davis and Knittel (2018) argue that to reduce carbon dioxide emissions, many countries use fuel economy standards which are generally considered as less efficient.

Enabling domestic carbon tax policies to emerge as part of a global solution is important to help address this (Metcalf, 2019). As an example, in the United States, a carbon tax could increase fiscal flexibility by collecting new revenues to finance reforms and helps economic growth. This approach is more effective than cap and trade policies. Furthermore, Congress should enable carbon tax revenue being returned to taxpayers (Metcalf, 2019). Casey (2019) finds that in the United Sates tax-inclusive energy prices, as an environmental policy to mitigate climate change, must be 273% higher than laissez faire levels in 2055 in order to meet international agreements. The implementation of a carbon tax and a value-added tax on transport fuel in Sweden, CO2 emissions from transport decreased about 11% in which the carbon tax had the largest share. (Andersson, 2019).

Applying green fiscal policies to address local and global externalities would lead to environmental benefits; this later would help to gain environmental revenues that may be used for broader fiscal reforms. Moreover, a package of environmental and non-environmental reforms can result a better efficiency and better respond to distributional concerns. 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 effects of climate change in various regions around the world are very different; hence, there are relative effects rather than average effects. Although the average effect of carbon tax on welfare would be positive, some regions (56%) will gain and some regions (44%) lose. Therefore, large transfer payments are needed to compensate those losing from carbon tax (Krusell and Smith, 2018).

18.5.3.5 Political Arenas, Actors and Modes for CRD

CRD is embedded in social systems, in the political economy and its underlying ideologies, interests and institutions (see 18.5.1). The struggle for CRD, and transitions away from prevailing development pathways, 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, as the political nature of CRD is revealed, post-AR5 literature shows how there is a closing down of political 'space' in many settings (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).

Beyond the structural abstraction of institutions, economies, politics and media, everyday interactions unfold in historically situated and relational settings in which people can be included or excluded in collective action (Siméant-Germanos, 2019), including for CRD. In this lies the transformative potential of small-scale collective environmental action in political settings as diverse as the UK (MacGregor, 2019) and China (Huang and Sun, 2020).

In addition to the 'arm's length' acts of voting, social mobilisation, protest and dissent can be critical junctures, catalysts and arenas for democratic rupture and transformative change (Porta, 2020). These are struggles for recognition and authority (Nightingale, 2017) that take place in settings as diverse as the energy sector in Bangladesh (Faruque, 2017) and Germany (Becker et al., 2016). Experience in Bolivia shows that the transformative potential of political struggles depend on transcending narrow issues to form broad coalitions with a collective identity capable of subverting the dominant institutional order; ambitions for emancipatory democracy transcending the scope of the state. In practice, such projects tend to dissolve within the prevailing institutional architecture, and yet remain vital to counter the adverse impacts of prevailing development trajectories (Andreucci, 2019).

The community can be a vanguard against environmentally destructive practices (Villamayor-Tomas and García-López, 2018). Social movements can counter fossil fuel extraction (Piggot, 2018) and open up political opportunities in the face of a rising tide of climate-related resource capture (Tramel, 2018), bolstered by resistance from within some corporations (Fougère and Bond, 2016; Swaffield, 2017).

Yet, there has been a simultaneous rise of political conservatism and populism in this post-truth era (Mahony and Hulme, 2016; Swyngedouw, 2019). Climate change may constitute a grand-scale cultural trauma, the prospect of which results in social inertia compounded by efforts to maintain the status quo (Brulle and Norgaard, 2019). Intentional transformational change at scale depends on political innovation and imagination, and insights might be gained from fiction (Milkoreit, 2017). 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).

18.5.3.6 Knowledge, Science & Technology, Media Arenas, actors and modes

While knowledge may be power, it is inequitably distributed (Mormina, 2019). Scientific inputs may be useful, but in some cases, remain subordinate to political agendas. Hence, connecting science with policy is challenging for both scientists and policymakers.

Participatory decision-making, for example, assumes that multiple actors, with differing motivations, agency and influence, engage with climate decision making and co-produce actions. However, some of these actors may not participate in this process, if the proposed actions do not align with their motivations (Section 18.5.3.2) or if they do not have adequate agency (Roelich and Giesekam, 2019).

Science, technology and innovation (STI) policies are expected to shape expectations of the potential for a better world based on clean technologies, higher labour productivity, economic growth and a healthier environment (Schot and Steinmueller, 2018; Mormina, 2019). However, top-down control may overstate how effective these proposed actions may be. STI is considered as 'social goods for development'. Hence, the increasing need use to STI policies to align responses to climate change, reduction of inequality and poverty and pollution (Mormina, 2019).

Even science communication is changing, 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 mobilising communities through citizen science (Heigl et al., 2019). This also presents opportunities to incorporate local knowledge with scientific research, and better match scientific capability to societal needs.

The engagement of the private sector in CRD is a welcome development and a major economic opportunity expected to also benefit the next generation (see Box 18.5).

[START BOX 18.5 HERE]

Box 18.5: The Role of the Private Sector in CRD via Climate Finance, Investments and Innovation.

Climate finance broadly refers to resources that catalyse 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 18.5.2.4 and 18.5.3.4).

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).

[END BOX 18.5 HERE]

18.5.3.7 Community arenas, actors and modes

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 (see Chapters 1, 6, 8, 10 and 17).

At the formal end of the spectrum, 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 behaviour 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).

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. Calling for enhanced climate action by governments and other societal actors, the youth movement was supported by many other societal groups and networks.

At an individual level, researchers are documenting clinically significant levels of climate distress (Bodnar, 2008) experienced as a continuing distress over a changed landscape which no longer offers solace, also known as solastalgia (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 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 fulfils many of these needs.

While the SR1.5 (de Coninck et al., 2018) for the first time comprehensively assessed behavioural dimensions of climate change adaptation, most literature still has a greater focus on what triggers mitigation behaviour, less so on adaptation behaviour (Lorenzoni and Whitmarsh, 2014; Clayton et al., 2015) while there is little literature to assess on what motivates action towards CRD (also see Chapters 1, 8, 17).

18.5.4 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 mobilisation necessary for deep societal transformation (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 (Lee et al., 2020; Thackeray et al., 2020) and has helped rethink the role of science with society (Isgren et al., 2019). 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. Their methods have also proven effective to end fossil fuel sponsorship (Civicus, 2020). 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. New climate movements have shown new mechanisms to accelerate social transformation.

18.6 Conclusion

18.6.1 Knowledge Gaps

Researches to improve the understanding of CRD has not progressed much as "integrating climate change mitigation, climate change adaptation, and sustainable development is a relatively new challenge" (Denton et al., 2014). The identified research gaps in AR5 (Denton et al., 2014) continued to be of interest – "researches on factors that influence deliberate transformations that are ethical, equitable, and sustainable; and, researches on strategies for institutional development, including improving understanding of how social institutions affect resource use , improving understanding of risk related judgment and decision-making under uncertainty and best practices in creating institutions that will effectively integrate climate change responses with sustainable development characteristics such as participation, equity, and accountability".

Climate science can support planners in making informed decisions on future investments aimed at optimising the use of scarce resources available to developing country governments and sub-national entities. Yet there is a lack of evidence for and detailed understanding of gaps in the uptake of science for long-term strategies for climate-resilient development. There is a need to improve the science-policy interface (Winterfeldt, 2013; Jones et al., 2014; Ryan and Bustos, 2019) for: risk and science communication; decision analysis and decision support system; critical knowledge deficits that affect climate change policy making and implementation; and, obstacles and difficulties facing collaborative processes of knowledge co-production between scientists and public policy actors.

Chapter 1 of this Report framed a climate resilient development pathway (CRDP) as a pathway that emerges in the future consisting of an assemblage of many decisions taken by many actors over time. These decisions could be challenged by large uncertainties and unprecedented changes in the long term, and the fact the the different actors across disciplines have varied understanding and appreciation of issues at hand (Moser, 2016). Chapter 18 assessed the advances in conceptual and methodological understandings of a climate resilient development (CRD), and tools to support research on, multiple drivers of CRDPs; possible feedback effects among mitigation, adaptation, and development; possible thresholds/ tipping points that could cause particular challenges for development; and possible transformations to reduce losses and damages and support sustainable development.

The SROCC (IPCC, 2019b) stated that "In light of observed and projected changes in the ocean and cryosphere, many nations will face challenges to adapt, even with ambitious mitigation (*very high confidence*). Profound economic and institutional transformative change will enable Climate Resilient Development Pathways in the ocean and cryosphere context (*high confidence*). But as to how, knowledge gaps still exist. CRD would benefit from further conceptualisation through the following dimensions:

- How resilience can be appraised under dynamic, diverse and unexpected drivers and shocks
- How co-evolutionary dynamics across scales can be accounted for in CRDP
- How deliberative, participatory learning can be integrated in CRDP approaches, representing the diversity of knowledge types, governance regimes and decision hierarchies
- How to connect future pathways and the current trajectory of a social-ecological system
- How transformation (Scoones et al., 2020) and its utility to climate resilient development can be understood (Vermeulen et al., 2018), and,
- How governance regimes can be conducive in transforming at various scales current development patterns onto long-term CRDPs

18.6.2 Conclusions

The concept of CRD presents an ambitious agenda for actors at multiple scales – global to local, particularly in the manner 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 objectives 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. Current policy objectives 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 18.4.5), 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 (Section 18.4.4).

