Gender, Climate Justice and Transformative Pathways

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

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Key Messages

- Gender and other social inequities (e.g., racial, ethnic, age, income, geographic location) compound vulnerability to climate change impacts (*high confidence*). Climate justice initiatives explicitly address these multi-dimensional inequalities as part of a climate change adaptation strategy (Box 9.2: Vulnerability Synthesis: Differential Vulnerability by Gender and Age in Chapter 9).
- Addressing inequities in access to resources, assets and services, as well as participation in decision making and leadership is essential to achieving gender and climate justice (*high confidence*).
- Intentional long-term policy and programme measures and investments to support shifts in social rules, norms and behaviours are essential to address structural inequalities and support an enabling environment for marginalised groups to effectively adapt to climate change (*very high confidence*) (Equity and Justice box in Chapter 17).
- Climate adaptation actions are grounded in local realities so understanding links with Sustainable Development Goal (SDG) 5 is important to ensure that adaptive actions do not worsen existing gender and other inequities within society (e.g., leading to maladaptation practices) (*high confidence*). [Section 17.5.1]
- Adaptation actions do not automatically have positive outcomes for gender equality. Understanding the positive and negative links of adaptation actions with gender equality goals, (i.e., SDG 5), is important to ensure that adaptive actions do not exacerbate existing gender-based and other social inequalities [Section 16.1.4.4]. Efforts are needed to change unequal power dynamics and to foster inclusive decision making for climate adaptation to have a positive impact for gender equality (*high confidence*).
- There are very few examples of successful integration of gender and other social inequities in climate policies to address climate change vulnerabilities and questions of social justice (*very high confidence*).

Gender, Climate Justice and Climate Change

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

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

Cross-Chapter Box GENDER (continued)

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

Gendered Vulnerability

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

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

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

Integrating Gender in Climate Policy and Practice

Climate change policies and programmes across regions reveal wide variation in the degree and approach to addressing gender inequities (see Table SMCCB GENDER.2). In most regions where there are climate change policies that consider gender, they inadequately address structural inequalities resulting from climate change impacts, or how gender and other social inequalities can compound risk (*high confidence*). Experiences show that it is more frequent to address specific gender inequality gaps in access to resources. Regionally, Central and South American countries (Section 12.5.8) have a range of gender-sensitive or gender-specific policies such as the intersectoral coordination initiative Gender and Climate Change Action Plans (PAGcc), adopted in Perú, Cuba, Costa Rica and Panamá (Casas Varez, 2017), or the Gender Environmental policy in Guatemala that has a focus on climate change (Bárcena-Martín et al., 2021). However, countries often have limited commitment and capacity to evaluate the impact of such policies (Tramutola, 2019). In North and South America, policies have failed to address how climate change vulnerability is compounded by the intersection of race, ethnicity and gender (Radcliffe, 2014; Vinyeta et al.,

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Cross-Chapter Box GENDER (continued)

2016) (see also Section 14.6.3). Gender is rarely discussed in African national policies or programmes beyond the initial consultation stage (Holvoet and Inberg, 2014; Mersha and van Laerhoven, 2019), although there are gender and climate change action strategies in countries such as Liberia, Mozambique, Tanzania and Zambia (Mozambique and IUCN, 2014; Zambia and IUCN, 2017). European climate change adaptation strategies and policies are weak on gender and other social equity issues (Allwood, 2014; Boeckmann and Zeeb, 2014; Allwood, 2020), while in Australasia, there is a lack of gender-responsive climate change policies. In Asia, there are several countries that recognise gendered vulnerability to climate change (Jafry, 2016; Singh et al., 2021b), but policies tend to be gender-specific, with a focus on targeting women, for example in the national action plan on climate change as in India (Roy et al., 2018) or in national climate change plan as in Malaysia (Susskind et al., 2020).

Potential for Change and Solutions

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

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

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

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

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

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

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

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

For example, gender-transformative and nutrition-sensitive agroecological approaches strengthen adaptive capacities and enable more resilient food systems by increasing leadership for women and their participation in decision making and a gender-equitable domestic work (*high confidence*) (Gumucio et al., 2018; Bezner Kerr et al., 2019; Deaconu et al., 2019) (Cross-Chapter Box NATURAL in Chapter 2, Sections 5.12, 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 include health, education, nutrition and family planning, among others (Daron et al., 2021).

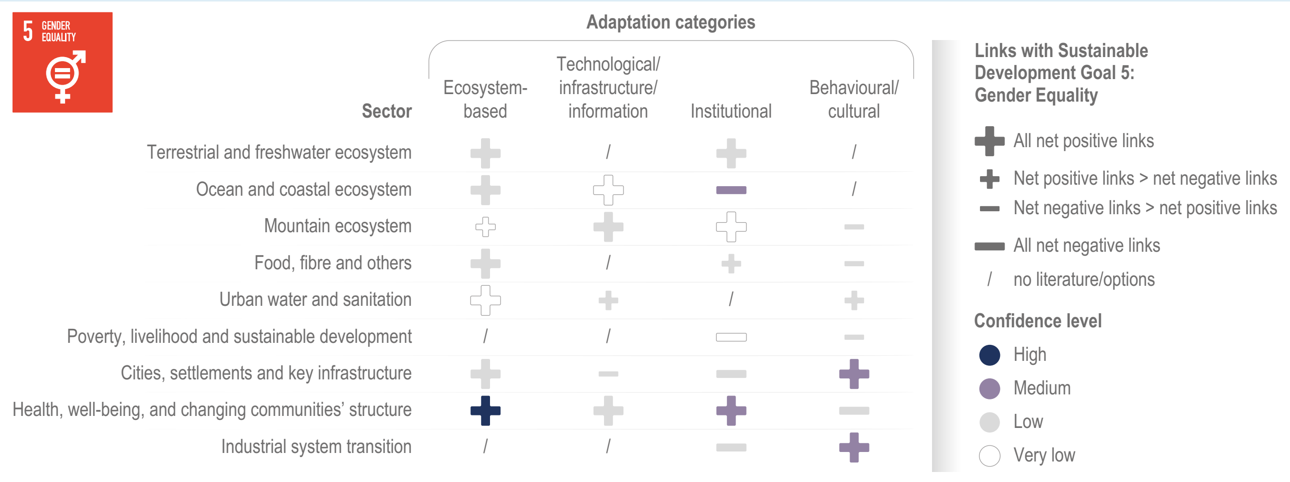
Cross-Chapter Box GENDER (continued)

Climate Change Adaptation and SDG 5

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

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

Table Cross-Chapter Box GENDER.1 | Inter-relations between SDG5 (gender equality) and adaptation initiatives in nine major sectors



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

Adaptation actions being implemented in each sector in different local contexts can have positive (synergies) or negative (trade-offs) effects with SDG 5. This can potentially lead to net positive or net negative connections at an aggregate level. How they are finally realised depends on how they are implemented, managed and combined with various other interventions, in particular, place-based circumstances. Ecosystem-based adaptation actions and terrestrial and freshwater ecosystems have higher potential for net positive connections (Roy et al., 2018) (Table Cross-Chapter Box GENDER.1 and Supplementary Material). Adaptation in terrestrial and freshwater ecosystems has the strongest net positive links with all SDG 5 targets (*medium evidence*, *low agreement*). For example, community-based natural resource management increases the participation of women, especially when they are organised into women's groups (Pineda-López

Cross-Chapter Box GENDER (continued)

et al., 2015; de la Torre-Castro et al., 2017) (Supplementary Material). For poverty, livelihood and sustainable development sectors, adaptation actions have generated more net negative scores (*limited evidence*, *low agreement*) (Table Cross-Chapter Box GENDER.1). For example, patriarchal institutions and structural discriminations curtail access to services or economic resources as compared with men, including less control over income, fewer productive assets and lack of property rights, as well as less access to credit, irrigation, climate information and seeds which devaluate women's farm-related adaptation options (Adzawla et al., 2019; Friedman et al., 2019; Ullah et al., 2019) (Supplementary Material).

