17 Decision-Making Options for Managing Risk

Coordinating Lead Authors: Mark New (South Africa), Diana Reckien (the Netherlands/Germany), David Viner (UK)

Lead Authors: Carolina Adler (Switzerland/Chile/Australia), So-Min Cheong (Republic of Korea), Cecilia Conde (Mexico), Andrew Constable (Australia), Erin Coughlan de Perez (USA), Annamaria Lammel (France), Reinhard Mechler (Austria/Germany), Ben Orlove (USA), William Solecki (USA)

Contributing Authors: Rawshan Ara Begum (Malaysia/Australia/Bangladesh), Lea Berrang-Ford (UK/Canada), Rachel Bezner Kerr (Canada), Sukaina Bharwani (UK), Robbert Biesbroek (the Netherlands), Laurens Bouwer (the Netherlands), Emily Boyd (Sweden), Lily Burge (UK), Massimo Cattino (Italy), Isabelle Cojocaru-Durand (Canada), Riyanti Djalante (Japan), Mauricio Domínguez Aguilar (Mexico), Kristie Ebi (USA), Hannah Farkas (USA), Simon French (UK), Katja Frieler (Germany), Matthias Garschagen (Germany), Adugna Gemeda (Ethiopia), Francois Gemenne (Belgium), Michael Gerrard (USA), Elisabeth Anne Gilmore (USA), Nicoletta Giulivi (Italy/Guatemala), Maron Greenleaf (USA), Marjolijn Haasnoot (the Netherlands), Ralph Hamman (Germany), Kirstin Holsman (USA), Christian Huggel (Switzerland), Margot Hurlbert (Canada), Kripa Jagannathan (India/USA), Catalina Jaime (UK/Colombia), Richard Jones (UK), Sirkku Juhola (Finland), Rachel E. Keeton (the Netherlands/USA), Zoe Klobus (USA), Carola Kloeck (Germany/France), Bettina Koelle (South Africa/Germany), Robert Kopp (USA), Carolien Kraan (the Netherlands), Judy Lawrence (New Zealand), Timo Leiter (Germany/UK), Robert Lempert (USA), Debora Ley (Mexico), Tabea Lissner (Germany), Megan Lukas-Sithole (South Africa), Katharine Mach (USA), Alexandre Magnan (France), Kathleen Miller (USA), Lionel Mok (Canada), Veruska Muccione (Italy), Rupa Mukerji (India), Johanna Nalau (Australia/Finland), Baysa Naran (Mongolia), Camille Parmesan (USA), Lei Pei (China), Mark Pelling (UK), Rosa Perez (Phillippines), Lavinia Perumal (South Africa), Patricia Pinho (Brazil), Madeleine Rawlins (UK), Neha Rai (UK), Britta Rennkamp (South Africa/Germany), Alexandra Rinaldi (USA), Olivia Rumble (South Africa), Liane Schalatek (USA), Emma Lisa Freia Schipper (Sweden/USA), Pasang Yangjee Sherpa (USA/Nepal), Sabrina Shih (USA), Roopam Shukla (India/Germany), Rachael Shwom (USA), Nick Simpson (Zimbabwe/SouthAfrica), Chandni Singh (India), Doreen Stabinsky (USA), Adelle Thomas (Bahamas), M. Cristina Tirado-von der Pahlen (USA/Spain), Cathy Vaughn (USA), Maria Alejandra Velez (Colombia), Ivo Wallimann-Helmer (Switzerland), Charlene Watson (UK), Romain Weikmans (Belgium), Andrew Jordan Wilson (USA), Katy Wilson (UK), Mark Workman (UK), Anita Wreford (New Zealand)

https://doi.org/10.1017/9781009325844.026

Review Editors: Richard Klein (Germany/the Netherlands), Zinta Zommers (Latvia/Sierra Leone)

Chapter Scientists: Megan Lukas-Sithole (South Africa), Massimo Cattino (Italy), Lauren Arendse (South Africa), Vita Karoblyte (UK), Leah Jones (USA)

This chapter should be cited as:

New, M., D. Reckien, D. Viner, C. Adler, S.-M. Cheong, C. Conde, A. Constable, E. Coughlan de Perez, A. Lammel, R. Mechler, B. Orlove, and W. Solecki, 2022: Decision-Making Options for Managing Risk. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2539–2654, doi:10.1017/9781009325844.026.

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Executive Summary

Introduction and Framing

Chapter 17 assesses the options, processes and enabling conditions for climate risk management, a key component of climate resilient development. While Chapter 16 assesses the risks that society and ecosystems face, and residual risks after adaptation, this chapter focuses on the 'how' of climate risk management and adaptation. It covers: the adaptation and risk management options that are available; the governance and applicability of options in different contexts; residual risk and Loss and Damage; the methods and tools that can be drawn on to support climate risk management planning and implementation; enabling conditions and drivers for adaptation; the role of monitoring and evaluation for integrated risk management and tracking progress, success and the risk of maladaptation; and finally, integration of risk management across sectors, jurisdictions and time horizons, under dynamic conditions of environmental and societal change.

Adaptation options for managing a wide range of climate risks have been proposed, planned or implemented across all sectors and regions, with prospects for wide-ranging benefits to nearly all people and ecosystems (*high confidence*[1]). Many options are widely applicable and could be scaled up to reduce vulnerability or exposure for the majority of the world's population and the ecosystems they depend on (*high confidence*). These include nature restoration (*high confidence*), changing diets and reducing food waste (*high confidence*), infrastructure retrofitting (*high confidence*), building codes (*medium confidence*), disaster early warning (*high confidence*) and cooperative governance (*medium confidence*). The portfolio of adaptation options that could be successfully implemented varies across locations, with resource-limited and conflict-affected contexts bearing large amounts of residual risk (*high confidence*) {17.2, 17.2.1, 17.5.1}.

The majority of climate risk management and adaptation currently being planned and implemented is incremental (*high confidence*). Transformational adaptation will become increasingly necessary at higher global warming levels (*medium confidence*) but can be associated with significant and inequitable trade-offs (*medium confidence*). Adaptations with some of the highest transformative potential include migration (*high confidence*), spatial planning (*medium confidence*), governance cooperation (*medium confidence*), universal access to health care (*medium confidence*) and changing food systems (*medium confidence*). Options that tend to modify existing systems incrementally include early-warning systems (*high confidence)*, insurance (*medium confidence*) and improved water use efficiency (*high confidence*) {17.2, 17.5.1}.

Governance, especially when inclusive and context sensitive, is an important enabling condition for climate risk management and adaptation (*very high confidence*). The use of formal and informal governance approaches, often in polycentric arrangements of public, private and community actors, is being increasingly recognised as important across many decision-making settings (*high confidence*). Public governance leadership has the largest role for social safety nets, spatial planning and building codes (*high confidence*). Private sector governance is important for insurance and for minimising the stressors that can negatively impact ecosystems and their functions, especially in the absence of public regulations or enforcement (*medium confidence*). Communities and individuals play the largest role in governance of adaptations to farming and fishery practices and ecosystem-based adaptations (*medium confidence*). Informal or individual-led decision-making is more common in food security and livelihood-related adaptations, such as changes to diets, livelihood diversification and seasonal migration (*high confidence*). People who have experienced climate shocks are more likely to take on informal adaptation measures, and in places where people are more exposed to extreme events, autonomous adaptation is more common (*high confidence*) {17.2.1, 17.3.2, 17.4.2}.

National and international legal and policy frameworks and instruments support the planning and implementation of adaptation and climate risk management across scales, especially when combined with guidelines for action (*medium confidence*). Nationally Determined Contributions (NDCs) have been drivers of national adaptation planning, with cascading effects on sectors and sub-national action, especially in developing countries (*high confidence*). Nearly all developing countries (particularly Small Island Developing States [SIDS]) that included an adaptation component in their NDCs consider adaptation the most urgent aspect of their national climate change response (*high confidence*). A steady increase in national and sub-national laws, policies and regulations that mandate reporting and risk disclosure has promoted adaptation response across public agencies, private firms and community organisations (*high confidence*). Greater adaptation is present where national climate laws and policies require adaptation action from lower levels of government and include guidelines on how to do so (*medium confidence*) {17.4.2}.

Recognition of the critical role of financing for adaptation and resilience as an important enabler for climate risk management has strengthened (*high confidence*). Yet, since the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5), the gap between the estimated costs of adaptation and the documented (tracked) finance allocated to adaptation has widened (*high confidence*). Estimated global and regional costs of adaptation vary widely due to differences in assumptions, methods and data; the majority of more recent estimates are higher than the figures presented in AR5 (*high confidence*). A high proportion of developing country NDC adaptation contributions are conditional on external financial support, emphasising the crucial role of international finance to achieving adaptation efforts commensurate with climate risks (*high confidence*). Developed country climate finance leveraged for developing countries for mitigation and adaptation has fallen short of the 100 USD billion yr^{-1} Copenhagen

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

commitment for 2020 (*very high confidence*). Substantial opportunities exist for improving access to climate finance, as well as its impact and effectiveness {17.4.2; Cross-Chapter Box FINANCE in this Chapter}.

Private sector financing for adaptation has been increasingly promoted as a response to realised adaptation finance needs (*high confidence*). However, private sector financing of adaptation has been limited, especially in developing countries (*high confidence*). Tracked private sector finance for climate change action has grown substantially since 2015, but the proportion directed towards adaptation has remained small (*high confidence*); in 2018, these contributions were 0.05% of total climate finance and 1% of adaptation finance. A key challenge for private sector financing of adaptation is demonstrating financial return on investment, as many benefits of adaptation arise as avoided damages or public goods, rather than direct revenue streams (*medium confidence*). Leveraging private finance in developing countries is often more difficult because of risk (perceived and real) to investors, reducing the pool of potential investors and/or raising the cost (interest) of investment (*medium confidence*) {17.4.3.; Cross-Chapter Box Finance in this Chapter}.

Information and knowledge on climate risk and adaptation options, derived from different knowledge systems, can support risk management and adaptation decisions (*high confidence*). Processes, such as co-production, that link scientific, Indigenous, local, practitioner and other forms of knowledge can make climate risk management processes and outcomes more effective and sustainable (*high confidence*) {17.3.2; 17.4.4}.

Climate services that provide reliable, relevant and usable climate information for the short or long term are increasingly being produced and used in climate risk management (*high confidence*). In many regions and sectors, the utility of climate services is strengthened by sustained engagement between stakeholders and experts and by co-production (*medium confidence*). Significant gaps remain in the evaluation of climate services, and some studies indicate that climate services often do not reach the most vulnerable and more isolated people, maintaining or exacerbating inequality{17.4.4; Cross-Chapter Box Climate Services WGI Chapter 12}.

Catalysing conditions and windows of opportunity can drive shifts in motivation and adaptation effort, stimulating more rapid uptake of existing and new adaptation options (*medium confidence*). Decision makers can take advantage of windows of opportunity to promote rapid and effective responses in reactive and proactive cases. Disaster events or shocks such as wildfires, tropical cyclones, heatwaves or coral bleaching have catalysing characteristics (*high confidence*). Additional types of catalysing conditions include climate litigation and the presence of individuals and organisations that act as policy and decision innovators, including government and business innovators in cities (*medium confidence*), stimulating action within and beyond their immediate contexts (*medium confidence*). Litigation on failure of government and business to adapt is becoming more frequent and is expected to increase as climate impact attribution science matures further (*high confidence*) {Cross-Chapter Box LOSS in this Chapter; 17.4.5.2, 17.4.5.3}.

Urgency can stimulate prompt climate risk management (*high confidence*). A moderate level of urgency contributes to enhanced climate action, while both high and low levels of urgency can impede response (*high confidence*). Well-designed communication strategies can move decision makers from low to moderate levels of urgency, stimulating action. As conditions approach a crisis state, however, urgency can weaken decision-making rather than support it (*medium confidence*) {17.4.5.1}.

Decision support tools and decision-analytic methods are available and are being applied for managing climate risks in varied contexts, including where deep uncertainty is present (*high confidence*). These tools and methods have been shown to support deliberative processes where stakeholders jointly consider factors such as the rate and magnitude of change and their uncertainties, associated impacts and timescales of adaptation needed along multiple pathways and scenarios of future risks (*high confidence*). However, comparative evidence on the relative utility of different analytical methods in their use by decision makers for managing climate risks is an important gap (*medium confidence*). Nevertheless, robust decision-making, using pathway analyses to determine 'no regrets' options among trade-offs, has been shown to be a useful starting point under deep uncertainty (*medium confidence*). Methods for analysing options differ across geopolitical scales, with modelling studies being a particularly prominent method across scales from community and urban to regional and national (*high confidence*) {17.3.1, 17.3.2, 17.6, Cross-Chapter Box DEEP in this Chapter}.

Successful adaptation and maladaptation form the opposite poles of a continuum (*medium confidence*). The evaluation of an adaptation option and its location on this continuum are context specific and vary across time, place and evaluation perspectives (*high confidence*). Despite knowledge gaps, adaptation options can be assessed according to several criteria, such as benefits to humans, benefits to ecosystem services, benefits to equity (marginalised ethnic groups, gender, low-income populations), transformational potential and contribution to greenhouse gas emission reduction (*medium confidence*). These factors can aid evaluation of co-benefits and trade-offs within and between adaptation responses (*high confidence*) facilitating successful adaptation and reducing the likelihood of maladaptation (*medium confidence*) {17.5.1, 17.5.2}.

Adaptation options across a range of climate risk settings (Representative Key Risks) have potential for some degree of maladaptation alongside varied potential for success (*very high confidence*). Maladaptation can result from unaccounted trade-offs with low-income groups and the transformational potential of adaptation (*medium confidence*). Success is greatest when adaptation enhances gender equity (*medium confidence*) and supports ecosystem function and services (*medium confidence*). Among adaptation options, coastal infrastructure is an example that has particularly high risk for maladaptation through trade-offs for natural system functioning and human vulnerability over time. Examples of options with high potential for successful adaptation are nature restoration (*medium confidence*), social safety nets (*medium confidence*) and adaptations relating to changes of diets and reducing food waste (*medium confidence*) {17.5.2}.

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Monitoring and evaluation (M&E) are essential for tracking adaptation progress and learning about adaptation success and maladaptation (*high confidence*). M&E application has increased since AR5 at the local, project and national level, but is still at an early stage in most countries (*high confidence*) and underutilised as a way to assess adaptation outcomes at longer time frames (*high confidence*). About one-third of countries have undertaken steps to develop national adaptation M&E systems, but fewer than half of these are reporting on implementation (*medium confidence*). M&E, as well as tracking global progress on adaptation, are confronted with a number of challenges (*high confidence*), such as a comparability in what counts as adaptation and limited availability of data across scales. The relative strength and weaknesses of different approaches and their applicability have not been systematically assessed, but the diversity of approaches being used could provide a more comprehensive assessment of global adaptation progress {17.5.2, Cross-Chapter Box PROGRESS in this Chapter}.

Understanding of residual impacts and risks in vulnerable regions and implications for Loss and Damage (L&D) has become increasingly relevant as the limits to adaptation are projected to be reached in natural and human systems (*high confidence)*. The international L&D policy debate has seen heightened attention, with some coalescence around key issues, including risk management, limits to adaptation, existential risk, finance and support, including liability, compensation and litigation. Advisory groups have been set up with participation of policy and experts from research, civil society and practice to inform debate. Yet, the policy space and concrete remit for L&D has remained vague, which renders policy formulation complex (*high confidence*) {17.2.2.5; Cross-Chapter Box LOSS in this Chapter }.

Effective management of climate risks is dependent on systematically integrating adaptations across interacting climate risks, ensuring that measures of success include factors important to climate resilient development, and accounting for the dynamic nature of climate risks over time (*very high confidence*). Across the Working Group II report are examples of how managing adaptations to reduce climate risks can negatively or positively affect sustainable development, thereby impacting the potential for climate resilient development. Climate risks can emerge at different rates and time horizons, and the interactions between risks vary from region to region (very high confidence). The need to manage these risks in an integrated manner is demonstrated by the diverse and interacting impacts of climate risks on ecosystems, cities, health, and poverty and livelihoods, such as in the water–energy–food nexus (high confidence). Expertise and resources for integrated risk management vary between the developed and developing countries (high confidence). Integrated pathways for managing climate risks will be most suitable when 'low regrets' anticipatory options are established jointly across sectors in a timely manner, path dependencies are avoided in order to not limit future options for climate resilient development, and maladaptations across sectors are avoided (high confidence). National Adaptation Plans have potential to integrate participatory, iterative processes to monitor, review and update adaptations as knowledge, experience and resources become available {17.6; Cross-Chapter Box DEEP in this Chapter}.

17.1 Objectives and Framing of the Chapter

17.1.1 Introduction

Addressing the impacts and risks associated with observed and projected climate change (Chapter 16) is fundamentally and intricately tied to the decision-making options available to manage those risks. Climate risk decision-making focuses on the processes needed to identify and characterise those risks as well as generate plans and policies to reduce the likelihood and/or magnitude of adverse potential consequences, based on assessed or perceived risks (derived from the definition of risk and risk management in Chapter 1). This chapter presents an assessment of the evidence on climate risk decision-making as a set of processes that involve a range of actors in different contexts resulting in diverse outcomes. The climate risk decision makers and their actions are the central focus of the assessment. The chapter is an assessment of the evidence of the decision-making options that are available in practice, and functions as a central pivot point between the identification of key climate risks (Chapter 16) and the means to integrate and leverage action on climate risk decision-making into the broader requirements of climate resilient development pathways (Chapter 18). This section introduces the main entry points on decision-making that have framed this assessment (Sections 17.1.1.1–17.1.1.5), as well as the key terms used to frame this assessment and its organisation in this chapter (Section 17.1.2).

A central framing point is the connection between climate risk decision-making and adaptation. Adaptation for human systems in this report is introduced in Chapter 1 and defined in the Glossary as 'the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities'. In natural systems, adaptation is the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects (see IPCC 6th Assessment Report [AR6] Glossary [Annex II]). In this chapter, we consider adaptations that may be implemented by people, whether they be to support human, managed, or natural systems, and the processes and factors that underpin adaptation in these diverse settings. Different types of adaptation have been distinguished in Chapter 1, including anticipatory versus reactive, autonomous versus planned, and incremental versus transformational (IPCC WGII glossaries; Chapters 16–18). These dichotomies and interactions are assessed here. Implementation of adaptation through iterative risk management decision-making emphasises that anticipating and responding to climate change does not consist of a single set of judgements at a single point in time, but rather an ongoing cycle of assessment, action, reassessment, learn and response (Chapter 1).

17.1.1.1 Decision-Making for Managing Climate Risks in AR6

The UN 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs), as well the United Nations Framework Convention on Climate Change (UNFCCC) Paris Climate Agreement, the UN Sendai Framework Disaster Risk Reduction and the UN Habitat New Urban Agenda, helped push climate risk management and adaptation forward from the global to the national level, from the planning stage into implementation, and provide benchmarks for adaptation progress. To assess adaptation progress (Section 17.5), the interplay between top-down (institutional) and bottom-up (individual/social/community) processes, multi-scale interaction (local, regional, national and international), iterative risk management, differing forms of knowledge, and equity are especially crucial (particularly Sections 17.2, 17.4). Parallel to these advances is an understanding and assessment of appropriate decision support tools, methods and evaluation metrics (Section 17.3).

Since AR5, significant advances have been made in regard to the understanding of the drivers of decision-making and contexts in which climate risk decision-making takes place. Climate risk decision-making generally, and adaptation specifically, has been a focus within the IPCC special reports in the sixth assessment cycle. An overall goal of climate risk management is to eliminate or reduce the risk to levels that are socio-politically and economically acceptable. Risk management to an acceptable level may not be feasible because of limits or barriers to adaptation. Future potential risks are a more complex matter given the need to define time scales and spatial extent, and uncertainties. In the IPCC Special Report on Global Warming of 1.5°C (SR1.5) (IPCC, 2018a), the risks associated with climate-related impacts were found to be higher under emission scenarios above 1.5°C, raising awareness for the need to limit the impacts of warming through the acceleration of climate mitigation and both incremental and transformational adaptation (IPCC, 2018a).

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The AR6 IPCC Special Report on Climate Change and Land (SRCCL) (IPCC, 2019b) added the dimensions of pace, intensity and scale of climate impacts and adaptation or mitigation responses and adverse consequences. Relevant land-based adverse consequences include those on lives, livelihoods, health and well-being, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species.

While a generic understanding of the decision-making process has emerged from the literature, the chapter assesses how these components and their dimensions interact across a range of temporal (short, long term as defined in the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [SROCC]), scalar (household to global), institutional/governance (formal, informal, bottom-up, top-down) and magnitude (micro adaptation, small scale; macro adaptation, large scale) (Section 17.2). The IPCC SRCCL placed emphasis on acknowledging co-benefits and trade-offs to avoid barriers to implementation, with particular attention to land use decisions. It states that this coordination can be supported by building networks of decision makers across scales and sectors, including local stakeholders from vulnerable groups, and by adopting and implementing policies in a flexible and iterative manner (IPCC, 2019b).

17.1.1.2 Approaches to Assess and Synthesise Options for Managing Risk

This chapter utilises several points of departure to assess climate risk management that emerge from AR5 and AR6, specifically. SR Climate Change and Land, especially Chapter 7 (IPCC, 2019b; Hurlbert et al., 2019) and throughout SROCC (). These works provide foundational assessment of evidence on decision-making systems that connect different spatial and temporal scales and diverse cultural contexts in which climate risk management takes place, the varying interactions of decision makers and their stakeholder groups, and the barriers and enablers to decision-making, including governance, finance and knowledge (Section 17.4).

Another significant advance is that, instead of cataloguing decision-making strategies, the literature has now evolved to the point where adaptation progress, effectiveness and efficiency can be more meaningfully assessed through increased monitoring and evaluation capacity, although the ability to measure success and effectiveness is not fully developed and is hampered by lack of data, agreed methods and terms, and time to fully evaluate adaptation actions (see Sections 17.3.3 and 17.5, Cross-Chapter Box PROGRESS in this Chapter). The ambition to describe effectiveness and success illustrates further maturation of the literature on climate risk decision-making as a system process. Overall, the process of climate risk decision-making remains dynamic, and the chapter attempts to assess a variety of proactive management approaches being developed and tested to address adverse, diverse and complex risks in a wide range of developing and developed country contexts (Figure 17.1). The chapter provides a synthesis of how these new approaches are reflected in the sectoral and regional chapters and cross-chapter papers of this report (Chapters 2–15; Cross-Chapter Papers 1–7). Specifically, the goal is to provide a line of sight between the sectoral and regional chapters and cross-chapter papers' decision-making assessment to sections in this chapter. This synthesis also helps to present the varying and context-driven character of adaptation strategies now in practice and being considered.

17.1.1.3 Key Risks Considered in the Assessment of Climate Risk Decision-Making

In AR6 (Chapter 16 and cross-chapter papers), over 100 key risks have been identified across regions and sectors, which have the potential to manifest into severe impacts that are relevant to the interpretation of UNFCCC Article 2, specifically on the objective to avoid dangerous anthropogenic interference with the climate system. These risks are *likely*[2] to become more severe under higher warming scenarios and social-ecological conditions that yield high exposure and vulnerability to the associated climate-related hazards. In this report, these key risks have been grouped into categories represented by eight overarching risks (called Representative Key Risks, RKRs) relating to: (1) coastal socio-ecological systems; (2) terrestrial and ocean ecosystems; (3) critical physical infrastructure, networks and services; (4) living standards; (5) human health; (6) food security; (7) water security; and (8) peace and human mobility (Chapter 16). Decision-making options for managing these risks, such as selecting the relevant adaptation options to implement, require an assessment of the local context in which these impacts are likely to be experienced, as well as the local to global collective implications of those actions (Sections 17.2 and 17.5).

17.1.2 Objectives and Key Terms

17.1.2.1 Drivers

AR5 provides a broad overview of drivers as the determinants of climate decision-making by individuals and organisations, including social, institutional and regulatory contexts, cultural values and norms, economic resources and constraints, and the availability of information and of tools to process it. This chapter expands the discussion of the contexts for decision-making in a number of ways (Section 17.4), including an examination of informal as well as formal decisions, an attention to emerging actors, particularly social movements, and consideration of several dimensions of governance. It expands the treatment of decision processes, with particular attention to framing and to the integration of multiple time frames (Sections 17.3 and 17.6).

Since AR5, there has been an increasing ambition for adaptation, signalled by growing attention to the adaptation gaps and deficits, which call for extensive and intensive levels of action (Chen et al., 2016; UNEP, 2017; Tompkins et al., 2018; Valente and Veloso-Gomes, 2020; UNEP, 2021a), as well as increased attention to co-benefits between climate risk reduction and other benefits, such as equity and biodiversity conservation (Colloff et al., 2017, Section 17.5.1; Smith et al., 2020). Climate risk decision-making as an object of study has emerged in a more central location within the literature as adaptation moves from planning into the realm of practice. The broad sense of urgency (summarised in Wilson and Orlove, 2019; Wilson and Orlove, 2021) shows growth of the term 'urgency' in both scholarly publications and the popular press since 2014, building on earlier increases starting around 2005, and a dramatic spike of the terms 'climate crisis' and 'climate emergency'. Paralleling this call for more extensive and rapid action is the emergence of the term 'transformational' adaptation and decision-making. Transformational adaptation (defined and deeply examined in Chapters 1 and 16 and Section 17.2) highlights efforts that involve large-scale, systemic change (Wilson et al., 2020) and involves 'adapting to climate change resulting in significant changes in structure or function that go beyond adjusting existing practices including approaches that enable new ways of decision-making on adaptation' (IPCC, 2018a). The complex relationship between incremental adaptation and transformational adaptation is presented and reviewed in Section 17.2. Furthermore, the literature since the AR5 report has moved beyond the question of limits and barriers to adaptation as relevant aspects for decision-making to additionally assessing drivers of change, with increasing focus devoted to more nuanced and differentiated contexts for action.

17.1.2.2 Enabling Conditions

AR5 extensively assessed the conditions of adaptation with a focus on the role of governance, finance, knowledge and capacity. AR6 extends this examination of adaptation and the decision-making process around it by focusing on enablers. Adaptation enablers are defined as those conditions or properties that specifically promote or advance the adaptation process (Chapter 1). Enablers are positively associated

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

with likelihood that adaptation planning occurs, and strategies will be put into practice. Three broad enabling conditions are presented in the chapter (Section 17.4): governance (legislation, regulation, institutions, litigation), finance (needs, sources, intermediaries, instruments flows, equity) and knowledge (capacities, climate services, big data, Indigenous/local knowledge, co-production, boundary organisations). As an extension of enabling conditions, the chapter also examines catalysing conditions for adaptation (Section 17.4.5). Catalysing conditions motivate and accelerate the process of decision-making, leading to more frequent and potentially substantial adaptations. The chapter recognises that the relative influence of enabling conditions and catalysing conditions is set within the human dimensions of climate change including vulnerability, inequality, poverty and the achievement/non-achievement of SDGs (Figure 8.1).

17.1.2.3 Mechanisms for Decision-Making

The mechanisms and conditions for decision-making provide the basis for the chapter. AR5 provided a detailed chapter on the support of climate decision-making. Chapter 2 of AR5 (Jones et al., 2014) concluded, with *high confidence*, that risk management provides a useful framework for most climate change decision-making, and that iterative risk management is most suitable in situations characterised by large uncertainties, long time frames, the potential for learning over time, and the influence of both climate as well as other socioeconomic and biophysical changes. Furthermore, decision support is situated at the intersection of data provision, expert knowledge and human decision-making at a range of scales from the individual to the organisation and institution.

The climate risk management decision-making process follows a set of general considerations. The detail of each decision is often highly context specific. Climate risk decision-making is bound to the question of how and under what circumstance it is appropriate to alter, reduce or transfer and retain risk. Different types of risk (e.g., gradual compared with catastrophic) and conditions of risk (e.g., known versus uncertain) are associated with different types of responses (e.g., incremental versus transformational). As the risk decision process proceeds, individuals and organisations will formally or informally utilise any number of mechanisms to guide, aid or facilitate the decision-making process. Decision-making can then take place in a linear set of steps or through a complex iterative process involving reflexive and recursive steps.