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, 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, 2019a; IPCC, 2019b) 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 18.5.3). This includes formal policy mechanisms pursued by governments, the catalysation 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 alternative pathways by which actors can achieve their development and climate objectives 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 operationalising 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 non-participation (Jenkins et al., 2018; Fisher et al., 2019; Schipper et al., 2020a). These consequences could ultimately slow, rather than accelerate, CRD. Hence, developing programs and practices for prioritising 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 energy transitions. 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 policies and practices that promote of human and ecological well-being.

Frequently Asked Questions

FAQ 18.1: 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 liveable 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.

FAQ 18.2: 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.

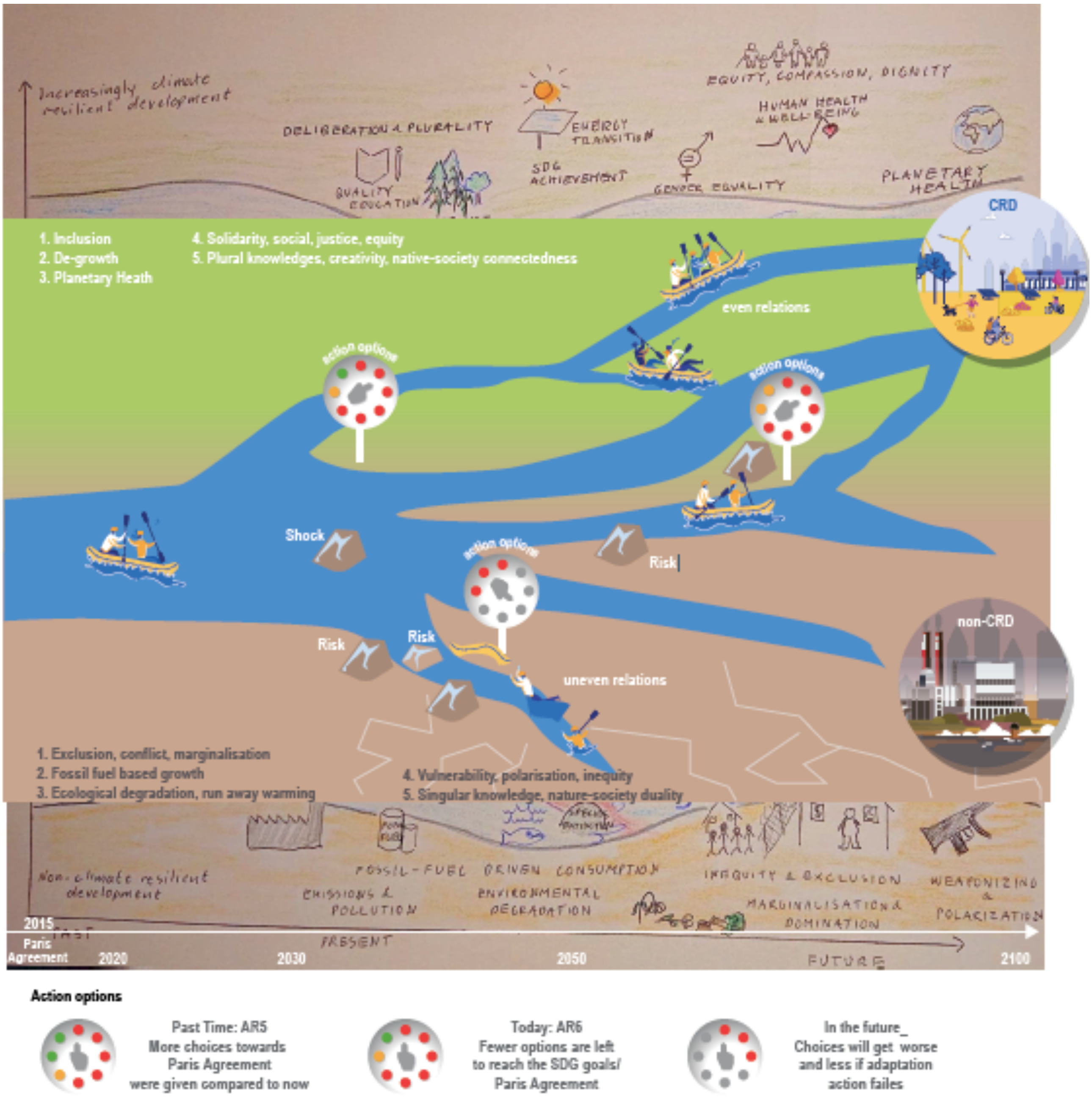

Figure FAQ 18.2.1: Multiple intertwined climate resilient development pathways [PLACEHOLDER FOR FINAL DRAFT: Figure will be updated to include time line and icons for increasing climate resilient development (top) and non-climate resilient development (bottom)]

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, polarisation, 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.

FAQ 18.3: 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, marginalisation, 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.

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 visualise 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 an 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.

FAQ 18.5: 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 prioritise 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 SR1.5C

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CCB FEASIB.1 Scope

The Paris Climate Agreement marked a significant shift of IPCC AR6 assessment focus towards a structured and systematic exploration of climate solution spaces, and a suite of linked implementation options (IPCC, 2018; IPCC 2019 a, b). This was initiated in the SR1.5, whose plenary approved outline sought to define "the potential for development and deployment of adaptation and mitigation responses to accelerate transitions within and across scales and systems (e.g., food production, cities)" (IPCC, 2016). Based on this mandate, SR1.5C identified (with high confidence) rapid and far-reaching transitions in four systems: energy, land and terrestrial ecosystems, urban and infrastructure (including transport and buildings) and industrial systems, necessary to enable pathways to limit global warming to 1.5°C (IPCC, 2018; Bazaz et al., 2018). This was deepened for terrestrial systems in SRCCL, while SROCC added additional evidence from ocean and cryosphere systems. A notable addition is the feasibility of carbon-dioxide removal as an adaptation option: Compared to previous Assessment Reports, it is clear that the ambitious temperature targets agreed upon in Paris in 2015 will require at least some removal of CO_2 (CDR) – all of the 1.5°C pathways featuring yearly removals at Gigaton level (Rogelj et al. 2018). At this level, it is important to also assess the interaction this might have with adaptation. The feasibility assessment will cover those CDR options, which also feature adaptation characteristics, i.e., afforestation and restoration of ecosystems, but which may – depending on implementation also lead to maladaptation. Other CDR options will clearly interact with adaptation in the sense that expensive CDR strategies will consume resources no longer available for adaptation, evidently. However, the corresponding literature is scant, and this is a major knowledge gap.

The assessment of feasibility of adaptation options is situated within the four systems transitions identified in SR1.5 (de Coninck et al. 2018). Feasibility is defined as "the degree to which climate goals and response options are considered possible and/or desirable" (IPCC 2018). Feasibility depends on geophysical, ecological, technological, economic, social and institutional conditions for change and these conditions are understood as dynamic, spatially variable, and variable between different groups. 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 16.1).

This cross-chapter box presents a global multi-dimensional 1.5ºC-relevant feasibility assessment undertaken around six feasibility dimensions: economic, technological, institutional, socio-cultural, environmental and geophysical, using a structured set of indicators and questions to facilitate an expert-led judgement of available and relevant literature (Singh et. al, 2020, de Coninck et al. 2018). Select Regional and sectoral chapters assess the temperature elevation agnostic feasibility of options in their particular contexts.

[PLACEHOLDER FOR FINAL DRAFT: potential forthcoming AR6 regional feasibility assessments]

There has been growing research emphasis on synthesising adaptation literature through meta-reviews of adaptation readiness (Ford and King 2015; Ford et al. 2017); adaptation progress (Araos et al. 2016); adaptation barriers and enablers (Biesbroek et al. 2013; Eisenack et al. 2014; Barnett et al. 2015); and adaptation outcomes (Owen et al. 2020) (Cross-Chapter Box ADAPT in Chapter 1, Nalau et al.). 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. 2020)(Chapter 17, Section 17.5.2 on Successful Adaptation). Effectiveness studies often use metrics such as 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.