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

Towards Climate-Resilient, Gender-Responsive Transformative Pathways

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

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

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

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

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

18.4 Agency and Empowerment for Climate Resilient Development

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

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

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

18.4.1 Political Economy of Climate Resilient Development

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

First, the political economy drives coupled development–climate change trajectories and determines vulnerability, thereby potentially subjecting those least responsible for climate change to the greatest risk (Sovacool et al., 2015; Barnett, 2020). The legitimacy, viability and sustainability of the prevailing political economy is being called

FAQ 5.1 (continued)

Multiple intertwined climate resilient development pathways

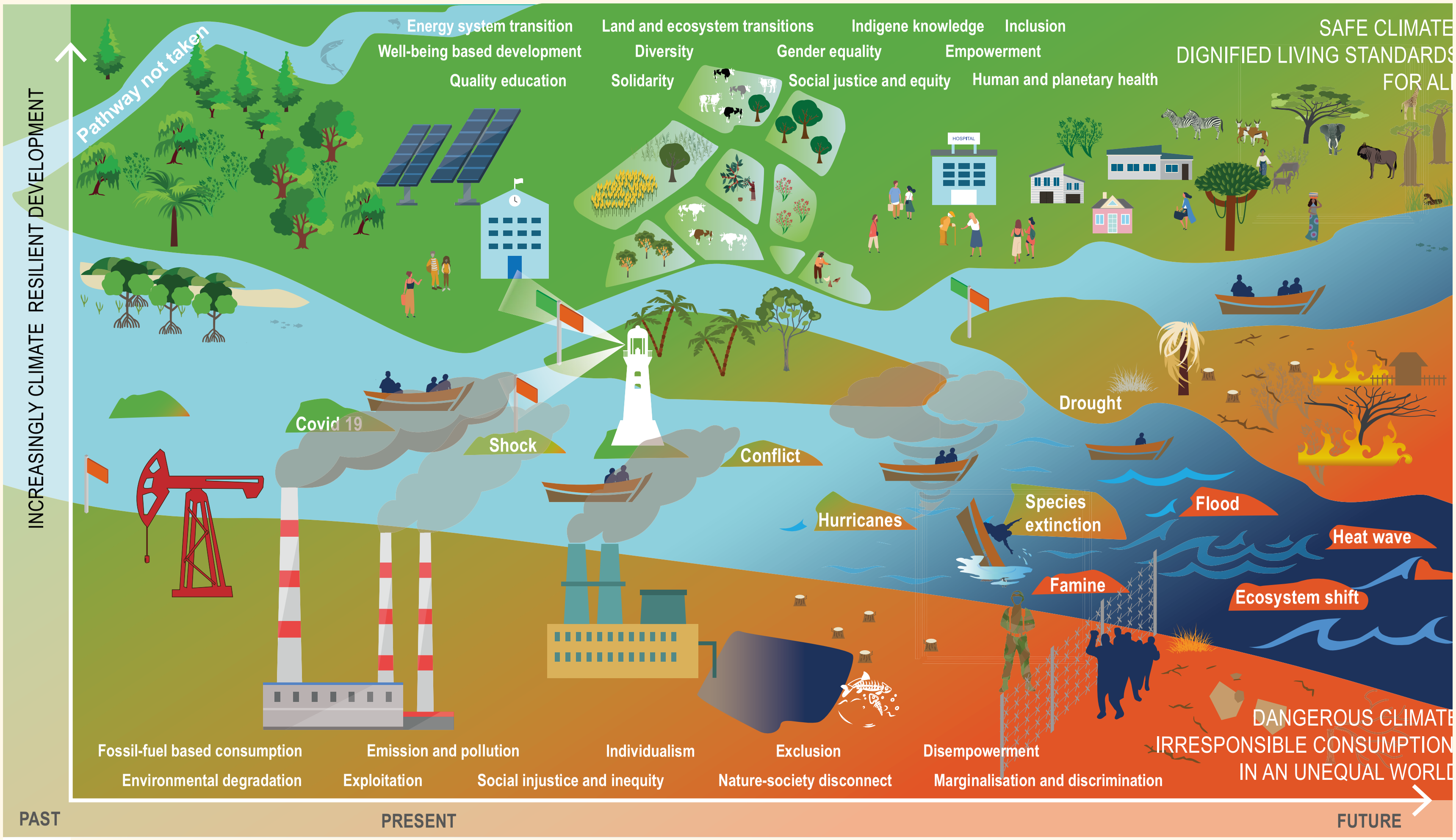


Figure FAQ18.2.1 | Multiple intertwined climate resilient development pathways. Climate change adaptation is one of several climatic and non-climatic measures carried out through decision making by multi actors that may drive a pathway in a CRD or non-CRD direction. Adaptation, mitigation and sustainable development actions can push a society in a CRD direction, but only if these measures are just and equitable. There 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 pathw 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 s from a non-CRD to a CRD pathway. Such a shift becomes more difficult as risks/shocks increase (more rocks) and non-CRD processes and outcomes progress, limiting future options. Low CRD processes and outcomes at bottom are characterised 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 figu are characterised by equity, solidarity, justice, human well-being, planetary health, stewardship/care and system transitions.

Frequently Asked Questions

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 as well as 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, non-governmental organisations (NGOs) and civil society.

Given such tensions, contestation and debate are inherent to the definition and pursuit of CRD. 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 including governmental, economic and financial, political, knowledge, science & technology, and community. Decisions and actions may be influenced by uneven interactions among 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 reflect new modalities of action in response to social, economic, and political inaction. The new climate movement, led mostly by youth, seeks science-based policy and, more importantly, rejects a reformist stance toward climate action in favour of radical climate action. This is mostly pursued 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 suggest a need to rethink the role of science in society. On 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 stimulated public engagement with climate change at unprecedented levels beyond what the scientific community can do alone.

Frequently Asked Questions

FAQ 18.4 | 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 SR1.5 report identified transitions in four key systems, including energy, land and ocean ecosystems, urban and infrastructure, and industry, as being fundamental to the pursuit of CRD. In addition, this report identifies societal transitions, in terms of values and worldviews that shape aspirations, lifestyles and consumption patterns, as another key component of CRD. Acknowledging societal transitions has implications for how one assesses options and values different outcomes from the perspectives of ethics, equity, justice and inclusion. Collectively, these system transitions can widen the solution space and accelerate and deepen the implementation of sustainable development, adaptation, and mitigation actions by equipping actors and decision-makers with more effective and more equitable options. However, the way they are pursued may not necessarily be perceived as ethical or desirable to all actors. Moreover, system transitions are necessary precursors for more fundamental climate and sustainable-development transformations. Yet, these transitions can themselves be outcomes of transformative actions.