17.1.2.4 Costs and Non-monetised Loss, Benefits, Synergies and Trade-Off

AR5 provided an extensive discussion of the costs to human and natural systems associated with climate risks. It recognised the challenges which long time frames, uncertainty and the differing values held by stakeholders create for the monetisation of losses. The AR6 SROCC built on the discussion of cultural values—typically also difficult to monetise—through a consideration of cultural ecosystem services and cultural forms of valuation, with cases from high mountain areas and polar regions (Hock et al., 2019; Meredith et al., 2019; IPCC, 2019c). AR6 expands this discussion of multiple forms of valuation in several ways. It considers regulation and litigation as mechanisms for promoting the consideration of both monetisable and non-monetisable losses in decision-making (Cross-Chapter Box LOSS in this Chapter). AR5 treated the issues of equity and justice primarily with regard to mitigation, especially in WGIII AR5 Chapter 3 (Kolstad et al., 2014); these issues in the adaptation sphere are considered extensively in this chapter in areas such as finance, governance, success of adaptation, maladaptation, and monitoring and evaluation. The discussions of maladaptation and success of adaptation (Section 17.5) consider questions of synergies and trade-offs across values and goals, while the consideration of decision processes and tools shows opportunities to use co-benefits to promote effective decision-making, including approaches to decision-making under conditions of deep uncertainty (Section 17.3; Cross-Chapter Box DEEP in this Chapter). Successful adaptation across the report (as specified in Chapter 1) is associated with conditions when co-benefits are high and (negative) trade-offs are low.

17.1.2.5 Monitoring and Evaluation

This chapter assesses the evidence of monitoring and evaluation (M&E) (see AR6 Glossary, Annex II) and their approaches as part of the adaptation process at the national, local and project level as well as in global assessments (Section 17.5.2; Cross-Chapter Box PROGRESS in this Chapter). M&E can serve multiple functions, for example, to: (1) facilitate an understanding on whether and how interventions work in achieving intended objectives; (2) inform ongoing and future implementation; and (3) provide information that helps to substantiate upward and downward accountability (Preston et al., 2009; UNFCCC, 2010b; Pringle, 2011; Spearman and McGray, 2011) (see BOX 17.1 for more discussion). This chapter also addresses the relevance of iterative learning as part of the design of M&E processes, as a means by which actors and institutions engaged in M&E acquire new insights on how these processes work (or not) to achieve set objectives.

17.1.3 Outline of the Chapter

The chapter is organised around the broad narrative of climate risk decision-making and management (Figure 17.1), building from the assessment of risks within RKRs (Chapter 16) and options available to address these risks and within a broader context of climate resilient development pathways (Chapter 18). Decision-making is considered to be a reflexive and recursive process where different evidentiary threads and information inputs become relevant to the understanding and assessment of factors underlying specific decisions. Additionally, this is also a discursive process, whereby actors and institutions' interpretations of climate risks are also key to these deliberations.

Decision-making processes of risk management and adaptation are varied and numerous. Section 17.2 assesses the risk management and adaptation options already in practice. Section 17.3 assesses decision-support methods and tools available for application and the effectiveness of these in supporting climate decision-making across degrees of uncertainties and levels of governance and expected reach (scale) across populations from households to international cooperation. Closely interlinked across the decision-making process are the enabling and catalysing conditions for decisions on adaptation and risk management (Section 17.4). Section 17.5 synthesises evidence on maladaptation and adaptation successes, and assesses the current knowledge on M&E

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Box 17.1 | How Is Success in Adaptation Characterised in Chapter 17?

Whether an adaptation is considered successful is context specific. It depends on who evaluates adaptation and at what time as well as on the ability to compare the outcome of adaptation with a hypothetical situation without adaptation and without other parallel changes, such as development interventions (Singh et al., 2021; Dilling et al., 2019). The ability to compare the risk situation post and prior adaptation is complicated through the long time horizons at which adaptation outcomes often become apparent (Cross-Chapter Box ADAPT in Chapter 1; Section 17.5.1; Dilling et al., 2019).

However, a wealth of information has recently become available on how success and effectiveness of adaptation could be assessed, defined or investigated in certain settings (Patt and Schröter, 2008; Morecroft Michael et al., 2019; Tubi and Williams, 2021) or across a larger set of adaptations (Hegger et al., 2012; Eriksen et al., 2015; Gajjar et al., 2019a; Owen, 2020; Singh et al., 2021). Accordingly, successful adaptation is understood as effective adaptation, in that it reduces climate impacts, vulnerabilities and risk, and additionally balances synergies and trade-offs across diverse objectives, perspectives, expectations and values (Eriksen et al., 2015; Juhola et al., 2016; Gajjar et al., 2019a; Owen, 2020; Singh et al., 2021). Across this report, four factors are identified as enabling conditions of successful adaptation, which include a focus on recognitional, procedural and distributional justice as well as flexible and strong institutions that seek policy integration and account for long-term goals.

To operationalize 'success' in this chapter, it is characterised by the degree to which an adaptation response benefits (1) human systems (number of people), (2) ecosystems or ecosystem services, (3) marginalised ethnic groups, (4) women and girls, (5) and low-income populations, and can be characterised as (6) transformational adaptation, and (7) contributing to greenhouse gas emission reductions (Section 17.5.1). Overarching to these factors are uncertainty and potential path dependency of decisions that may result in lock-in and maladaptation in the long term, and recognition that what is successful in the near term is not necessarily successful in the long term.

Success in adaptation is antithetical to maladaptation. Maladaptation refers to current or potential future negative consequences, including failed or partially successful adaptation (or risk reduction) but also trade-offs or side effects of adaptation (see Glossary, Annex II). Thus, success of adaptation and maladaptation form the ends of a continuum that represents the balancing of synergies and trade-offs across regions, populations or sectors (Singh et al., 2016; Magnan et al., 2020; Schipper, 2020). Every adaptation action may be placed along such a continuum reflecting the empirical evidence of adaptation practices and their assessment (Section 17.5).

of adaptation, including financial accounting, to support learning on those, respectively. Here, M&E is considered distinct from the tracking of financial flows related to adaptation, given that financial accounting does not necessarily provide information on the implementation of adaptation measures and their results (see also Section 17.2.1.2). Finally, in Section 17.6, decision-making, climate risk responses and their relevance for climate resilient development are presented, where evidence on their respective contributions to facilitate actions in the adaptation solution space within a broader context for development is shown (Chapter 18). Throughout the decision-making process, crucial feedback loops are present that define the results of specific actions and recursive nature of climate risk management and adaptation.

17.2 Risk Management and Adaptation Options

There has been substantial progress in risk management and adaptation responses around the world, as demonstrated in the sectoral and regional chapters of this report and illustrated in Chapter 16. This section presents an overview of different options available to manage risk, explaining how they are currently governed and the extent to which they can be applied around the world. The section contains an assessment of the ways in which different options are being combined to create adaptation portfolios, and describes how incremental and transformational change is starting to be considered. Based on the human dimension of climate change, as described in Chapter 8, vulnerability, inequality and poverty influence these portfolios of adaptation and transformational change. Particularly for change where residual risks remain that may lead to exceeding the limits of adaptation, increasingly transformational adaptation and policy innovation will be important. Section 17.2.1 assesses options for climate risk management from around the world that reduce, manage or retain climate-related risks and assesses their contribution to reducing vulnerability and exposure, how they are governed, and the benefits to humans and ecosystems. Section 17.2.2 presents portfolios of risk management, including the design principles and observed variations across the globe, before it discusses the need and potential for transformational adaptation to complement incremental adaptation, for which we present evidence across the report for selected adaptation options and some key risks. The Cross-Chapter Box LOSS in this Chapter synthesises recent literature and assesses key strands of the international policy dialogue on Loss and Damage, which discusses options that help to deal with impacts and residual risks in vulnerable countries.

17.2.1 Adaptation Options for Climate Risk Management

This section assesses options for climate risk management (CRM) across common risk settings that have been grouped into Representative Key Risks (RKRs; see Section 16.5.2.2). These risk management and

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Schematic representation of the climate risk management decision-making process

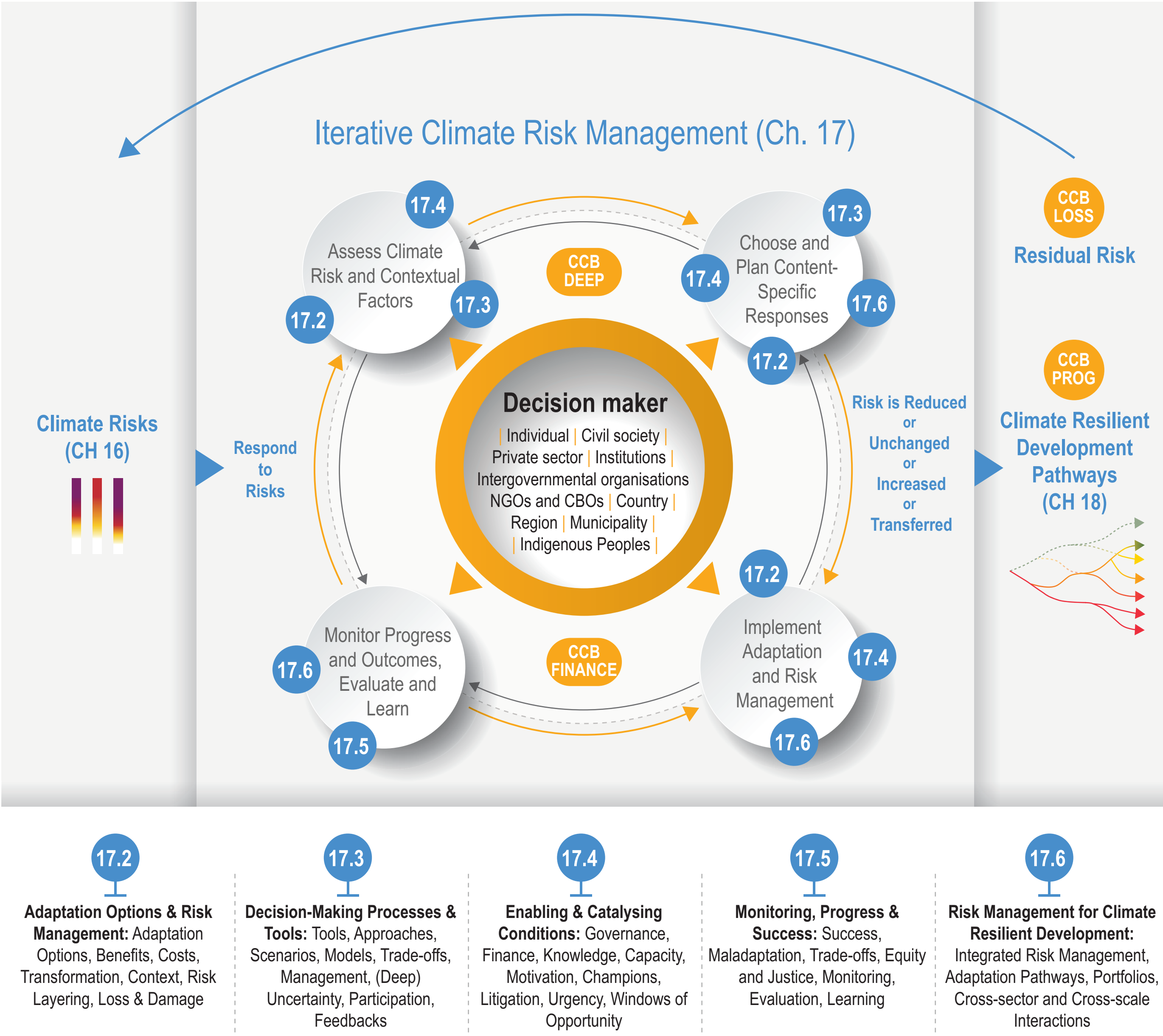

Figure 17.1 | Schematic representation of the climate risk management decision-making process as introduced in Chapter 1 (Figure 1.6) and the key elements of this chapter that address additional aspects of this process. In Chapter 17, climate risk management (middle box) is framed as the iterative response (i.e., what society could do and how it could be done) to the climate risks described in Chapter 16, with outcomes (ideally reduced risk) that can support (or perhaps hinder) climate resilient development, as assessed in Chapter 18. Decision makers from diverse contexts sit at the centre of the climate risk decision-making process and interact with and drive these processes as they play out. The main sections of Chapter 17 (bottom panel of boxes) address a wide range of issues (keywords in bottom panel) that manifest at one or more stages of climate risk management processes, illustrated by icons for section numbers and Cross-Chapter Boxes in the interactive risk management process.

adaptation actions target the components of risk: hazards, vulnerabilities and exposure associated with sudden or slow-onset events (see Chapter 1 for more details on the definition of risk).

For each of the RKRs, three commonly discussed adaptation options are identified across the regional, sectoral and cross-chapter papers of this report. These 24 options have been selected to cover a representative variety of strategies to adapt to climate change, while a particular adaptation option can be relevant to many of the RKRs. For example, the adaptations listed under the RKR of 'Food security' are also related to the RKR on 'Human health' (Ebi and Prats, 2015). See SM17.1 for more detail. The list is not comprehensive of all possible adaptations listed in the regional and sectoral chapters. For example, this does not include adaptations by institutions who might become unable to cope with increasing pace and magnitude of extreme events (Chapter 11).

17.2.1.1 Adaptation Options and Their Contribution to Reduce Vulnerability and Exposure

Table 17.1 provides examples of each of these 24 adaptation options from across AR6 WGII. Detailed information about sectors and regions where these adaptations are being discussed can be found in the indicated chapters. Note that this list is curated to ensure a diversity of options; therefore, most of the options will apply to more than one RKR.

Of this list of adaptation options, many focus on reducing vulnerability to climate change (*high confidence*), as vulnerability is one of the components of risk (see Chapter 1 and Chapter 8). Vulnerability is the propensity or predisposition to be adversely affected, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (see Chapter 1 for more details). In the world's threatened ecosystems, reducing vulnerability often means reducing other non-climate negative pressures on ecosystems, such as pesticide use or fishery overexploitation (Section 3.3).

Vulnerability reduction is also a major focus in human systems, and this includes development of investments that help people adapt to climate change. Examples include irrigation or diversifying crops. Building infrastructure resilient to climate-related risks is another example; many of the structural and physical adaptation options can reduce sensitivity to disasters, such as elevating houses or doing beach nourishment in coastal areas (Section 15.5). Extreme events often catalyse investment in adaptation to reduce vulnerability for the future (Kreibich et al., 2017; Slavíková et al., 2021).

Next to vulnerability reduction, a large number of adaptation options focus on reducing exposure to climate change (*high confidence*). Selecting low-risk locations is the most basic example of reducing exposure; for example, private companies are relocating factories to reduce flood-related disruptions to their supply chain (Neise and Revilla Diez, 2019), and species are autonomously adjusting their ranges to a changing climate (Section 2.4). Land use planning or investing in resilient infrastructure can avoid exposure in rapidly urbanising areas; however, the design and enforcement of these regulations can negatively impact marginalised people (Anguelovski et al., 2016).

Managed retreat is an example of exposure reduction that, while often controversial, is increasingly being considered and implemented (CCP 2.2.2, Section 15.3.4; Cross-Chapter Box LOSS in this Chapter; Siders et al., 2019). Examples include the US Hazard Mitigation Grant Program, which, among other activities, has helped people resettle outside of flood zones, and a 'no-build zone' established in the Philippines after Typhoon Haiyan (Hino et al., 2017). However, relocation is not always an option; immobility is sometimes involuntary, such as in the case of 'trapped' populations in Zambia (Nawrotzki and DeWaard, 2018; Section 8.2.1.3).

Adaptation efforts can have negative impacts on ecosystems and vulnerable groups (*high confidence*); see Figure 17.3 and Section 17.5 for further information on maladaptation. While 'hard' structural investments have been popular to reduce exposure to climate extremes, barrier-type measures provide protection only up to a certain limit, and are designed to fail in more extreme events. Given the risk of catastrophe from a climate extreme overcoming a physical barrier, policy advancements in recent years encourage any investment in structural measures to be complemented by 'softer' vulnerability reduction measures, such as accommodating building construction (Wesselink, 2016).

When it comes to 'softer' vulnerability reduction initiatives, these were traditionally seen as 'no regrets' options for adaptation. However, subsequent studies have cautioned that notion as vulnerability is a dynamic quality, and can be co-created while development or adaptation efforts are being implemented (Schipper and Pelling, 2006; Tempels and Hartmann, 2014; Dilling et al., 2015). Some scholars have suggested the application of a 'do no harm' principle to climate change adaptation efforts (Mayer, 2016).

17.2.1.2 Governance of Adaptation Options

For each adaptation option identified for the RKRs (Table 17.1), this section presents an assessment of how decisions are made and how the adaptations are being governed. The following section then covers benefits to humans and ecosystems, and potential for maladaptation is covered in Section 17.5. See SM17.1 for more information on the assessment methods and underlying citations.

The following analysis of adaptation options provides a synthesised overview of adaptation globally, but does not prescribe how important each adaptation should be in specific locations. Chapter 16 finds that the 'scope' and 'speed' of adaptation is limited in many areas.

When it comes to decision-making, most of these 24 adaptations rely strongly on formal decision-making (*high confidence*), which follows the procedures of a group of people rather than ad hoc individual action. Formal decisions play a particularly strong role in the adaptations identified for infrastructure, early-warning systems and water systems (Kolen and Helsloot, 2014; Calvello et al., 2015; Zhao et al., 2017; Belčáková et al., 2019; Teo et al., 2019).

In contrast, informal or individual-led decision-making is more common in several food security-related and livelihood-related adaptations, such as changes to diets, livelihood diversification and seasonal migration (*high confidence*) (Li et al., 2017; Radel et al., 2018; Robinson et al., 2020). People who have experienced climate shocks are more likely to take individual decisions to implement adaptation measures, and in countries where people are more exposed to extreme events, autonomous adaptation is more common (Koerth et al., 2017; Aerts et al., 2018b; van Valkengoed and Steg, 2019).

All adaptation options can occur under a range of governance arrangements (*high confidence*), with cases of either private, public or community governance typically playing the dominant role, as depicted in Figure 17.2. Public governance is the most frequent governance type for most adaptations considered. This is particularly true for social safety nets and spatial planning, where governments are often required to lead adaptation efforts (*high confidence*) (Mesquita and Bursztyn, 2016; Hssaisoune et al., 2020; Wang et al., 2021). While government actors do the day-to-day management of these systems, civil society and international organisations also play a role in shaping agendas and priorities of government actors (Nagle Alverio et al., 2021).

Table 17.1 | Selected adaptation options per Representative Key Risk (RKR; see Section 16.5.2.2), with examples of each option from across the report. Many of the adaptation options are relevant to multiple RKRs, and have been selected to be representative of the wide variety of adaptation options implemented or suggested around the world.

RKR	Adaptation option	Examples from regional and sectoral chapters and cross-chapter papers
Risk to coastal socio-ecological systems	Coastal accommodation	Raising of dwellings, raising of coastal roads (Section 15.5.2), amphibious building designs (CCP2), improved drainage (Section 11.3.5.3)
	Coastal infrastructure	Seawalls, beach and shore nourishment (Sections 3.6, 15.5.1), breakwater structures (Section 15.5.1), dykes, revetments, groynes or tidal barriers. (Section 6.3.4.8), land reclamation (Section 15.5.2)
	Strategic coastal retreat	Retreating from coastal areas (Section 3.6, Cross-Chapter Box SLR in Chapter 3, Section 6.3.5.1, CCP2), relocation/resettlement (CCP2)
Risk to terrestrial and ocean ecosystems	Restore/create natural areas	Marine protected areas (FAQ 3.5), active restoration of coral reefs (Section 3.6.2.3.2), ridge-to-reef management (CCP1), restoring dunes (CCP4), planting salinity-tolerant trees (Section 4.5.2.1) Increasing forest cover (CCP7), detect and manage forest pests (Section 11.3.4.3)
	Reduce ecosystem stress	Reduce pollution and eutrophication (Section 3.3.3), reduce anthropogenic pressures on the Great Barrier Reef (Box 11.2), sustainable fisheries harvest (Section 3.6.2), increasing connectivity between natural areas (Section 2.6.2)
	Ecosystem-based adaptation	Marine habitats to protect against storm surge (Section 3.6), agroecology (Section 5.14.1.1), coastal and marine vegetation and reefs (Section 6.3.3.4), vegetation corridors, greenspace, wetlands (FAQ 6.3), mangrove habitat restoration (Sections 8.5.2.2, 9.8.5.1), restoring coasts, rivers, wetlands to reduce flood risk (Section 2.6.3, CCP1), urban green space to reduce temperatures (Section 2.6.3)
Risks associated with critical physical infrastructure, networks and services	Infrastructure retrofitting	Air conditioning (Section 6.3.4), using thermosiphons for permafrost degradation (Section 10.4.6.4.1), increasing rooftop albedo (for reflectivity) (Section 11.3.5.3), shading (Section 13.A.4)
	Building codes	Drainage systems (Section 4.5.2.1), architectural and urban design regulations (Section 6.3.4.2), infrastructure standards initiatives (CCP6), Chile's Sustainable Housing Construction Code (Section 12.5.5.3)
	Spatially redirect development	Zoning/land use planning (Section 6.3.2.1), spatial development planning to regulate coastal development (CCP2)
Risk to living standards and equity	Insurance	Agricultural insurance and micro-credit (Sections 4.5.2.1, 10.4.5.5), index-based insurance, market and price insurance (Section 5.14.1.3), flood insurance (Section 10.5.3.2), collective insurance schemes (Section 12.5.7.5)
	Diversification of livelihoods	Combining income-generating activities within fisheries sector (Section 3.6.2.2) Community level adaptation by Pangnirtung Inuit through diversification to stabilise income and food resources (CCP6)
	Social safety nets	Food for work programmes (Section 4.5.2.1), school feeding programmes (Section 7.4.2.1.3), social protection programmes, such as unemployment compensation (Section 10.5.6)
Risk to human health	Availability of health infrastructure	Safe drinking water infrastructure (Section 4.5.2.1), temperature-controlled low-income housing (Section 11.3.6.3), health care clinics (Section 6.4 case study), place-specific mental health infrastructure and 'nature therapy' (Section 14.4.6.8)
	Access to health care	Access to health care services (Section 11.3.6.3), access to health, nutrition services and healthy environments (water and sanitation) (Section 7.6), enhanced access to culturally appropriate mental health resources; 'Telemedicine' (information technologies and telecommunications for health and public health service delivery) (Section 12.6.1.5)
	Disaster early warning	Early warning of marine heatwaves (Section 3.6.2.3.3) early warning for pests (Section 5.12.5), Heat Action Plans (HAP) (Section 7.4.2.1.2), raising public awareness through campaigns (FAQ13.3)
Risk to food security	Farm/fishery improvements	Changing fishing gear or vessel power (Section 3.6.2.2.3), change crop variety or timing (Section 4.5.2.1, CCP5, Section 8.5), close productivity gaps (Section 5.12.5), biotechnology (Section 5.12.5), irrigation schemes (Section 9.12.5.3), integrated crop/livestock systems (Section 5.10.1), relocating livestock linked to improved pasture management (Section 13.5.2)
	Food storage/distribution improvements	Improve transportation infrastructure and trade networks, shortened supply chains (Sections 5.12.5, 9.12.5.3), improved food storage (Sections 5.12.5, 7.4.2), local food production/chains (Cross-Chapter Box COVID in Chapter 7)
	Behaviour change in diets and food waste	Reduce food loss and waste (Section 5.12.5), shifts to more plant-based diets (Section 7.4.5.2), creating demand for organically sourced food (Section 10.5.3.2)
Risk to water security	Water capture/storage	Farm ponds and revival of water bodies (Section 4.5.2.1), rain gardens, bioswales or retention ponds (Section 6.3.3.6), water storage tanks (Section 10.5.3.2), multi-purpose water reservoirs and dams (CCP5)
	Efficient water use/demand	Precision/drip irrigation (Section 4.5.2.1), Managed Aquifer Recharge (MAR) (Section 9.4), cooperative policies across multiple sectors (CCP4), changing water consumption patterns (CCP4)
	Efficient water supply/distribution	Constructing irrigation infrastructure (Section 4.5.2.1), inter-basin transfers (Section 6.3.3.6), water reuse (Section 13.A.3), slum/water upgrading (Section 6.4.3)
Risk to peace and migration	Seasonal/temporary mobility	Fishing fleet mobility to follow species distribution (Section 3.6.2.2.2), mobility for seasonal employment and remittances (Section 4.5.2.1, Cross-Chapter Box MIGRATE in Chapter 7), legal/illegal labour migration (CCP3), pastoralist seasonal migrations (Cross-Chapter Box MIGRATE in Chapter 7)
	Cooperative governance	Transboundary fishing agreements (Section 3.6.4.1), ocean governance (Section 3.6.2.2), collective water management (Section 4.5.2.1), indigenous water-sharing systems (Section 4.5.2.1), enforcing the land rights of indigenous populations (CCP7), adaptive co-management in Arctic fisheries (CCP6), international compact on migration (Cross-Chapter Box MIGRATE in Chapter 7), policies for adaptive governance (Section 8.5)
	Permanent migration	Resettlement of flood-prone communities (Section 4.5.2.1), rural–urban migration (Section 6.1 case study), internal migration (Box 10.2), international migration and remittances (Sections 8.6.3, 14.4.7.3)

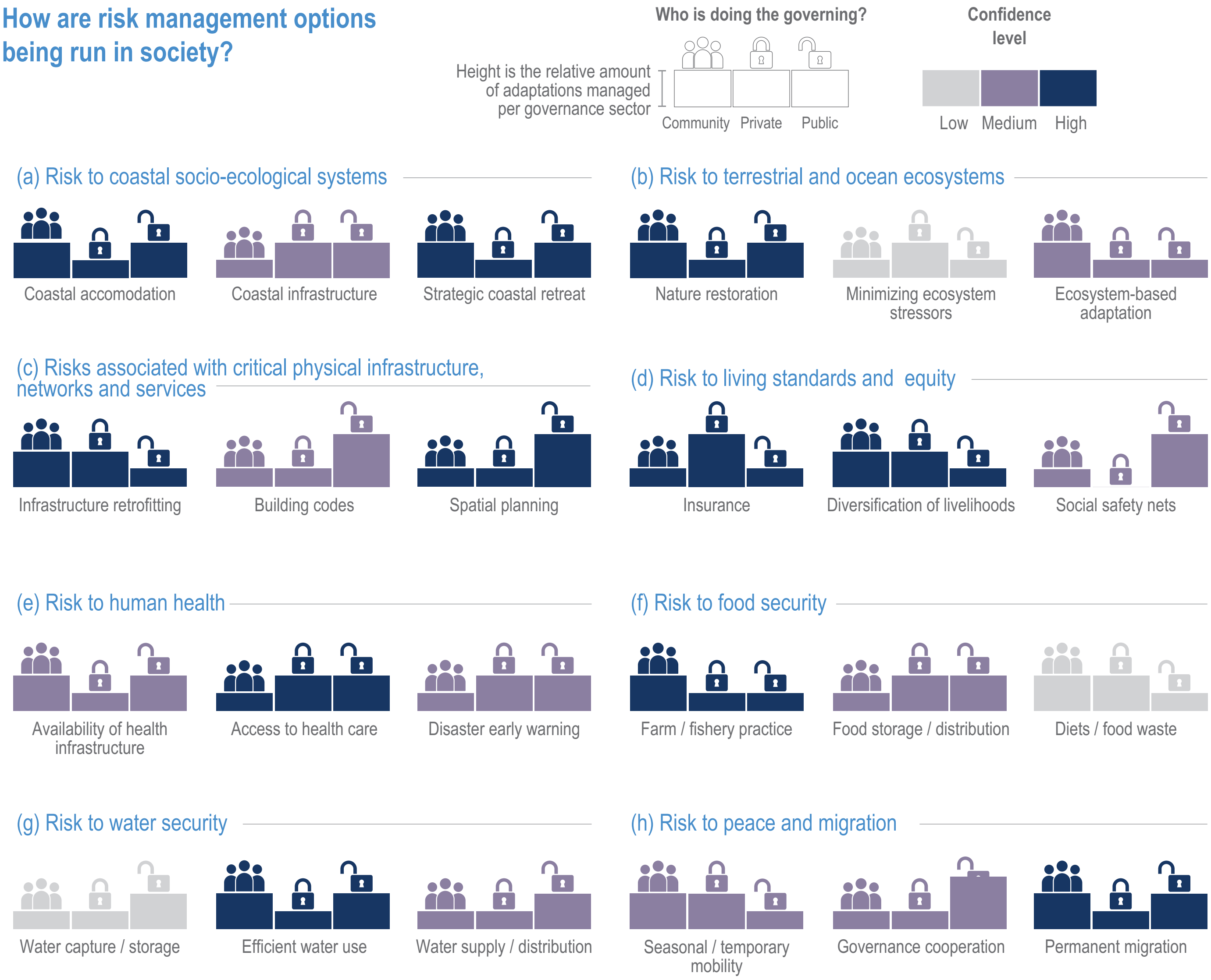

Figure 17.2 | Governance of 24 major risk management options, grouped by relevance to the Representative Key Risks. Each option depicts the relative governance roles, between communities/individuals, private sector and public sector. The intensity of the colour refers to the level of confidence in the assessment.