<table>
<tr><th>Systems transitions
RKRs</th><th>Energy Systems Transitions</th><th>Land and Ecosystems Transitions</th><th>Urban & Infrastructure Systems Transitions</th><th>Overarching Adaptation Options</th></tr>
<tr><td rowspan="2">Risk to coastal socio-ecological systems</td><td rowspan="2"></td><td>Coastal defence and hardening</td><td rowspan="2"></td><td rowspan="16">Social safety nets

Risk Insurance

Disaster risk management, Climate services, including EWS

Public health systems

Resettlement, relocation and migration (including planned relocation)</td></tr>
<tr><td>Sustainable aquaculture</td></tr>
<tr><td rowspan="3">Risk to terrestrial and ocean ecosystems</td><td rowspan="3"></td><td>Integrated coastal zone management including wetland, mangrove conservation</td><td rowspan="3"></td></tr>
<tr><td>Reforestation/afforestation/ forest protection, biodiversity management, conservation</td></tr>
<tr><td>Ecosystem connectivity</td></tr>
<tr><td rowspan="2">Risks associated with critical physical infrastructure, networks, and services</td><td rowspan="2">Resilient power infrastructure</td><td rowspan="2"></td><td>Green infrastructure & ecosystem services</td></tr>
<tr><td>Sustainable land-use & urban planning</td></tr>
<tr><td>Risk to living standards and equity</td><td></td><td>Livelihood diversification</td><td></td></tr>
<tr><td>Risk to human health</td><td colspan="3"></td></tr>
<tr><td rowspan="5">Risk to food security</td><td rowspan="3"></td><td>Improved cropland management (including integrated soil management, conservation agriculture)</td><td rowspan="3"></td></tr>
<tr><td>Farm level adaptation: e.g. diversifying/changing crops/animals, timing, irrigation, gene technology</td></tr>
<tr><td>Efficient livestock systems (including improved grazing land management)</td></tr>
<tr><td></td><td>Agroforestry</td><td></td></tr>
<tr><td></td><td>Behavioural change with regards to food: reducing waste, dietary change</td><td></td></tr>
<tr><td>Risk to water security</td><td>Improve water use efficiency</td><td>Water use efficiency and water resource management</td><td>Sustainable urban water management</td></tr>
<tr><td>Risk to peace and migration</td><td colspan="3"></td></tr>
</table>

Figure CCB FEASIB.1: Feasibility assessment option mapped against Representative Key Risks (RKRs)

CCB FEASIB.2 Methodology

In SR1.5, the feasibility of adaptation options is defined as ‘the degree to which climate goals and response options are considered possible and/or desirable’ (Allen et al. 2018). Multi-dimensional feasibility of adaptation options is assessed using a ‘barriers approach’ (Singh et al. 2020). The approach examines what constrains adaptation, by assessing feasibility across six dimensions: economic, technological, institutional, sociocultural, geophysical, and environmental feasibility. This multidimensional framework goes beyond technical or economic feasibility alone to capture how adaptation is mediated by the political environment and agents, sociocultural norms and contexts (Evans et al. 2016), cognitive 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 20 indicators. Each adaptation option is scored as having high, medium or low evidence on barriers based on a review of literature that is 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) and that reports from studies that are 1.5C relevant. The indicator-level scores are combined using arithmetic mean. The assessment also identifies gaps in the literature, either on particular indicators or from particular regions.

The scoring process is undertaken by one author and reviewed by at least two more authors to ensure robustness and geographical coverage. To demonstrate how feasibility differs by context, the last column showcases how local context mediates feasibility. 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 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 are shown at the end of this section in Figure CCB FEASIB.2.

CCB FEASIB.3.1 Energy systems transitions

The adaptation options assessed for energy system transitions resilience of existing power infrastructure and water management, focused on water efficiency and cooling, for all types of generation source. Since SR1.5, there has not been significant change in the feasibility of the options as they continue to be implemented successfully, allowing for power generation to maintain or increase its reliability and service (Zhang, et.al., 2018; DeNooyer, et.al., 2016; Ali and Kumar, 2016). As in the case of SR1.5, these options are not sufficient for the far-reaching transformations required in the energy sector, which have tended to focus on technologies to shift from a fossil-based to a renewable energy system (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).

For both options, the socio-cultural feasibility dimension is considered *not applicable* as both options are implemented in existing power generation systems that are either privately or government operated and have no interaction with populations and communities. There is *medium evidence and high agreement* for the medium feasibility of environmental and geophysical dimensions, with the main benefits focused on the improvement to freshwater sources of a diminished use of water. There is *high evidence and high agreement* on the technological feasibility of both options. For resilient power infrastructure, there is medium economic feasibility (*medium evidence, medium agreement*), however, this is dependent upon the generation source and location of each specific generation plant. There is medium institutional feasibility (*medium evidence, medium agreement*) as there is a lack of policies or regulations for resilient infrastructure, although there is high acceptability for these options. In the case of water efficient options, there is high economic and institutional feasibility. In this case, there is high political acceptability, existence of water use policies and regulations as well as the institutions and frameworks to ensure their compliance (Zhang, et.al., 2018; DeNooyer, et.al., 2016; Ali and Kumar, 2016).

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 & hardening ("hard engineering"), as adaptation measures. Economic and social viability potentially limit the feasibility of these options as they usually represent high investments (both construction, maintenance and monitoring) (Hamin et al., 2018; Magnan and Duvat, 2018; Morris et al., 2018, 2019; Hanley et al., 2020). There is also emerging literature identifying that these kinds of measures benefit more wealthy sectors of the society, increasing the vulnerability of already vulnerable populations (Siders and Keenan, 2020). Additionally, they are considered as non-adaptive (i.e., non 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; Hanley et al., 2020) and unsustainable measures in some contexts (i.e., negative impacts on local environment and communities, ecosystem services, etc.)(Morris et al., 2018, 2019; Foti et al., 2020; Hanley et al., 2020). There are generally few synergies with environmental, ecological and geophysical aspects, and they can have negative impacts on ecosystem services, natural habitats, and may not be able to cope with the changing climate (Antunes Do Carmo, 2018; Hall et al., 2018; Morris et al., 2018, 2019; Foti et al., 2020; Hanley et al., 2020).

CCB FEASIB.3.2.2 Sustainable aquaculture

There is mixed evidence on economic and social aspects regarding how vulnerable communities and small-scale fisheries could benefit from this option, which includes economic social and health aspects (nutrition might be affected when access to fish supply is limited) (Shaffril et al., 2017; Blasiak and Wabnitz, 2018; Chan et al., 2019; Galappaththi et al., 2020). Access to financial resources is a barrier to implement this option, although there is evidence on the economic feasibility of sustainable aquaculture which has potential to increase employment opportunities as well as increase resilience of coastal livelihoods to climate change (Shaffril et al., 2017; Blasiak and Wabnitz, 2018). Recent literature has highlighted the importance of technological (Shaffril et al., 2017; Blasiak and Wabnitz, 2018; Aubin et al., 2019; Galappaththi et al., 2019), institutional (Shaffril et al., 2017; Blasiak and Wabnitz, 2018; Le Cornu et al., 2018; Aubin et al., 2019; Blasiak et al., 2019; Galappaththi et al., 2019), and socio-cultural factors for the implementation of sustainable aquaculture (Shaffril et al., 2017; Blasiak and Wabnitz, 2018; Aubin et al., 2019; Galappaththi et al., 2019, 2020).

CCB FEASIB.3.2.3 Integrated coastal zone management

Marsh management, vegetation of shorelines, community based 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 as part of ICZM. 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; Le Cornu et al., 2018; Propato et al., 2018; Rosendo et al., 2018; Warnken and Mosadeghi, 2018; Hamin et al., 2018; Morecroft et al., 2019; Morris et al., 2019; Alves et al., 2020; O'Mahony et al., 2020; Donatti et al., 2020; Erftemeijer et al., 2020; Foti et al., 2020; Gómez Martín et al., 2020; Hanley et al., 2020; Jones et al., 2020; Krauss and Osland, 2020) . Diverse socio-economic co-benefits have been identified of ICZM (tourism activities, reduction of storm damages, increasing adaptive capacities at institutions) (Morris et al., 2019; Donatti et al., 2020; Erftemeijer et al., 2020; Gómez Martín et al., 2020; Hanley et al., 2020; Jones et al., 2020), as well in environmental and geophysical benefits (mitigation potential and hazard risk reduction) (Propato et al., 2018; Erftemeijer et al., 2020; Hanley et al., 2020; Jones et al., 2020) that this approach offers. ICZM measures are often 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., 2020; Jones et al., 2020), but the costs for its implementation is a barrier, especially in developing countries (Lamari et al., 2016; Villamizar et al., 2017; Rosendo et al., 2018). The implementation of ICZM measures requires a strong institutional framework, where all relevant stakeholders (especially representatives of communities to be intervened) are part of the decision-making process (Pérez-Cayeiro and Chica-Ruiz, 2015; Lamari et al., 2016; Hassanali, 2017; Antunes Do Carmo, 2018; Rosendo et al., 2018; Warnken and Mosadeghi, 2018; Hamin et al., 2018; Phillips et al., 2018; Walsh, 2019; Morecroft et al., 2019; Morris et al., 2019; Donatti et al., 2020; O'Mahony et al., 2020), and is a key challenge in developing countries (Pérez-Cayeiro and Chica-Ruiz, 2015; Villamizar et al., 2017; Rosendo et al., 2018; Alves et al., 2020). Perception that "hard" infrastructure (i.e., coastal defence & hardening) are more efficient to reduce risk can affect the implementation of "soft" or NBS measures (Magnan and Duvat, 2018).