Frequently Asked Questions

FAQ 18.5 | What are success criteria in climate resilient development and how can actors satisfy those criteria?

CRD 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 those values. Any achievement or success is always a work in progress driven by with continuous, directed, intentional actions. These actions will vary according to the priorities and needs of each population or system; therefore, specific criteria for, and indicators of, CRD will vary according to each specific context. This respect for context ensures the pursuit of CRD prioritizes people, planet, prosperity, peace and partnership, per the broad goals of the Agenda 2030 on sustainable development.

If CRD is defined as a process of implementing greenhouse gas mitigation and adaptation options to support sustainable development for all, this implies various potential criteria for success. These include the adoption of mitigation and adaptation measures to secure a safe climate, meet basic needs, eliminate poverty and enable equitable, just and sustainable development for all. Therefore, the 17 United Nations' SDGs provide a good (although limited) measure of progress toward CRD. The SDGs aim at ending poverty and hunger globally and protect life on land and underwater until the year 2030. Although there are proven synergies between the SDGs and mitigation, there remain synergies between the SDGs and adaptation that need to be explored further.

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

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Key Messages

The feasibility assessment (FA) presents a systematic framework to assess adaptation and mitigation options organised by system transitions. This Cross-Chapter Box assessed the feasibility of 23 adaptation options across six dimensions: economic, technological, institutional, socio-cultural, environmental-ecological, and geophysical to identify factors within each dimension that present barriers to the achievement of the option. The results are presented below.

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

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

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

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

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Cross-Chapter Box FEASIB (continued)

There is *medium confidence* on the feasibility of sustainable aquaculture and fisheries as adaptation options. There are financial barriers to implementing sustainable aquaculture and fisheries, even though they can improve employment opportunities, especially for local communities (*medium confidence*). Technical resource availability is still lacking and could represent a barrier to implementing sustainable aquaculture and fisheries (*medium confidence*). Robust institutional and legal frameworks are needed to guarantee effective adaptation (*high confidence*). Sustainable aquaculture and fisheries are highly dependent on healthy and resilient ecosystems (*high confidence*). They can provide diverse ecosystem services and support coastal ecosystems restoration (*medium confidence*).

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

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

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

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

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

There is strong evidence that disaster risk management (DRM) is highly feasible when supported by strong institutions, good governance, local engagement and trust across actors (*medium confidence*). DRM is constrained by lack of capacity, inadequate institutions, limited coordination across levels of government (*high confidence*), lack of transparency and accountability, and poor communication (*medium confidence).* There is a preference for top-down DRM processes, which can undermine local institutions and perpetuate uneven power relationships (*medium confidence*). However, local integration of worldviews, belief systems and local and

Cross-Chapter Box FEASIB (continued)

Indigenous Knowledge into DRM activities can facilitate successful, disability-inclusive and gender-focused DRM (*medium confidence*). Moves towards community-based and ecosystem-based DRM are promising but uneven and may increase vulnerability if they fail to address underlying and structural determinants of vulnerability (*high confidence*).

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

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

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

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

CCB FEASIB.1 Scope

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

Cross-Chapter Box FEASIB (continued)

This feasibility assessment (FA) of adaptation options is situated within four system transitions identified in SR1.5 (de Coninck et al., 2018b). In this report, feasibility refers to the potential for an adaptation option to be implemented. Twenty-three key adaptation options have been identified in AR6, across these system transitions, and mapped against representative key risks at global scale (Chapter 16) (Figure 1).

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

Feasibility assessment options mapped against Representative Key Risks (RKR)

<table>
<tr><th>Systems transitions RKRs</th><th>Energy systems transitions</th><th>Land and ecosystems transitions</th><th>Urban and infrastructure systems transitions</th><th>Overarching adaptation options</th></tr>
<tr><td>Risk to costal socio-ecological systems</td><td></td><td>• Coastal defense and hardening
• Sustainable aquaculture</td><td></td><td rowspan="8">• Social safety nets
• Risk spreading and sharing
• Climate services (including EWS)
• Disaster risk management
• Population health and health systems
• Human migration and displacement
• Planned relocation and resettlement</td></tr>
<tr><td>Risk to terrestrial and ocean ecosystems</td><td></td><td>• Integrated coastal zone management including wetland, mangrove conservation
• Sustainable forest management and conservation, forestations and afforestation
• Biodiversity management and ecosystem connectivity</td><td></td></tr>
<tr><td>Risk associated with critical physical infrastructure, networks, and services</td><td>• Resilient power infrastructure
• Improved power reliability</td><td></td><td>• Green infrastructure and ecosystem services
• Sustainable land-use land 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></td><td></td><td></td></tr>
<tr><td>Risk to food security</td><td></td><td>• Improved cropland management (including integrated soil management, conservation agriculture)
• Efficient livestock systems (including improved grazing land management)
• Agroforestry</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></td><td></td><td></td></tr>
</table>

Figure Cross-Chapter Box FEASIB.1 | Feasibility assessment option mapped against representative key risks (RKRs)

Cross-Chapter Box FEASIB (continued)

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

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

The multi-dimensional feasibility of 23 adaptation options is assessed across six dimensions. This multi-dimensional framework goes beyond technical or economic feasibility alone to capture how adaptation is mediated by the political environment, sociocultural norms (Evans et al., 2016), cognitive and motivational factors (van Valkengoed and Steg, 2019), economic incentives and benefits (Masud et al., 2017), and ecological conditions (Biesbroek et al., 2013).

The six feasibility dimensions are underpinned by a set of 20 indicators. Each adaptation option is scored as having *robust*, *medium* or *limited evidence* on barriers based on a review of literature published from 2018 onwards (pre-2018 literature is expected to be covered by SR1.5 but in some cases pre-2018 literature was added) that reports studies that are 1.5°C-relevant. Further details and motivations for this methodology can be found in Singh et al., 2020c.

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

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

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

CCB FEASIB.3.1 Energy systems transitions

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

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

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

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Cross-Chapter Box FEASIB (continued)

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

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

CCB FEASIB.3.2 Land and ecosystems

CCB FEASIB.3.2.1 Coastal defence and hardening

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

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

CCB FEASIB.3.2.2 Sustainable aquaculture

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

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

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degradation such as deforestation, enhancing land use potential (Ahmed et al., 2018; Stentiford et al., 2020; Turolla et al., 2020; Mustafa et al., 2021).

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

CCB FEASIB.3.2.3 Integrated coastal zone management (ICZM)

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

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

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

CCB FEASIB.3.2.4 Agro-forestry

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

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and positive synergies between adaptation and mitigation (Section 8.6.2.2) (Coulibaly et al., 2017; Hernández-Morcillo et al., 2018; Tschora and Cherubini, 2020; Duffy et al., 2021).