The private sector plays a large role in governance of insurance, minimising ecosystem stressors, and livelihood diversification (*medium confidence*) (Allen et al., 2018; Mimet et al., 2020; Alam et al., 2020a). While having a key role in shaping and implementing many other adaptations, the private sector is not often the governing entity.

There are a number of adaptation options that tend to be governed by communities and individuals, including adaptations to farming and fishery practices and ecosystem-based adaptations (*high confidence*) (Reid, 2016; Basupi et al., 2019; Giffin et al., 2020; Karlsson and Mclean, 2020). In rapidly urbanising areas of Asia and Africa, individual- or community-led adaptation is the norm in informal settlements that have poor governance structures. Residents of Mathare slum in Nairobi have established methods to pool risks, such as pooling labour to police looting during flood events and developing community health centres in churches (Thorn et al., 2015). This is in addition to risk reduction measures such as building structures to withstand rising water levels (Thorn et al., 2015). Residents in Bangkok have built walls around settlements, dug informal drainage channels to vacant lots, and filled areas of land (Limthongsakul et al., 2017). In these cases, individual-led adaptation can have negative side effects, such as the building of flood defences in affluent communities increasing the flood impacts in less affluent regions of a city (Limthongsakul et al., 2017).

17.2.1.3 Benefit to Humans and Ecosystems

While some of the 24 adaptation options are specific to certain risk contexts (e.g., coastal areas, agricultural production), others are more widely applicable (e.g., early-warning systems, health care systems, creation/restoration of natural areas). Figure 17.3 depicts which of these are most context specific, for example benefitting less than 1 billion people. This is contrasted with the extent to which each adaptation option is beneficial to ecosystem services. Many of the more generalisable adaptations have also been shown to have benefits to ecosystem services, such as nature restoration and changes to diets/food waste (*medium confidence*). While health care systems and the establishment of health-

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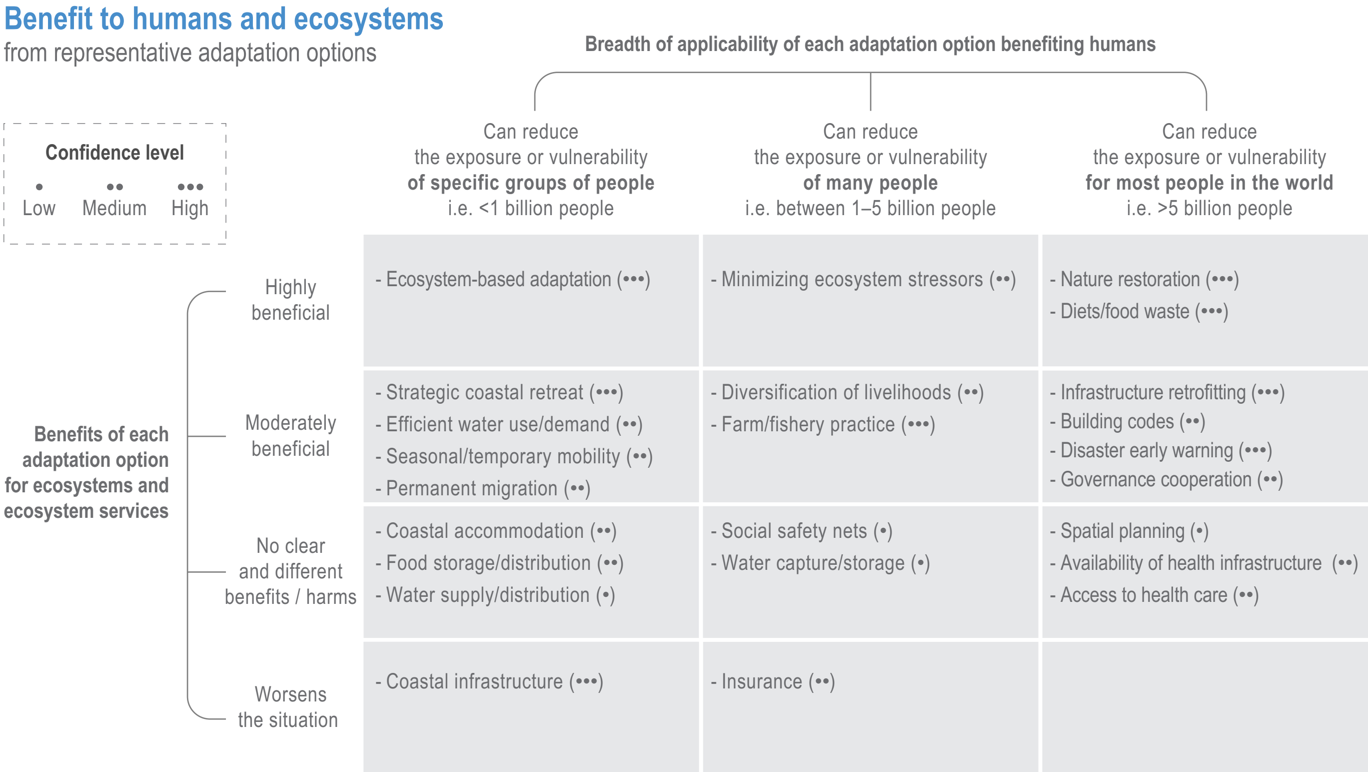

Figure 17.3 | Benefit of representative adaptation options to humans and ecosystems. The breadth of applicability of each adaptation option benefiting humans is estimated by the degree to which each adaptation can be applied across multiple contexts, depicted on the x axis. The benefit of each adaptation option for ecosystems and ecosystem services is depicted on the y axis. See Annex A for literature underpinning each assessment. This figure uses the 24 representative adaptation options from Table 17.1 and Figure 17.2. Confidence levels are represented by dots.

related infrastructure can be widely used as adaptation options, their design and application to date have not generally benefitted ecosystems or ecosystem services (*medium evidence*, *low agreement*).

As a general method related to adaptive management, ‘early warnings’ are the most frequently discussed adaptation option to deal with a changing climate across all key risks, sectors and regions. Early-warning systems are an adaptation that can benefit more than 5 billion people (*high confidence*). Examples range from short-term disaster early-warning systems to revision of sea level rise plans based on monitoring. For example, the humanitarian community is investing in forecast-based financing systems to prepare for extreme events (Coughlan de Perez et al., 2015; MacLeod et al., 2021). Forecasts are also used to manage hydropower dams (Ahmad and Hossain, 2020), to trigger interventions before public health emergencies (Section 7.4.2) and to alert fishermen of algal blooms in the world’s oceans (Section 3.6.2.3.3). Table 17.2 provides examples of adaptations using early-warning systems that have been used to address each of the key risks.

In addition to immediate investments that reduce vulnerability and exposure, monitoring and early-warning systems allow people to take additional actions when there is an imminent event on the horizon (e.g., temporary evacuation during extreme events rather than permanent migration). This allows for ongoing adaptive decision-making (Alessa et al., 2016; Ebi et al., 2016; Barnard et al., 2017; Haasnoot et al., 2018). However, these systems are only cost-effective for forecastable and actionable hazards, and require effective institutional governance (Wilkinson et al., 2018; IPCC, 2019c).

17.2.2 Combining Adaptation Options: Portfolios of Risk Management and Risk Governance

While the above assessments underlying Figures 17.2 and 17.3 isolate specific risk management options for specific risks, several adaptation measures are present in any given location, affecting the overall risk of a particular place. Policymakers are charged to evaluate risk comprehensively, deciding on a variety of measures that are effective, feasible and aligned with other policy goals for a specific place, or implementing a new activity because of how it complements the existing package of risk management activities (Girard et al., 2015).

17.2.2.1 From Risk Prevention to Risk Financing and Risk Retention

Portfolios of adaptation options generally include actions to reduce vulnerability and exposure, complemented by risk financing mechanisms that help people avoid the impacts of loss events, particularly very rare ones. There is also explicit or implicit risk retention, where further risk management is not desirable, cost-effective or feasible (Mechler and Deubelli, 2021). Risk financing can include a variety of instruments, with insurance as the most widely known. Formal insurance uptake is lower in developing and emerging economies than in wealthier countries (Ali

Table 17.2 | Examples of adaptation investments and early-warning system options for adaptive management for each of the key risks in Chapter 16.

Key risk	Adaptive early-warning systems-based measures
Risk to coastal socio-ecological systems	Storm surge early warnings (Section 15.5.7) Early warnings of water-borne disease (Section 3.6.2.3.3)
Risk to terrestrial and ocean ecosystems	Fishery marine heatwave warnings and mobile fishing equipment (Section 3.6.2.3, Chapter 13) Forecast of shifts and regime changes in ecosystems (Pace et al., 2015; Bauch et al., 2016; Burthe et al., 2016).
Risks associated with critical physical infrastructure, networks and services	Early warning for infrastructure and services (Sections 13.2.2.1, 10.4.6.4.1)
Risk to living standards and equity	Adaptive social protection systems (Schwan and Yu, 2018; Ulrichs et al., 2019; Daron et al., 2021).
Risk to human health	Heat health early-warning systems (Section 7.4.2.1.2) Health and disease monitoring and outbreak prediction (Sections 7.4.2.1.1, 12.5.6)
Risk to food security	Forecasting rainfall and droughts for seed selection (Section 10.5.2.2.3) Food price early warnings (Section 7.4.2.1.3)
Risk to water security	Early warnings for flood and drought (Sections 4.4.1, 10.5.2.2.3, 15.5.7)
Risk to peace and migration	Transboundary flood early warnings (Tuncok, 2015).

et al., 2020). To overcome some of the barriers to insurance uptake, index-based insurance has been offered for agriculture and livestock in many developing economies, with varying levels of success (Chantarat et al., 2013; Isakson, 2015; Dewi et al., 2018). In recent years, regional disaster insurance pools for sovereign states have been established, such as the Caribbean Catastrophe Risk Insurance Facility (CCRIF) (Iyahen and Syroka, 2018). Insurance can encourage the quantitative evaluation of climate-related risks and adaptation limits, and it can incentivise risk reduction by charging lower premiums for less risky situations (Schäfer et al., 2019).

While insurance is increasingly accepted as an adaptation option (Linnerooth-Bayer and Hochrainer-Stigler, 2015), positive outcomes are not guaranteed (*high confidence*). First, there are concerns as to whether this will shift responsibility to the most vulnerable people to pay premiums (Surminski et al., 2016). There is also high risk for insurance to cause maladaptation (Müller et al., 2017); for example, Annan and Schlenker (2015) showed that insured crops were less well adapted to heat stress. To avoid this, people simultaneously invest in insurance and adaptations that reduce vulnerability/exposure (*medium confidence*) (Surminski et al., 2016; Highfield and Brody, 2017; Schäfer et al., 2019; Reguero et al., 2020).

The combination of interventions that reduce risk and risk financing for residual risk (often through insurance for sudden-onset events, or social protection for risks including those linked to slow-onset processes) will reduce collective risk to a certain level. For very extreme and potentially catastrophic events, it is often impossible (or financially infeasible) to fully reduce vulnerability and exposure, and people, communities and countries therefore retain risk requiring the *ex post* management of unavoided and unavoidable residual impacts in case of events.

Ex-post risk management relies on national assistance, social safety nets (Section 7.4.2.1.3; Béné et al., 2012; Elmi and Minja, 2019) and support from social networks as well as lending from international institutions (*high confidence*) (Hochrainer-Stigler et al., 2014). Even in places where normalised losses have stabilised in recent years with investments in adaptation, effective planning to manage losses remains necessary (Jongman, 2018). Resilient recovery can support adaptation goals in periods of losses and damages (Slavíková et al., 2021).

To coordinate between a suite of applicable risk management interventions, the concept of risk layering has been discussed and used in (financial) risk governance of disaster risk management (Mechler et al., 2006; Cummins and Mahul, 2009; Clarke and Mahul, 2011) and climate risk management (Lal et al., 2012; Mechler et al., 2014; Herron et al., 2015; Schäfer et al., 2016; Mechler and Deubelli, 2021). Incremental risk prevention and preparedness as well as risk financing occurs within national systems. Over the years, regional cooperation, such as through the regional sovereign insurance pools in the Caribbean, the Pacific and Africa, but also transboundary risk management elsewhere have become more important (*medium confidence*) (see Martinez-Diaz et al., 2019). Also, with risks increasingly experienced as severe and existential (Boyd et al., 2017), global governance and solidarity have been invoked (see Linnerooth-Bayer et al., 2019; Pill, 2021), largely as part of the policy discourse on Loss and Damage (Mechler et al., 2019) with further momentum provided by discussions on the global goal of adaptation and recognition of climate risk as transboundary (Benzie and Persson, 2019; Cross-Chapter Box INTERREG in Chapter 16). Transformational risk management has emerged where incremental and *in situ* adaptation is not effective in managing risks, such as for managed or strategic retreat for communities facing severe coastal and riverine flooding (Siders et al., 2019). Transformation has not been well documented, including as to its governance (Section 17.2.2.5).

17.2.2.2 Global Variation in Portfolios of Risk Management

While many studies assess adaptation trends by geographical region or by sector, the amount of residual risk varies across countries with different income and governance structures. Vulnerability, poverty and inequality, which constitute the human dimensions of climate change, affect how these portfolios of adaptation options are structured around the world (Chapter 8). Figure 17.5 depicts several illustrative 'typologies' of how risk is addressed. While no country or location fits any one typology, this illustrates a range of risk portfolios found in different contexts.

Extensive protection category

The first category in this typology, that of 'extensive protection', requires substantial financial investment (Figure 17.5). In higher-income contexts, this is often more feasible than in contexts with

https://doi.org/10.1017/9781009325844.026

A graphical representation of layered risk management

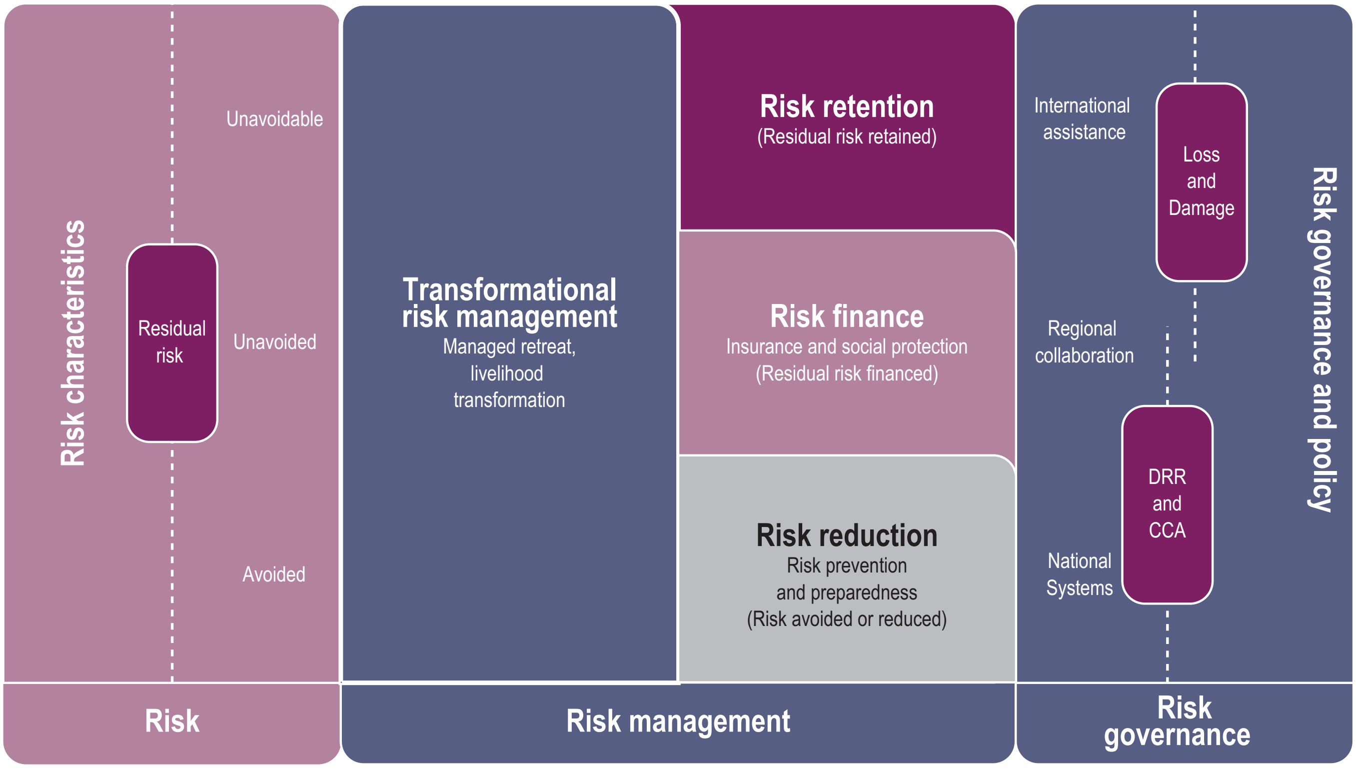

Figure 17.4 | A graphical representation of layered risk management. Risks can be reduced or managed by risk finance (insurance and other means), but some residual risk remains, particularly for high-impact unavoided and unavoidable risk, which is retained implicitly or explicitly. Where incremental and *in situ* adaptation is not effective in managing risks, transformational adaptation supports systemic change. Risk management occurs in national systems, and regional insurance systems have stimulated regional collaboration. Particularly for high impact risks and impacts in specific events, international assistance is required. Policy domains on disaster risk reduction (DRR) and climate change adaptation (CCA) as well as Loss and Damage overlap in their governance of risk management. Figure building on Mechler et al. (2014); Cummins and Mahul (2009); Lal et al. (2012); Mechler and Deubelli (2021).

limited resources, and adaptation investments are more likely to include structural measures to reduce exposure, complemented by vulnerability-reducing measures and insurance protection (*medium confidence*). While this typology is not universally representative of high-income areas (within or between countries), expensive exposure-reduction measures tend to be easier to implement in high-income countries. For example, flood protection is largest in countries with larger amounts of public spending and least amounts of corruption (Scussolini et al., 2016). It is seen as more economically efficient to invest in expensive protection measures in wealthy regions, under different scenarios of sea level rise and river flooding, although these calculations have equity and justice implications (Peduzzi, 2017; Lincke and Hinkel, 2018). After flood events happen in regions with high levels of protection, damages are comparatively limited, and people tend to continue living in close proximity to the protected river (Mard et al., 2018). In contrast, flood displacement is higher in low-income countries (Kakinuma et al., 2020).

Risk financing, especially insurance, is also common in higher-income countries with well-developed insurance markets and higher levels of insurance penetration than in lower-income countries, illustrated by the purple bar in Figure 17.5 (*high confidence*) (Linnerooth-Bayer et al., 2019). Of climate-related disasters, floods and storms cause the largest amount of reported economic losses; however, at least 40% of these losses are uninsured, even in the regions with high insurance penetration (Baur et al., 2018). Government involvement in insurance schemes is associated with higher penetration rates of the general population (Paleari, 2019). While some, predominantly high-income countries can make use of disaster contingency funds or dedicated budget items, these do not exist or are not well endowed to adequately support relief, recovery and reconstruction (Linnerooth-Bayer and Hochrainer-Stigler, 2015). To help stabilise public finance in regions with little market-based insurance coverage and fiscal response mechanisms, regional public insurance pools have been set up with donor assistance, such as in the Caribbean, Africa and the Pacific for flood and droughts (Schäfer et al., 2016; Surminski et al., 2016; Linnerooth-Bayer et al., 2019).

Moderate investment focused on adaptive capacity

In contrast to the 'extensive protection' scenario, many regions of the world bear greater resemblance to the second typology in Figure 17.5 'moderate investment focused on adaptive capacity' (*medium confidence*). These contexts see greater adaptation funding invested in capacity building activities to reduce vulnerability, rather than structural or ecosystem-based protection measures to reduce

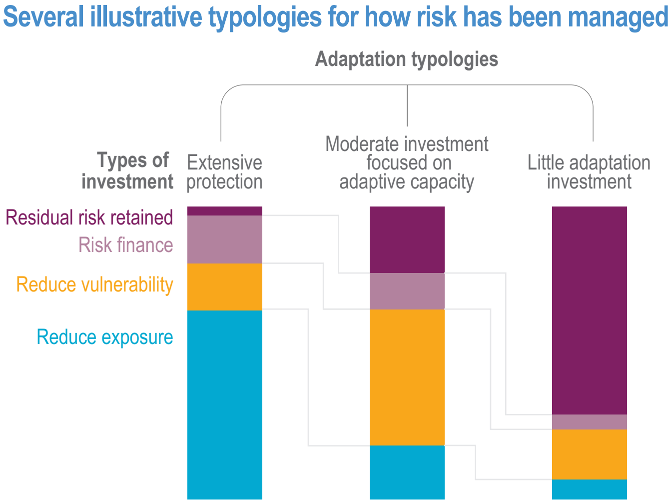

Figure 17.5 | Several illustrative typologies for how risk has been managed. The first is 'extensive protection', in which the bulk of investments is made in reducing exposure, through protection up to limits (e.g., flood levees) and including retreat. The second category is 'moderate investment focused on adaptive capacity', in which the bulk of investment is made in reducing vulnerability (e.g., improved housing). The third category is 'little adaptation investment', in which there is little investment in either reducing vulnerability or exposure, and the bulk of risk is residual, borne by the population.

exposure (Biagini et al., 2014). Because of limited international and domestic finance for large structural investments to reduce exposure, the most prevalent adaptation choices in low-income contexts are household-level vulnerability-reducing measures (Koerth et al., 2017).

Lack of access to finance can be one of the reasons countries engage more readily in adaptive capacity-building activities. Countries that rank highly on the Corruption Perceptions Index engage less in technological solutions for risk management (Berrang-Ford et al., 2014). In addition, countries with higher levels of corruption receive less adaptation aid (Betzold and Mohamed, 2017; Weiler et al., 2018). Countries are more likely to receive adaptation aid if they import goods from a donor country, or are a former colony of that donor (Betzold and Mohamed, 2017; Weiler et al., 2018). In countries with poor governance and limited aid flows, remittances make up a substantial portion of finance available to the local population for risk management (Samuwai and Hills, 2018).

Risk financing does play a large role in the 'moderate investment' category; there are a variety of instruments in use globally. Many countries in the Global South have created national policies and a number of regional catastrophe risk insurance pools, subsidised by international assistance, which make pay-outs to the national government of affected nations when an extreme event happens and have helped to build risk awareness (Clarke et al., 2015; Thirawat et al., 2017). Beyond this, residual risk is often borne directly by affected people (Andrianarimanana, 2015).

Little adaptation investment typology

In the third typology, there are limited resources for adaptation, and populations bear large amounts of residual risk (depicted by the purple bar in the third typology in Figure 17.5, 'little adaptation investment'). SIDS can often find themselves in this situation, because small populations, small economies, lack of economies of scale, subsistence livelihoods and other challenges mean risk reduction and risk financing are both costly (Chapter 15).

Another example of this third typology are people living in conflict-affected areas. These populations are highly vulnerable to the impacts of climate change (Basher, 2006; OCHA, 2011; IPCC, 2012; Zommers and Singh, 2014; Marktanner et al., 2015; Walch, 2018; Eckstein et al., 2019; Peters et al., 2019). In conflict-affected areas similar to the third category of 'little adaptation investment', a combination of high vulnerability and relatively less support for adaptation means that there is a large amount of 'residual risk', in which residents cope with the impacts of extreme events on a regular basis (*high confidence*). For example, deaths from 'natural' disasters are 40% higher in areas that are undergoing armed conflict (Marktanner et al., 2015) (Box 17.2).

17.2.2.3 Adaptation beyond Risk: Exploiting Opportunities

Several studies and many government planning documents reference how people can benefit from a changed climate, beyond reducing risks. For example, several regions are expecting an increase in visitors to eco-tourism sites or national parks with a changing climate (Fisichelli, 2015; Lwasa, 2015). In Europe, several national adaptation plans include planning for potential benefits of a changing climate, including reduced winter mortality and improved conditions for hydropower (Biesbroek et al., 2010). Recognising the need for economic diversification, people working in certain industries, such as coastal management, perceive climate change as a factor increasing the need for their services (Fatorić et al., 2017). Northern countries are taking advantage of ice-free waters for shipping routes in the Arctic (Eguiluz et al., 2016; Melia et al., 2016; IPCC, 2019c). In Africa, opportunistic adaptation has been observed by smallholder farmers, to plant crops that are better suited for a changing climate (Lalou et al., 2019). Similar agricultural adaptation in Pakistan has been associated with improved food security and reduced poverty (Ali and Erenstein, 2017; Rahman et al., 2020). In each of these cases documenting benefits, there are also potential negative impacts on other populations or ecosystems, such as ecosystem impacts from increased Arctic shipping (Ng et al., 2018).

While adaptation is rarely focused on taking advantage of opportunities presented by a changed climate, there are numerous co-benefits of adaptation opportunities, from health to reduced emissions to ecosystem services (*high confidence*) (Watts et al., 2015; Geneletti and Zardo, 2016; Spencer et al., 2016). There is also literature proposing that the actual process of adaptation planning can enable people to take advantage of opportunities, including, for example, opportunities for larger policy and governance reform (Coleman and Sandhu, 1965; Ernst and Preston, 2017; Brown et al., 2017a).

Box 17.2 | Climate Risk Management in Conflict-Affected Areas

Consequences of conflict that exacerbate vulnerability to climate change include: displacement, loss of access to employment leading to illegal livelihoods, gender-based violence, lack of land tenure, low literacy, poor access to social and health services, destruction, looting and theft of key assets, such as houses, food stocks and livestock, among others (Jaspars and Maxwell, 2009; Chandra et al., 2017; Anguita Olmedo and González Gómez del Miño, 2019). Such impacts perpetuate cycles of poverty (World Bank, 2013), making conflict-affected populations more susceptible to suffer from climate-related events (Basher, 2006; Coughlan de Perez et al., 2019). For example, in Mindanao, Philippines, poverty is closely linked to long-standing armed conflicts; both climate change and conflict have significantly increased smallholder vulnerability, resulting in loss of livelihoods, financial assets, agricultural yield and the worsening of debt problems (Chandra et al., 2017). In Colombia, displacement induced by conflict has pushed the population to live in high-risk areas such as steep slopes susceptible to landslides and river banks exposed to flooding (Albuja and Adarve, 2011). This conflict-induced vulnerability, with little adaptation activity, has in turn resulted in climate-related disasters (Kuipers, 2019; Siddiqi et al., 2019).

Conflict can also limit the effectiveness of adaptation measures that do exist; a study across Africa, the Caribbean and Asia concluded that poor governance can limit the effectiveness of early-warning systems in these regions (Lumbroso et al., 2016). Poor state services have health consequences and can limit social support networks (Peters, 2018). States are unable (even if they are willing) to assist or protect citizens in disasters. Non-governmental stakeholders play a large role in these contexts, but questions of long-term implications and accountability remain unaddressed (Peters, 2018).

Climate risk management and adaptation in conflict-affected contexts is challenging, first, given the complex and dynamic nature of vulnerability (Hilhorst, 2003; Frerks et al., 2004) and, second, given factors such as weak or non-existent disaster risk governance, restricted access, human rights violations, power dynamics between parties in conflict, and environmental degradation, among others (Kloos et al., 2013; Marktanner et al., 2015; ICRC, 2016; Quinn et al., 2017; Field and Kelman, 2018; Siddiqi, 2018). Climate can also be a contributing factor to conflict (Mach et al., 2019). There is little peer-reviewed documentation available on adaptation in climate-affected contexts, and what exists is narrowly focused on agriculture at the expense of other sectors, such as cities, infrastructure and humanitarian operations (Sitati et al., accepted).

To address risks to livelihoods, conflict-sensitive livelihood programming has used vouchers to meet immediate needs, legal support to resolve land disputes, and disaster preparedness planning to identify safe places for displacement (Jaspars and Maxwell, 2009). For example, cooperation in the Philippines between Moro Islamic Liberation Front and United Nations agencies included training of farmers in disaster risk reduction, drought management and production of improved crop varieties to support a transition away from subsistence farming (Walch, 2018). In Mali, negotiations on fertilizer access and safe transport to agricultural lands were brokered by the International Committee of the Red Cross, and in Afghanistan, conflict-sensitive approaches have promoted ecosystem-based adaptation to support reforestation (Walch, 2018; Mena and Hilhorst, 2020). Despite several examples of conflict-sensitive adaptation practices, little is known about the effectiveness of such efforts in reducing climate risks in these complex contexts (see Section 17.5 for further discussion of 'effectiveness').