CCB FEASIB.3.2.4 Agroforestry

There is *high agreement* and *robust evidence* that measures to promote agroforestry systems increase ecological (Schoeneberger et al. 2012; Apuri et al. 2018; Minang et al. 2014; Smith et al. 2013) and adaptive capacity (Schoeneberger et al. 2012; Apuri et al. 2018; Minang et al. 2014; Kmoch et al. 2018), including preservation of ecosystems services, such as water resources and soil conservation. It also results in social and economic benefits and positive synergies between adaptation and mitigation (Coulibaly et al. 2017; Hernández-Morcillo et al. 2018). Medium evidence suggests that economic, cultural barriers and potential land use change trade-offs may hamper the implementation of agroforestry systems (Hernández-Morcillo et al. 2018; Quandt et al. 2017; Cedamon et al. 2018).

CCB FEASIB.3.2.5 Afforestation and reforestation, ecosystems conservation and biodiversity management

There is *robust evidence* and *medium agreement* on the economic feasibility of reforestation and conservation strategies. Some studies (Chow et al. 2019; Seddon et al. 2020a) highlight that the net benefits of measures such as afforestation, ecosystem restoration and nature-based solutions 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 especially in the face of upfront investment costs and – at a macro-level – alternative, more profitable land uses like agriculture (Ota et al. 2020; Bustamante et al. 2019; Seddon et al. 2020b). Reforestation and conservation are costly adaptation options for local communities, and in many cases will depend on government support, multilateral development banks and international funds (Bustamante et al. 2019; Seddon et al. 2020b). In Brazil, competition between reforestation and the expansion of agricultural and cattle ranching combined with a lack of markets for commercial products from restored areas constrains the socio-economic viability of large-scale reforestation (Nunes et al. 2020). There is *medium evidence* and *medium agreement* on the socio-economic vulnerability reduction potential: Reforestation has the potential to substantially reduce poverty in rural areas. Through reforestation, smallholders can diversify their livelihood and increase household income as well as the availability of products for subsistence (Bustamante et al. 2019; Fleischman et al. 2020; Ota et al. 2020). Similarly, ecosystem restoration has been found to be potentially inclusive and participatory, given that ecosystems can be managed jointly and in traditional ways (Woroniecki et al. 2019). However, without social inclusion, the gap between the wealthy and the poor can increase. For instance, in Nepal, poor people did not benefit from community forestry and were even affected negatively (Ota et al. 2020). The majority of pertinent literature links reforestation and afforestation to job creation (*robust evidence* and *high agreement*) (Rahman et al. 2019; Bustamante et al. 2019; Ota et al. 2020; Chausson et al. 2020) and may enhance landholders' confidence and entrepreneurial skills through participation in reforestation programs (Ota et al. 2020).

There is *medium evidence* but *high agreement* that some logistical barriers to reforestation may include insufficient production and supply of seeds and seedlings, long transport distances and low infrastructure (Bustamante et al. 2019; Nunes et al. 2020). Similarly, Ota et al. (2020) found that limited technical capability constrains not only the tree planting activity itself, but also diversification of agricultural systems, appropriate management for improved tree growth performance and the realization of the potential financial returns. There is a relatively *high degree of agreement* that reforestation and nature-based solutions have a positive effect on reducing risks of climate change. Reforestation and afforestation strategies are found to protect in-land infrastructure from landslides and coastal infrastructure from storm surges (Seddon et al. 2020a, b). Ecosystems avoid millions of dollars' worth in property and infrastructure damage every year and can be up to five times cheaper than engineered grey solutions (Chausson et al. 2020).

While some studies point out that nature-based solutions enjoy of wide local and regional support (Lange et al. 2019) and highlight that nature-based solutions have gained wide international support and acceptability (Seddon et al. 2020b; Chausson et al. 2020), elements of political acceptability remain under-researched. Challenges with implementation are mostly associated with institutional capacity. In Brazil and Indonesia, for example, the introduction of environmental policies has resulted in increased legislation and regulation promoting restoration and conservation (Lange et al. 2019; Bustamante et al. 2019). There is *medium evidence* and *medium agreement* that a lack of coordination among agencies or deficient institutional capacity may hinder environmental conservation (Chow et al. 2019; Seddon et al. 2020b). Ota et al. (2020) highlight that funds for restoration are often accrued by a small group of people within a community because of a deficient governance system and lack of transparency of resource allocation.

There is *robust evidence* and *high agreement* in the literature pointing to a broad range of social co-benefits resulting from the implementation of environmental restoration policies. Social co-benefits include poverty reduction, job creation, de-marginalization, improved health, recreational benefits and improved livelihoods. There is high agreement that many environmental programs result in improved livelihoods for indigenous, rural and remote communities.

There is *robust evidence* and *high agreement* on the positive impacts that forest restoration and nature-based solutions have on improving gender equality. Ota et al. 2020, found increased social equity in respect to access to resources, including gender equality, resulting from socially sound extension activities of reforestation projects. Nature based-solutions had similar effects on Ethiopia and Togo (Seddon et al. 2020b). Moreover, Ambrosino et al. (2020) conclude that failure to engage women in management efforts, coupled with women's prominent roles as environmental stewards, results in lost opportunities to improve conservation practices and sustainably manage natural resources upon which these communities' livelihoods depend. Integrating gendered considerations into conservation and development interventions increases the likelihood that they will achieve targeted outcomes of poverty alleviation and improved food security in coastal communities.

There is *robust evidence* and *medium agreement* on the positive effects that forest restoration and nature-based solutions have on ecosystems' ecological capacities, including better regulation of microclimate, groundwater recharge, reduced soil erosion, improved habitat for wildlife and biodiversity, also improved water quality and stream flow restoration, improved quality of air, biomass coverage and reduced water shortage (Shannon et al. 2019; Lochhead et al. 2019; Weng et al. 2019; Chow et al. 2019; Bustamante et al. 2019; Morecroft et al. 2019; Sinay and Carter 2020; Ontl et al. 2020; Seddon et al. 2020a,b; Chausson et al. 2020; Takata and Hanasaki 2020; Dooley et al. 2020; von Holle et al. 2020). Some literature warns about the negative effects that afforestation can have on non-forest ecosystems, such as grasslands, shrublands, and peatlands, and potentially biodiversity (Fleischman et al. 2020). Afforestation might also have detrimental effects on water availability in ecosystems. There is mixed evidence regarding the potential for improved adaptive capacity. Reforested areas can act as buffers to climatic and market conditions adverse to smallholders (e.g., droughts and low market prices for a specific farming product). Hence, the availability of natural resources can increase socio-ecological resilience to smallholder vulnerability (Ota et al. 2020). (International Resource Panel 2019), on the other hand, warn that restoration may also imply trade-offs with other ecological or societal goals.

Not only at the economic level, but also geophysically, land is the limiting factor (Bustamante et al. 2019; Morecroft et al. 2019; Ontl et al. 2020; International Resource Panel 2019; Moomaw et al. 2019). However, there are also synergies to be reaped, e.g., there is *high agreement* and *robust evidence* that reforestation, environmental conservation and nature-based solutions result in increased carbon sinks (de Coninck et al. 2018; Griscom et al. 2017; Fuss et al. 2018). Some authors argue that ecosystem conservation and nature-based solutions remove larger amount of carbon than tree plantations (Fleischman et al. 2020; Seddon et al. 2019, 2020b). 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 (Nunes et al. 2020). However, too much reliance on reforestation and green alternatives might increase water shortages and wildfires.

CCB FEASIB.3.2.6 Ecosystem connectivity

There is a relatively *high degree of agreement* and *robust evidence* that financial motivations are a critical determining factor for the implementation of ecosystem connectivity strategies (Lausche et al. 2013; Jones et al. 2020); given that biodiversity corridors will in many occasions cut through private property, their feasibility will strongly depend on the existence of a regulatory framework that appropriately balances property rights, environmental regulations and monetary incentives. Government funding, subsidies, donations, tax benefits and other financial instruments are fundamental to ensure landowners willingness to participate and maintain ecosystem corridors. Participation is expected to be lower on high opportunity costs lands, because land managers can earn more from farming, timber, or other extractive activities compared to what is offered by an ecological corridor (Jones et al. 2020).

While legal and regulatory barriers are not perceived as major barriers to ecosystem connectivity projects (D'Aloia et al. 2019; Lausche et al. 2013), private land ownership may be an obstacle to implementation and formal involvement of landowners as critical partners has been found to be key in successful corridors (Keeley et al. 2018) next to leadership by NGOs in many world regions (Lausche et al. 2013).

Several social co-benefits are found to follow from ecosystem's connectivity strategies, such as improved community health as a result of better air and water quality (Lausche et al. 2013). Connectivity conservation areas also provide recreational, tourism, educational, spiritual, and scientific benefits.