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

Over the last decade, agro-forestry schemes have grown in acceptability and political support, most notably observed in their broad inclusion in countries' NDCs and National Adaptation Plans (NAPs). Governance and institutional arrangements, however, have not been conducive to broader implementation of agro-forestry initiatives at the landscape level (Dhyani et al., 2021; Williams et al., 2021b). *Medium evidence* with *medium agreement* suggests that economic and cultural barriers may explain difficulties with the implementation of agro-forestry systems (Coe et al., 2014; Quandt et al., 2017; Cedamon et al., 2018; Hernández-Morcillo et al., 2018; Ghosh-Jerath et al., 2021). Also, unclear land tenure and ownership issues, together with inappropriate mapping and incomplete databases for monitoring vegetation, continue to hinder the adoption of broader agro-forestry strategies, particularly in remote areas and tropical forests (Martin et al., 2020).

Notably, agro-forestry practices are often part of Indigenous and local Knowledge (Santoro et al., 2020), and so far, most literature refers to the evaluation of existing agro-forestry practices or autonomous adaptation, with few studies evaluating the effects of targeted interventions, especially in low- and middle-income countries (Miller, 2020; Castle et al., 2021).

CCB FEASIB.3.2.5 Forest-based adaptation, including sustainable forest management, forest conservation and restoration, avoided deforestation, reforestation and afforestation

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

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

There is *robust evidence* and *medium agreement* that forest-based solutions support ecosystems' capacity to adapt to climate change, including better regulation of microclimate, increased groundwater recharge, improved quality of air and water, reduced soil erosion, improved and climate-adapted biodiversity habitats and expansion of biomass, as well as continuous provision of renewable wood

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products (Nabuurs et al., 2017b; Chow et al., 2019; Lochhead et al., 2019; Shannon et al., 2019; Weng et al., 2019; von Holle et al., 2020; Dooley et al., 2021; Forster et al., 2021; Tagliari et al., 2021). In well-designed systems, adaptation and mitigation can then go hand in hand, as in climate-smart forestry. What is more, adaptive forest management is already being tested in climate-smart forestry pilots in several temperate regions (Nabuurs et al., 2017b). However, large afforestation and non-native monoculture plantations may negatively impact non-forest ecosystems, such as grasslands, shrublands and peatlands, their water resources and biodiversity (Seddon et al., 2019; Seddon et al., 2020a; Seddon et al., 2020b). Similarly, the International Resource Panel (2019) warns that restoration may also imply trade-offs with other ecological and societal goals.

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

CCB FEASIB.3.2.6 Biodiversity management and ecosystem connectivity

There is *robust evidence* and *medium agreement* supporting the overall feasibility of biodiversity management and ecosystem connectivity as adaptation options. With respect to its economic feasibility, financial constraints continue to hinder broader implementation of biodiversity-based solutions (Lausche et al., 2013; Chausson et al., 2020; Jones et al., 2020a). Seddon et al. (2020a) highlights that only 5% of climate finance goes towards adaptation strategies, and only 1% is destined to disaster risk management including NbS and biodiversity management. Government support via subsidies and fiscal transfers is critical for broader biodiversity management interventions. In addition, REDD+ (Reduced Emissions from Deforestation and Land Degradation) initiatives have been promoted as a profitable mechanism to advance biodiversity conservation strategies while reducing carbon emissions. As far as ecosystem connectivity is concerned, its feasibility will strongly depend on the existence of a regulatory framework that appropriately balances property rights, environmental regulations and monetary incentives to ensure landowners' willingness to participate and maintain ecosystem corridors (Jones et al., 2020b). The demands of commodity-based economies, favouring extractive land uses, present serious barriers to upscaling biodiversity-based adaptation interventions (Seddon et al., 2020a). In addition, integrated assessments have shown how biodiversity-based solutions can deliver jobs from landscape restoration or income from wildlife tourism and how those benefits are fairly distributed (Chausson et al., 2020).

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

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

There is *high agreement* and *robust evidence* supporting the ecological capacity enhancement of biodiversity-based and ecosystem connectivity strategies (Thompson et al., 2017; Lavorel et al., 2020). Forest management that favours mixed-species rather than non-

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native monocultures can promote the resilience of timber production and carbon storage while also benefiting biodiversity (Chausson et al., 2020). Similarly, monocultures have been found to impoverish biodiversity and hold less resilient carbon stocks than natural and semi-natural forests (Seddon et al., 2020a).

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

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

CCB FEASIB.3.2.7 Improved cropland management

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

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

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

CCB FEASIB.3.2.8 Efficient livestock systems

Enhancing the production efficiency of livestock systems through, for example, improved livestock diets, enhanced animal health, breeding and manure management, can contribute to adaptation and mitigation (Ericksen and Crane, 2018; Accatino et al., 2019; Paul

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

CCB FEASIB.3.2.9 Water use efficiency and water resource management

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

CCB FEASIB.3.2.10 Livelihood diversification

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

CCB FEASIB.3.3 Urban and infrastructure system transitions

CCB FEASIB.3.3.1 Sustainable land use and urban planning

Urban planning is a medium feasibility option to support adaptation by prioritising it in city plans, such as land use planning, transportation (Liang et al., 2020), and health and social services (Carter et al., 2015; Araos et al., 2016b); by procuring the design and construction of resilient infrastructure; by promoting community-based adaptation through community-based design and implementation of adaptation activities (Archer, 2016); and by protecting and integrating biodiversity and ecosystem services into city planning. Research since SR1.5 documents the challenging high costs of infrastructure (Georgeson et al., 2016; Woodruff et al., 2018); potential loss of municipal revenue in the case of managed retreat (Shi and Varuzzo, 2020; Siders and Keenan, 2020); and the fraught causal connection between planning

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and the reduction of socioeconomic vulnerability (Keenan et al., 2018; Anguelovski et al., 2019a; Elliott, 2019; Paganini, 2019; Shokry et al., 2020). However, adaptation benefits could potentially outweigh costs (Carey, 2020). There is financial viability of green infrastructure (Meerow, 2019; Zhang et al., 2019; Van Oijstaeijen et al., 2020; Ossola and Lin, 2021); and availability of technical expertise, although the inequitable planning processes and distribution of those resources remains a significant concern (Serre and Heinzlef, 2018; Szewrański et al., 2018; Fitzgibbons and Mitchell, 2019; Hasan et al., 2019; Heikkinen et al., 2019; Colven, 2020; Goetz et al., 2020; Goh, 2020).

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

CCB FEASIB.3.3.2 Green infrastructure and ecosystem services

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

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

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

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

Governments across scales can support urban sustainable water management with high feasibility by undertaking projects to recycle wastewater and runoff from higher intensity storms, with implications for decarbonisation and adaptation. Green infrastructure, for example, has shown a high potential to reduce water-use footprints and to save potable water for consumption (Liu and Jensen, 2018), and contributing to a 'circular' water system in cities (Oral et al., 2020). Supportive governance can yield positive outcomes such as improved water security (Jensen and Nair, 2019) and there is *medium evidence* and *high agreement* that participation, such as involving

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informal settlement residents in water management can improve social inclusion (Pelling et al., 2018; Williams et al., 2018; Leigh and Lee, 2019b; Sletto et al., 2019). Green infrastructure can support the planning of 'sponge cities', such as in China, wherein large areas of green space, permeable surfaces and sustainable water sourcing combine to purify urban runoff, attenuate peak runoff and conserve water for consumption (Chan et al., 2018; Nguyen et al., 2019). Similar approaches in Dutch cities focus on designing and planning for the capturing, storing and draining of storm water (Dai et al., 2018). However, some interventions suffer from uncertainties in design, planning and financing (Nguyen et al., 2019). As drought becomes more severe in some regions, physical barriers in the form of reduced availability of water may become pressing (Singh et al., 2021b).