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17.2.2.4 The Spectrum from Incremental to Transformational Adaptation in Risk Management Portfolios

Section 1.4.5 noted that transformational adaptation is increasingly being considered necessary to allow a system to extend beyond its (soft) limits as incremental adaptation cannot guarantee to avoid intolerable risks. Section 16.4 presents evidence on RKRs where a need for transformational adaptation and climate risk management has been identified in order to further reduce climate risks and avoid breaching adaptation limits. The following section identifies how the 24 adaptation options representative of the RKRs may support incremental and transformational risk management/adaptation that can lead to small, medium and large systemic change, often as part of portfolios of options. This subsection further discusses the role of transformational adaptation vis á vis incremental adaptation by reviewing evidence across chapters (see also Box 17.3). The Cross Chapter Box on Loss and Damage further expands on the international debate regarding the role of decision-making on incremental and transformational adaptation for dealing with residual risks to address soft as well as hard adaptation limits (see Cross-Chapter Box LOSS in this Chapter).

As the literature distinguishes active transformation to shape future risks from passive and unintended transformation (Lonsdale et al., 2015; Chapter 1), the section queries how to inspire actors to consider how to develop or implement transformational adaptation to complement incremental adaptation/risk management when and where appropriate.

In contrast to a broadening literature on conceptualisation and policy proposal, there has been little evidence reported in the literature on transformational adaptation and risk management at scale of implementation (*high confidence*) (Klein et al., 2017; Ajibade and Egge, 2019; Tàbara et al., 2019; Mechler and Deubelli, 2021).

Deubelli and Venkateswaran (2021) review evidence on largely non-governmental organisation (NGO)-implemented community-level adaptation for floods, heat and drought across the globe. They suggest that transformational adaptation success, while multi-facetted and challenging, depends on the availability of appropriate enabling environments including experiential and niche learning, alignment of transformational change objectives with strategic (government or other actor's) priorities, strong bottom-up governance grounded in local contexts, phased long-term program support and appropriate financing.

To distinguish incremental from transformational adaptation, Lonsdale et al. (2015), building on Mustelin and Handmer (2013), identify criteria related to framing, learning and decision-making, space and time, power, and type of change management. Tàbara et al. (2019), additionally discuss transformation in light of informing climate pathways, strategies and solutions. Broadly considering these criteria, they identify 12 dimensions with additional discussion of change with regard to systems and dynamics, options and solutions, agency, and the consideration of equity (see also Chapters 1, 6, 18 for more discussion). In particular, the following key aspects for understanding the spectrum from incremental to transformational adaptation are of relevance: change, within or across the system; agency, single or heterogenous; a role for visioning and normative futures; the type of learning required (from first order, business-as-usual, to second order); and how equity and distributional issues are explicit.

Applying these key aspects to the list of 24 adaptation options from Table 17.1, certain options are assessed to be more transformational, often requiring large system changes that go beyond addressing individual risks. Adaptations that are more transformational offer potential to lead to systemic change. Less transformational adaptations allow people to address specific climate-related risks while maintaining existing systems (see SM17.1 for more details; see also Box 17.3).

For example, several adaptations related to the RKR on risks to peace and migration, namely permanent migration, and cooperative governance, require moderate to high levels of transformation (*high confidence*). Some behavioural adaptations, such as changing diets and reducing food waste, can also require large transformations in land use and food culture (*medium confidence*). Spatial planning, including urban zoning, also tends to be more transformational (*medium confidence*).

On the other end of the spectrum, disaster early-warning systems tend to be incremental rather than transformational (*high confidence*), because they enable people to maintain/protect existing systems. Several other adaptations allow people to maintain livelihoods and systems in the face of changing risks. For example, improvements in agricultural and fishing practices can be done with moderate transformation to systems (*medium confidence*). Similarly, insurance tends to require less transformation, as it can allow people to maintain existing systems while being more resilient to climate-related shocks (*medium confidence*).

None of the 24 adaptation options are consistently beneficial for vulnerable and marginalised groups (*high confidence*). For each adaptation, there are examples of how it has been implemented in a way that benefits poor, low-income, ethnic groups and/or females, and other examples of implementation in different contexts that have worsened the risks for those groups specifically. For example, while the goal of cooperative governance can be to support the marginalised, these same marginalised groups are usually excluded from participating in the design of the solutions, and many articles criticise governance results as protecting only the interests of the wealthier and more powerful parties in the negotiations, especially in governance of migration (Groutsis et al., 2015; Pijnenburg et al., 2018). This reinforces the need for context-specific planning to ensure marginalised groups will benefit from an adaptation plan. See Table 17.3 for examples of how each adaptation option can have or not have equity benefits.

17.2.2.5 Incremental and Transformational Adaptation for Managing Risk in the Context of Adaptation Limits

With evidence on soft and hard limits being experienced in natural and human systems, including in terrestrial, aquatic and marine ecosystems, coastal and island systems, agriculture, health systems, urban spaces and tourism (Table 16.5, 16.4.2, *medium confidence*), transformation is also being considered to expand the adaptation space beyond soft limits and before hard limits are being reached. As a key area of advancement since AR5, this section assesses the relationship of residual risks, limits and incremental as well as transformational adaptation integrating the assessment of limits in Section 16.4 with Chapter 17 adaptation and risk management assessment along a spectrum of adaptation change. Section 17.2.2.5 thus contributes to understanding in which systems and regions transformational adaptation is increasingly required and considered once incremental adjustments are exhausted in the context of soft and hard limits.

Assessing risk and limits requires in-depth analysis of the adaptability of human and natural systems under different warming and risk levels, also considering socioeconomic exposure and vulnerability drivers, informed by perspectives on what breaching limits means, especially if significant change and losses and damages occur (Sections 16.4, 8.4). Assessments differ between natural systems (where adaptation potential is often very limited; Klein et al., 2014) and human systems where incremental and transformational adaptation can help to extend soft limits so that hard limits are not met or to buy time until hard limits are reached with higher levels of warming.

The assessment synthesises global and regional evidence across regional and thematic report chapters along a continuum from observed to projected impacts and risks, the spectrum of incremental and transformational adaptation, and finally any evidence on soft and hard limits. We present regional evidence for two types of salient natural and human systems and RKRs: RKR-B (risk to terrestrial and ocean ecosystems), where we assess risks from marine heatwaves to coral reefs; and RKR- E (risk of heat on human health as a human system). Both RKRs and systems are facing substantial (residual) risk, characterised by adaptation limits and sharing heatwaves as the hazard, for which climate change has been considered the major driver of increasing intensity and frequency (*high confidence*) (IPCC, 2021). The assessment synthesises evidence on transformation as reported in the chapters as well as categorises identified adaptation options

Table 17.3 | The 24 adaptation options from Table 17.1 grouped and coloured by their potential for transformation. (See Appendix A for assessment methodology.) Adaptations in red tend to require small amounts of transformation, adaptations in orange tend to require middling levels of transformation, and adaptations in yellow tend to require large levels of transformation, or systemic change. Each option is paired with examples of how that adaptation can be done in a way that does not benefit or worsens, the situation for marginalised groups, as well as an example in which that adaptation has benefitted those groups. Examples of equity focus on benefits to poor, low-income, ethnic groups, or females.

Adaptation	Example of the adaptation excluding or worsening the situation for marginalised groups	Example of the adaptation benefitting marginalised groups
Less transformation (small systemic change)		
Insurance[b]	Index-based insurance policies in Mongolia were accessible primarily to wealthy herders (Taylor, 2016b).	The availability of capital after disaster events can avoid a poverty trap from disasters (Alam et al., 2020a).
Coastal accommodation[c]	Accommodation strategies in Jakarta have led to a false sense of security in an impoverished and vulnerable neighbourhood (Esteban et al., 2017).	The mosaic restoration project provided training for women to support local accommodation of climate changes on Yap (Krishnapillai, 2018).
Early-warning systems[c]	People of higher socioeconomic status tend to receive warnings, while marginalised groups can be left out (Baudoin et al., 2016).	Famine and drought early-warning systems have helped avoid starvation among the world's most vulnerable people (Funk et al., 2019).
Water use/demand[c]	Small farmers were unable to access supports to implement drip irrigation in Morocco, and uptake was greater among wealthy farmers (Jobbins et al., 2015).	Retrofits for water use efficiency were made available free of charge to low-income communities in the USA (Lee and Tansel, 2013).
Coastal hard protection[b]	Construction of hard barriers increased flood risk for several low-income communities in Bangladesh (Adnan et al., 2020).	Successful coastal embankments can help people avoid poverty traps in Bangladesh by reducing exposure to flood events (Borgomeo et al., 2017).
Moderate transformation (medium systemic change)		
Infrastructure retrofitting[b]	Low-income people often do not own their homes, and there are few incentives for landlords to upgrade (Tardy and Lee, 2019).	Energy policy could promote solar infrastructure in Nigeria, which can offer electrification in underserved regions (Ohunakin et al., 2014).
Building codes[c]	Building codes in Nepal and Bangladesh often fail to increase resilience because many buildings are built informally (Ahmed et al., 2019).	Slum upgrading projects in Latin America reduced the vulnerability of informal settlements by improving built infrastructure (Núñez Collado and Wang, 2020).
Farm/fishery practice[b]	Many agriculture improvement strategies create higher workloads for women and do not directly enfranchise them, as seen in Uganda, Ghana and Bangladesh (Jost et al., 2015).	Improved crop varieties have supported the income of low-income farmers in Zambia (Khonje et al., 2015).
Diversification of livelihoods[a]	Diversifying livelihoods can increase women's workloads, in a review of semiarid regions across Africa and Asia (Rao et al., 2020).	A study on diversity of income sources in Ghana indicated that diversification can make people less vulnerable to extreme events (Baffoe and Matsuda, 2017).
Social safety nets[b]	Social protection systems in Bangladesh focus on specific groups in rural areas, and they often fail to reach urban poor and other very disadvantaged people (Coirolo et al., 2013).	Adaptive social protection can help poor people avoid the impact of extreme events by scaling up support at critical moments (Bowen et al., 2020).
Infrastructure for health[c]	The development of sanitary water infrastructure in Germany had less benefit in areas with higher income inequality (Gallardo-Albarrán, 2020).	Improvements to water and sanitation infrastructure that avoid people fetching water are associated with improvements to women's health (Geere and Hunter, 2020).
Food storage/distribution[b]	Increasing/improving livestock markets can favour high-income livestock producers (Gautier et al., 2016).	Investments in large produce storage houses has supported indigenous livelihoods in the face of climate change (Mugambiwa, 2018).
Restoration/creation of natural areas[b]	Urban greening programmes in the USA avoided minority neighbourhoods or caused displacement of people of colour (Anguelovski et al., 2016; Watkins et al., 2016).	Afforestation reduced landslide risk for informal settlements in Brazil (Sandholz et al., 2018).
Minimising ecosystem stressors[a]	Fish quota reduction had negative economic impacts when done quickly (Barbeaux et al., 2020).	South Africa's Working for Water programme employed poor people to control invasive species (van Wilgen and Wannenburgh, 2016).
Ecosystem-based adaptation[b]	Payments to Indigenous groups in return for protecting conservation land can be less than their original livelihoods and disadvantage those not receiving the payments, such as women (Bedelian and Ogutu, 2017).	Integrated water resource management is proposed in the Caribbean as a way to maintain ecosystem services while improving economic welfare (Mycoo, 2017).
Water supply/distribution[b]	Water tariffs during the Cape Town drought negatively impacted poor households (Millington and Scheba, 2021).	City Water Forums in Nepal have focused on equitable water allocation as an adaptation (Pandey and Bajracharya, 2017).
Seasonal/temporary mobility[b]	Women tend to have greater restrictions on mobility than men (Lama, 2018).	Indigenous communities in Guatemala use temporary migration to manage rainfall variability (Ruano and Milan, 2014).
Most transformation (largest systemic changes needed)		
Spatial planning[b]	Spatial planning in American cities has often resulted in less green space in ethnic minority neighbourhoods (Connolly and Anguelovski, 2021)	While difficult, strategic approaches to urban planning can promote inclusive development (Chu et al., 2017).
Diets/food waste[a]	Low-income groups have less opportunity to diversify diets if certain foods become more expensive or difficult to obtain (Reynolds et al., 2019).	Changing dietary intake during heatwaves (e.g., eating cooler foods) is seen as a low-cost adaptation accessible to low-income people in the UK (Porter et al., 2014).

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Adaptation	Example of the adaptation excluding or worsening the situation for marginalised groups	Example of the adaptation benefitting marginalised groups
Health care systems[b]	Facilities in poor communities are often poorly sited and can lack capacity to support people during climate-related extreme events (Codjoe et al., 2020).	Universal health coverage can be highly beneficial to poor people (Atun et al., 2015), when needed for climate-related health outcomes.
Water capture/storage[b]	Many Indigenous populations have been negatively affected by loss of their land when displaced for dam construction (Siciliano and Urban, 2017).	Improving water harvesting supports marginalised populations in dryland areas (Bobadoye et al., 2016).
Cooperative governance[b]	International cooperation among national governments regarding migration can encourage human rights abuses and increase migration (Crawley and Skleparis, 2018).	International cooperation has the potential to remove barriers to adaptation in informal settlements in developing countries by sharing knowledge and expectations (Oberlack and Eisenack, 2014).
Permanent migration[c]	Permanent migration from small island nations can entail a loss of identity for Indigenous groups (Bordner et al., 2020).	Migration supported by social protection systems can be sustainable for poor populations (Schwan and Yu, 2018).
Strategic coastal retreat[c]	Minority groups faced tensions with host communities when relocated in India, and faced difficulties in terms of fishing access and land size (Mortreux et al., 2018).	In several cases of post-disaster relocation, community members initiated the retreat and there were broader benefits to society (Hino et al., 2017).

Notes:
(a) *low confidence*
(b) *medium confidence*
(c) *high confidence*

along an adaptation spectrum according to the criteria discussed in Section 17.2.2.4, specifically whether adaptation leads to systems' change or only change within a system is driven by multi-scale agency and considers equity impacts specifically.

Figure 17.6 organises global and regional findings for observed and projected health risks from heat (RKR-E) from chapters across the report and organises options according to findings on the potential for transformational change as presented in Section 17.2 and Table 17.3. The discussion shows that heat has become a significant health risk globally, incurring severe mortality and morbidity in all world regions with annual heat-related deaths estimated around 300,000 with millions affected (*high confidence*) (Section 9.3.1). Evidence shows that adaptation and risk management can be effective in reducing (relative) risks in developed countries, with inconclusive evidence in low-middle-income states (Sections 9.2.4.1, 13.7.3, 13.6). In absolute terms, risk in terms of heat-related mortality and morbidity is projected to increase under medium and high heating scenarios in many regions, even with implemented adaptation. By 2050 (compared with 1961–1991 and for a mid-range emissions scenario), an excess of 94,000 deaths yr^{-1} is projected globally as attributable to climate change (Section 9.3.1).

Planned and implemented adaptation interventions in all regions have remained largely incremental, while uptake is being intensified in some regions; options have included air conditioning (as autonomously deployed), public cooling spaces, heat action plans that incorporate early warning and response and heat-adapted building design (Sections 9.9.5, 11.3.6, 12.5.6.1.1,13.11.3, 13.11.3, 15.6.2).

Given increasing risks projected and soft and hard limits already reported, transformation is being considered as a complement potentially leading to systemic and transformational change. Adaptation, if upgraded to also consider transformational interventions, will thus help to reduce heat risks (*medium* to *high confidence*, *limited evidence*), albeit with reduced effectiveness at higher levels of warming, particularly in regions (Africa, Asia) where lethal heatwaves are projected to occur almost annually towards later in the 21st (*medium confidence*) (Sections 9.1, 10.4.7).

This may involve urban redesign using nature-based solutions (such as green roofs and infrastructure) as well as rescheduling of outdoor labour or cross-sectorial coordination. Integrated approaches across interdependent systems (e.g., ecosystem-based approaches and climate-sensitive urban design) are being proposed. Also, it may mean bolstering social safety nets and health systems that better attend to heat impacts by providing universal coverage. Societal and political transformations to reduce climate change risks for vulnerable groups are considered particularly relevant in some regions (Sections 9.4.2.1.2, 9.9.5, 10.4.6.4.3, 12.5.3.2, 13.6.2.1, 14.6). Yet, across all regions there is *limited evidence* on proposed transformational adaptation and very little evidence regarding implementation (*high confidence*).

As a consequence, studies project soft limits to be further reached as increased mortality and morbidity will add stress to health systems, and labour productivity will be severely hampered, impacting economic systems (*medium* to *high confidence*) at medium to higher levels of global warming (Sections 7.2.4.1, 9.10, 10.4.4.4, 11.9.1, 13.6.2.3, 13.7.2, 13.7.4, 13.10.2.1, 13.8, 15.3.4.9).

Hard limits may be breached in some regions where critical heat tolerance thresholds are projected to be surpassed at medium to higher levels of global warming, such as physiological survivability thresholds, which, for example, may render urban outdoor labour in Asia, Africa and North America infeasible (Sections 10.4.6.3.2, 14.8, Box 9.1).

Marine heatwaves have affected tropical coral reefs, which are analysed as part of RKR-B (Table SM17.20). Coral reefs across the tropics have recently seen massive bleaching events (such as for the Great Barrier Reefs) (*very high confidence*). Risks are projected to be

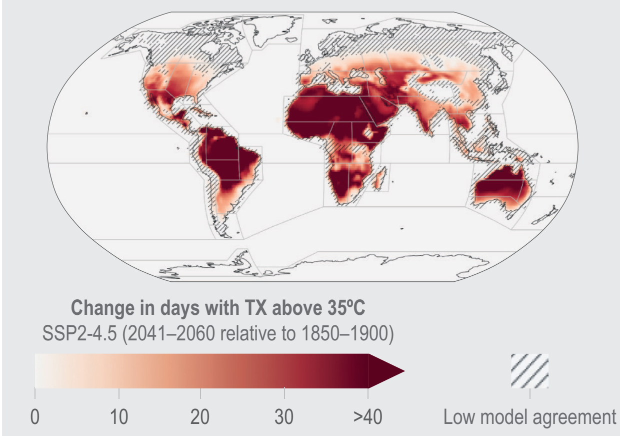
Understanding the spectrum of incremental to transformational planned adaptation for managing climate related heat risk to health including associated soft and hard adaptation limits

Risk to human health from heat (RKR-E)

- Observed impacts
- Projected risks
- Incremental adaptation complemented by transformational adaptation
- Transformational adaptation
- Soft limit (to incremental adaptation)
- Hard limit
- WG I Detection and attribution statement

Confidence

(•) Low (••) Medium (•••) High (••••) Very high (•••••) Virtually certain



Global

Heat is a significant health risk due to widespread urbanization, demographic changes and increase in hot weather (•••) 323,000 estimated heat-related deaths and 13 million heat-related DALYs in 2019.

Temperature-related mortality expected to increase under medium and high heating scenarios even with adaptation. By 2050 (compared to 1961–1991) an excess of 94,000 deaths per year attributable to climate change projected due to heat for medium warming.

Implementation of heat warning systems has reduced relative mortality risk in developed countries (•••), unclear trends in low-middle income countries. Multi-sectoral integrated approach beneficial including heat early warning and response systems targeting vulnerable groups (•••).

Longer term urban planning and design, including Nature based solutions (NBS) to reduce urban heat island effects. Improved basic protection for outdoor work including work rescheduling to cooler times of the day (•••).

Some regions with heat stress conditions approaching upper limits of labour productivity (•••).

Thresholds of survivability approached (•••).

Hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s (•••••).

Human-induced climate change is the main driver of these changes (•••).

Every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of heatwaves (•••).

Africa

Climate variability impacting the health of tens of millions of Africans through exposure to extreme heat. Heat extremes (hot days and hot nights) increased in frequency since 1980 (•••).

Increasing temperatures will cause tens of thousands of additional deaths under moderate and high global warming scenarios, particularly in North, West and Central Africa (•••).

Cooling stations, limited evidence of pro-active climate change adaptation in African cities (•••).

Urgent need for improved societal and political transformations to reduce climate change risks for vulnerable groups (••). Deployment considered necessary of NBS with demonstrated health, ecological, economic and social co-benefits.

Morbidity and mortality will escalate with further global warming, placing additional strain on health and economic systems (•••).

Under high warming scenarios annual exceedance of deadly heat thresholds in North, West and Central Africa (•••).

Asia

Short-term effects of high temperatures on daily mortality and morbidity reported in several cities throughout Asia.

More frequent hot days and intense heat-waves will increase heat-related risks and deaths in Asia (••).

Urban technological solutions (e.g. smart cities, early warning systems);and behavioural adaptation growing from initial stages but unevenly distributed across large and small cities (••).

Transformational adaptation largely lacking, some incipient in larger cities, including NBS.

Heat stress likely to approach critical health thresholds in West and South Asia under medium warming scenario, and in some other regions such as East Asia under high warming (•••).

Australasia

Heat-related deaths have increased with a third attributable to climate change in Australia (•••).

Increase in heat-related mortality and morbidity for people and wildlife in Australia (•••).

Urban cooling, education to reduce heat stress, heatwave early-warning systems, building standards that improve insulation/cooling. Current levels of adaptation largely incremental and reactive inconsistent with rising risks (•••).

NBS and well-resourced primary health care.

Fundamental limits include thermal threshold, some individuals and communities are already reaching their psycho-social adaptation limits (•••).

Central and South America

Heat stress a health concern (•••).

Significant increases in intensity, frequency and duration of heatwaves (•••), strong increases in heat-related mortality in urban areas.

Focus on early warning and surveillance systems for heat waves; political, institutional, and financial barriers limit feasibility to date (•••).

NBS proposed to be combined with community engagement and integration of diverse knowledge to foster transformational adaptation.

No limits for health risk discussed.

Europe

70,000 and 54,000 deaths during 2003 and 2010 heatwaves, adaptation actions have reduced heat-related mortality in parts of Southern Europe (•••).

Risk of heat mortality and morbidity to more than triple at 3°C compared to 1.5°C with projected 90,000 deaths in 2100 (•••).

Air cooling, heat warning and response systems, building interventions, but largely incremental adaptation (•••).

Increasing use and plans for NBS in urban spaces; large scale system transformations needed due to adaptation limits in Southern Europe (••) involving strong behavioural change combined with large portfolios of preventive and planning options.

Above 3°C limits to the adaptation potential of people and existing health systems, particularly in Southern and Eastern Europe and with health systems under pressure (•••).

North America

High temperatures have increased mortality and morbidity (••••) with impacts varying by age, gender, location, and socioeconomic conditions (••••).

Warming projected to increase heat-related mortality (••••) and morbidity (••).

Air conditioning and cooling stations.

Transformational, long-term adaptation action to increase resilience such as through redesign of urban space (•••).

Available (incremental) adaptation options unable to protect human health under high-emission scenarios (•••).

Hard limits to adaptation may be reached for rural and urban outdoor labor towards end of century (••).

Small Islands

Disproportionate health risks associated with changes in temperature. Heatwaves cause injuries and deaths.

Heat-related mortality and risks of occupational heat stress in small island states projected to increase with higher temperatures. Higher temperatures also can affect productivity of outdoor workers.

Limited evidence reported. Early warning and response systems; integrating climate services into health decision-making systems; public uptake and buy in; improving health data collection systems.

No evidence of transformational adaptation.

Reduced habitability of small islands through a compounding of key risks including from heat-related health stress for warming of 1.5°C (•••).

Figure 17.6 | Understanding the spectrum of incremental to transformational planned adaptation for managing climate related heat risk to health including associated soft and hard adaptation limits (Representative Key Risk-E (RKR-E)). Evidence from regional and thematic chapters. The figure from the WGI Atlas shows the change in extreme hot days (above 35°C) across regions for a medium-term scenario and medium global warming relative to 1850–1900. See Table SM17.19.

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https://doi.org/10.1017/9781009325844.026

further exacerbated by increases in intensity, frequency and duration of marine heatwaves (*high confidence*) as well as impacts from extreme events such as tropical cyclones (*low* to *medium confidence*) (Section 3.4.2).

Although there is some evidence of autonomous natural thermal adaptation, as indicated by the presence of stress-tolerant symbionts adapted to higher thermal thresholds observed in the Persian Gulf, there is *low confidence* (*limited evidence*, *low agreement*) that enhanced thermal tolerance can be maintained over time (Chapter 3 Box 5) as the adaptability in natural system is considered very limited and risks are driven by water temperature. Evidence suggests that already at further warming of 1.5°C coral reefs are put at high risk (*very high confidence*) (Section 3.4.2.1).

Planned adaptation can help to buy some limited time, including through recovery and restoration efforts that target resistant coral populations and interventions to culture heat-tolerant algal symbionts as well as by setting up marine protected areas. Under higher warming levels, transformation has been proposed as possibly complementing available management approaches with high-risk interventions, including enhanced corals and reef shading, which may help to sustain some coral reef systems beyond 1.5°C of global warming. Modelling has shown, however, that the effectiveness of such high-risk interventions declines beyond 2°C of global warming (Figure 3.23, Section 3.4.2.1) (*medium confidence*).

Already for limited warming beyond 1.5°C for mid-century with increasing intensity and frequency of marine heatwaves, hard limits are projected to become manifest in terms of widespread decline and loss of structural integrity (*very high confidence*) (Section 3.4.2.1), including for the two largest such systems, the Great Barrier Reef and the Mesoamerican coral reef (Section 11.3.2, Box 11.2, Tables 11.14, 12.4).

In terms of planned adaptation options that would provide benefits to populations, evidence suggests these are very limited and uncertain and bring along substantial risks to people, culture and ecosystems (Section 3.5.2, Cross-Chapter Box SLR). Concurrent with the loss of coral reefs, important ecosystem services, including to fishery, tourism and coastal protection, would be lost. Transformational adaptation, while requiring difficult choices to be made, is being discussed to help overcome soft limits through livelihood diversification for alternative income sources, assisted migration and planned relocation of communities dependent on the services provided by the reef ecosystem (*medium confidence*) (Section 3.5.2).

17.3 Decision-Making Processes of Risk Management and Adaptation

AR5 (Chambwera et al., 2014; Jones et al., 2014; Klein et al., 2014; Kunreuther et al., 2014; Mimura et al., 2014) represented a significant step forward in focusing attention on how decision-making may facilitate effective and robust responses to climate risks remaining after mitigation measures have been taken, following recognition of these needs in the IPCC 4th Assessment Report (AR4), including the diverse contexts that face decision makers (Klein et al., 2007).

AR5 (Jones et al., 2014; Kunreuther et al., 2014) recognised that the decision-making procedures are as important to consider in managing risks as are the options for responding to climate change, mostly because the procedures can themselves constrain the choices of actions, which could, in turn, lead to constrained pathways which are undesirable. The importance of iterative risk management is emphasised because risk and adaptation are dynamic. It also identified that (i) risk assessments, decision-support tools, early-warning systems, accounting for uncertainty and delivering no-regret options by examining trade-offs are important, (ii) integration across different governance portfolios is needed due to potential conflict of different actions between portfolios, and (iii) planning, implementation and decision-making, including the use of methods, are dependent on local context.

Since AR5, the IPCC special reports have provided the value of integrated assessment processes for assessing trade-offs and synergies (IPCC, 2018a), adaptive management and governance, the roles of formal and informal decision-making (IPCC, 2019b) and the importance of developing policy and governance options for risk management, including managing disasters, enhancing resilience, addressing decision-relevant uncertainties and being prepared for abrupt change and extreme events (IPCC, 2019c)

Chapter 16 has shown that climate risks vary greatly from small to large, local to regional, uncertain to deeply uncertain. The plethora of risks means there are many types of decisions, and many forms of analyses and processes that may be drawn on. Decisions can differ according to whether they are strategic, tactical or operational; whether there are one or many decision makers, from a domestic setting to national governments; the level of uncertainty present; the time available to take the decision; and many more factors (Chapter 1; Section 17.1).

The pathway to a decision may not be linear, depending on when and in what detail the decision-making or consultative group may need to be understanding the climate risk and its real-world context (*sense-making*, *modelling*), has sufficient background to analyse and explore options for ameliorating the risk (*analysis*, *exploration*), or is ready for interpreting the analyses and deciding on the requirements and strategies for implementing a chosen strategy (*interpretation–implementation*) (*high confidence*) (Figure 17.7; French et al., 2020). The development of decision-support tools for climate risk management (Palutikof et al., 2019a; Palutikof et al., 2019b) and more generally (Papathanasiou et al., 2016), along with archives of experiences from practitioners (Watkiss and Hunt, 2013; Section 17.5; Bowyer et al., 2014; French, 2020), means that some aspects of the decision-making process can be circumvented or at least streamlined as that experience is re-used (*high confidence*).