There is *high agreement* and *robust evidence* supporting the ecological capacity enhancement of ecosystem connectivity strategies (Thompson et al. 2017; Lavorel et al. 2020). There is a *relatively high agreement* that ecosystem connectivity has the potential to improve the adaptive capacity both of ecological systems and humans. Krosby et al. (2018), 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 human adaptation to climate change and also climate change mitigation (Lausche et al. 2013), but empirical evidence of the adaptation benefits for humans is scant.

CCB FEASIB.3.2.7 Improved cropland management

Improved cropland management includes a suite of agricultural adaptation strategies such as integrated soil management, no-tillage, conservation agriculture, and/or mulching (Prestele et al. 2018; Sova et al. 2018). Despite higher initial costs in some cases, there is *high evidence* and *high agreement* economic feasibility of improved cropland management is high through improved productivity, higher net-returns, reduced input costs (Aryal et al., 2018b; Aryal et al., 2019; Batabyal et al., 2017; Das et al., 2017; Jat et al., 2015; Kannan and Ramappa 2017; Keil et al., 2017, 2019; Khatri-Chhetri et al., 2016; Kumar et al., 2018a; Mottaleb et al., 2017; Phonglosa et al., 2015; Sapkota et al., 2015; Sarkar et al., 2018). The presence of subsidies, extension services, training, commercial custom-hire services enable adoption (Aryal et al., 2015a, b; Kannan and Ramappa 2017; Keil et al., 2015; Khatri-Chhetri et al., 2017). In some regions, technological feasibility is constrained by cost, and inadequate information and technical know-how on particular practices and their benefits and tradeoffs (*medium evidence, high agreement*) (Findlater et al., 2019; Dougill et al., 2017; Aryal et al., 2018a,b; Khatri-Chhetri et al., 2016; Bhatta et al., 2017; Keil et al., 2015; Kannan and Ramappa 2017; Sova et al. 2019). Temporal delays between actions and tangible benefits can reduce public 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 (Aryal et al., 2019; Bhattacharyya et al., 2016) 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). Critically, adoption of improved cropland management practices are strongly mediated by gender: structural barriers such as unequal access to land, machinery, inputs, extension and credit services, constrain adoption of such practices among women farmers (Aryal et al., 2019; Aryal et al., 2018c; Aryal et al., 2018a; Aryal et al., 2018b; Mponela et al., 2016; Ntshangase et al., 2018; Somasundaram et al., 2020; Tripathi and Mishra 2017; Van Hulst and Posthumus 2016; Wekensah et al. 2017). There is *high evidence* and *high agreement* that improved cropland management practices have social and ecological co-benefits in terms of better health, education and food security (Agarwal and Pandey 2017; Farnworth et al., 2017; Hörner and Wollni 2020b) and better soil quality and ecosystem functioning (Adams et al., 2020; Agegnehu and Amede 2017; Aryal et al., 2019; Batabyal et al, 2017; Bhattacharyya et al., 2016; Gonzalez-Sanchez et al., 2019; Kumar et al., 2018a; Kumar et al., 2018b; Mottaleb et al., 2017; Mutuku et al., 2020; Parihar et al., 2020; Patra et al., 2020; Phonglosa et al., 2015; Sarkar et al., 2018; Schulte et al., 2017; Shah and Wu 2019; Somasundaram et al., 2020; Thierfelder et al., 2017; Zomer et al.,2017).

There is *robust evidence* with *medium agreement* that improved cropland management can have mitigation co-benefits but exact amounts of emissions reductions depend on ecosystem type and cropping practices (Adams et al., 2020; Aryal et al., 2015b; Aryal et al., 2019; Das et al., 2017; Gonzalez-Sanchez et al., 2019; Han et al., 2018; Keil et al., 2015; Khatri-Chhetri et al. 2017; Kumar et al., 2018b; Li et al., 2017; Li et al., 2020; Mayer et al., 2018; Ogle et al., 2019; Prestele et al. 2018; Sapkota et al., 2014; Sarkar et al., 2018; Shah and Wu 2019; Singh et al., 2018; Sommer et al., 2018; VandenBogaard 2016; Wang et al., 2020; Yadav et al., 2019).

CCB FEASIB.3.2.8 Efficient livestock systems

Improving the efficiency of livestock systems is an adaptation strategy with significant mitigation co-benefits (Ericksen & Crane 2018; Accatino et al. 2019). While there is *medium evidence* and *medium agreement* that the technological and ecological feasibility of improving livestock production systems is high (i.e., there are technologies available to adapt livestock systems, in a range of ecological conditions and for different animal types), barriers include market-related and institutional barriers, especially in sub-Saharan Africa and South America (Escarcha et al. 2018); relatively lower research in small ruminants (Pardo & del Prado 2020 in the EU); physical constraints such as shrinking land available for grazeland and fodder production; and socio-cultural barriers such as women or low-income groups being less likely to access better breeds or feed (Salmon et al. 2018). In dryland livestock systems in Ethiopia and Kenya, Ericksen & Crane (2018) find low governance capacities to implement improved grazing regimes and prevent overgrazing constrain improved grazeland management.

CCB FEASIB.3.2.9 Water use efficiency and water resource management

There is high technological feasibility (*robust evidence, high agreement*) for this option as technologies as there are currently more numerous technologies, each of which has improved in efficiency. Technologies include rainwater harvesting, drip irrigation, laser land leveling, drainage management and cover crops method (Dasgupta, et.al., 2017, Velasco-Muñoz, et.al., 2018, Khatri-Chhetri, et.al., 2017, Sojka, et.al. 2019, Darzi-Naftchali and Ritzema, 2018, Terencio, et.al. 2018, Rahman, 2017, Adham, 2018). These technologies have a range of benefits, including rainwater collection, application of water directly at the root, leveling of the fields to avoid uneven water distribution, removal of excess water during floods, and reduction of evaporation loss, amongst others. Water efficient technologies and management have medium evidence and high agreement of the economic feasibility due to water and energy cost savings enhanced by low-cost monitoring systems in some cases (Viani, et.al. 2017, Kodali and Sarjerao, 2017). 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, erosive water use and sharing practices, especially across boundaries, and fragmented, sectoral resource management approaches (Singh et al. 2020; Lardizabal 2015; Margerum & Robinson 2015).

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; Torell et al., 2017; Liu and Lan, 2015; Goulden et al., 2013; Radel et al., 2018; Nyantakyi Frimpong, 2017; Buechler and Lutz, 2019; Kihila, 2018; Orchard et al., 2016; Salam and Bauer, 2020; Tian and Lemos, 2018; Makate et al., 2016; Schubhauer et al., 2017). There is *high evidence* and *medium agreement* that diversifying livelihoods improves incomes and reduces socio-economic vulnerability, but depending on livelihood type, opportunities, and local context, feasibility changes (Martin and Lorenzen, 2016; Barrett, 2013; 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), with diversification predominantly out of rural farm-based livelihoods on the rise (Shackleton et al. 2015; Rigg & Oven, 2015; Ober & Sakdapolrak P (2020). Key barriers to livelihood diversification include social and institutional barriers (including social networks (Goulden et al., 2013)) and inadequate resources and livelihood opportunities that hinder the full adaptive possibilities of existing livelihood diversification practices (Nightingale 2017; Shackleton et al. 2015). 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 and increase inequality (Tanner et al., 2015; Gautam and Andersen, 2016; Wilson, 2014; Ford et al., 2014; Asfaw et al, 2018; Torrel et al., 2017; Loison, 2015; Ibrahim et al., 2019; Baird and Hartter, 2017; Brown et al., 2019; Salam and Bauer, 2020). Livelihood diversification can be facilitated in key technical areas (Schubhauer et al., 2017; Shackleton et al., 2015; Brown 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 (Martin and Lorenzen, 2016; Barrett, 2013; Sina et al., 2019; Herrero et al., 2016 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 can support adaptation by mainstreaming it into city plans, such as land-use planning, transportation, and health and social services (Araos et al., 2016; Carter et al., 2015); by procuring the design and construction of resilient infrastructure including housing; by promoting community-based adaptation through supporting local design and implementation of adaptation activities (Archer et al., 2014); and by protecting and integrating biodiversity and ecosystem services into city planning. Research since SR 1.5 provides *medium evidence* with *medium agreement* on the challenging high costs of infrastructure (Georgeson et al., 2016; Woodruff et al., 2018); potential lost municipal revenue from retreat (Shi &