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

CCB FEASIB.3.4 Cross-cutting adaptation options

CCB FEASIB.3.4.1 Social safety nets

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

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CCB FEASIB.3.4.2 Risk spreading and sharing

There is *high confidence* on risk spreading and sharing, most commonly arranged through insurance, as an adaptation option, but high to medium feasibility depending on context (e.g., developed versus developing countries). Technological, economic and institutional feasibility is high, as insurance can spread risk, provide a buffer against the impact of climate hazards, support recovery and reduce the financial burden on governments, households and businesses (Wolfrom and Yokoi-Arai, 2015; O'Hare et al., 2016; Glaas et al., 2017; Jenkins et al., 2017; Patel et al., 2017; Kousky et al., 2021). Insurance can shift the mobilisation 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 behaviour that reduce vulnerability and exposure (Linnerooth-Bayer and Hochrainer-Stigler, 2015; Shapiro, 2016; Jenkins et al., 2017). Socio-cultural barriers, such as social inclusiveness, socio-cultural acceptability and gender equity constrains feasibility (Bageant and Barrett, 2017; Budhathoki et al., 2019). Insurance can provide disincentives for reducing risk through the transfer of the risk spatially and temporally, distorting incentives for adaptation if the pricing is too low (moral hazard) and is often unaffordable, poorly understood, and not widely utilised in developing nations even when subsidised, possibly leading to maladaptation (García Romero and Molina, 2015; Joyette et al., 2015; Lashley and Warner, 2015; Jin et al., 2016; Müller et al., 2017; Tesselaar et al., 2020). Insurance can reinforce exposure and vulnerability through underwriting a return to the 'status-quo' rather than enabling adaptive behaviour (e.g., through 'no-betterment' principles) (Collier and Cox, 2021). For low-income nations and in the absence of global support, insurance shifts responsibility to those least responsible for climate change (Surminski et al., 2016).

CCB FEASIB.3.4.3 Disaster risk management

There is *robust evidence* (*high agreement*) that DRM aids adaptation decision making, particularly where it is demand-driven, context-specific and supported by strong institutions, good governance, strong local engagement and trust across actors (Hasan et al., 2019; Kim

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and Marcouiller, 2020; Peng et al., 2020; Smucker et al., 2020; Uddin et al., 2020; Webb, 2020; Ali et al., 2021; Anderson and Renaud, 2021; Glantz and Pierce, 2021; Ji and Lee, 2021; Villeneuve, 2021). These conditions are rarely met, and therefore DRM is often constrained by institutional factors that may even increase vulnerability (Booth et al., 2020; Islam et al., 2020b; Islam et al., 2020c; Marchezini, 2020; Goryushina, 2021; Mena and Hilhorst, 2021). The feasibility of DRM continues to be constrained by limited coordination across levels of government, lack of transparency and accountability, poor communication and a preference for top-down DRM processes that can undermine local institutions and perpetuate uneven power relationships (Atanga, 2020; Booth et al., 2020; Bordner et al., 2020; Bronen et al., 2020; Goryushina, 2021; Mena and Hilhorst, 2021; Son et al., 2021; Yumagulova et al., 2021). However, local integration of worldviews, belief systems and local and Indigenous Knowledge into DRM activities improves feasibility (Bordner et al., 2020; Cuaton and Su, 2020; Hosen et al., 2020; Sharma and Sharma, 2021), including disability-inclusive and gender-focused DRM (Ruszczyk et al., 2020; Crawford et al., 2021). Data access and availability continues to challenge DRM despite advances in data analytics, especially in rapidly growing informal settlements, including population estimates and limited mobility data (Goniewicz and Burkle, 2019; Marchezini, 2020).

Moves towards community-based and ecosystem-based DRMs are promising but uneven (Klein et al., 2019; Seebauer et al., 2019; Almutairi et al., 2020; Bordner et al., 2020; Hosen et al., 2020; Murti et al., 2020; Sharma and Sharma, 2021), and may increase vulnerability if they fail to address underlying, structural determinants of vulnerability, particularly among marginalised groups and by gender (Sections 8.4.4 and 8.4.5) (Seleka et al., 2017; Hossen et al., 2019; Ramalho, 2019b; Atanga, 2020; Cuaton and Su, 2020; Gartrell et al., 2020; Kenney and Phibbs, 2020; Khalil et al., 2020; Ngin et al., 2020; Ruszczyk et al., 2020; Webb, 2020; Ali et al., 2021; Geekiyanage et al., 2021; Villeneuve, 2021).

CCB FEASIB.3.4.4 Climate services, including early warning systems

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

CCB FEASIB.3.4.5 Health and health systems adaptation

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

Health systems can provide sufficient and high-quality healthcare to all where capacity is well developed, and where options are aligned with national priorities, engage local to international communities, and address the needs of particularly vulnerable regions and population groups (Hanefeld et al., 2018; Austin et al., 2019; Nuzzo et al., 2019; Sheehan and Fox, 2020). Microeconomic feasibility and socioeconomic vulnerability reduction potential are high where a system's capacity is well developed. Economic feasibility poses a significant challenge in low-income settings, with many governments projected to require international climate finance for health systems which is not currently available (WHO, 2019; Watts et al., 2021), and where adequate household-level financial security is a cross-cutting barrier (Paudel and Pant, 2020). Risk mitigation potential is high where capacity is well developed, for example through technologies to monitor and alter environmental conditions (Lock-Wah-Hoon et al., 2020; Kouis et al., 2021; Ligsay et al., 2021). Social co-benefits of mainstreaming health and climate change are also present, such as the inclusion of environmental health in medical education curricula training programmes (Kligler et al., 2021). There is growing recognition that lack of institutional capacity and low availability of resources represent major barriers to health system adaptation options, particularly for health systems struggling to manage current health risks

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(Ebi et al., 2018; Brooke-Sumner et al., 2019; Chersich and Wright, 2019; Gilfillan, 2019; Negev et al., 2019; Hussey and Arku, 2020), for neglected populations (Hanefeld et al., 2018; Negev et al., 2019), and where there are conflicting mandates or poor coordination across ministries (Austin et al., 2019; Fox et al., 2019; Gilfillan, 2019; Kendrovski and Schmoll, 2019; Sheehan and Fox, 2020). Barriers to adapting health systems to climate change include lack of institutional funding, staff and data access (Austin et al., 2019; Schramm et al., 2020; Opoku et al., 2021), inadequate resources for evaluation and management of adaptation (Pascal et al., 2021), competing stakeholder goals and costly technology (Negev et al., 2021). Within the healthcare community, surveillance systems generally lack ways to integrate climate observation data, as well as expertise to critically evaluate these data, limiting their ability to plan and prepare for climate hazards and hospital-associated vulnerabilities (Runkle et al., 2018; Chersich and Wright, 2019; Liao et al., 2019). Although understanding of health vulnerability is growing (Berry et al., 2018), knowledge on the health effects of climate change among health practitioners remains limited (Ebi et al., 2018; Brooke-Sumner et al., 2019; Chersich and Wright, 2019; Fox et al., 2019; Liao et al., 2019; Albright et al., 2020). Mechanisms to ensure transparency and accountability of implementing, monitoring and evaluating adaptation within the health sector are lacking, across scales and contexts (Gostin and Friedman, 2017; Huynh and Stringer, 2018; Parry et al., 2019).