No single approach to decision-making best suits an individual climate risk across any adaptation context (Richards et al., 2013), although there is now a greater awareness of the methods and approaches that are available and their requirements for best practice (Hurlbert et al., 2019) (*high confidence*). This section aims, firstly, to assess the factors that people responsible for organising and facilitating decision-making may wish to consider in choosing the methods and approach for them to make decisions in their context. It also assesses existing experience in analysing the utility of methods for climate risk decision-making. The second part then assesses progress in integrating decision-making across a portfolio of risks.

https://doi.org/10.1017/9781009325844.026

Cross-Chapter Box LOSS | Loss and Damage

Authors: Reinhard Mechler (Austria/Germany), Adelle Thomas (Bahamas), Christian Huggel (Switzerland), Emily Boyd (Sweden), Veruska Muccione (Italy), Ivo Wallimann-Helmer (Switzerland), Laurens Bouwer (the Netherlands), Sirkku Juhola (Finland), Chandni Singh (India), Carolina Adler (Switzerland/Chile/Australia), Kris Ebi (USA), Patricia Pinho (Brazil), Rawshan Ara Begum (Malaysia/Australia/Bangladesh), Adugna Gemeda (Ethiopia), Johanna Nalau (Australia/Finland), Katja Frieler (Germany), Richard Jones (UK), Riyanti Djalante (Japan), Rosa Perez (Philippines), Tabea Lissner (Germany), Anita Wreford (New Zealand), Mark Pelling (UK), Francois Gemenne (Belgium), Nick Simpson (Zimbabwe/South Africa), Doreen Stabinsky (USA)

An intensifying dialogue

This Cross-Chapter Box offers an assessment of the growing literature on Loss and Damage. Capitalised letter 'Loss and Damage' (L&D) has been used to refer to negotiations under the UNFCCC. Research has used lowercase 'losses and damages' for residual effects from (observed) impacts and (projected) risks (see Glossary, Annex II).

Dialogue around L&D issues started with a proposal for insurance and compensation by the Alliance of Small Island States (AOSIS) (INC, 1991) and has intensified over recent years with suggestions made to consider complements to adaptation in order to manage residual impacts and risks 'beyond adaptation' in vulnerable developing countries (Section 1.4.5). L&D was formally recognised in 2013 at the 19th meeting of the Conference of the Parties (COP19) through the *Warsaw International Mechanism on Loss and Damage* (UNFCCC, 2013), governed by an Executive Committee (ExCom), to advance knowledge, foster dialogue and enhance action and support. Article 8 of the Paris Agreement provided a permanent legal basis for the Warsaw International Mechanism (WIM) (UN, 2015).

IPCC's first assessment of L&D in 2018 found residual risks to rise with further global warming leading to soft and hard adaptation limits in some natural and human systems (e.g., coral reefs, human health, coastal livelihoods) (Roy et al., 2018). Sections 8.4.5.6, 16.4 and 17.2 corroborate these findings concluding that, depending on mitigation and adaptation pathways, residual risks in key systems in many regions will create potential for negative impacts beyond adaptation limits (*medium confidence*). The assessment in 2018 also noted that there is 'not one definition of L&D'. This ambiguity has persisted, and a policy space for L&D has not clearly been delimited (*high confidence*). There is, however, coalescence in dialogue among academia, civil society and policy around a distinct set of themes as identified by stakeholder surveys as well as literature, methods and evidence reviews (Vanhala and Hestbaek, 2016; Boyd et al., 2017; Mechler et al., 2018; Calliari, 2019; McNamara and Jackson, 2019): risk management, limits to adaptation, existential risk, finance and support, including liability, compensation and litigation (Sections 8.3, 16.4; *medium confidence*; Figure Cross-Chapter Box LOSS.1). Various advisory groups have been set up with participation of policy and experts from research, civil society and practice to help inform the implementation of WIM workplans (UN, 2015; UN, 2019).

Risk management

An increasing body of research has focused on the role of climate risk management (Sections 8.3, 16.4 and 17.2; *high confidence*) (Birkmann and Welle, 2015; Gall, 2015; van der Geest and Warner, 2015; Mechler and Schinko, 2016; Boyd et al., 2017; IPCC, 2018b; IPCC, 2019b; Boda et al., 2020; Broberg and Romera, 2020). A technical expert group on comprehensive risk management (TEG CRM) advises the WIM ExCom, while other expert groups focus on slow-onset events and non-economic L&D (UNFCCC, 2019a).

There is evidence that, without strong risk management and adaptation, losses and damages will continue to affect the poorest vulnerable populations, potentially creating poverty traps (*high confidence*) (Sections 8.3, 8.4.5.6 and Tables 8.7, 17.2; Serdeczny, 2019; Tschakert et al., 2019; Thomas et al., 2020). Research has started to develop global inventories on losses and damages, including on intangible effects (Tschakert et al., 2019; Otto et al., 2020), and engaged with the practice community for data collection. Practice has provided guidance to report on losses and damages in countries (I)NDCs (WWF & Practical Action, 2020). Yet, systematic risk assessments of climate-related losses and damages including adaptation limits (see, e.g., Leal Filho and Nalau, 2018; Robinson, 2018) have remained scarce (Section 16.4; *high confidence*). Thus, many vulnerable countries lack comprehensive data at scale of risk management including on economic (e.g., loss of livelihood assets and infrastructure) and non-economic losses and damages (e.g., culture, health, biodiversity), thus hampering effective risk management (Thomas and Benjamin, 2018; Martyr-Koller et al., 2021; Singh et al. 2021). Van den Homberg and McQuistan (2019) propose a losses and damages inventory also to be used to monitor how technologies may shape risks as well as adaptation limits. While early warning and other risk reduction options as well as risk retention considerations are being discussed, L&D dialogue has strongly focused on risk finance for residual risks, particularly through the donor-supported provision of public insurance systems (Linnerooth-Bayer et al., 2019; Schäfer et al., 2019; Broberg and Romera, 2020; Nordlander et al., 2020).

Cross-Chapter Box LOSS (continued)

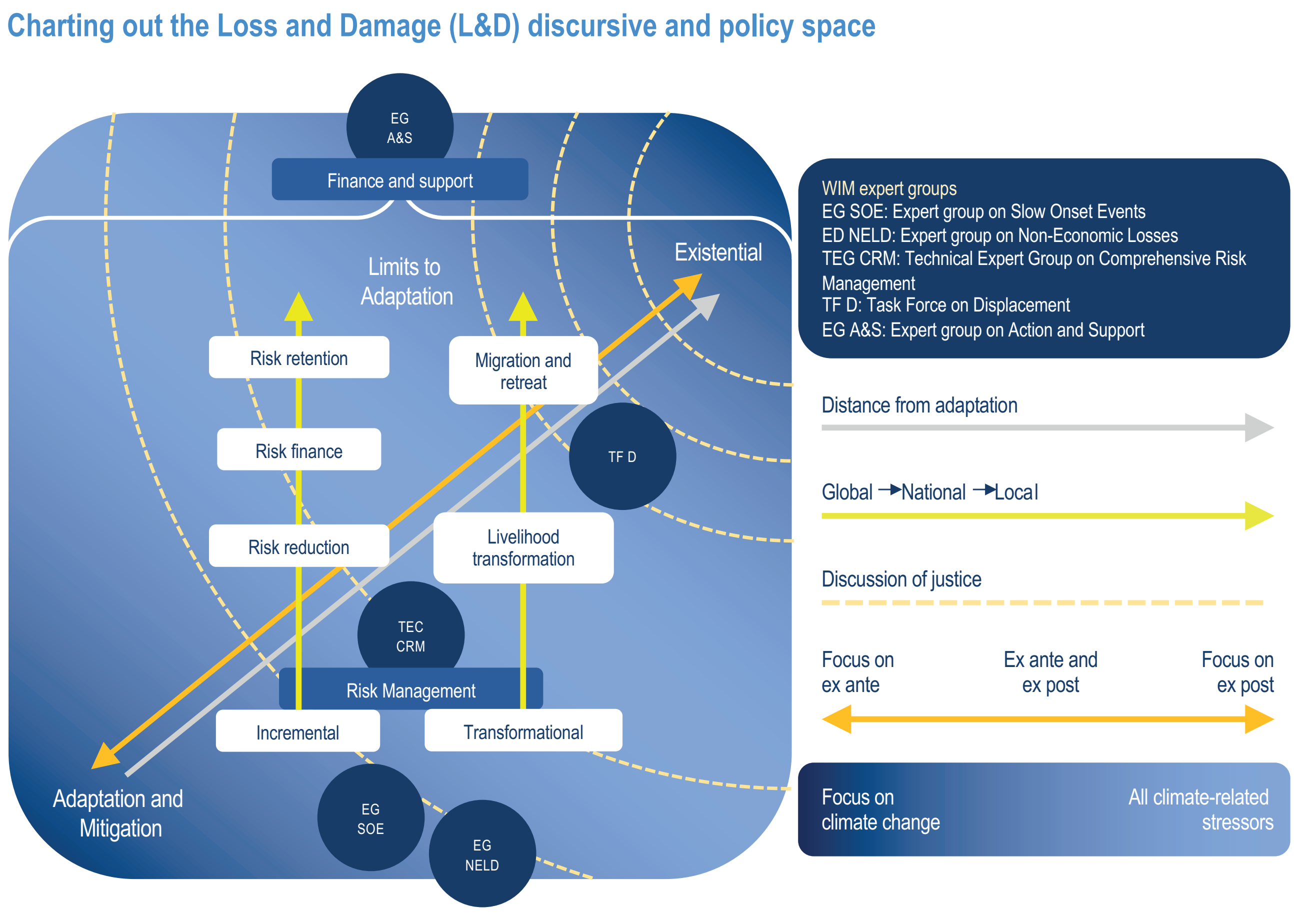

Figure Box Cross-Chapter Box LOSS.1 | Charting out the L&D discursive and policy space. The figure shows key discursive strands relevant for L&D, including their inter-relationships with and distinction from adaptation. The figure also identifies expert groups set up under the WIM and showcases the scale of responses discussed, a focus on *ex ante* risk management and *ex post* attention to losses and damages as well as contributions by climate change and other stresses for the themes. Adapted from Boyd et al. (2017) and building on Vanhala and Hestbaek (2016), Mechler et al. (2018), McNamara and Jackson (2019) and Calliari (2019).

Transformation

The role of transformation in risk management for overcoming any soft limits to adaptation is seeing emerging attention (*medium confidence*, *limited evidence*), and the TEG CRM has also been tasked to consider transformation. Relocation and retreat of assets and communities, where *in situ* adaptation is considered impossible, is increasingly being debated in research and practice, including in terms of finance and L&D implications (Section 8.4.4; Boston et al., 2021; Desai et al., 2021; Mach and Siders, 2021; van der Geest and van den Berg, 2021; Zickgraf, 2021). Livelihood transformation occurs where current livelihoods become unfeasible in the face of multiple climatic and non-climatic stressors (Section 8.3.4.1) requiring change within sectors (such as switching from cropping to livestock rearing (Escarcha et al., 2020) or across sectors, when farming households relocate to offer labour elsewhere (Section 9.1; Rasel et al., 2013). Biermann and Boas (2017) suggest revamping global governance systems to effectively address the protection and voluntary resettlement of those displaced by climate variability and change. A WIM taskforce on displacement is tasked to further advise on human mobility, including migration, displacement and planned relocation (UNFCCC, 2019a).

The existential dimension

There has been less and often implicit discussion on the existential dimension of climate-related risk as pertaining to L&D (*medium confidence*). McNamara and Jackson (2019) infer an existential dimension from notions of inevitability and irreversibility associated with migration and relocation of communities (Eckersley, 2015; Mayer, 2017; McNamara et al., 2018), socio-cultural impacts linked to glacial retreat (Jurt et al., 2015) and adverse psychological and inter-subjective effects (Herington, 2017; Adams et al., 2021). Many SIDS in their NDCs refer to sea level rise in particular posing existential threats, and call for enhanced international support for L&D (Thomas and Benjamin, 2017).

Cross-Chapter Box LOSS (continued)

Finance and support

International support and finance, including compensation for losses and damages, have been in the spotlight from the beginning of the dialogue (*high confidence*), starting with AOSIS' proposal (INC, 1991). Recent work has focused on *finance sources*, such as solidarity-based donor and other support for experienced losses and damages and climate-induced displacement as well as questions of compensation and litigation (Roberts et al., 2017; Gewirtzman et al., 2018; Mechler and Deubelli, 2021; Robinson et al., 2021). A selection of finance *options* has also been explored such as donor-supported insurance systems with built-in risk reduction provisions (Gewirtzman et al., 2018) as well as roles for social protection (Aleksandrova and Costella, 2021). International policy and donors have provided technical assistance for insurance-related options (Insuresilience Global Partnership, 2018).

As national and donor-related funding for impacts and risk management remains limited (Schäfer and Künzel, 2019; 17.2; Serdeczny, 2019) even at current global warming, many highly exposed developing countries remain financially constrained in their capacity to attend to residual impacts and risk management needs (Linnerooth-Bayer and Hochrainer-Stigler, 2015; Roberts et al., 2017; UNEP, 2021a) (*high confidence*). Discussion on options for the risk retention layer 'beyond adaptation' are likely to see further attention as the dialogue proceeds.

Although there is no explicit mandate regarding L&D, about a quarter of the Green Climate Fund's approved projects explicitly refer to L&D, while 16% of projects have thematic links to L&D across their main project activities (Kempa et al., 2021). Any estimate of L&D finance needs and spending, however, remains highly speculative, as long as its exact remit including in relation to adaptation has not been clarified politically (*medium evidence*, *high agreement*) (Markandya and González-Eguino, 2019).

Liability and compensation, implying legally defined reimbursement of losses and damages attributable to climate change, remain contentious in L&D dialogue (*high confidence*). Yet, in half of the academic and grey literature surveyed by McNamara and Jackson (2019), compensation is mentioned. Studies have laid out responsibility principles, such as historical responsibility based on the polluter pays principle, beneficiary pays and ability to pay. Discussions on compensation are closely linked to justice and equity scholarship which has studied compensatory, distributive and procedural equity considerations for burden sharing (Roser et al., 2015; Wallimann-Helmer, 2015; Huggel et al., 2016; Boran, 2017; Page and Heyward, 2017; Roberts et al., 2017; Shockley and Hourdequin, 2017; Wallimann-Helmer et al., 2019; Garcia-Portela, 2020).

Litigation and liability are linked, and a growing research body has examined the role of litigation and international law for the L&D context finding that litigation risks for governments and business may increase as the science, particularly on attribution, matures further (Mayer, 2016; Banda and Fulton, 2017; WGI CWGB Attribution, 8.2.1.2); Marjanac and Patton, 2018; James et al., 2019; Simlinger and Mayer, 2019; Wewerinke-Singh and Salili, 2019; Toussaint and Martinez Blanco, 2020) (*high agreement*, *medium evidence*).

Outlook

The WIM has been reviewed twice as to its delivery on its key functions. As an outcome of the second review in 2019, an expert group on Action and Support has been set up to further discuss issues pertaining to finance, technology and capacity building and a Santiago Network for Technical Assistance will be established to consider providing technical support directly to developing countries (UNFCCC, 2019b). Overall, the L&D dialogue under the WIM supported by an increasing body of research has made important advances with regard to the two functions of knowledge generation and coordination, yet less so on action and support (*medium confidence*) (Calliari et al., 2020). Resolution on the last item will need additional attention as, despite the coalescence of themes, the L&D dialogue continues to proceed across interlinked yet contested discussion strands.

Processes and methods to facilitate decision-making, from problem recognition to implementing a solution, have evolved in many contexts, disciplines and applications over the last century (*high confidence*). As a result, decision-making terminology has a vast number of synonyms that are not compiled here. For clarity, the term 'decision-analytic methods' refers to procedures or tools that may be used by decision makers to help develop, analyse and contrast alternative actions/adaptations; 'approaches' refers to processes that may be undertaken by decision makers to facilitate the development of proposed actions/adaptations; 'decision-support tools' refers to software or procedures that facilitate the use of knowledge and data (Papathanasiou et al., 2016).

17.3.1 Decision-Analytic Methods and Approaches

Different classes of decision-analytic methods have been variously presented in IPCC reports since AR4 but without a summary assessment of their capacity to deal with different contexts of the decision maker. 'Communities-of-practice' are developing tool boxes

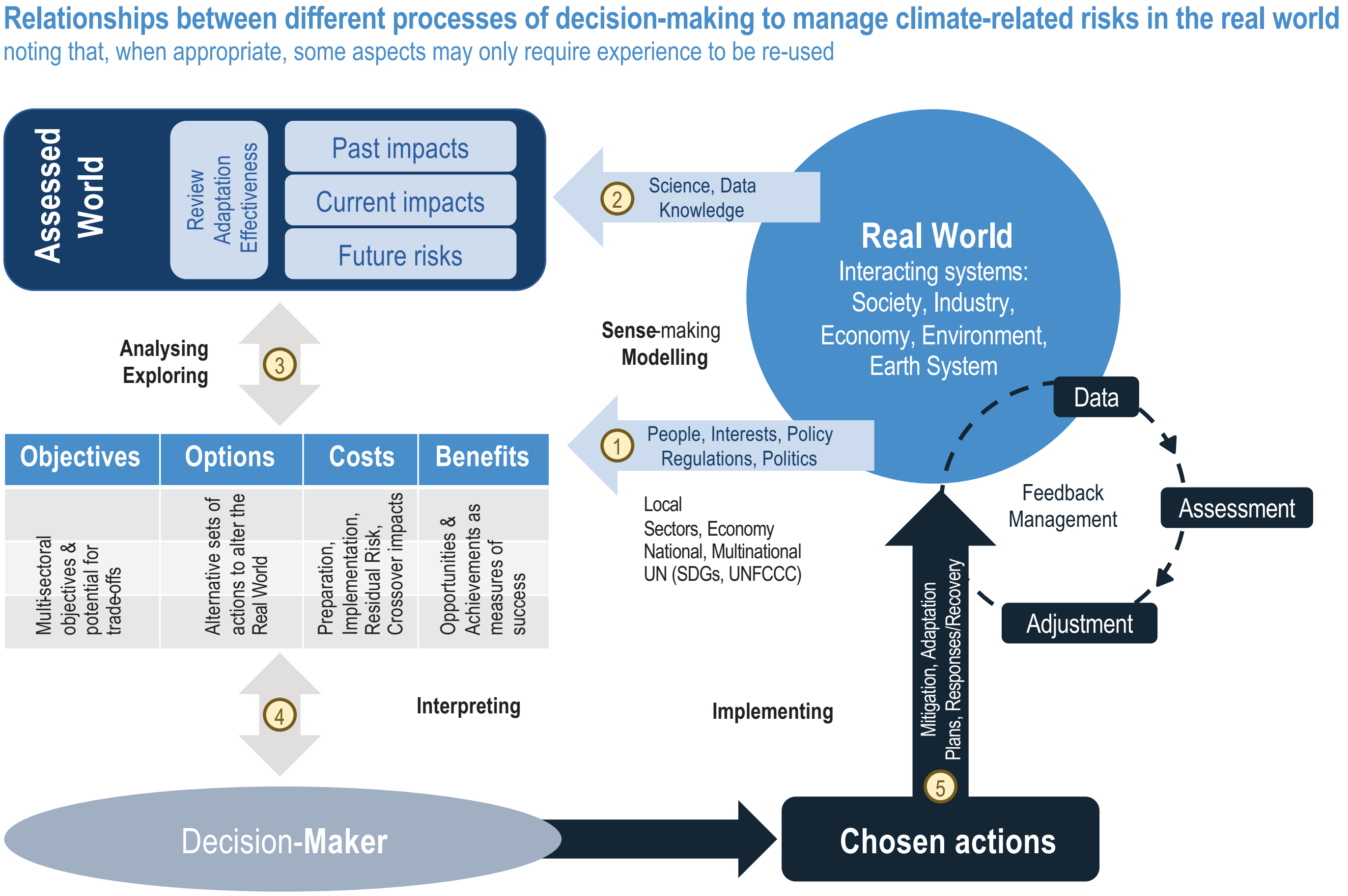

Figure 17.7 | Relationships between different processes of decision-making to manage climate-related risks in the real world, noting that, when appropriate, some aspects may only require experience to be re-used. (1) Formulation of risks of concern and accompanying policies and objectives for managing those risks, forming prescriptive models for the decision maker. (2) Knowledge, understanding and observations of the real world are used to assess past and current impacts and future risks using descriptive models, based on the perspectives and prescriptive models arising from (1). If not well formulated from other experience, processes in (1) and (2) interact to make sense of the world and what needs to be done. In iterative management, (1) and (2) also form the basis for monitoring, reviewing and evaluating effectiveness of adaptations. (3) Use of decision-support and decision-analytic tools to appraise costs and benefits of different options for ameliorating future risks. The double-headed arrow indicates where two-way interactions occur between different activities (likely to be iterative, feedback and nonlinear processes); modelling and assessments are repeated and revised in tandem with the planning and evaluation of options, based on interactions with the policymakers and stakeholders. (4) The decision maker, which may be a group of people, interacts with the evaluation of options (two-way interaction) and interprets the efficacy of the options and the implications for the real world, ultimately choosing one or more actions to satisfy the policy objectives to manage the risks. (**5**) Implementation of the actions in the real world, which may be once-only actions or instigation of a feedback management system that enables ongoing adjustments to meet objectives.

to support analysing and making of decisions generally (French, 2020). These communities of decision analysts can act like broad-based statisticians to advise on matching methods to the climate risk and its context, before individual decision specialists are consulted. Some scientific literature is presenting guides for choosing different methods, tools and approaches (Shi et al., 2019). This sub-subsection provides a summary guide for policy analysts and decision makers to help identify the classes of decision-analytic methods that may be suitable for their context for managing climate risks. It focuses on decision-analytic methods, noting that decision-support tools will underpin many of these methods by organising information (Bourne et al., 2016; Papathanasiou et al., 2016; Ceccato et al., 2018; Haße and Kind, 2018) or support modelling (Papathanasiou et al., 2016; Kwakkel, 2017; Gardiner et al., 2018), sometimes with a particular decision-analytic process in mind (Hadka et al., 2015; Torresan et al., 2016; Tonmoy et al., 2018).

17.3.1.1 Factors to Consider in Selecting Methods to Facilitate Decision-Making

The choice of methods and approaches to decision-making for climate risks (next section) will depend on (i) the cognitive needs of the deliberations, otherwise considered to be the phase in developing a decision, (ii) the types of models and modelling available to facilitate the deliberations, (iii) the degree of uncertainty surrounding the choices and (iv) the context of a choice (*high confidence*) (Richards et al., 2013; Jones et al., 2014; Shi et al., 2019; French, 2021).

17.3.1.1.1 Cognitive phases of decision-making

The decision process often involves overlapping and iterative development of the components leading towards a decision, resulting in the blurring of stages but involving different phases of cognitive activity (Figure 17.7; Holtzman, 1989; French, 2015; French, 2020). Framing the problem (Orlove et al., 2020), by modelling its relationships with the human and natural systems and eliciting objectives, values and scope of the problem from stakeholders, is a precursor to analyses of options but may be returned to whenever a phase of '*sense-making and modelling*' is required (*high confidence*) (Ackermann, 2012; Keeney, 2012; Slotte and Hämäläinen, 2014; Abbas and Howard, 2015; Marttunen et al., 2017; Korhonen and Wallenius, 2020; French, 2021).

The cognitive phase of '*analysing and exploring*' uses models and existing data and/or knowledge services as available to explore the relevance/efficacy of adaptations to ameliorate risk or to meet other adaptation objectives, as well as possible flow-on effects of those actions (Section 17.3.1.4). Sensitivity and robustness analyses can be useful if conditions are favourable to supplement the decision analysis, setting bounds on some of the residual uncertainty (*high confidence*) (Borgonovo and Plischke, 2016; Ferretti et al., 2016). Validation of models and verification of data (Tittensor et al., 2018) are becoming highlighted as important steps in this phase or in the sense-making phase, particularly in their capacity to understand and test decision makers and stakeholders' perceptions (*medium confidence*). Randomisation methods, Bayesian methods, interval methods, multi-criteria decision analysis (MCDA), decision-making under deep uncertainty (DMDU) and economic and financial approaches (e.g., Real Options Analysis) are tools of choice in this phase (*high confidence*) (Table 17.4) (Abbas and Howard, 2015; Bendoly and Clark, 2016; Borgonovo and Plischke, 2016; Iooss and Saltelli, 2017; Korhonen and Wallenius, 2020; Saltelli et al., 2020). Decision-support tools in the provision of data and/or modelling methods are regularly used in this and the sense-making phase (*high confidence*) (Section 17.3.1.2).

The phase of interpreting the analyses to make decisions on climate adaptation followed by implementation is the least described in the literature (Figure 17.8). Decision process management tools and methods for communicating choices, outcomes and implementation are expected to be used to provide support in this phase, particularly for understanding whether the advice is fit for purpose, and the efficacy of choices are clear (*low confidence*) (Spetzler et al., 2016).

17.3.1.1.2 Types and capacity of models to support decision-making

'Descriptive models' of socio-biophysical systems and their responses to different drivers (Argyris and French, 2017; French and Argyris, 2018; Saltelli et al., 2020) and 'prescriptive models', which capture the beliefs, values and objectives of decision makers and stakeholders (Parnell et al., 2013; Keisler et al., 2014; French and Argyris, 2018), provide the foundations of sense making (*high confidence*) and thereby influencing the options and choices available in the phase of analysis and exploration (*medium confidence*) (Gorddard et al., 2016).

Socio-biophysical models may be qualitative network models, statistical models or dynamic mathematical models (Melbourne-Thomas et al., 2017). Qualitative network modelling can help assess the nature and consequences of the interactions, as well as facilitate understanding of possible structures to be used in dynamic models for assessing long-term adaptation options (Reckien et al., 2013; Reckien, 2014; Reckien and Luedeke, 2014; Symstad et al., 2017). These approaches help articulate the direct and indirect effects of fixed, long-term engineering or structural adaptations. Dynamic stochastic modelling (Fulton and Link, 2014; Ianelli et al., 2016) has been used to assess short- to medium-term interactions of more dynamic and variable sectors, such as those with annual adjustments and management of water, agriculture, land and marine uses (Holsman et al., 2019; Hollowed et al., 2020; Bahri et al., 2021). On a longer time frame, scenarios are used to test long-term interactions but often with less variability and chance (Giupponi et al., 2013; Adam et al., 2014; Rosenzweig et al., 2017).

Many sensitivity analyses based on scenarios, including procedures to randomise across model uncertainty, relate to descriptive dynamic mathematical models with the user of the models characterised as an objective observer (Borgonovo and Plischke, 2016; Ferretti et al., 2016; Symstad et al., 2017; French, 2020). Bayesian approaches enable these descriptive analyses to take account of the subjective choices in model construction and implementation (Abbas and Howard, 2015; Sperotto et al., 2017; Jäger et al., 2018; Sperotto et al., 2019; French, 2020). Organising descriptive analyses and deciding on a suitable option across a diversity of opinions among stakeholders use prescriptive processes, which can be supported with prescriptive modelling tools (Williamson and Goldstein, 2012; Gelman et al., 2013; Abbas and Howard, 2015; Dias et al., 2018; Phan et al., 2019; Hanea et al., 2021). These approaches are subjective, in that they are constrained or directed by the particular views and emphases of the decision-making group (Gorddard et al., 2016). Not all tools are appropriate for all these activities.

Decision makers will be better able to choose decision-analytic methods when they have an understanding of the types, scale and breadth of uncertainties around the climate risk (*high confidence*) (Symstad et al., 2017). The *Cynefin* framework (Snowden, 2002; French, 2013) is a policy-driven framework that broadly categorises the decision context of uncertainty within which decision makers and policy analysts may find themselves (*medium confidence*) (Hurlbert et al., 2019; Helmrich and Chester, 2020). As *Cynefin* has helped frame previous IPCC presentations on contexts of uncertainty (Hurlbert et al., 2019) and has a community of practice to consult on its use (French, 2020), it is used here, also because it considers the uncertainty in knowledge around cause and effect in general terms, rather than specifically focusing on uncertainty in formal models. Helmrich and Chester (2020) show how *Cynefin* can be used to frame climate adaptation decision-making in the infrastructure sector.

The *Cynefin* contexts relate to how well the system is understood for knowing precisely the outcomes of actions that may be taken, ranging from known, knowable and complex to chaotic. If a context is known or knowable, then it will be possible to build sophisticated models and make sound predictions. If the context is complex and chaotic the outcomes of actions will be less predictable, no matter how complex the models may be, although more complex dynamic models may be useful to test 'what if' scenarios in these cases (Marchau et al., 2019). Under complex and chaotic circumstances an ensemble of models and approaches may be needed to help categorise a satisfactory 'solution space' across the broad knowledge of relationships and dependencies, but will need to have iterative processes to update and refine adaptations as knowledge improves (Marchau et al., 2019).