Varuzzo, 2020; A. Siders & Keenan, 2020); and the fraught relationship between planning and the reduction of socioeconomic vulnerability (Anguelovski, Connolly, Garcia-Lamarca, et al., 2019; Elliott, 2019; Keenan et al., 2018; Paganini, 2019; Shokry et al., 2020). Yet others document how benefits potentially outweigh costs (Carey, 2020); the financial viability of green infrastructure (Meerow, 2019; Zhang et al., 2019); enhancement of productivity and employment (Cohen, 2020; Rice et al., 2019; Woodruff et al., 2018); and availability and accessibility of technical expertise (Colven, 2020; Fitzgibbons & Mitchell, 2019; Goh, 2020; Hasan et al., 2019; Heikkinen et al., 2019; Serre & Heinzlef, 2018; Szewrański et al., 2018). Structural disincentives and institutional arrangements create challenges for planning even where political willingness may be high (Di Gregorio et al., 2019; DuPuis & Greenberg, 2019; Rasmussen et al., Under Review; Shi, 2019; Zen et al., 2019). 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" (Anguelovski, Connolly, Garcia-Lamarca, et al., 2019; Keenan et al., 2018), if residents do not perceive themselves as included in the crafting of plans (Araos, *Under Review*; Rasmussen et al., *Under Review*), if the options such as managed retreat are perceived as culturally unacceptable (Koslov, 2019; A. Siders, 2019), or if wealthier and advantaged residents benefit from planning at the expense of socially vulnerable groups (E. K. Chu, 2018; E. Chu & Michael, 2019; Fainstein, 2018; Pelling & Garschagen, 2019; Ranganathan & Bratman, 2019; Rice et al., 2019; Rosenzweig et al., 2018). Nonetheless, potential social co-benefits related to health and education are high (Keeler et al., 2019; Klinenberg, 2018; Meerow, 2019; Raymond et al., 2017; Spaans & Waterhout, 2017). Finally, the option is highly feasible in relation to ecological and geophysical characteristics, as one of urban and land-use planning's primary tools is to manipulate the built environment and natural spaces to protect to reduce the vulnerability of residents.

CCB FEASIB.3.3.2 Green infrastructure & ecosystem services

Urban green infrastructure and ecosystem services have emerged as an important vehicle to support climate adaptation and mitigation efforts in cities (Belcakova et al. 2019, Sota et al. 2019, Stefanakis, 2019; Perrotti and Stremke, 2020). While green infrastructure options are cost-effective and provide co-benefits in terms of ecosystem services (Depietri and McPhearson, 2017; Morris et al., 2018; Reguero et al., 2018) (*robust evidence, high agreement*), there remains a need for systematically assessing co-benefits, particularly for flood risk management (Alves et al 2019, Stefanakis 2019) and sustainable material flow analysis (Perrotti and Stremke, 2020).

Institutional barriers constrain the feasibility of urban green infrastructure, 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. 2020). Further social and political acceptability of green infrastructure is constrained by lack of confidence in efficacy (Thorne et al. 2018) or issues of accessibility (Biernaka & 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, 2020) 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 the 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 and cost-benefit (Hobbie and Grimm 2020).

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

Sustainable urban water management recognises the goals of integrating climate adaptation concerns (Tosun and Leopold, 2019) but, in spite of low economic and technical barriers, is saddled with challenges of institutional heterogeneity (Chu et al. 2018, Pandey et al 2019), scalar mismatch; particularly between river basin and city scales (van den Brandeler 2019) and equity and justice concerns (Chu et al. 2018, Pelling et al. 2018). 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). Assessing vulnerability of urban water infrastructures at city-scale remain an important knowledge gap (Dong et al. 2020). Land use management that recognises the 'city as a sponge' has emerged as an important strategy for urban water management (Avashia and Garg, 2020) but some interventions, suffer from uncertainties in design, planning, and financing (Nguyen et al. 2019). Deployment of decentralised water management, through effective local governance frameworks, is an important water management strategy (Leigh and Lee, 2019, Herslund and Mguni, 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, Esmail and Suleiman, 2020).

CCB FEASIB.3.4 Overarching adaptation options

CCB FEASIB.3.4.1 Social safety nets

Social safety nets are well-established to meet development goals (e.g., employment, poverty alleviation, accessible education and health services) and are increasingly being reconfigured to also provide assistance to build adaptive capacities of the most vulnerable (Aleksandrova, 2020; Fischer et al. 2020; Bowen et al. 2020; Mueller et al. 2020; Coirolo et al. 2013). They include a range of policy and market-based strategies such as public works programmes and conditional or unconditional cash transfers, in-kind transfers to support access to education, housing, and health services; and insurance schemes (Aleksandrova, 2020; FAO and Red Cross Red Crescent Climate Centre 2019). While there is *high evidence* with *medium agreement* that social safety nets are well-suited to build adaptive capacities, reduce socio-economic vulnerability, and mitigate hazard risk (Mueller et al. 2020; Fischer 2020); macroeconomic, institutional, and regulatory barriers such as limited state resources, underdeveloped credit and insurance markets, and leakages constrain feasibility (Aleksandrova 2020; Bowen et al. 2020; Strøbech et al. 2020; Singh et al. 2018; Hansen et al. 2019). As expected, social safety nets have strong co-benefits with development goals such as education, poverty alleviation, and food security (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 - Aleksandrova 2020; Strøbech et al. (2020); Singh et al. 2018; or focus on rural areas overlooks urban vulnerable groups Coirolo et. al, 2013).

CCB FEASIB.3.4.2 Risk Insurance

There is *high evidence* and *medium agreement* on insurance as an adaptation. Technological, economic, and institutional feasibility is high, as insurance can spread risk, provide a buffer against the impact of climate-hazards, support recovery and reducing financial burden on governments, households, and businesses (Glaas et al., 2017; Jenkins et al., 2017; O'Hare et al., 2016; Patel et al., 2017; Wolfrom and Yokoi-Arai, 2015). 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 (Jenkins et al., 2017; Linnerooth-Bayer and Hochrainer-Stigler, 2015)(Shapiro, 2016). Socio-cultural barriers constrain feasibility. 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 (García Romero and Molina, 2015; Jin et al., 2016; Joyette et al., 2015; Lashley and Warner, 2015). 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). Surminksi et al (2016) raises 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, Climate services, including EWS

There is high evidence and high agreement that DRM and climate services aid adaptation decision-making, particularly where they are demand-driven and context-specific and supported by strong institutions, good governance, strong local engagement, and trust across actors (Vaughan et al., 2018; Soares et al. 2018) (Hasan, Nasreen, & Chowdhury, 2019; Ji & Lee; Kim & Marcouiller, 2020; Uddin, Haque, & Khan; Webb, 2020). Climate service interventions and DRM are constrained by low capacity, inadequate institutions, and difficulties in maintaining systems beyond pilot project stage (Soares et al. 2018; Vincent et al. 2018; Tall et al. 2018). 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; Hore, Gaillard, Davies, & Kearns, 2020; Rai & Khawas, 2019; Ramalho, 2019a, 2019b; Thompson, Shrestha, Chhetri, & Agusdinata, 2020; Tiepolo & Braccio, 2020). Metrics to assess outcomes of climate services remain project-based and insufficiently capture longer-term economic and non-economic benefits of interventions (Parton et al. 2019; Tall et al. 2018; Perrels 2020). Data access and availability continue to challenge DRM despite advances in data analytics, especially in rapidly growing informal settlements, including population estimates and limited mobility data (Dujardin, Jacques, Steele, & Linard, 2020). Moves towards community-based and ecosystem-based DRM are promising but uneven (Almutairi, Mourshed, & Ameen, 2020; Klein et al., 2019; Murti, Mathez-Stiefel, Garcia, & Rist, 2020; Seebauer, Ortner, Babcicky, & Thaler, 2019), and may increase vulnerability if they fail to address underlying and structural determinants of vulnerability, particularly among the poor and by gender (Atanga, 2020; Hossen et al., 2019; Ramalho, 2019a; Webb, 2020).

CCB FEASIB.3.4.4 Population health and health systems

Climate change will exacerbate existing health challenges. Options for enhancing current health services include providing access to safe water and improved sanitation, enhancing access to essential services such as vaccination, 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 vulnerability if combined with iterative management that incorporates climate change considerations and monitors effectiveness in-light of climate impacts (Linares et al. 2020, Rudolph et al. 2020, Hanefeld et al. 2018, Haines and Ebi 2019) (*medium evidence, high agreement*). Feasibility is high where options are aligned with national priorities, engages local to international communities, address the needs of particularly vulnerable regions and population groups, and health system capacity is well-developed (Austin et al. 2019, Nuzzo et al. 2019, Sheehan and Fox 2020, Hanefeld et al. 2018). There is growing recognition that institutional capacity and resource availability represent major barriers to health system adaptation options, particularly for health systems struggling to manage current health risks (Hussey and Arku 2020, Gilfillan 2019), for neglected populations (Negev et al. 2019, Hanefeld et al. 2018), and where there are conflicting mandates and poor coordination across ministries (Gilfillan 2019, Sheehan and Fox 2020, Austin et al. 2019, Kendrovski and Schmoll 2019, Fox et al. 2019). Understanding on health vulnerability is growing (Berry et al. 2018) but knowledge on the health effects of climate change among health practitioners remains limited (Liao et al. 2019, Chersich and Wright 2019, Brooke-Sumner et al. 2019, Ebi et al. 2018, Fox et al. 2019, Albright et al. 2020), with the health care community generally lacking climate data surveillance efforts (Runkle et al. 2018).