CCB FEASIB.3.4.6 Human migration

Much climate-related migration is associated with labour migration. Rural–urban migrant networks are important channels for remittances and knowledge that help build resilience to hazards in sending areas (Bragg et al., 2018; Obokata and Veronis, 2018; Semenza and Ebi, 2019; Maharjan et al., 2020; Porst et al., 2020). Whether migration reduces vulnerability for migrants depends on levels of control over the migration decision and assets such as wealth, and education of the migrant household (Thober et al., 2018; Cattaneo, 2019; Hoffmann et al., 2020; Maharjan et al., 2020; Sedova and Kalkuhl, 2020). Individuals from households of all levels of wealth migrate. However, poorer households do so with lower levels of choice and often more likely under duress, and in these cases, migration can undermine well-being (Suckall et al., 2016; Mallick et al., 2017; Nawrotzki and DeWaard, 2018; Natarajan et al., 2019). In some cases, migration can increase poverty in sending communities (Jacobson et al., 2019). Women in the sending community can experience an increase or decrease in the vulnerability, depending on the livelihoods people are moving into and existing asset bases (Banerjee et al., 2018; Banerjee et al., 2019b; Goodrich et al., 2019; Maharjan et al., 2020; Rao et al., 2020; Singh and Basu, 2020; Singh et al., 2020b).

Migration has been highly politicised, and climate-related immigration has been conceptualised in public and media discourse as a potential threat which limits adaptation feasibility (Telford, 2018; Honarmand Ebrahimi and Ossewaarde, 2019; McLeman, 2019; Wiegel et al., 2019; Hauer et al., 2020). Existing international agreements provide potential frameworks for climate-related migration to benefit adaptive capacity and sustainable development (Warner, 2018; Kälin, 2019). However, agreements to facilitate temporary or circular migration and remittances are often informal and limited in scope (Webber and Donner, 2017b; Margaret and Matias, 2020) and migrant receiving areas, particularly urban areas, can be better assisted to prepare for population change (Deshpande et al., 2019; Adger et al., 2020; Hauer et al., 2020). Policies and planning are lacking that would ensure that positive migration outcomes for sending and receiving areas and the migrants themselves (Wrathall et al., 2019; Adger et al., 2020; de Salles Cavedon-Capdeville et al., 2020; Hughes, 2020).

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

CCB FEASIB.3.4.7 Planned relocation and resettlement

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

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Cross-Chapter Box FEASIB (continued)

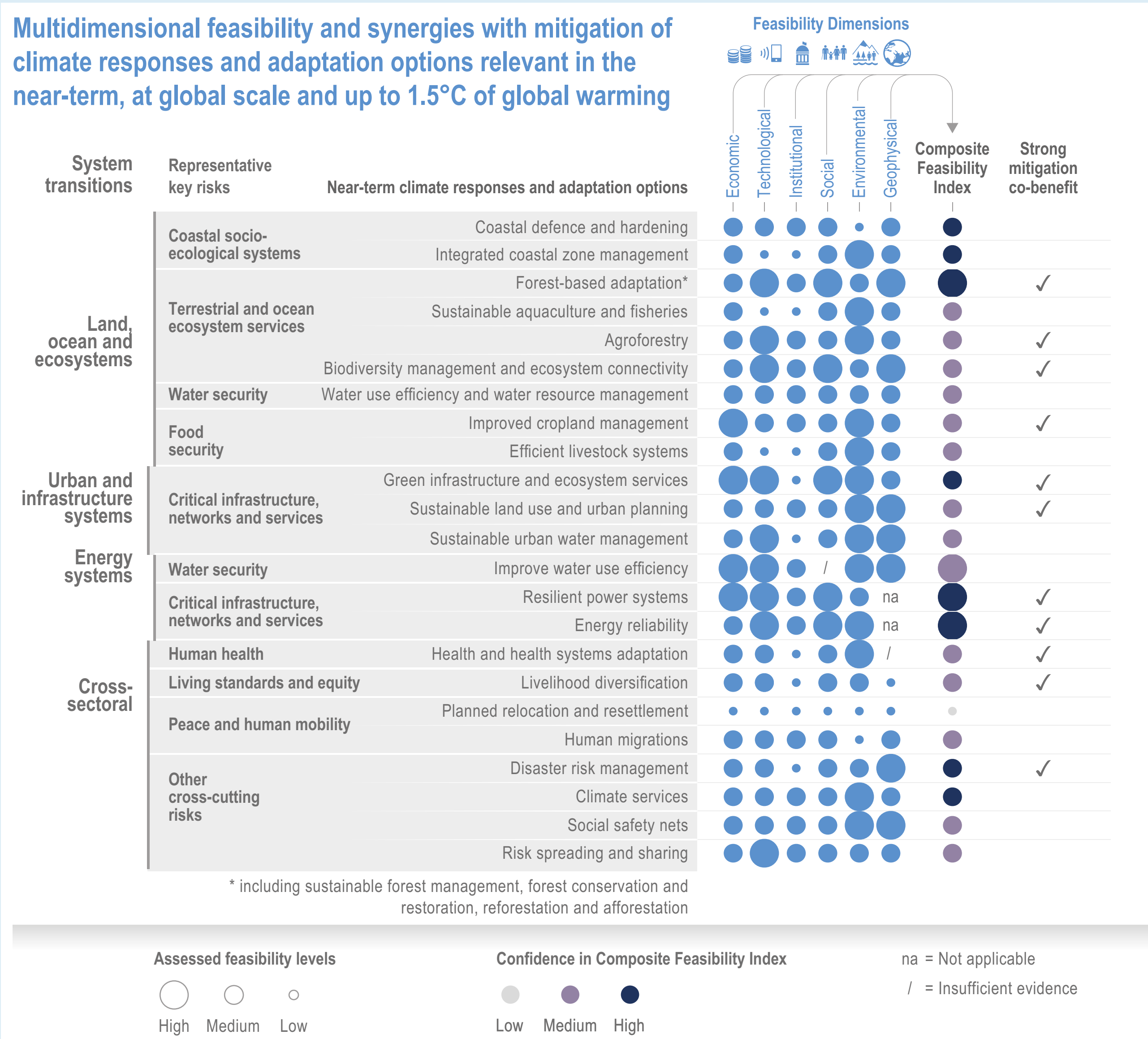


Figure Cross-Chapter Box FEASIB.2 | This figure summarizes the assessment results classifying options by System Transitions and Representative Key Risks. Each option is assessed across six dimensions: economic, technological, institutional, socio-cultural, environmental and geophysical. Each dimension is assessed as high (big circle), medium (medium circle), low (small circle) feasibility, and limited evidence or no evidence (LE/NE, as a dash). Composite feasibility is calculated across the six dimensions following the same key as above, with feasibility levels determined by circle size and confidence levels by shades of colour. The last column shows options with strong synergies with mitigation, which is then broken down in Fig. CCB FEASIB.3.