17.3.1.1.3 Uncertainty and attitudes to risk

Uncertainty does not just relate to what might happen given climate drivers or adaptations, but also to how much one values potential consequences (Butler et al., 2016; Beven et al., 2018a; Cross-Chapter Boc DEEP; Beven et al., 2018b; French, 2020) (*high confidence*); the balance between how particular decision analyses address uncertainties relating to the external world (descriptive models) and those relating to the values driving the decision-making (prescriptive models) is important (Butler et al., 2016). Some analyses partially ignore uncertainties relating to the former in order to focus on conflicts in the values held by different stakeholders and help structure debate (Korhonen and Wallenius, 2020; French, 2020), while others build very sophisticated models of the external world to predict potential consequences, but in doing so lose transparency and risk becoming untrustworthy black boxes to many stakeholders (*low confidence*) (Peterson and Thompson, 2020).

Much of the readily available literature on how uncertainties affect decision-making relates to the uncertainty in the biophysical models, with a recognition that the choice of tools will be influenced by the types of uncertainty to be addressed (Le Cozannet et al., 2017; Symstad et al., 2017; Beven et al., 2018a; Beven et al., 2018b; Durbach and Stewart, 2020b; French, 2020). While terminology varies among disciplines, three types of uncertainty are important in understanding assessments of the future from descriptive models: epistemic (uncertainty in model construction relating to the lack of knowledge about the system being represented), analytic (the degree to which a model fits observations, and its accuracy) and stochastic (the natural variability or randomness in the system). The probability of an event arising in the future is determined from all three uncertainties, noting that stochastic uncertainty is a property of the system rather than a limitation of research (Le Cozannet et al., 2017; Beven et al., 2018a; Beven et al., 2018b).

Uncertainty in what constitutes a risk of concern is increasingly identified as important to consider when managing risk (Chapter 16; Butler et al., 2016; Prober et al., 2017; French et al., 2020; Reis and Shortridge, 2020). The uncertainty here arises from what is an acceptable risk. Acceptability relates to the value or importance of the consequence, which may include moral and ethical uncertainties (Prober et al., 2017), as well as how ambiguous the understanding of the consequence may be between different groups (Beven et al., 2018a; Beven et al., 2018b). The development of strategies to ameliorate risk will benefit from considering these two uncertainties in specifying the risk to be managed (Prober et al., 2017; French et al., 2020) because they can help set boundaries on a required likelihood of success, rather than simply casting stakeholders or decision makers as risk averse or risk tolerant, and can help identify and accept pathways of success (Gregory et al., 2012). This can be important when decisions need to be made well in advance of the actions needing to take effect, such as for many climate risks (Chapter 1; Chapter 16; Section 17.2.3; Cross-Chapter Box DEEP in this Chapter).

Elicitation methods help reduce these uncertainties (*high confidence*) (Butler et al., 2016; Prober et al., 2017; Symstad et al., 2017; Beven et al., 2018b). In addition, informal decision processes can assist in developing consensus in approaches and outcomes (Orlove et al., 2020).

17.3.1.2 Decision-Analytic Methods Used in Decision-Making and Climate Risk Management

Entities making decisions (countries, regions, organisations and individuals) select methods that best suit them in their context (Fünfgeld et al., 2018; Shi et al., 2019; French, 2020) (*high confidence*).

Classes of tools (Watkiss and Hunt, 2013; French, 2020) include Bayesian methods, interval methods, decision-making under deep uncertainty (DMDU; see Cross-Chapter Box DEEP in this Chapter), cost–benefit analyses, multi-criteria decision analysis, elicitation and general decision support tools (Table 17.4). A summary guide for policy analysts and decision makers is presented in Table 17.4 to help identify the classes of decision-analytic methods that may be suitable for their context for managing climate risks. The table summarises how well the methods address the *Cynefin* context, the phase of decision-making, the types of uncertainties that exist through the decision-making process and the resources required. As terminology may vary between disciplines and research groups, suitable references to better explain the methods within the class are provided. Also, there may be overlap between the classes as individual methods are often paired with other methods to address specific requirements and approaches (Buurman and Babovic, 2016; Haasnoot et al., 2019). In that respect, these methods are referred to in the next section discussing advances in the different approaches to managing climate risks.

Case studies in Table 17.4 describe the utility of classes of decision-analytic tools to facilitate decisions about climate adaptations (SM 17.2). These case studies are presented in Figure 17.8 according to the type of decision-making body and mapped according to their contribution to a decision outcome relative to the geopolitical scale of the actions being assessed. The effectiveness of these methods and tools in Table 17.4 in the context of climate change adaptation (Box 17.1) has yet to be evaluated.

Many published studies on the utility of decision-analytic methods in managing climate risks are theoretical, and therefore it is difficult to find studies on the value of analytic methods for underpinning final decisions on climate risk adaptation. Bayesian, Deep Uncertainty and elicitation methods and tools to support decision-making were the most easily located classes of methods to be used in different contexts (Figure 17.7), while the other classes were more oriented towards government processes. This result highlights a key gap at present in the need to have real-world experiences published and mapped for their utility for different tasks, thereby creating a resource for policymakers to identify suitable tools, such as in emerging communities-of-practice of decision practitioners (Watkiss and Hunt, 2013; Street et al., 2019; French, 2020).

17.3.1.3 Approaches to Support Decision-Making

The common approaches presented here are not undertaken in isolation and are often combined throughout, or applied at different stages of, a decision process, as illustrated in Figure 17.7.

Table 17.4 | Characteristics of the main approaches to decision analysis with respect to their *Cynefin* context, the manner in which they can be used to address different uncertainties, where they may be used in different cognitive phases of the decision-making process, the resources required and some case studies for further exploring how they might be used. Numbers in square brackets after references in case studies refer to the references plotted in Figure 17.8.

A: Bayesian methods (Keeney and Raiffa, 1993; Smith, 2010; Gelman et al., 2013; Reilly and Clemen, 2013; Abbas and Howard, 2015; Sperotto et al., 2017; Marchau et al., 2019)
A structured approach to assembling information around the consequences of choices, either by modelling, by analysis of multiple scenarios or by structuring deliberation; underpinned by a theoretical base, coherent assumptions and powerful computational methods; can use both observational data and expert knowledge, weighting them appropriately; same approaches as in artificial intelligence algorithms. Biases (information, stakeholders, decision makers) can be made explicit. Traditionally, Bayesian methods computationally identify an 'optimal' decision, based on maximising the expected utility across a number of specified requirements, represented as functions.

Examples include the general application of decision network models (Richards et al., 2013; Sperotto et al., 2017); the use of decision network analyses based on elicitation to choose adaptations to coastal management in a lagoonal area in Italy (Catenacci and Giupponi, 2013) and coastal community in UK (Jäger et al., 2018); combination of economic models and decision models to assess research and development priorities (Baker and Solak, 2011); combining outputs from models, observations and opinions in a decision framework for assessing climate impacts on water nutrient loads in Italy (Sperotto et al., 2019) and a general review for water resource management (Phan et al., 2019); combining results from different dynamic models to assess human mortality from ozone in the USA (Alexeeff et al., 2016); assessing adaptive capacity of surf lifesaving in Australia (Richards et al., 2016); and assessing urban flood risks in Denmark (Åström et al., 2014).

Cognitive phase			***Resources required***	***Case studies***
Sense-making and modelling	*Analysing and exploring*	*Interpreting and implementing*		
Construction of hierarchical models, belief nets (Sperotto et al., 2017; Phan et al., 2019), decision trees (Keeney and Raiffa, 1993) and influence diagrams (Keeney and Raiffa, 1993; Reilly and Clemen, 2013) supplemented by many soft elicitation techniques helps build models for quantitative analysis (Gelman, 2003; Bendoly and Clark, 2016).	Bayesian updating and expected utility analysis supplemented by robustness and sensitivity analyses (Rios Insua, 1999; Rios Insua and Ruggeri, 2000; French et al., 2009; Smith, 2010; Reilly and Clemen, 2013; Abbas and Howard, 2015).	Use of graphical models (decision trees, belief nets and influence diagrams) and sensitivity plots can help make transparent and explain reasoning for strategy to stakeholders and implementers (Bendoly and Clark, 2016) and provide for auditable building of consensus.	Bayesian decision-analytic models can be applied with increasing complexity and sophistication to any given problem. Coherence between different levels of sophistication can be maintained. Thus, the resources can be tailored to the time and support available for the analysis. The most sophisticated analyses are computationally demanding.	Alexeeff et al. 2016) [1], Åström et al. (2014) [2], Baker and Solak (2011) [3], Catenacci and Giupponi (2013) [4], Jäger et al. (2018) [5], Phan et al. (2019) [6], Richards et al. (2013) [7], Richards et al. (2016) [8], Sperotto et al. (2017) [9], Sperotto et al. (2019) [10]

Uncertainties		***Cynefin context***			
Stochastic, epistemic, analytical (descriptive modelling)	*Ambiguity value (prescriptive modelling)*	*Known*	*Knowable*	*Complex*	*Chaotic*
All can be modelled probabilistically, perhaps supplemented by sensitivity analysis (Rios Insua, 1999; Rios Insua and Ruggeri, 2000; Iooss and Saltelli, 2017). Deep uncertainties can be investigated via scenarios (French, 2020).	Uncertainties resolved or reduced by discussion, then values modelled by multi-attribute values and utilities (Keeney, 1992; Keeney and Raiffa, 1993; Gregory et al., 2012). Residual uncertainties explored via sensitivity analysis.	Any stochastic uncertainties modelled probabilistically; otherwise, deterministic modelling with sensitivity analysis. Value functions tend to be used more than utility functions (Keeney and Raiffa, 1993; Goodwin and Wright, 2014).	Epistemic uncertainties updated via Bayesian statistics/machine learning, then remaining stochastic uncertainties modelled probabilistically. Full Bayesian decision modelling possible (French et al., 2009; Smith, 2010; Abbas and Howard, 2015).	More exploratory analysis (Gelman, 2003) to understand behaviours with less complex Bayesian modelling support by sensitivity and robustness studies (Rios Insua, 1999; French, 2003). Scenario-focused decision analysis to cope with deep uncertainties (French, 2020). Careful deliberations to construct values and utilities. (Keeney and Raiffa, 1993; Gregory et al., 2012).	Formal modelling impossible. Much exploratory work to identify potential causes and effects. Little if any complex analysis.

B: Decision-making under deep uncertainty (DMDU) (Hallegatte et al., 2012; Weaver et al., 2013; Marchau et al., 2019; Workman et al., 2021)
Deep uncertainty relates to circumstances in which data are too sparse, experts are in too much disagreement or time is too short to model the uncertainty. As such, DMDU methods are focused on working in the *Cynefin* Complex Space context. Approaches emphasise robustness ('no regrets' options) and the use of scenarios, and often link well with scenario-focused robust Bayesian studies (Cross-Chapter Box DEEP in this Chapter). DMDU studies draw in many other approaches to decision analysis, using them to identify robust rather than optimal strategies, as in robust decision-making (RDM). DMDU analyses can help decision makers to think contingently and build a more wide-ranging recognition of the risks. They often integrate with other classes of tools.

Examples include RDM for hydro-power design using down-scaled climate data in Sub-Saharan Africa (Taner et al., 2017), RDM for water management in California, USA (Lempert and Groves, 2010), the Colorado River, USA, and for international climate investment strategies (Groves et al., 2019), use of decision scaling (Brown et al., 2019), comparison of RDM and Info-gap methods (Hall et al., 2012) and review of using climate modelling in RDM (Weaver et al., 2013).

Cognitive phase			*Resources required*	*Case studies*
Sense-making and modelling	*Analysing and exploring*	*Interpreting and implementing*		
Some of the simpler DMDU tools complement soft elicitation tools and can help to identify relevant scenarios and help formulate problems.	Many Bayesian or MCDA tools can be used here but with DMDU's additional emphasis on robustness and the exploration of several/many scenarios.	DMDU with its emphasis on robustness encourages contingency planning in implementation with careful monitoring to identify emerging risks.	Some of the simpler models do not require substantial resources, but the application of parallel sophisticated analyses in several scenarios can be computationally demanding. Also, the emphasis on discussion of robustness can be demanding on the time of problem-owners, experts and stakeholders.	Brown et al. (2019) [11], Groves et al. (2019) [12], Hall et al. (2012) [13], Lempert and Groves (2010), [14], Taner et al. (2017) [15], Weaver et al. (2013) [16]

Uncertainties		*Cynefin context*			
Stochastic, epistemic, analytical (descriptive modelling)	*Ambiguity value (prescriptive modelling)*	*Known*	*Knowable*	*Complex*	*Chaotic*
Methods are designed for deep epistemic uncertainties. Some can deal with stochastic uncertainties. Analytical uncertainties seldom accounted for.	Some DMDU methods draw on MCDA methods and thus consider ambiguity and value uncertainties. In any case, DMDU methods support wide deliberation with stakeholders.	Deep uncertainty is absent, but the principles and processes of decision-making may be used.	Deep uncertainty is absent, but the principles of decision-making may be used.	The complex and chaotic spaces are home to deep uncertainties. DMDU tools and more particularly processes are relevant here. The emphasis on robustness is very relevant. The tools themselves are relatively simply structured but are effective at stimulating discussion.	Deep uncertainties are rife in the chaotic contexts. DMDU emphases on robustness and possible scenarios can stimulate creative discussions of ill-understood issues.

C: Decision process management (Raz and Micheal, 2001; Dalkir, 2005; Burstein and W. Holsapple, 2008; Jashapara, 2011; Bonczek et al., 2014; Sauter, 2014; Holsapple et al., 2019)
A range of tools and techniques to help manage the decision-making process and support risk management and the implementation of the chosen strategy. Some tools organise data and analyses, often being built on a geographic information system, known as decision support tools. Others manage processes, organising workflows. Some have inevitably expanded in function to support decision-making itself, even though their primary focus might be on, say, implementation and monitoring risks. Such tools are closely related to knowledge management systems; knowledge management processes and decision process management differ more in terminology than in substance.

Examples include tools for agriculture (Biehl et al., 2017), evaluating and comparing CMIP climate models (Parding et al., 2020), development of action cycles (Park et al., 2012) and decision support systems across a range of sectors and decision-group applications (Papathanasiou et al., 2016).

Cognitive phase			*Resources required*	*Case studies*
Sense-making and modelling	*Analysing and exploring*	*Interpreting and implementing*		
Process, project, knowledge elicitation and risk management tools help identify how to structure decision-making processes. Decision process tools can capture details for implementation and document process for audit trail.	Tools help structure decision-making processes and ensure timely involvement of problem owners, stakeholders, and experts. Knowledge management tools can capture details for implementation and document process for audit trail.	Project management tools plan implementation and risk management tools identify what to monitor during implementation. Knowledge management tools maintain audit trail and track reasoning for choices made during implementation.	Decision process management tools can reduce resources needed in the decision-making process. However, this assumes that the tools are already installed on local information systems and that the analysis team is experienced in using them. Otherwise, resource is needed to understand and train in the use of the tools.	Biehl et al. (2017) [17], Papathanasiou et al. (2016) [18], Parding et al. (2020) [19], Park et al. (2012) [20]

Uncertainties		***Cynefin context***			
Stochastic, epistemic, analytical (descriptive modelling)	*Ambiguity value (prescriptive modelling)*	*Known*	*Knowable*	*Complex*	*Chaotic*
Not designed to address uncertainties involved in the decision itself, but may handle project risks in the decision process, especially implementation.	Not usually addressed, since ambiguities and value uncertainties will be addressed in the decision-making itself, but may use those values in risk management of implementation.	Simple project management tools may be sufficient here.	Project management and risk management tools apply easily here.	Project management and risk management tools may be used, but attention needs to be paid to risks that are complex in nature with little knowledge of precise relationships between cause and effects.	Project management and risk management tools may be used, but attention needs to be paid to risks that are complex in nature with little knowledge of precise relationships between cause and effects.

D: Economic and financial methods (Howell et al., 2001; Pearce et al., 2006; Boardman et al., 2017; Atkinson et al., 2018a; Hurlbert et al., 2019)
Stem from economic theory and accounting practices: for example, cost–benefit analysis, which seeks to price out all aspects of the consequence of a strategy, portfolio analysis, or real options theory, which seeks to value financial investments allowing for their risks and the contingent buying and selling. Such methods are perceived as objective when dealing with tangibles, but are more controversial in their valuing of intangibles. Since these methods model uncertainties with probabilities and then work with expectations, they share much in common with Bayesian methods. However, many applications of cost–benefit analysis omit any detailed treatment of uncertainty.

Examples examine the economic costs and benefits of adaptation pathways for storm water infrastructure in Singapore (Manocha and Babovic, 2017), and a coastal mega city, Los Angeles in the USA (de Ruig et al., 2019)

Cognitive phase			***Resources required***	***Case studies***
Sense-making and modelling	*Analysing and exploring*	*Interpreting and implementing*		
In themselves, these methods do not support sense-making and modelling, though discussions of how to value impacts, both tangible and intangible can be catalytic in understanding the issues.	These tools focus mainly on analysis and evaluating the costs and benefits of various options. They are not designed to be used interactively so are more often deployed and communicated via reports than interactive workshops.	Since community-based adaptation (CBA) methods do not emphasise the analysis of uncertainties and risks, they are less suited for use in developing and communicating an implementation plan. Real options with their emphasis on contingency are much more suited (Fischhoff, 2015).	Cost–benefit analysis for complex projects is a major undertaking, with much data collection needed to value outcomes. Real options also require data on risks and uncertainties. Both may have high computational needs.	de Ruig et al. (2019) [21], Manocha and Babovic (2017) [22]

Uncertainties		***Cynefin context***			
Stochastic, epistemic, analytical (descriptive modelling)	*Ambiguity value (prescriptive modelling)*	*Known*	*Knowable*	*Complex*	*Chaotic*
Cost–benefit methods usually deal with uncertainty via expectations with little attention to probability distributions; real options methods tend to treat uncertainty in much more sophisticated ways. Both methods, when applied fully have many points of contact with Bayesian methods (Neely and de Neufville, 2001; Bedford et al., 2005)	These methods reduce all value and preference information to financial equivalents. The key issue is to find a market in which all outcomes may be valued financially. Modern CBA methods use much more subtle techniques for this than those applied in the last century (Bedford et al., 2005; Saarikoski et al., 2016).	Although CBA and many financial methods work in theory, the complexity makes them seldom worth the effort.	The methods may be applied to evaluate complex projects, but CBA tends to 'average out' rather than analyse uncertainty.	The recognition of the need to treat deep uncertainties using real options has been investigated (Hallegatte et al., 2012; Buurman and Babovic, 2016).	Formal modelling impossible. Much exploratory work to identify potential causes and effects. Little if any complex analysis.

E: Interval methods (Shafer, 1976; Pedrycz et al., 2011)

Because of concerns that the statistical accuracy of some data is unknown, and that decision makers and experts cannot make numerical judgements accurately, analyses have been suggested which work with ranges of values in categories (intervals) as their inputs. While avoiding accuracy issues, weakening the arithmetic may result in other foundational assumptions not being met, including some basic principles of rationality. Different types of uncertainty can often be confused, and the analyses can contradict basic probability theory. Interval models of semantics and imprecision can be useful in exploring ambiguity and value uncertainty, though modelling rather than resolving such uncertainties does not necessary help in decision-making. Some interval methods can be thought of more as sensitivity techniques applied to other decision-analytic approaches. Typical approaches here relate to the fuzzy or possibility theory, and evidential reasoning.

Examples include using fuzzy methods to assess climate adaptations in ports in China (Yang et al., 2018), water supply vulnerability in South Korea (Kim and Chung, 2013) and resilience of the Nile River Delta (Batisha, 2015); and evidential reasoning in an environmental impact assessment for flood mitigation in Manila Philippines (Gilbuena et al., 2013).

Cognitive phase			***Resources required***	***Case studies***
Sense-making and modelling	*Analysing and exploring*	*Interpreting and implementing*		
The emphasis on modelling ambiguity may help structure a model initially, but the lack of structures to model and explore complex interdependencies may inhibit the ability to build a valid representation of the issues.	If there are substantial data available, then even the simplest of these methods can produce useful results. But with small quantities of data, their data analysis may be too inefficient. Evidential reasoning MCDA can be insightful on the preference side.	The emphasis on linguistic uncertainty may in some cases mask some of the issues (French, 1995).	Many methods are rather simple in application and require only moderate resources, but they may face issues in scaling up to major complex problems.	Batisha (2015) [23], Gilbuena et al. (2013) [24], Kim and Chung (2013) [25], Yang et al. (2018) [26]

Uncertainties		***Cynefin context***			
Stochastic, epistemic, analytical (descriptive modelling)	*Ambiguity value (prescriptive modelling)*	*Known*	*Knowable*	*Complex*	*Chaotic*
There are issues of operational definition of quantities in some methodologies. Some simpler interval methods have no concept of conditionality so cannot model learning effectively, but there are some very sophisticated theories of evidence that can. Interval methods can also provide sensitivity analyses for Bayesian and MCDA methods (Shafer, 1976; Rios Insua, 1990).	Some methods can be simplistic, with quantities not being operationally defined. The evidential reasoning approach to MCDA allows exploration of the relative weights on different criteria or between levels in criteria (Xu, 2012; Zhang et al., 2017).	Methods can be applied here without major issue, possibly because the simple, repetitive nature of the problem allows access to much data and the possibility of tuning the methods to the application.	Since the methods often capture rather than explore and resolve ambiguity and value uncertainties, they can hide issues. Also, the lack, in some cases, of operational definitions may mean that some quantification is dubious. Evidential reasoning methods can help analyse conflicting objectives (French, 1995; Xu, 2012).	The recognition of the need to treat deep uncertainties using real options has been investigated (Hallegatte et al., 2012; Buurman and Babovic, 2016).	The ability to deal with ambiguity may be helpful in poorly understood situations, but the emphasis on capturing ambiguity may ultimately slow the building of understanding.

F: Multi-criteria decision analysis (MCDA): Full ranking and optimal seeking (Bell et al., 2001; Belton and Stewart, 2002; Bouyssou et al., 2006; Zopounidis and Pardalos, 2010; Tzeng and Huang, 2011; Velasquez and Hester, 2013; Kumar et al., 2017)

Covers many approaches: indeed, Bayesian, DMDU and interval methods are sometimes considered MCDA. Some MCDAs seek an optimal or best strategy; others form partial rankings, eliminating weak strategies but not discriminating fully between the better ones. Many MCDA methods eschew dealing with uncertainties and focus on modelling and exploring conflicting objectives and balancing these. MCDA techniques are especially useful in working with senior decision makers in setting policy and broad objectives, and in processes of stakeholder engagement.

Examples include ranking adaptation and mitigation priorities at a national level in the Netherlands (de Bruin et al., 2009), Lithuania (Streimikiene and Balezentis, 2013) and Bangladesh (Haque, 2016), in the forestry sector in Nicaragua (Guillén Bolaños et al., 2018) and in emissions trading in the European Union (Konidari and Mavrakis, 2007).

Cognitive phase			*Resources required*	*Case studies*
Sense-making and modelling	*Analysing and exploring*	*Interpreting and implementing*		
There is growing experience in combining soft elicitation with tools to formulate problems (Marttunen et al., 2017). Many MCDA tools naturally encourage discussion and deliberation on developing appropriate value structures. However, exploration and formulation of stochastic and epistemological uncertainties is less developed (Durbach and Stewart, 2020a).	Emphasis is usually on analysing and exploring, resolving conflicting objectives. MCDA methods come into their own at this stage of the process. Sensitivity tools and intuitive graphical displays exist for many of the methods (Gunawan and Azarm, 2005; Boardman et al., 2017).	Use of graphical models and sensitivity plots can help explain reasoning for strategy to stakeholders and implementers (Bendoly and Clark, 2016).	The more exploratory methods can be quite light in terms of computational resource, but require interactions with decision makers and stakeholders in workshops. Methods with use complex stochastic mathematical programming can be computationally demanding and require substantial data.	(de Bruin et al., 2009) [27], (Guillén Bolaños et al., 2018) [28], (Haque, 2016) [29], (Konidari and Mavrakis, 2007) [30], (Streimikiene and Balezentis, 2013) [31]

Uncertainties		*Cynefin context*			
Stochastic, epistemic, analytical (descriptive modelling)	*Ambiguity value (prescriptive modelling)*	*Known*	Knowable	Complex	Chaotic
These methods tend to focus on balancing and resolving conflicting objectives and include little or no analysis of stochastic and epistemic uncertainties. Interactive methods that use complex objective functions do need to consider convergence criteria for analytic uncertainties.	Many methods here use multi-attribute value functions and focus on using weights to explore different emphases on conflicting objectives. One very popular method is analytic hierarchy processing (AHP) (Saaty, 1980) though this has issues in scaling up to evaluate more than a handful of policies.	Usually in the known context, the objective function is well understood; but in cases where it is not, interactive multi-objective programming can offer a way forward (Klamroth et al., 2018).	If the objective function is not well understood, then these methods can be useful and can be extended to stochastic programming, but epistemic uncertainties are not really addressed (Gutjahr and Pichler, 2016).	Methods can explore conflicting objectives, but seldom are able to address deep epistemic uncertainties, unless combined with scenarios (Stewart et al., 2013; Marchau et al., 2019; Durbach and Stewart, 2020a).	Formal modelling impossible. Much exploratory work to identify potential causes and effects. Little if any complex analysis.

G: Multi-criteria decision analysis (MCDA): Partial ranking (Roy, 1996; Bell et al., 2001; Belton and Stewart, 2002; Bouyssou et al., 2006; Behzadian et al., 2010; Zopounidis and Pardalos, 2010; Tzeng and Huang, 2011; Bouyssou and others, 2012; De Smet and Lidouh, 2012; Velasquez and Hester, 2013; Figueira et al., 2016; Govindan and Jepsen, 2016)

Examples include developing criteria for assessing climate protection strategies and applying these to retrofitting a school to manage climate risks in Germany (Markl-Hummel and Geldermann, 2014); evaluating outranking approaches for managing heat stress in a large city in Australia (El-Zein and Tonmoy, 2015); using MCDA to manage the interactions of climate change with tourism in Greece (Michailidou et al., 2016); and identifying priorities to manage droughts and floods in agriculture in Bangladesh (Xenarios and Polatidis, 2015).

Cognitive phase			*Resources Required*	*Case Studies*
Sense-making and modelling	*Analysing and exploring*	*Interpreting and implementing*		
Graphical representations of partial orders are useful in model formulation, and the emphasis on exploring what can be said objectively about dominance relations can build a kernel of consensus between decision makers and stakeholders.	ELECTRE and PROMETHEE implementations of outranking approaches have many tools for exploring partial relations and analysing agreements and the reasoning behind these.	The analysis of dominance can provide a sound footing for building risk registers to aid implementation. Understanding the kernel of consensus can also aid communication.	If an outranking algorithm is essentially combinatorial in its approach, then for complex problems there may be computational problems. Some of the methods may require less interaction with decision-makers and stakeholders if they can deduce many partial relations from objective data.	(El-Zein and Tonmoy, 2015) (Markl- [32], Hummel and Geldermann, 2014) [33], (Michailidou et al., 2016) [34], (Xenarios and Polatidis, 2015) [35]

Uncertainties		*Cynefin context*			
Stochastic, epistemic, analytical (descriptive modelling)	*Ambiguity value (prescriptive modelling)*	*Known*	Knowable	Complex	Chaotic

Modelling of all forms of uncertainty including epistemic uncertainty is not the primary objective of these methods. Stochastic uncertainty may be included as probability distributions, but there is no formalism for learning to address epistemic uncertainties (Hyde et al., 2003; Behzadian et al., 2010; Gervásio and Simões da Silva, 2012).	Partial ranking or outranking methods seek, first of all, to identify dominance between options and preference relations that can be agreed somewhat objectively. Thus, first they eliminate suboptimal alternatives before seeking a fuller ranking. Ambiguity and value uncertainty may also be quantified (Behzadian et al., 2010; Figueira et al., 2016; Govindan and Jepsen, 2016).	Usually in the known context, the objective function is well understood; but when it is not, outranking methods can identify a partial ranking without needing too many interactions with problem-owners.	Since epistemic uncertainties are not fully addressed, these methods can only help in relation to conflicting objectives, but robustness to uncertainties will need addressing (Hyde et al., 2003).	Outranking methods may be combined with scenarios to explore and analyse decisions under deep uncertainty (Hyde et al., 2003; Durbach, 2014).	Formal modelling impossible. Much exploratory work to identify potential causes and effects. Little if any complex analysis.

H: Soft elicitation (Rosenhead and Mingers, 2001; Shaw et al., 2006; Shaw et al., 2007; Ackermann, 2012; Bendoly and Clark, 2016)
Also known as problem structuring, it is the process of asking problem owners, experts and stakeholders for the knowledge, perceptions, beliefs, uncertainties and values that a model needs to embody before being populated with numbers. Methods here help in problem formulation, structuring understanding: for example, cognitive maps, soft operational research diagrams, soft systems, prompts such as PESTLE and other qualitative tools (Prober et al., 2017; Symstad et al., 2017). The output of soft elicitation can lead to the building of sophisticated quantitative models (Symstad et al., 2017) and can also structure communications and deliberations with stakeholders. Exploratory data analysis and visual analytics are also relevant. Soft elicitation has enormous advantages in setting the frame for communication between all parties (Prober et al., 2017); there are many cases in which the clarity brought by framing the issues well has obviated the need for formal quantitative analysis.