CCB FEASIB.3.4.5 Resettlement, relocation and migration

Planned or autonomous resettlement, relocation, and migration are being undertaken to deal with disaster risk and climate change, though that these strategies are mostly driven by a combination of climatic and non-climatic drivers (Adger et al. 2020; Maharjan et al. 2020; Kaczan & Orgill-Meyer 2020; Hoffmann et al. 2020; McLeman 2019; Cross-Chapter Box MIGRATE in Chapter 7). There is *high evidence* and *medium agreement* that moving away from high-risk locations (either through planned resettlement and relocation initiatives or through autonomous migration) can contribute to adaptive capacity through higher remittances, better livelihood opportunities, and potentially moving out of risk-prone locations (Nawrotzki & Bakhtsiyarava 2017; Sedova & Kalkuhl 2020; Jacobson et al. 2019; Tebboth et al. 2019; Maharjan et al. 2020; Hughes, 2020) but there is mixed evidence on whether or not moving introduces migrants to new vulnerabilities in destination areas (Sedova & Kalkuhl 2020; Singh & Basu 2020; Singh 2019; Zickgraf 2019; Jacobson et al. 2019; Mortreux et al. 2018; Maharjan et al. 2020; Miller, 2020; Adger et al., 2020).

Across all the indicators, the feasibility of migration as an adaptation is mediated through who is moving (age, gender, ethnicity, occupation), type of movement (permanent, seasonal, temporary, cyclic), social capital, and livelihoods migrants are moving into. The key barrier to moving is institutional, legal and regulatory factors: e.g., political acceptability (of migrants) is low because of low acceptance of internal migrants within countries (e.g., Deshpande et al. 2019 in India) and of international migrants globally (e.g., Hauert et al. 2019). However, in some places, where climate risks are acute, political acceptance for planned relocation is high (e.g., McNamara 2015 in Kiribati). There is also inadequate institutional capacity to enable movement with global and national policies addressing relocation identified as too abstract and lacking guidance on ensuring equity (Hauer et al. 2019; Sedova & Kalkuhl 2020; Kelman et al. 2019; Mortreux et al. 2018; Maharjan et al. 2020; Hughes, 2020). There is increasing evidence on how changing mobility patterns (e.g., Ford et al. 2020 in the Arctic) and immobility are key aspects of migration and relocation where certain people cannot or choose not to move due to barriers to moving or place attachment (Ayeb-Karlsson et al. 2018; Zickgraf 2019).

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

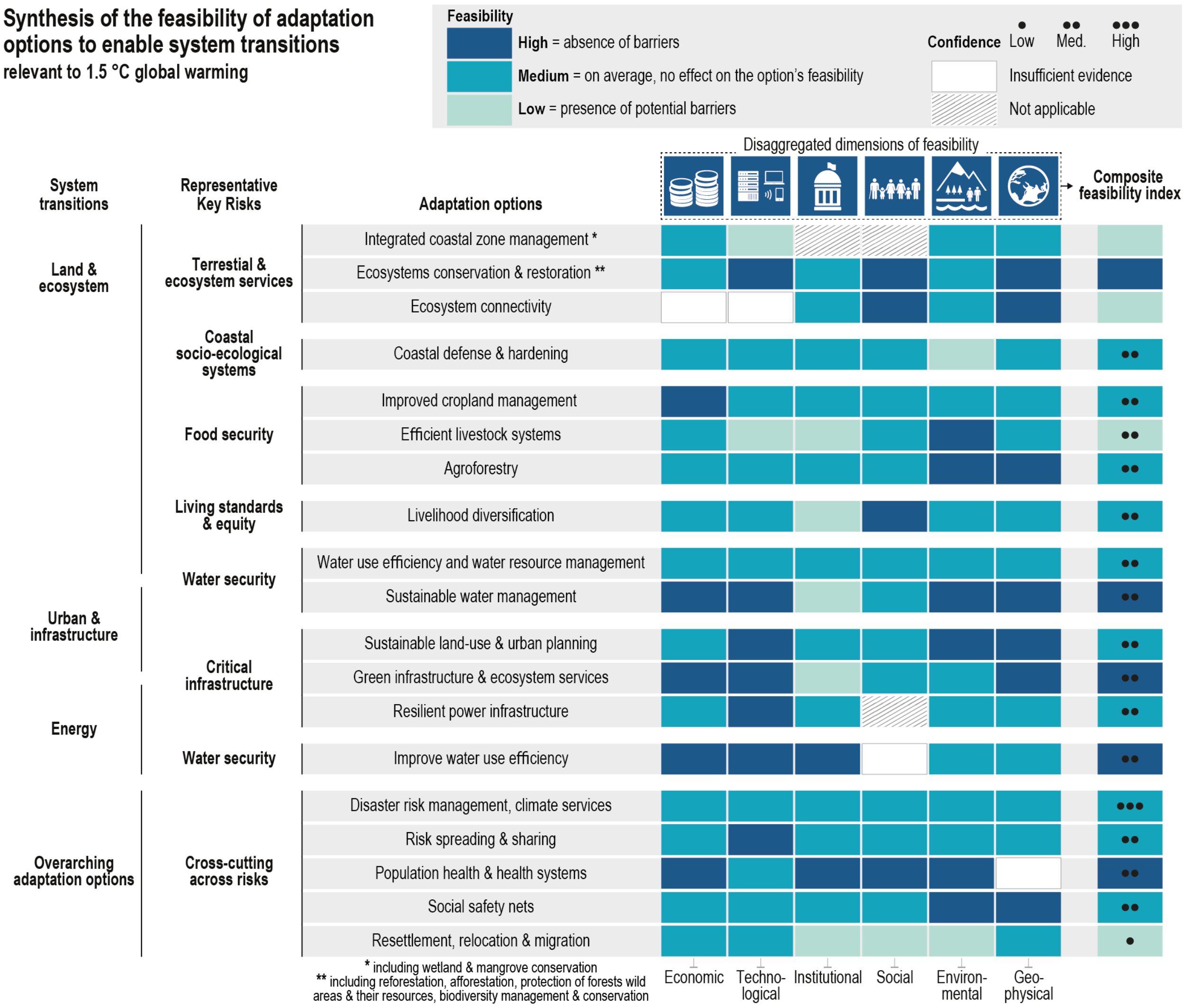

Figure CCB FEASIB.2: Multi-dimensional feasibility. [PLACEHOLDER FOR FINAL DRAFT: evidence and agreement after the full assessment of options is completed]

CCB FEASIB.4 Synergies and Trade-offs

The feasibility assessment for each of the options listed above considers the option taken by itself. However, under a systems transition analysis, the implementation of a mitigation or adaptation option can impact the feasibility of another option. Therefore, a separate analysis is being carried out to analyse the synergies and trade-offs between a) adaptation options, and b) mitigation and adaptation options.

The SR1.5 undertook two separate analyses of synergies and trade-offs between mitigation and adaptation (deConinck et al. 2018) and between mitigation and sustainable development (Roy et al. 2018). This section will present an integrated analysis synergies and trade-offs between mitigation and adaptation for the options under review.

Table CCB FEASIB.1: Adaptation options synergies and trade-offs with mitigation

Adaptation option	**Implications for mitigation**	
	Synergies	**Trade-offs**
Energy systems	Strong synergies with mitigation goals as resilient infrastructure allows power generation systems to continue operations without disruptions (or minimal disruptions), Improved water use efficiency increases generation efficiency in certain natural gas combined cycle plants (Pan, et.al., 2018), while at the same time improving freshwater use and ensuring that water sources' ecological flows are not disturbed (Sánchez and Izzo, 2018, Rasul and Sharma, 2016, Stańczuk-Gałwiaczek, et.al., 2018). In rural landscapes, resilient power infrastructure ensures electricity availability during emergencies and protects the communities from any malfunction of the infrastructure itself. The improved water use efficiency, for example, in community micro-hydroelectric plants, allows for integrated water management across the watersheds that ensures water for irrigation, human consumption and other productive uses (Ley, 2017).	
Sustainable aquaculture		Vulnerable or poor communities may not benefit from commercial "sustainable aquaculture" (e.g., limited or no access to increased fish supply) (Chan et al., 2019)
Integrated Coastal Zone Management	Implementation of nature-based solutions for coastal management can enhance carbon sequestration capacity of the ecosystems (Gómez Martín et al., 2020) (Donatti et al., 2020) (Jones et al., 2020) (Morecroft et al., 2019) (Propato et al., 2018) (Morris et al., 2019) (Krauss and Osland, 2020) (Hanley et al., 2020) (Erftemeijer et al., 2020)	
Coastal defence & hardening		Hard-engineering infrastructures can affect ecosystem services (Antunes Do Carmo, 2018) (Hamin et al., 2018) Concrete (one of the main material used for hard-engineering infrastructure) is carbon-intensive (Hamin et al., 2018)
Ecosystem conservation, restoration and biodiversity management	Forest-based adaptation strategies have positive impacts on mitigation and carbon sequestration (Shrestha and Dhakal 2019; Ontl et al. 2019). Avoided deforestation, prevented forest degradation and pro-forestation strategies have the effect of reducing the emission of carbon into the atmosphere (Moomaw et al. 2019), while forest restoration and afforestation options effectively remove carbon from the atmosphere, increasing nature's carbon-sequestration capacity (Ontl et. al 2019; Ota et al. 2020). These forest-based adaptation strategies have important climate change mitigation effects, particularly in the case of developing countries, with large tropical forest cover, such as Brazil and India and Indonesia (Bustamante et al. 2019).	Over reliance on forest-based adaptation strategies may lead to an increased susceptibility to other climate-related hazards, such as wildfires, which in turn have the effect of emitting large amounts of carbon into the atmosphere (Nunes et al. 2020). Forest restoration initiatives that promote fast-growing plantations of pulp and timber species such as *Pinus* and *Eucalyptus*, which are extremely flammable, exacerbate wildfire risk and ecosystem carbon loss, leading to increased greenhouse gas emissions (Fleischman et al. 2020).