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

Cross-Chapter Box FEASIB (continued)

a lack of appropriate mechanisms through which to deliver that funding (Boston et al., 2021). For example, planned relocation projects cannot access disaster relief funds in the USA because of the slow onset nature of the impacts (Bronen and Chapin, 2013).

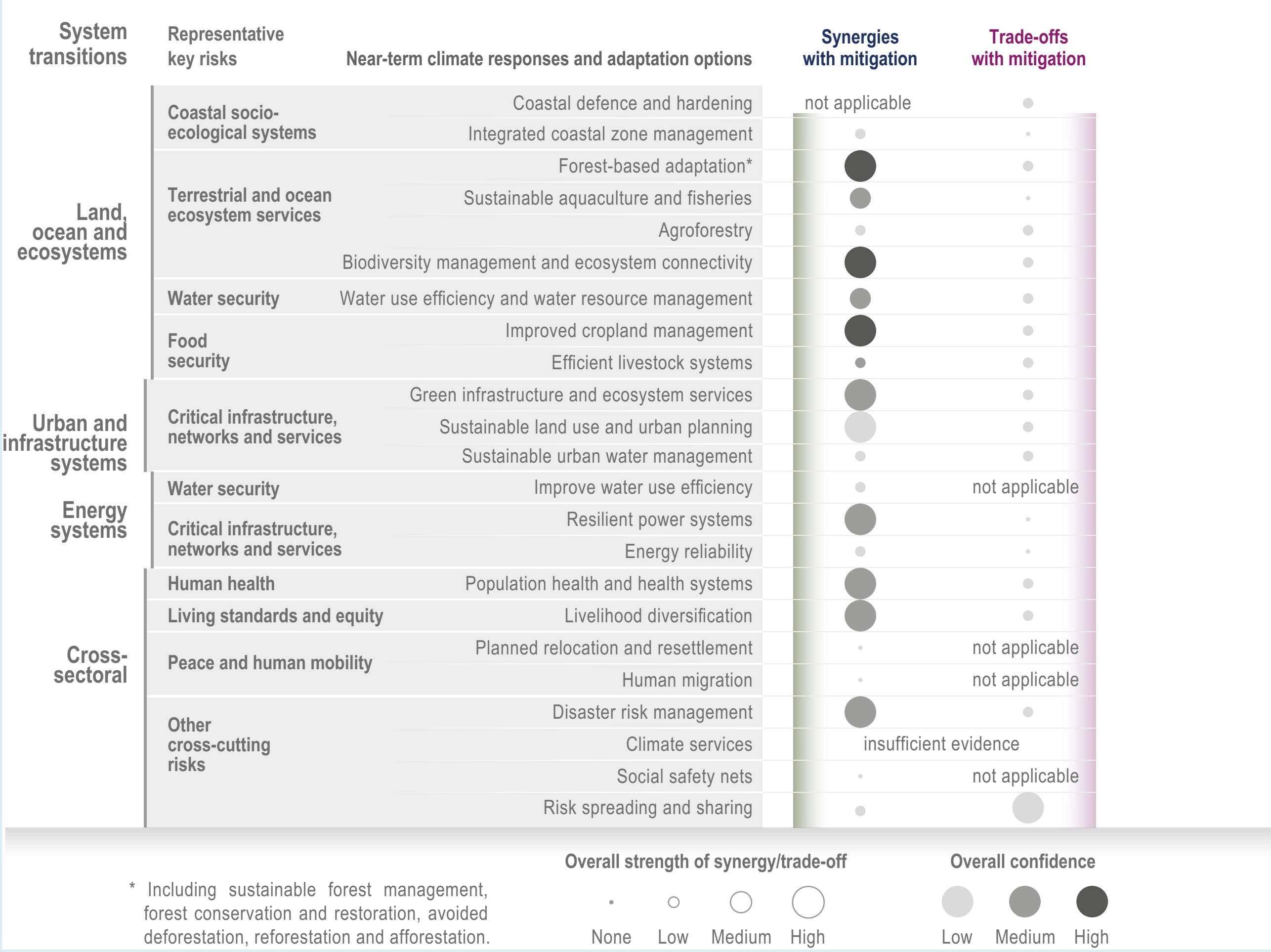
Without consultation, relocated people can experience significant financial and emotional distress as cultural and spiritual bonds to place and livelihoods are disrupted (Neef et al., 2018; Roy et al., 2018b; Piggott-McKellar et al., 2019; Bertana, 2020; McMichael and Katonivualiku, 2020; McMichael et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

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

CCB FEASIB.4 Synergies and trade-offs

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

(a) Climate responses and adaptation options and their implications for mitigation



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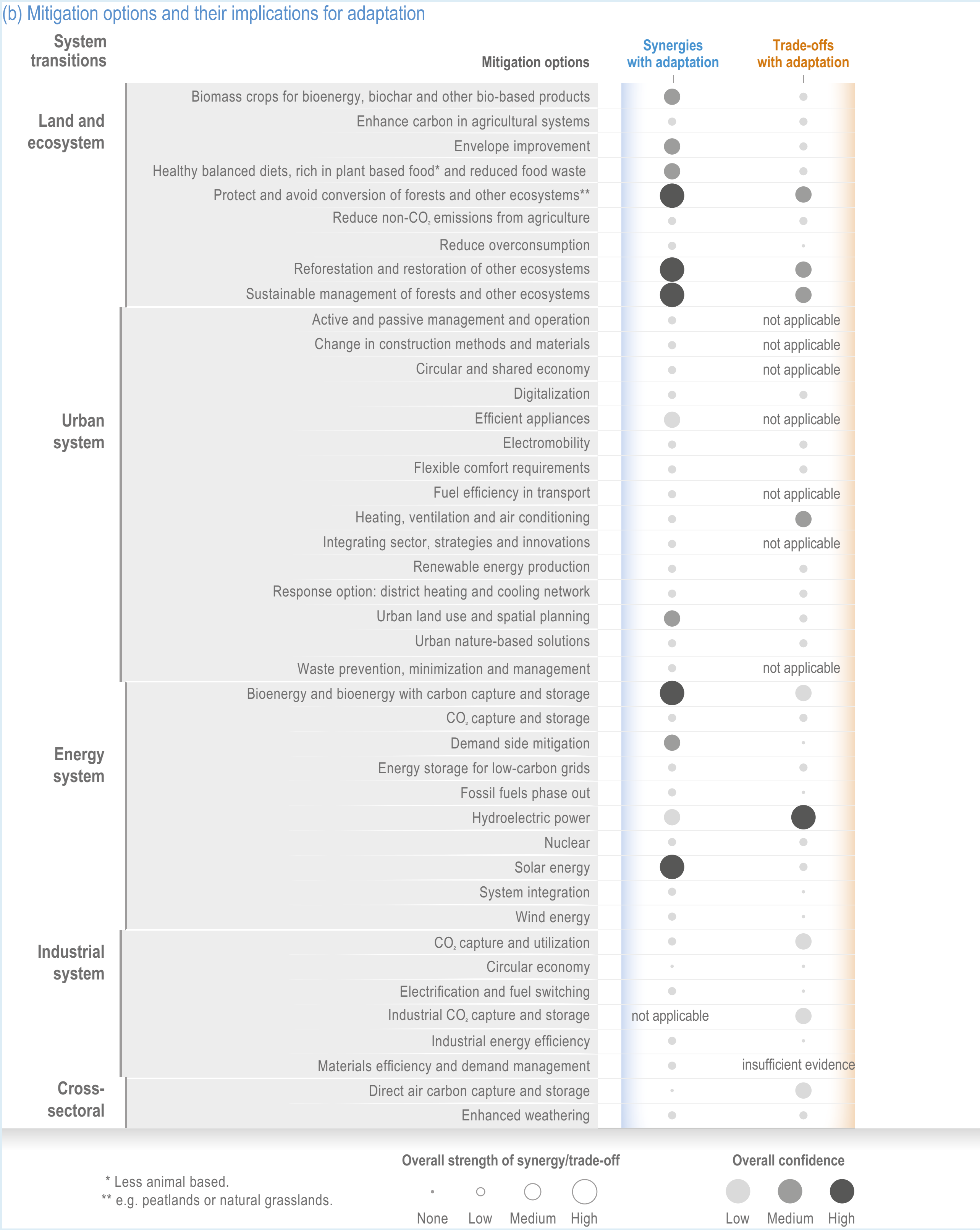