Examples include Adaptation Pathway planning and elicitation on managing a national park in the USA (Symstad et al., 2017), poverty alleviation in a province in Indonesia (Butler et al., 2016), woodland landscapes in Australia (Prober et al., 2017) and general considerations for contested adaptations (Bosomworth et al., 2017).

Cognitive phase			***Resources required***	***Case Studies***
Sense-making and modelling	*Analysing and exploring*	*Interpreting and implementing*		
Soft elicitation tools provide much support to sense-making, formulating problems and identifying relevant issues to be addressed (Shaw et al., 2006; Shaw et al., 2007; Ackermann, 2012).	Soft elicitation is not relevant to quantitative analysis and evaluation per se, but can support the exploration of residuals to understand the quality of the models and detect further factors to be addressed.	The results of soft elicitation provide the dimensions for communication by identifying the issues that are important to stakeholders and building understanding in those implementing the policies.	Physical resources requirements are relatively slight: sometimes post-its and a white board can be sufficient, though modern visual analytics can require substantial computing resource. However, the demands on the time of problem owners, stakeholders and experts can be significant.	(Bosomworth et al., 2017) [36], (Butler et al., 2016) [37], (Prober et al., 2017) [38], (Symstad et al., 2017) [39]

Uncertainties		***Cynefin context***			
Stochastic, epistemic, analytical (descriptive modelling)	*Ambiguity value (prescriptive modelling)*	*Known*	Knowable	Complex	Chaotic
Soft elicitation tools are available to elicit problem-owners' and experts' perceptions of these uncertainties and, more particularly, dependences and independences between them. Exploratory data analysis is also relevant (Steed et al., 2013; Bendoly and Clark, 2016).	There are tools to catalyse deliberations and help problem-owners and stakeholders clarify their meanings and contextualise their values to the specific issues being considered (Keeney, 1992).	Usually, problems falling into known contexts are well understood and there is little need to elicit or structure models to perform analyses.	Problems falling into knowable space are usually well structured and problem owners' values are also well understood. However, there may be a need to explore error structures in preparation to estimate parameters in the models (Gelman, 2003; Steed et al., 2013; Fekete and Primet, 2016).	Many soft elicitation tools were developed for complex contexts: 'wicked' problems with deep uncertainties: e.g., soft systems, cognitive maps and similar tools to elicit perceptions of relationships between entities and problem owners' and stakeholder's values (Keeney, 1992; Rosenhead and Mingers, 2001).	Soft elicitation tools and processes can be used to catalyse creative thinking about poorly understood contexts.

Decision-analytic tools used across different geo-political scales and how they contributed to decision outcomes

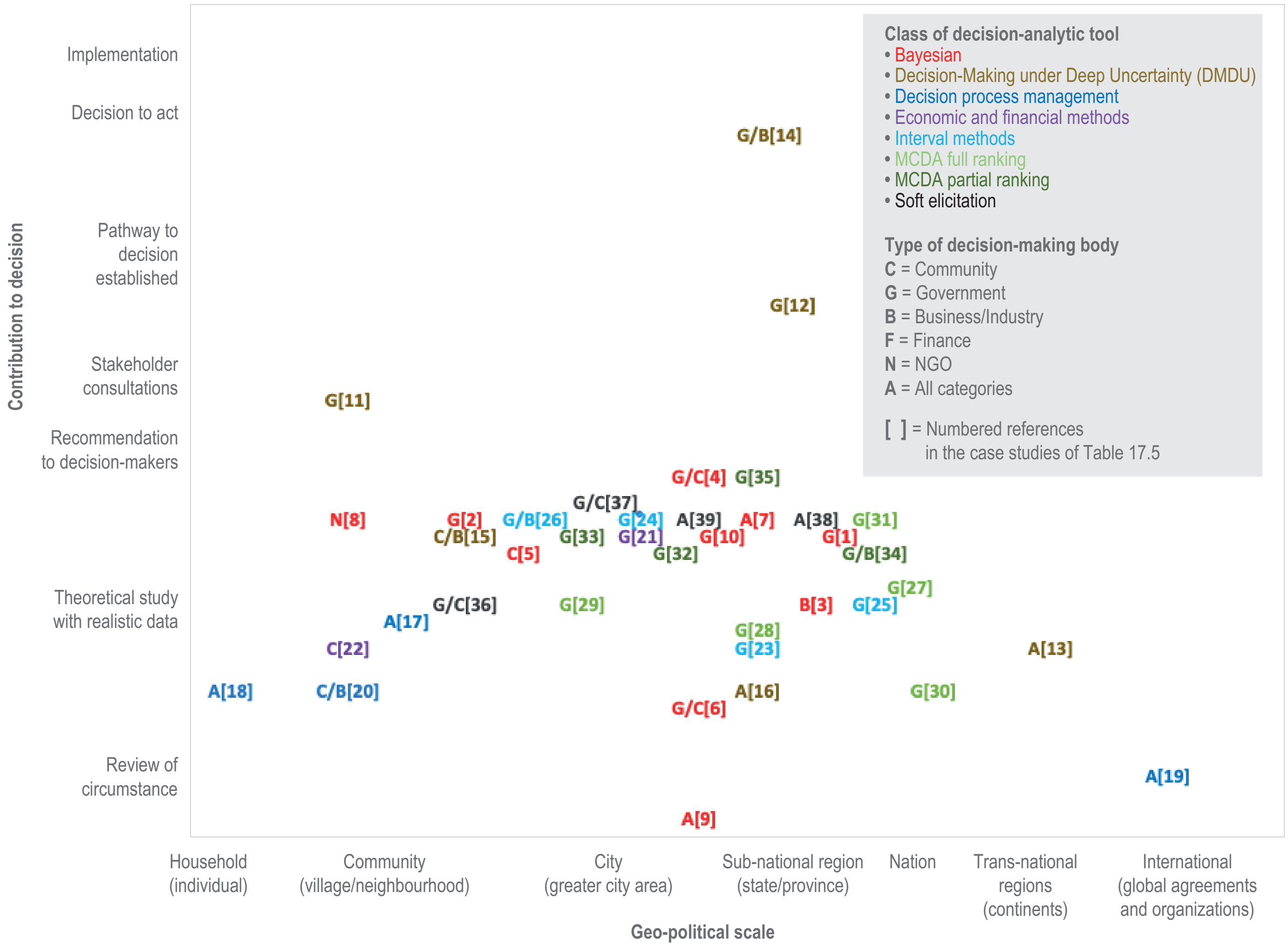

Figure 17.8 | Decision-analytic tools used across different geo-political scales and how they contributed to decision outcomes. Points comprise the type of decision-making body (C = Community; G = Government; B = Business/Industry; F = Finance; N = NGO; A = All categories) coupled with the reference number in square brackets, which correspond to numbered references in the case studies of Table 17.4. Colours of the points correspond to the class of decision-analytic tool: Bayesian (red), DMDU (decision-making under deep uncertainty) (brown), decision process management (dark blue), economic and financial methods (purple), interval methods (light blue), MCDA—full ranking (light green) or partial ranking (dark green), soft elicitation (Black).

17.3.1.3.1 Role of informal processes

Informal decision-making pervades decision-making in all contexts (*high confidence*) (Orlove et al., 2020); decisions relating to climate change are affected not only by rational processes but also by many informal, often behavioural responses to the situation, some of which may not require formal processes. Informal processes were officially studied in only a few of the publications contributing to Figure 17.8, but all of the studies have hints to informal decision-making that pervades all levels of governance. Although there are not many concrete studies, citing roles of study participants can lead to a perception of a disconnect between the process and the outcome that resulted (see Section 17.5.1 for enablers of success).

Generally, while governance requirements may define the processes of formal deliberations and decision-making, informal deliberations will carry on in parallel, supported by social media, and these informal deliberations may be used to affect the outcome of the formal processes. Stakeholders may feel excluded from the formal deliberations either by governance structures or because they do not agree with their representatives. Conflicting value systems may cause some stakeholders to feel side-lined, particularly if some of the key decision makers are perceived holding different personal views and interests or to have engaged in political horse-trading, which connect independent decisions. There may be emotional responses, driven by poor comprehension of risk and probabilistic information, and potential for group biases or insularity of participants (Engler et al., 2019). Well-designed decision processes recognise the informal and seek to gain information from it without introducing bias (*medium confidence*) (French and Argyris, 2018).

17.3.1.3.2 Stakeholder engagement

Stakeholder engagement has become increasingly part of climate-relevant decision processes (Orlove et al., 2020). The degree of stakeholder engagement ranges from instructive and consultative to cooperative, which are equivalent to information exchange, influence and partners in decision-making (Sen, 2000; Cattino and Reckien, in press). Since the AR5, climate change adaptation and resilience literature has seen an increase in participatory approaches that deepen engagement and overcome challenges, as well as making some assessments of their effectiveness (Newton Mann et al., 2017; Wamsler, 2017; Esteve et al., 2018), including structured interactions among different types of stakeholders and the use of place-based boundary organisations to strengthen the interactions and heighten the awareness of the institutional context. A higher degree of public participation can lead to more transformational adaptation as well as to higher ambition for local mitigation (*medium confidence*) (Section 17.4.4.2; Cattino and Reckien, in press). Challenges to stakeholder participation are access to state-of-the-art science, capacity to recognise and respond to non-reliable or false climate science information, and the removal of cognitive and other biases (*high confidence*) (Gorddard et al., 2016; Engler et al., 2019; Fulton, 2021).

Participatory and elicitation approaches, where the concerns and involvement of a broader range of interest groups and stakeholders are taken into account, can improve the effectiveness of decision-making (*medium confidence*) (Gregory et al., 2012; Cvitanovic et al., 2019). Participatory planning includes a variety of co-generative strategies and approaches (e.g., qualitative scenario or adaptation pathway development) through which goals and objectives, knowledge and strategy implementation and evaluation can be decided collaboratively between practitioners, policymaking, local interests and groups, and scientists (Butler et al., 2016; Prober et al., 2017; Symstad et al., 2017). Specifically, for climate change adaptation, these decision-making strategies can incorporate expert, Indigenous and local knowledge (*high confidence*) (Cross-Chapter Box INDIG; Gustafson et al., 2016). The challenge will be to bring together these different actors, as stakeholders tend to act within rather than among systems and procedures, and it is important that platforms are developed to integrate data effectively (Rizzo et al., 2020). Furthermore, reflexive and iterative risk management may further ensure acceptance by participating groups.

Bayesian methods are increasingly used in advancing approaches for decision-making and support in climate adaptation (Sperotto et al., 2017), by being able to include stakeholder and decision-maker perceptions and biases (Dias et al., 2018; Engler et al., 2019; Phan et al., 2019; Fulton, 2021) in a transparent modelling environment, thereby facilitating consensus and impartiality (*medium confidence*) (Catenacci and Giupponi, 2013; Gelman and Hennig, 2017). Increasing computational efficiency means that these methods can enable different approaches to be addressed and different descriptive and prescriptive models to be included within a single probabilistic environment, which also can be updated in iterative processes (*high confidence*) (Table 17.4; Sperotto et al., 2017; Phan et al., 2019).

17.3.1.3.3 Scenario analyses

Scenarios are described in SR1.5 (IPCC, 2018a) and SRCCL (IPCC, 2019b) as a description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Scenarios are neither predictions nor forecasts but are used to provide narratives and trajectories equipped with alternate outcomes. SR1.5 and the SRCCL describe a range of scenarios methods and how scenarios are used to guide risk management decision-making. Scenario analysis includes a range of potential future conditions from low-end and mid-range to high-end projections. Scenarios can also include a temporal component, that is, short term, medium term and long term, as defined in the SROCC (IPCC, 2019c).

Scenarios and pathways, combined with elicitation methods, are becoming widely used to assess adaptation and resilience strategies (*high confidence*) (Butler et al., 2016; Prober et al., 2017; Symstad et al., 2017; Lawrence et al., 2019; Phan et al., 2019; Sperotto et al., 2019; Haasnoot et al., 2020a). They can support the consideration of a wide range of alternative possible futures (Catenacci and Giupponi, 2013; Jäger et al., 2018), enabling identification of potential path dependencies caused by adaptation options (*high confidence*) (Pretorius, 2017; Haasnoot et al., 2020a). They can also increase the willingness of stakeholders to consider costly actions, by placing them within broader sequences of action (*limited evidence*) (Barnett et al., 2014). The development, consideration and understanding of scenarios can be enhanced by using visualisation tools to better display storylines, enabling the discussion of alternative futures by participants in decision-making processes (*limited evidence*) (Winters et al., 2016).

17.3.1.3.4 Evaluating trade-offs, robust decision-making and deep uncertainty

Trade-offs are pervasive in decision-making for climate change adaptation, including between adaptation and mitigation, economic/social and environmental cost including distributional/equity considerations, affordability and risk reduction, short- and long-term consequences, and spatial variations (Borgomeo et al., 2016; Hudson et al., 2016; Gil et al., 2018; Landauer et al., 2019).

Trade-offs are often directly compared in cost–benefit analyses which require rigorous estimation of the monetised costs and benefits, where monetisation is feasible and values uncontested (such as for infrastructure) (*high confidence*) (de Ruig et al., 2019; Table 17.4). Other tools can be employed, such as cost-effectiveness analysis and multi-criteria analysis in order to draw stakeholders into the process (Posner, 2004; Matheny, 2007; Mechler and Schinko, 2016). Stakeholder participation in measuring costs and benefits and in the modelling can aid the process (Doukas and Nikas, 2020).

Logic trees include a range of decision protocols and multi-criteria rules, either based on quantitative or qualitative categories (Roncoli et al., 2016), often termed multi-criteria analyses. The concept of the logic tree has been increasingly applied in climate risk decision-making contexts (Nikas et al., 2018).

Since the AR5, robust decision-making methods are increasingly used to account for deep uncertainty in many climate-related risks (*high confidence*) (Marchau et al., 2019; Table 17.4), particularly when decisions need to be made well in advance of when the adaptations need to be implemented (Cross-Chapter Box.5 in SROCC Chapter 1; Cross-Chapter Box DEEP in this Chapter). Reducing risk and building resilience under the context of these types of wicked problems require asking 'what if' questions about the future, remaining flexible in the face of uncertainty and seeking out policies that provide good outcomes no matter what the future climate might bring (*high confidence*) (Section 17.6; e.g., Larson et al., 2015; Bhave et al., 2016; Bhave et al., 2018). In these cases, trade-offs can be assessed and options can be prioritised through iterative decision-making processes, such as multi-criteria decision-making, robust decision-making and dynamic adaptation pathway planning (*high confidence*) (Table 17.4; Kwakkel et al., 2014; Kwakkel et al., 2016; Shortridge et al., 2016; Lawrence and Haasnoot, 2017; Haasnoot et al., 2019; Lempert, 2019; Roelich and Giesekam, 2019; Haasnoot et al., 2020a). They can address limitations of data-intensive robust decision-making in developing countries (Daron, 2015), use proxy data to enable the use of robust decisions in data-scarce contexts (Shortridge and Guikema, 2016; Ahmad et al., 2019), incorporate multiple-objectives into robust decision-making (Singh et al., 2015), and supplement pathway development with real options analysis (Buurman and Babovic, 2016; Smet, 2017; Haasnoot et al., 2019; Lawrence et al., 2019). Often, there are close synergies between the application of these methods and using scenario analyses (Workman et al., 2021).

17.3.1.3.5 Adaptive feedback management

Iterative decision-making requires that the implementation of adaptations be reviewed to determine whether the adaptation effectively achieved the objectives, and whether adjustments or additional actions were required (Section 17.5). Adaptive feedback management is an approach to managing dynamic climate risks by designing a field monitoring programme to provide data to an assessment procedure which in turn advises on what adjustments need to be made to a 'control action', all of which are part of the adaptation to be implemented (Hurlbert et al., 2019; Figure 17.7). Adaptive feedback management is more able to account for the dynamic nature of risk and the future emergence of unforeseen risks because of the active design of how to adjust the management approach (Dickey-Collas, 2014).

Adaptive feedback management is important for managing climate risks that fall within the *Cynefin* context of chaos, relying on observations and indicators to learn about the system and to trigger actions (*medium confidence*) (Helmrich and Chester, 2020). It has been a valued approach for managing wildfish fisheries in many oceans (*high confidence*) (Fulton et al., 2019; Hollowed et al., 2020; Bahri et al., 2021) and is important for responding to the challenges of climate change (*high confidence*) (Holsman et al., 2019; Hollowed et al., 2020; Bahri et al., 2021).

While the benefits of investment in data and assessments can outweigh the costs of implementation (*low confidence*) (Fulton et al., 2019), the implementation may take time when resources are limited, particularly in developing nations, where low-cost approaches will be needed for deciding on pathways for adaptation (Bhave et al., 2016; Shortridge et al., 2016).

Iterative decision-making and adaptive feedback management meet when the feedback management procedure is reviewed in total for its effectiveness in one of the review and adjustment iterations. At present, a common approach for assessing different adaptation options and their interaction is using, for example, scenarios in dynamic models (Adam et al., 2014; Girard et al., 2015). An emerging field in adapting fisheries to climate change is to embed the decision-making system in the scenario models in order to assess the capability of feedback management (decision-making, monitoring and capacity for adjustment of the options over time) to achieve satisfactory trade-offs among the objectives of the different stakeholders (*medium confidence*) (Melbourne-Thomas et al., 2017; Holsman et al., 2019; Hollowed et al., 2020). This method can enable prospective evaluation of future whole-of-management scenarios described in this chapter.

17.3.2 Integration across Portfolios of Adaptation Responses

In recent years, methods for simultaneously considering multiple societal and sectoral objectives, climate risks and adaptation options have been emerging, often termed 'integrated' approaches (Hadka et al., 2015; Garner et al., 2016; Rosenzweig et al., 2017; Giupponi and Gain, 2017a; Stelzenmuller et al., 2018; Marchau et al., 2019). Different decision-making approaches can be complementary (Kwakkel et al., 2016), and multiple approaches will be needed to manage risks across sectors, in space and over short to long time scales (Section 17.6).

Higher-level integration was first presented in the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (Burton et al., 2012; Lal et al., 2012; O'Brien et al., 2012) and includes concepts of planning, coordination and mainstreaming (Lal et al., 2012), consideration of cross-scale dynamics and nested vulnerabilities (Klein et al., 2014), and decision-making across governments and sectors (Denton et al., 2014; Mimura et al., 2014).

Since AR5, recognition of the importance of using integrated adaptation to improve climate risk management across the nexus between many sectors and across regions has increased (*high confidence*) (Harrison et al., 2016; Challinor et al., 2018). This was highlighted in the Special Report on Climate Change and Land (Hurlbert et al., 2019); advanced planning and integration of adaptation responses are needed over many levels (*medium confidence*) (Göpfert et al., 2019; Section 17.6; Woodruff and Regan, 2019). The complexity of managing this nexus may be compounded by the potential for antagonistic or synergistic effects among and between climate impacts, and changes arising from local sectoral activities and independent adaptation responses to those risks (*high confidence*) (Crain et al., 2008; Piggott et al., 2015; Adger et al., 2018; Brown et al., 2018; Stelzenmuller et al., 2018; Simpson et al., 2021), such as the cross-sectoral demands for freshwater (Xue et al., 2015; Azhoni et al., 2018). Integrated adaptation will also help facilitate management of new and emerging risks, help identify when response plans may need to be changed in light of the dynamics of risk over time, and help identify solutions that are less likely to constrain future options for adapting to future needs (Wise et al., 2016).

Cross Chapter Box DEEP | Effective adaptation and decision-making under deep uncertainties

Authors: Carolina Adler (Switzerland/Chile/Australia), Robert Lempert (USA), Andrew Constable (Australia), Marjolijn Haasnoot (the Netherlands), Judy Lawrence (New Zealand), Katharine J. Mach (USA), Simon French (UK), Robert Kopp (USA), Camille Parmesan (USA), Mauricio Dominguez Aguilar (Mexico), Elisabeth A. Gilmore (USA), Rachel Bezner Kerr (Canada), Adugna Gemeda (Ethiopia), Cristina Tirado-von der Pahlen (USA/Spain), Debora Ley (Mexico), Rupa Mukerji (India).

Decision-relevant uncertainties for managing climate risk

Adaptation decision-making can benefit from assessments that support planning for both 'what is most likely' as well as for stress-testing adaptation options over a range of scenarios (Sections 11.7 and 17.3; Cross-Chapter Box.5 in SROCC Chapter 1). This Cross-Chapter Box summarises how deep uncertainties (Section 1.2; IPCC, 2019a) can be assessed in decision-making and addressed practically for adaptation.

The concept of deep uncertainty has evolved in IPCC assessments, expanding beyond a focus on reducing uncertainty, to also considering a range of tools and approaches that guide robust and timely decisions to address climate risks. Deep uncertainty is defined as circumstances where experts or stakeholders do not know or cannot agree on one or more of the following: (1) appropriate conceptual models that describe relationships among drivers in a system; (2) the probability distributions used to represent uncertainty about variables and parameters; and/or (3) how to weigh and value desirable alternative outcomes (Cross-Chapter Box 5 in Chapter 1; Lempert et al., 2003; IPCC, 2019a; IPCC, 2019c).

Decisions by individuals, households, the private sector, governments and public–private partnerships are generally made with partial or uncertain information. This is also the case for adaptation and development decisions where there is often deep uncertainty about the impacts and the societal conditions, preferences and priorities, and responses over time. Under such conditions, decision makers employ decision processes and scientific information differently from situations where most decision-relevant information is available, uncontested and confidently characterised with single joint probability distribution. Assuming scientific information is certain, when it is not, is a barrier to effective communication of risks and to successful decisions under uncertainty, increasing the potential for failure and regret of investments, lost opportunities and transfers of costs to future generations (Sarewitz and Byerly, 2000; Marchau et al., 2019; Sections 11.7 and 17.6).

Addressing deep uncertainty is contextual as it depends on the decision options available, outcomes at stake and the available scientific information (Box 1.1. in Marchau et al., 2019). The IPCC uncertainty guidance note (Mastrandrea et al., 2010) addresses only the latter (see also Mastrandrea and Mach, 2011; Section 1.3.4). Deep uncertainty is generally more salient when policy-relevant statements have *low confidence* or lack relevant data or information, or in cases where significant uncertainty contributes to disagreements and disputes (Sriver et al., 2018). Recent work has also included moral uncertainty (MacAskill et al., 2020) by evaluating the outcomes of alternative strategies with analyses organised around different perspectives on the appropriate principles of justice (Ciullo et al., 2020; Section 17.3; Jafino et al., 2021; Lempert and Turner, 2021).

To better communicate deep uncertainty, WGI AR6 complements projections of likely global mean sea level change, driven by processes in which there is at least *medium confidence*, with projections that incorporate ice-sheet processes in which there is *low confidence* (Section 9.6.3 in Fox-Kemper et al., 2021). The latter are accompanied by storylines to highlight the physical processes that would generate extreme outcomes (Box 9.4 in Fox-Kemper et al., 2021). These *low confidence* projections and storylines are useful because the likelihood of high-end (>1.5 m) global mean sea level (GMSL) rise in the 21st century is difficult to determine but important to consider in coastal settings (e.g., Cross-Chapter Paper 2; Cross-Chapter Box SLR in Chapter 3). High-end GMSL rise by 2100 could be caused by earlier-than-projected disintegration of marine ice shelves, the abrupt, widespread onset of marine ice sheet instability and marine ice cliff instability around Antarctica, or faster-than-projected changes in the surface mass balance and dynamical ice loss from Greenland (Box TS.4 in Arias et al., 2021; Box 9.4 in Fox-Kemper et al., 2021). In a low-likelihood, high-impact storyline and a high CO_2 emissions scenario, such processes could in combination contribute more than one additional metre of sea level rise by 2100 (Box TS.4 in Arias et al., 2021; Section 9.6.3 and Box 9.4 in Fox-Kemper et al., 2021). Other hazards assessed in WGI AR6 that address similar aspects relevant for decision-making under deep uncertainty include drought (Section 8.4.1.6 in Douville et al., 2021; Section 11.6.5 in Seneviratne et al., 2021), flood (Section 8.4.1.5 in Douville et al., 2021; Section 11.5.5 in Seneviratne et al., 2021) and wildfire weather (days) (Section 11.8.3 and Box 11.2 in Seneviratne et al., 2021), among others.

Approaches and information requirements for managing deep uncertainty

Many approaches are available for evaluating robust decisions under conditions of deep uncertainty (Sections 17.3 and 11.7; Box 11.5 in Chapter 11). The majority use multiple scenarios to stress-test adaptation options and explore how alternative adaptation pathways might evolve under a range of different conditions (Swanson and Bhadwal, 2009). Approaches differ in terms of their focus, types of strategies best addressed, and data and other resources required (Marchau et al., 2019).

Cross Chapter Box DEEP (continued)

'Low regret' options are one relatively simple and common approach to deep uncertainty (Sections 17.3 and 17.6) expected to perform well over a wide range of scenarios and represent one example of robust strategies. However, such options will generally be insufficient for adaptive responses to adapt over long time frames and to avoid lock-in of investments (Section 11.7; Box 11.5 in Chapter 11).

'Adaptation pathways' provide another approach for addressing deep uncertainty and staging decisions over time (Haasnoot et al., 2013), by linking the choice of near-term adaptation actions with pre-determined future thresholds. Observation of such thresholds trigger subsequent actions in the planning or implementation stages of adaptation strategies. Adaptation pathways can begin with low-regret, near-term actions that aim to create and preserve future options to adjust if and when necessary. Alternative pathways can be explored and evaluated to design an adaptive plan with short-term actions and long-term options.

Climate resilient development (CRD), and the pathways (CRDPs) to it, can also involve decision-making under deep uncertainty. Literature assessed in sectoral and regional chapters of this report present several examples of potential risks to achieving development goals under climate change, at global as well as national and local levels (*high confidence*) (Chapter 18). Achieving CRD depends on negotiation, contestation and reconciliation of trade-offs among diverse actors, who in turn value preferred outcomes differently with respect to associated climate risks and uncertainties, hence the prospect for deep uncertainty to manifest (Section 18.5). Deep uncertainty also characterises the development process itself, given that fundamental changes and disruptions are part of the transformational changes required to shift towards CRDPs.

The 'keeping options open' approach, i.e. plans that use a series of sequential decisions and actions in the near term to avoid closing off potentially promising future options (Rosenhead, 2001; Section 2.6) or, by using real options, takes near-term actions that create currently unavailable options in the future (Kwakkel, 2020). Deep uncertainty approaches use a wide range of storylines as scenarios to test low-regret options and to provide information relevant for potential thresholds for use in adaptation pathways (Haasnoot et al., 2013; Boxes 11.4, 11.6; Sections 11.7, 17.3).

Deep uncertainty approaches enhance the value of monitoring to detect signals of change in a timely manner (*medium confidence*). Actionable warning can come from climate signals, and socioeconomic indicators/signposts, including drivers of change, vulnerability and impacts, best suited for timely, reliable and convincing signals for decision-making that anticipate future changes and the need for adaptation or the potential to seize opportunities (Hermans et al., 2017; Haasnoot et al., 2018; Stephens et al., 2018; Oppenheimer et al., 2019). For early warning signals to be decision relevant, they need to have institutional connectivity to enable action (Haasnoot et al., 2018; Sections 1.4, 11.4, 11.7; Table 11.18) (*medium confidence*).

Examples and case studies from across the WGII report

There are diverse examples of the practical application of deep uncertainty methods across different climate change hazards in many regions of the world. For instance, low-regret options have been used to address the impacts and risks of landslides and debris flows in mountains (Section CCP5.2.6). Their frequency and magnitude are already widely experienced (Section CCP5.2.6) and projected to increase (Section CCP5.3.2.1). However, managing these associated risks also requires joint consideration of projected vulnerabilities and exposure of people and infrastructure, including the multiple and dynamic non-climate-related factors that are relevant for how the impacts manifest in context, such as population growth and land use planning (CCP5.2.6). Here, context-specific deliberative processes are used that include scenarios to guide and specify preventive measures with higher effectiveness than protective (infrastructure) measures could achieve alone. Low-regret adaptation involves raising awareness and accounting for long planning horizons to address the uncertainties associated with such risks, for instance in mountain regions, including education (Sections CCP5.4.1; CCP5.2.6), with co-benefits such as addressing changes in water availability for supply and demand (CCP5.4.1).