	In addition, biodiversity has been found to positively impact forests' resilience and their long-term capacity as carbon sinks (Seddon et al. 2019; 2020b).	Without an ecosystem-based approach and biodiversity considerations, forest-based adaptation alternatives might result in mal-mitigation, as occurred in Germany with changing land use from forest to bioenergy crops (Yousefpour et al. 2020).
Improved cropland management (SS)	Improved cropland management practices and technologies (e.g., tillage methods, water application, nutrient management) reduce GHG emissions significantly but depend on technology type and the stage of its adoption. E.g., direct rice seeding can reduce methane emissions while laser land levelling can reduce energy used for irrigation (Aryal et al., 2020, in South Asia). A combination of improved cropland practices like reduced or no-tillage, nutrient management, and residue recycling have a higher rate of soil organic carbon sequestration of 427.9 kg/ha/yr under rice-rice system (Yadav et al., 2019, in North East India) Optimised nutrient management through organic farmyard manure and other micronutrients increases soil organic carbon in maize-mustard cropping system by up to 9.7% (Sarkar et al., 2018, in North East India). Improved soil management practices increase soil organic carbon (SOC) stocks, e.g., in the North China Plain, such practices have increased SOC by 56-73% compared to initial stocks in the 1980s. Implementation of such practices in just 27% of China's cropland increased annual carbon sequestration amount in surface soils to 10.9 Tg C/year, contributing an estimated 43% of total carbon sequestration in China's croplands (Han et al., 2018). Emerging cropland management practices like minimal tillage, stubble retaining and nutrient management can increase SOC stocks but the extent varies with site-specific conditions (Singh et al., 2018, global review). Integrated soil-crop system management can reduce greenhouse gas emissions by 19% and carbon footprint by 30% compared to traditional practices (Wang et al., 2020, in Yangtze river basin, China). Integrated soil-fertility management and conservation agriculture contribute to climate change mitigation by reducing SOC losses (Sommer et al., 2018 in Western Kenya; Shah and Wu 2019, global review). Conservation agriculture has an estimated annual carbon sequestration benefit of 143 Tg C per year (Gonzalez-Sanchez et al., 2019, in Africa).	Improved cropland management practices aimed at increasing carbon sequestration in agriculture soils could lead to increased greenhouse gas emissions if the nitrogen inputs are not managed effectively. By 2060, around half of sites in Europe with carbon-mitigating agricultural practices could turn into a net source of greenhouse gases (Lugato et al., 2018). The increase in soil organic carbon through climate-smart agriculture practices could be offset by increased nitrous oxide emissions within corn belt states in the US (McNunn et al., 2020).
Water use efficiency and water resource management (CS)	Water-saving irrigation practices such as alternate wetting and drying and soil water potential (SWP) have mitigation co-benefits through CH4 and NO2 emissions reductions. SWP also significantly reduced seasonal methane emissions by ~30% when combined with better fertiliser application (Islam et al 2020)	Some water use efficiency practices can increase water use and hence energy demand (Song et al. 2018 in China; Berbel et al. 2018 in)

	Integrated watershed management sequesters carbon by enhancing soil carbon storage through better yields and residue returns (Sikka et al. 2018) Drip irrigation can reduce cumulative CH4 flux (by 194% in a year when compared to conventional flooding in rice cultivation) (Fawibe et al. 2019, in Japan); increase 22% CH4 uptake and reduce N2O emissions by 14.6% (Wang et al. 2016, in rice in China) Micro-irrigation save energy use by 58% compared to conventional gravity irrigation (Kumar & Palanisami 2019)	
Green infrastructure and ecosystem services	Urban forestry and agriculture has mitigation benefits through increased carbon uptake. E.g., in Lugo, Spain, urban forestry and farming collectively sequester 0.26 t C ha-1 per year (Sota et al. 2019) Urban agriculture can reduce energy-intensive food transportation, improve soil carbon sequestration capacity (if sustainable agricultura practices are used), and enable transitions towards low-carbon, plant-based diets (Grafakos et al., 2019; Atman & Sartisan 2018). Green infrastructure options such as xeriscaping and water-sensitive urban design (permeable surfaces, bioswales, etc.) can sequester carbon and have cooling effects that indirectly lead to reduced energy consumption (Sharifi et al. 2021)	The lack of consideration of the heat-water-vegetation nexus can increase heat and water stress (Chen, et.al. 2019, Upreti, et.al. 2017, Ashfari, 2017, Zardo, et.al. 2017, Rahman, et.al. 2020, Peng, et.al. 2020) Mitigation policies towards urban greening can sometimes incentivize urban greening with low biodiversity value (e.g., afforestation with non-native monocultures) leading to maladaptive outcomes (Seddon et al. 2020).
Sustainable water management, urban and infrastructure system transitions	Reduction of energy and environmental implications of water supply methods (Ding and Ghosh, 2017, Liu and Jensen, 2018, Pérez-Uresti, et.al., 2019) Strong co-benefits of demand-side management measures, for example, reduced leakages and water loss (Arfanuzzaman and Rahman 2017, Chen, et.al. 2017, Stavenhagen, et.al. 2018)	Desalination has high energy demand with carbon emissions attached but technological improvement and renewable energy for desalination can offset these (Darre & Toor 2018)
Disaster Risk Management	Incorporating environmental considerations into recovery decision-making (Amin Hosseini et al., 2016), implementing disaster risk management plans and increasing ex-ante resilience to disasters are important to reduce the extent of rebuilding following disasters, and the emissions associated with recovery. Post-disaster recovery can help rebuild in a more resilient way with less GHG emissions, or to “build back better”, particularly where immediate impact is substantial but not overwhelming (Guarnacci, 2012; Mochizuki and Chang, 2017).	Effective disaster risk management may reduce the need for international transport of materials and other forms of aid, which can be emissions-intensive (Abrahams 2014). The urgency of recovery and the surge in demand for construction materials have been observed to promote unsustainable behaviours, including deforestation (Nazara and Resosudarmo, 2007; Chang et al., 2010; Ongpeng et al 2019) or uncontrolled extraction of sand and gravel (Abrahams, 2014). ‘Building back better’ requires capacity, time, and mechanisms for balancing competing desires and perspectives that are not necessarily available after severe disasters, and may be challenged by both local and external influences in the rebuilding process (Abrahams, 2014; O’Hare et al., 2016; Paidakaki and Moulaert, 2017).
Health	Heat management strategies, including tree planting and other green infrastructure, cool roofing and paving, and	Indoor use of air conditioning can be an effective strategy to reduce heat

	a reduction in waste heat emissions from buildings and vehicles can lessen the health risk of rising temperatures, as well as lessen greenhouse gas emissions (Stone et al (2019) Groundwater-source heat pumps (GWSHP) are considered environmentally friendly and economically wise to use for heating and cooling buildings, and consequently have great potential to moderate greenhouse gas emissions (Osman et al (2019)	exposure and illness. However, increased air conditioning use increases emissions, in turn worsening air quality and human health impacts (Abel et al 2018) Air conditioning (AC) equipment aimed at reducing heat stress may trigger large energy consumption and increase GHG emissions (Davide et al., 2019; Viguie et al 2020)

CCB FEASIB.5 Knowledge Gaps

The knowledge for the options assessed in SR1.5 has grown and there is new evidence to support the feasibility assessment. Despite the progress in new knowledge, there remain several knowledge gaps for the assessment of adaptation and mitigation options.

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

Under land and ecosystem system transitions, gaps include a limited evidence for some of the institutional and social 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 and land use change enhancement potential for resettlement, relocation and migration. Geophysical feasibility for resettlement, relocation and migration has limited evidence, but is currently 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 as compared to other world regions.

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