Figure Cross-Chapter Box FEASIB.3 | This figure shows a) adaptation options synergies and trade-offs with mitigation and b) mitigation options synergies and trade-offs with adaptation. The size of the circle denotes the strength of the synergy or trade-offs with big circles meaning strong synergy or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

Cross-Chapter Box FEASIB (continued)

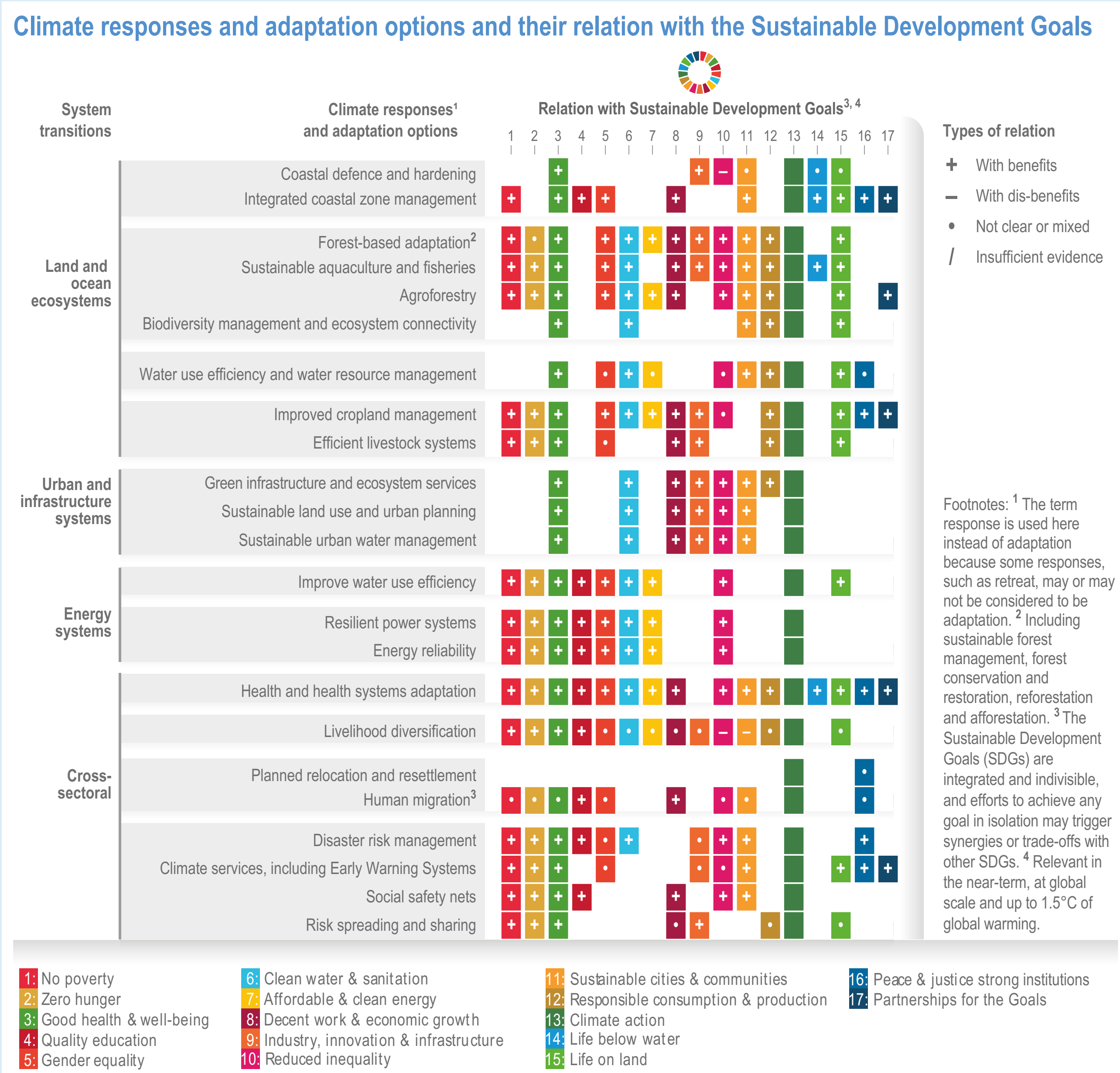

Figure Cross-Chapter Box FEASIB.4 | This figure summarises the assessment of the nexus of each adaptation option considered in this CCB with the 17 Sustainable Development Goals (SDGs). SDGs with which there is a nexus are colored and have a + for positive nexus, – for negative nexus and +/– for mixed nexus. Blank cells either don't have a nexus or there is no or limited evidence of such nexus.

CCB FEASIB.5 Knowledge Gaps

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

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

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Cross-Chapter Box FEASIB (continued)

Under land and ecosystem system transitions, gaps include *limited evidence* for some of the institutional and socio-cultural feasibility dimensions indicators of Integrated Coastal Zone Management. Specifically, there is lack of evidence for transparency and accountability potential and for gender and intergenerational equity. For coastal defence 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 options of forest-based adaptation and biodiversity management and ecosystems connectivity have 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. The efficient livestock systems option has no evidence for political acceptability and legal and regulatory feasibility, and *limited evidence* for overall institutional feasibility. Agro-forestry 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 cross-cutting options, the main knowledge gaps identified are socio-cultural acceptability for social safety nets. While the evidence on resettlement, relocation and migration is large and growing, there is disagreement on several indicators, marking the need for more evidence synthesis. Geophysical feasibility for resettlement, relocation and migration has *limited evidence*, but is an emerging area of research.

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

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