Adaptation pathways have been used to address SLR and changes in extreme rainfall through flood risk and management (Cross-Chapter Box SLR in Chapter 3; CCP2; Sections 13.2, 11.3 and 11.7): for example, adaptive plans in the Netherlands (Van Alphen, 2016; Bloemen et al., 2019), climate resilient development in Bangladesh (Hossain et al., 2018; Zevenbergen et al., 2018), adaptive spatial pathways for infrastructure retreat and for flood risk management in New Zealand (Lawrence et al., 2019a; Kool et al., 2020) and adaptive strategies such as in the cities of London (Ranger et al., 2013; Hall et al., 2019), New York (Rosenzweig and Solecki, 2014) and Los Angeles (Aerts et al., 2018a). This approach is mainstreamed into guidance documents such as the Climate Risk Informed Decision Analysis (CRIDA) (Mendoza et al., 2018), national guidance and policy briefs to address coastal hazards and sea level rise planning in New Zealand (Lawrence et al., 2018; Lawrence et al., 2019b), planning for sea level rise in California (OCP, 2018) and synthesis documents by the government of Canada on marine coasts (Lemmen et al., 2016). Furthermore, examples from the UK, New Zealand and the Netherlands point to the development of monitoring plans to detect signals for climate adaptation (Stephens et al., 2017; Haasnoot et al., 2018; Bloemen et al., 2019).

Cross Chapter Box DEEP (continued)

Climate-smart planning, with a focus on keeping options open, can play a role in reducing species extinction rates (Sections 2.5, 2.6). When and where and for whom particular irreversible impacts will occur is deeply uncertain, for example the extinction of a species. Even at the lowest emissions scenarios, some local species will become extinct, but estimates of extinction risk are highly uncertain, typically varying by factors of two to three even for one species (Section 2.5) (*medium confidence*). Risks of species' extinctions are lowered by reducing emissions, but keeping options open for as long as possible and avoiding irreversible actions are key to developing a climate-resilient adaptive pathway so that real-time climate-driven changes can inform actions. Nature-based solutions (NBS) are emerging as key players for mitigation. With smart planning, NBS offer approaches that not only provide substantial mitigation, but also considerable adaptation benefit to biodiversity, and human health and well-being. Done poorly, such projects can result in large negative impacts on humans and nature. An NBS climate-sensitive decision framework leading to 'win-win' solutions for mitigation and adaptation is shown in Figure 1 Cross-Chapter Box NATURAL in Chapter 2 (see also Sections 2.4.2.5, 2.5, 2.6, 5.4.4.4 and 5.14.1; Cross-Chapter Box ILLNES in Chapter 2; Cross-Chapter Box COVID in Chapter 7).

In view of these multiple and diverse examples, it is evident that the application of deep uncertainty methods is enabling decisions to be made in a timely manner that avoid foreseeable and undesirable outcomes and take opportunities as they arise (*high confidence*).

Prospects for adaptation decision-making

Deep uncertainty is increasingly salient for decision-making as recognition of climate-related risks and related uncertainties has increased (*high confidence*). These risks can compound and cascade to become new risks, increasing the breadth, frequency and severity of climate change impacts and the consequently increasing scale and scope of adaptation (*high confidence*) (Cross-Chapter Box Extremes in Chapter 2; Sections 1.3.1.2, 2.3, 2.5, 2.6, 11.5, 11.7, and CCP5.3.1). Waiting until uncertainties are resolved (if they ever can) may leave little or no time to adapt. The lead time for planning and implementation of adaptation can take decades (Haasnoot et al., 2020b; Cross-Chapter Box SLR in Chapter 3), and socioeconomic developments can lock in undesirable pathways where underlying vulnerabilities and exposure, such as poverty, conflict and their associated displacement of people, remain unaddressed (Sections 5.13.4, 16.5.2.3.8; Cross-Chapter Box Migrate in Chapter 7).

Overall, there is growing evidence that effective implementation of strategies developed for deeply uncertain problems require adequate mandates and funding frameworks, preparedness and disaster response plans, and monitoring and evaluation of the strategy outcomes, against how the future unfolds (*medium confidence*). Collaborative and adaptive governance arrangements, and education and awareness raising, promote learning environments for community engagement, and are essential for the effective implementation of robust adaptation plans (*medium confidence*) (Sections 5.14.1, 17.3 and 11.7).

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Implicit to managing cross-sectoral interactions, including the nexus concept, is that the interlinkages between multiple sectors are systemic, and therefore solutions to challenges arising from any one sector can only be satisfactorily addressed by considering the connections to other sectors at the same time (Wichelns, 2017). Challenges for integrated adaptation include: (1) to sufficiently capture the complexities between the nexus dimensions (Weitz et al., 2017); (2) to adequately consider the time, costs and challenges of coordination and cooperation (Wichelns, 2017); (3) to consider the political economy in which progress towards more integrated solutions could take place, not only accounting for technological requirements (Leck and Roberts, 2015); (4) to obtain sufficient temporal or spatial data to capture the interactions between natural and social processes (Shannak et al., 2018); (5) to connect these considerations to decision-making and policy processes in order to gain insights into the conditions for collaboration and coordination across sectors, including external dynamics and political and cognitive factors determining change (Weitz et al., 2017); and (6) to develop a coherent framework against which to assess results and observations (Crain et al., 2008; Wichelns, 2017).

17.4 Enabling and Catalysing Conditions for Adaptation and Risk Management

17.4.1 Introduction

The WGII AR5 identified—with *high confidence*—a range of factors that could enable or limit planning and implementation of adaptation options and potentially their effectiveness (Klein et al., 2014; Mimura et al., 2014; Noble et al., 2014). These included governance, finance, knowledge and capacity as enabling factors, as well as cultural, social, political and economic differences that influence individual and collective willingness and capability to act. The AR6 Special Reports (specifically, de Coninck et al., 2018; Roy et al., 2018; Collins et al., 2019; Hurlbert et al., 2019) reinforced the AR5 findings, further noting that the transitions needed for climate resilient development would need to be supported by radical shifts in governance, knowledge development, technology application, finance and economics, and social norms.

This section builds on the AR5 and AR6 Special Reports by reviewing new evidence on three key enablers identified in the AR5: governance, finance and knowledge. The focus is on assessing new evidence on (i)

https://doi.org/10.1017/9781009325844.026

understanding of these enabling conditions, (ii) how they have changed on the ground and (iii) whether these conditions have enabled progress on adaptation and risk management. The section also addresses an emerging related topic: the role of catalysing conditions and actors in accelerating action on climate change adaptation, such as litigation on failure to adapt, understandings of urgency, and the aftermath of extreme weather events. While enabling conditions are necessary for action, they are not by their presence enough; catalysing conditions emerge when game-changing circumstances become present, such as when a high-profile extreme weather event occurs or when a champion drives change in an organisation.

17.4.2 Enabling Condition 1: Governance

Governance is an inclusive concept of the range of means for deciding, managing, implementing and monitoring climate change responses. It can involve contributions of various levels of government (global, international, regional, sub-national and local) along with those from the private sector, of non-governmental organisations and of civil society. The importance of supportive governance arrangements is re-iterated widely across regional and sectoral chapters in this report, in multiple different contexts (*very high confidence*).

17.4.2.1 Legal, Policy and Regulatory Instruments

17.4.2.1.1 Climate legislation

Legal systems play an important governance role in facilitating responses to climate change across all levels of society (*high confidence*) (Ruhl, 2010; McDonald and Styles, 2014; Mehling, 2015). Laws can facilitate climate action in multiple ways, including through: (i) mandating and guiding the behaviour of governance structures and actors, (ii) fostering coordination between different levels of government, (iii) enforcing climate responses, (iv) its symbolic value and (iv) aligning scientific evidence and societal norms (Mehling, 2015; Scotford et al., 2017). Laws also can embed climate change planning within the administrative structure of a state, rendering policy less vulnerable to revocation (Scotford et al., 2017). Extensive revision to laws has occurred in the last decade: a survey of 164 countries showed that over 1200 climate-related national laws and policies have been published, with approximately 44% being acts of parliament (Nachmany et al., 2017).

National climate change laws are important for transposing ratified international commitments into domestic regimes, such as the Paris Agreement and the Convention on Biodiversity, as well as voluntary agreements such as the Sendai Framework for Disaster Risk Reduction. In turn, the enactment of domestic laws can yield useful experiences and foster engagements that positively influence and support the development of international commitments (Townshend and Matthews, 2013; Mehling, 2015). Strong and consistent regulatory frameworks also support the flow of climate finance to developing countries that have such frameworks (Nachmany et al., 2017). The successful implementation of national and sub-national climate change and related policies and strategies are often contingent upon the underlying legislative framework empowering, mandating or guiding their review, implementation and enforcement (Averchenkova and Matikainen, 2017; Scotford et al., 2017) (*medium confidence*).

Existing legal systems also pose potential barriers to adaptation, as described in Chapter 9 (Africa) and Chapter 8 (Poverty, Livelihoods and Sustainable Development). Laws may reinforce governance arrangements and regulations that do not support responses to climate change, and exacerbate existing vulnerabilities and inequalities (Craig, 2010; Arnold and Gunderson, 2013; Wenta et al., 2019). In such cases, laws may require review and revision or replacement, and at the same be written in ways that foster adaptive management (Craig, 2010; Ruhl, 2010; Cosens et al., 2017).

Even though there is no agreed definition of or typology for climate change laws (Mehling, 2015), studies have tended to classify climate change laws as being 'framework' or 'sectoral' (see Table 17.5 for examples). Framework laws offer a comprehensive, unifying basis for climate change policy, addressing multiple aspects or areas of climate change mitigation or adaptation (or both) in a holistic and overarching manner (Townshend et al., 2011; Fankhauser et al., 2014; Nachmany et al., 2015; Clare et al., 2017b); they are powerful levers for setting national and sub-national agendas, creating climate change institutional structures, enabling policy implementation and driving the passage of additional sectoral legislation and regulations (Clare et al., 2017b). Prior to 2010, national framework laws tended to have a mitigation focus, while more recent laws or amendments thereto have an increased adaptation focus (Rumble, 2019b). No evidence indicates whether general or specific framework laws yield better outcomes; however, reviews of more recent examples of framework laws in Africa suggest a trend towards more specificity in the required content of adaptation strategies and duties (Rumble, 2019b).

A sectoral approach to climate change legislation grafts climate-related provisions into existing laws, such as environmental impact assessment, flood insurance and infrastructure planning, collectively creating an aggregated legal landscape (Townshend et al., 2011; Gerrard and Fischer, 2012; Nachmany et al., 2015; Scotford et al., 2017; Rumble, 2019a). This approach is particularly relevant to adaptation challenges which intersect with numerous bodies of law that are dedicated to other societal concerns (Gerrard and Fischer, 2012). However, integrating such considerations can be challenging in certain areas of law, particularly those relating to property rights, water rights and endangered species protection (Gerrard and Fischer, 2012). The incorporation of adaptive management principles (including monitoring, periodic evaluation, and response modification) within existing laws can enhance their enabling role and foster greater resilience (Godden, 2012; Arnold and Gunderson, 2013; McDonald and Styles, 2014).

The legal regime for adaptation is too embryonic for assessment of good practice design and content, although similarities can be seen in the framework laws and draft bills across several countries. Some studies highlight the importance of domestic 'whole of legal system' analysis prior to development of modifying law. This can identify the range of existing legislative instruments that can directly intersect with climate change, along with related contextual factors such as national circumstances, governance frameworks, and political and economic realities as well as national administrative culture (Scotford

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et al., 2017). This helps any new climate change laws to be absorbed into, and harmonise with, the established legal system of each country (Scotford et al., 2017). Efforts are underway to assist countries in such assessments and the identification of areas for legislative reform, for example through the Commonwealth and UN Environment's Law and Climate Change Toolkit. Similarly, databases such as the Grantham Research Institute on Climate Change and the Environment and the Sabin Center on Climate Change Law are expanding the knowledge base of national climate legislation developments.

17.4.2.1.2 Climate change policies, strategies and plans

Climate change policies and plans are important in the translation of national commitments and legal requirements into specific on the ground strategies and guidelines, which enable actions across multiple spheres and scales of government and non-government institutions and actors.

Substantial developments in adaptation policy have occurred since AR5 (*high confidence*). Perhaps the most significant is the NDCs required under the Paris Agreement, where 184 out of 197 parties to the UNFCCC have already submitted their first plans (UNDP and UNFCCC, 2019). The NDCs have allowed countries to articulate their priorities and ambition with respect to climate action, and it has been suggested that these can in turn lead to cascading policies (and laws) that drive and enable adaptation and climate risk management. Analysis of the first NDCs submitted in the lead-up to and after the Paris Agreement showed that adaptation priorities were more often articulated by developing countries and least developed countries, while developed countries and emerging economies focused mostly on mitigation (Pauw et al., 2019). As of 2019, over 90 developing nations are at various stages of preparing National Adaptation Plans and 112 nations have indicated their intention to revise their NDCs for the 2020 update (UNDP and UNFCCC, 2019).

Several other international agreements, including the Sendai Framework for Disaster Risk Reduction and the UN Agenda 2030 Sustainable Development Goals, have had significant impacts on the adaptation and risk-management decision-making processes. For example, the Sendai Framework articulates the need for improved understanding of disaster risk in all its dimensions of exposure, vulnerability and hazard characteristics; accountability for disaster risk management; preparedness to 'Build Back Better'; recognition of stakeholders and their roles; mobilisation of risk-sensitive investment to avoid the creation of new risk resilience of health infrastructure, cultural heritage and workplaces; strengthening of international cooperation and partnership; and risk-informed donor policies and programmes, including financial support and loans from international financial institutions.

Specific adaptation policies have been formulated at national, regional/state and local levels across 68 countries and 136 coastal cities (Olazabal et al., 2019a). At the national level, the quantity and complexity of adaptation policies have increased since AR5, with most policies coming into force since 2009 (Nachmany and Setzer, 2018). Adaptation is addressed in the executive climate policies of at least 170 countries (Nachmany et al., 2019a). Documented sub-national adaptation policies are more prevalent in developed countries and emerging economies, as compared with low- and middle-income ones (Olazabal et al., 2019b). For example, by 2017, 26% of large and medium-sized European cities had an adaptation plan or a joint adaptation–mitigation plan in place (Reckien et al., 2018a).

Adaptation policies often comprise multiple goals and instruments, which develop over time, especially where jurisdiction over policy issues is shared among agencies or levels of government (Río and Howlett, 2013). The increase in the number and complexity of policy instruments across geared towards adaptation raises questions of coherence and alignment between the selected policy mixes and their effectiveness (England et al., 2018; Ranabhat et al., 2018; Lesnikowski et al., 2019).

Evaluation of national adaptation plans (NAPs) has only recently been undertaken. Woodruff and Regan (2019) compared national adaptation plans from 38 countries and concluded that most were strong in identifying vulnerabilities and identifying potential adaptation options but were weaker in articulating implementation pathways and monitoring of progress; plans written by multi-agency teams were nearly always of higher quality. Garschagen et al. (2021) showed that, while most NAPs consider future changes in climate hazard, many do not consider how vulnerability and exposure might change, concluding that this limits the potential effectiveness of the plans. Morgan et al. (2019) showed that NAPs that are consistent with the Paris Agreement can enable development pathways that promote synergies between environmental, social and economic goals.

17.4.2.1.3 Impact of legal and policy instruments

Commitment to act, and guidance on how to do so, from international and national governance levels can drive national and sub-national adaptation (Reckien et al., 2013; Heidrich et al., 2016; Reckien et al., 2018a). For example, more local plans have been developed in European countries where it is obligatory for local municipalities to develop climate change plans (Reckien et al., 2018a). Local government have also drawn on non-binding national climate frameworks, as well as international frameworks (such as European law) or international networks (such as Global Covenant of Mayors for Climate and Energy) to guide their actions (Reckien et al., 2013; De Gregorio Hurtado et al., 2015; Reckien et al., 2015; Heidrich et al., 2016; Reckien et al., 2018a).

However, a national framework is not always sufficient to trigger climate change action on the lower level, in particular when the national guiding document fails to clearly formulate how it should be used and 'translated down' to lower governance levels (De Gregorio Hurtado et al., 2015). Guidance on how to apply a national framework at lower governance levels can assist in their uptake.

In the case of climate change legislation, research on the impact of adaptation laws is limited, save for a few studies (Averchenkova and Matikainen, 2017), because many framework laws, particularly those with more of an adaptation focus, have only been published recently (Rumble, 2019b). Reviews of the implementation of the risk assessment and adaptation components of the UK's Climate Change Act 2008 suggest that they had a weaker implementation record compared with mitigation provisions (Fankhauser et al., 2018), potentially because implementation of adaptation is more complex as compared with mitigation

Table 17.5 | Selected examples of framework and sectoral law approaches adopted by different nations that represent a variety of regional contexts.

Example	Legal approach	Description	References
United Kingdom Climate Change Act 2008	Framework	Provides for development of climate change impact reports and programmes for adaptation. Dedicated institutional structure with advisory body, adaptation planning provision, reporting/information obligations, climate change mainstreaming, climate change trusts or financial arrangements.	Averchenkova et al. (2021)
Kenya Climate Change Act 2016	Framework	Modelled on the United Kingdom Climate Change Act. Provides for development of climate change impact reports and programmes for adaptation. Dedicated institutional structure with advisory body, adaptation planning provision, reporting/information obligations, climate change mainstreaming, climate change trusts or financial arrangements.	Rumble (2019b)
Mexican General Law on Climate Change 2012	Framework	Imposes positive duties upon government to implement 'adaptation actions'—conservation, sustainable use and rehabilitation of beaches and coasts; water programmes for watersheds; the establishment of protected areas and biological corridors; the development of risk atlases; human settlement and urban development programmes; and prevention programmes targeting diseases exacerbated by climate change. Includes development of economic instruments, including fiscal incentives, credits, bonds, civil liability insurance and market-based instruments.	Averchenkova and Guzman Luna (2018)
New Zealand Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012	Sectoral	Incorporates adaptive management principles by regulating the issuance of marine consents with conditions allowing change based on ecological change and indicators.	Godden (2012)
Seychelles Conservation and Climate Adaptation Trust of Seychelles Act 18 of 2015	Sectoral	Provides for the establishment of a dedicated trust fund for conservation measures and climate change adaptation measures.	Etongo et al. (2021)
Commonwealth of Dominica Climate Resilience Act 16 of 2018	Sectoral	Promotes disaster recovery and resilience building. Establishes the Dominica Climate Resilience Policy Board and sets out its functions and duties. Requires the development of a Climate Resilience and Recovery Plan.	Government of the Commonwealth of Dominica (2018)
Swedish National Strategy for Climate Change Adaptation (Government Proposition 2017/18:163)	Sectoral	Amends Sweden's Planning and Building Act (2010: 900) by requiring municipalities to assess the risk of damage to the built environment from climate risks as well as how such risks may change in the future; requires detailed plans for measures to address land permeability when issuing a land permit; adopts the Swedish National Climate Strategy into law.	Government of Sweden (2017)
Argentinian Glaciers Preservation Law N 32.016 (2010)	Sectoral	Provides for minimum budgets to protect the national glacial water sources that supply the Mendoza oasis. Establishes that all of Argentina's glaciers and its periglacial environment are to be protected, irrespective of size.	Warner et al. (2019)
Netherlands Delta Act on Water Safety and Fresh Water Supply	Sectoral	Protects the Netherlands from risks such as sea level rise and extreme rainfall. Establishes a Delta Programme to secure fresh water supply and address climate risks/sea level rise; a Delta Fund to operate the programme and a commissioner.	Van Alphen (2016)

as shown for the local level (Reckien et al., 2019). However, the UK Act is considered to have made action on climate change more predictable, more structured and more evidence based (Averchenkova et al., 2021).

There are numerous examples of regulatory and project-based innovations by local governments. Their impact, however, is uneven, with much depending on the implementation capacity of local governments and other socio-institutional barriers, including those relating to mandate and joint project implementation, cross-departmental working, planning cycles, concerns relating to legal liability and compensation, political appetite and cost (Godden, 2012; Taylor, 2016a). Notwithstanding implementation challenges, evidence is emerging that overarching framework laws play a foundational and distinctive role in supporting effective climate governance, including adaptation governance (Fankhauser et al., 2018), and are drivers of subsequent activity (Townshend et al., 2011; Fankhauser et al., 2014; Clare et al., 2017b), especially when formulated with clear guidance for all related actors, including lower level of governance (De Gregorio Hurtado et al., 2015). This may explain the rapid increase in both local and national climate change laws, now with an increased emphasis on regulatory provisions to increase resilience and reduce vulnerability.

17.4.2.1.4 Regulations and standards

The presence and articulation of regulations and standards that address climate risk, such as building codes and land use zoning are key enabling factors for effective decision-making (Kim et al., 2020). Regulations and standards provide a framework for common understanding of when and under what conditions action should be taken specifically in relation to the construction and maintenance of the built environment, infrastructure and environmental and social practice (Grynning et al., 2020). Regulations and standards for climate action emerge primarily from two settings: first, as an addition or augmentation to existing regulations and standards that emerged initially to address existing potential climate extremes and stresses (e.g., size of culverts in response to maximum rainfall and runoff conditions); and second, new regulations and standards that were developed in direct response to new or emergent climate risks (e.g., regulations in response to new presence of mean monthly high tide flooding) (Qiao et al., 2018). Commonly agreed upon social norms and conventions also can be described as regulatory and providing a set of standards.

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The regional and sectoral chapters of this report provide significant evidence of how regulations and standards enhance or hinder opportunities for climate risk management and adaptation. Relevant regulations and standards are especially evident in the oceans and coastal domains (Chapter 3 and CCP2, in cities and infrastructure (Chapter 6), and the water (Chapter 4) and food sectors (Chapter 5). Europe and North and South America (Chapters 12, 13 and 14) have the most frequent documented occurrences of examples of regulations and standards. Regulations and standards focused on building codes to protect against extreme event and loss, water regulations and agreements to protect water supply and lessen drought impacts, and health codes to limit heat exposure are the most frequent examples of such practices. Deficiencies of regulations and standards have been noted with respect to their capacity to manage species migrating from climate change, and to provide opportunities for transformative adaptation. The evidence from the sectors and chapters illustrate that more comprehensive regulations and standards lead to positive adaptation outcomes.

17.4.2.1.5 Environmental and social governance

Environmental and social governance refers to voluntary or non-legally required actions taken by participating parties to achieve a commonly defined goal (Bodin, 2017; DeCaro et al., 2017; Partzsch, 2020). While not explicitly described in the sectoral and regional chapters of this report, the maintenance and exercise of environmental and social governance decision-making strategies do enable adaptation practice and have become especially important when formal legal and policy regimes are not yet present. As formal regulation promotes clear and common understanding of climate risks and mechanisms to develop context specific appropriate solutions, voluntary code-making and self-regulation can forestall the need for legal action or can function as precursors to the formulation and implementation of legislation, laws and regulations.

Social and environmental governance has long been presented within climate risk decision-making, although more typically in the domain of climate mitigation (Wright and Nyberg, 2016; Vandenbergh and Gilligan, 2017). Corporate climate decision-making emphasises the importance of profit motives in shaping decisions; however, reputational factors as appropriate environmental stewards can also be important when linked to sensitivity of other stakeholders such as investors, lenders, customers and employees (Vandenbergh and Gilligan, 2017). Pulver (2011) notes that climate issues influence corporate decision-making more strongly in organisations that are networked with other organisations that also consider these issues and through direct experience with climate-related events and associated organisational learning.

Since AR5, more case studies of social and environmental governance within the domain of climate adaptation have become evident, especially within the context of adaptive management experimentation (Vella et al., 2016; Beunen and Patterson, 2019; Blühdorn and Deflorian, 2019). Environmental and social governance strategies for climate adaptation are diverse and reflect context-specific conditions of the decision-making process, including the role of the state, the individual and private interests, formality/informality, social responsibility, sources of financing, and transparency. Environmental and social governance enables the testing and definition of implementation solutions, enhancing the opportunities for defining successful adaptation (Surminski, 2013). Several models and approaches to adaptive governance to promote adaptation and resilience in response to extreme weather events have been observed. These include polycentric and multilayered institutions, participation and collaboration, self-organisation and networks, and learning and innovation (Djalante et al., 2011).

The effectiveness of social and environmental governance varies by sector. For example, in the private business sector, Aragòn-Correa et al. (2019) assess the effects of mandatory and voluntary regulatory pressure on firms' environmental strategies. In summary, they find that analyses of the effects of voluntary pressure demonstrate that by themselves they are unlikely to bring about significant improvement in environmental outcomes. Professional organisations, however, have made progress in addressing sectoral standards relative to the adaptation process. This includes the development of new industry guidelines, codes, standards and specifications, in addition to the implementation of infrastructure inventories that incorporate evaluation of vulnerabilities and identification of priority at-risk areas (Chapter 14). Voluntary pressures by themselves are not likely to result in positive outcomes and instead should be coupled with mandatory regulatory pressure to achieve the environmental response desired (Bianco, 2020).

Since AR5, another key development in environmental and social governance has been the establishment of the Task Force on Climate-related Financial Disclosures (TCFD), which aimed to develop guidelines for companies to voluntarily report the financial implications of two broad categories of climate risk: the transition risks of shifting to a lower-carbon economy and the physical risks of climate change itself (TCFD, 2017). As of 2019, ~1340 companies with a market capitalisation of USD 12.6 trillion and financial institutions responsible for assets of USD 150 trillion have expressed support for the TCFD (TCFD, 2020). An analysis of reports to the TCFD in 2016 showed that 83% of companies report on physical risks of climate change, and of these, 82% reported on strategies to adapt to some of the identified risks (Goldstein et al., 2019). The same analysis also noted that: (i) the total of estimates of assets at risk were two orders of magnitude lower than generally accepted estimates of total financial risk; (ii) a minority of companies consider risks outside of their own operations or in their value chains; (iii) most underestimate or do not estimate the costs of adaptation; and (iv) many assume linear impacts and responses, neglecting the potential for tipping points or acceleration in risk and potentially transformative adaptation requirements. At this stage, TCFD has influenced many companies' thinking and comprehension of physical climate risk, but it appears too early to assess whether this has driven substantive responses to manage these risks.

17.4.3 Enabling Condition 2: Finance

Finance has long been recognised as an important enabling and catalysing factor for adaptation, climate resilient development and climate risk management. In Chapter 17, financing for adaptation and climate risk management is covered in the extended Cross-Chapter Box, Financing for Adaptation and Resilience (FAR), below. The Cross-

Chapter Box aims to highlight key emerging evidence on financing of adaptation, covering both public and private sources and instruments. Climate finance is also covered in a dedicated chapter in the WGIII Report (WGIII AR6 Chapter 15 (Kreibiel et al., 2022)), and readers should refer to this chapter for a more comprehensive assessment of this subject from both a mitigation and adaptation perspective.

17.4.4 Enabling Condition 3: Knowledge and Capacity

17.4.4.1 Overview of Knowledge Systems

AR5 emphasised the importance of knowledge systems as an enabling condition for decision-making, as did earlier ARs, all of which include a focus on the policy relevance of knowledge (Section 1.1.4). First introduced in IPCC reports in AR4, the term 'knowledge system' is used extensively in AR5 and the SRs. The discussion below follows a widely cited definition of knowledge systems as sets of interacting 'agents, practices and institutions that organize the production, transfer and use of knowledge' (Cornell et al., 2013: 61). This definition emphasises the social nature of knowledge and the importance of the link between knowledge and action, rather than presenting knowledge simply as information about past, present and future states of the world which can be of use to decision makers.

This definition of knowledge systems indicates the importance of capacity—the ability and the motivation to use knowledge for action—since capacity is an important feature which allows knowledge systems to function. Capacity is a necessary enabling condition for knowledge to be put to use in adaptation activities (*high confidence*), as shown across sectors such as water (Section 4.5.2), food security (Sections 5.12.3, 5.14.3), cities and settlements (Sections 6.4.2, 6.4.4) and health and well-being (Sections 7.1.3, 7.2.6), and across regions, including Africa (Sections 9.13.1, 9.14.5), Asia (Sections 10.3.6, 10.4.4) and North America (Section 14.4.5).

Some research on knowledge systems retains the earlier attention to information as a resource for decision makers. A major focus, discussed elsewhere in this chapter, has been increasing the precision about the certainty, likelihood and confidence with which certain statements are made in relation to underlying evidence (see Cross-Chapter Box DEEP in this Chapter). This topic, which was first introduced in AR4, advanced significantly in AR5 (Mach et al., 2017).

In addition to these characteristics of information, the social and organisational aspects of knowledge systems have also been the subject of recent research. One strand of this discussion emphasises the distinctiveness of different knowledge systems, often focusing on three types of knowledge: scientific, Indigenous and local, and the latter are two sometimes grouped as 'traditional' knowledge (see Cross-Chapter Box INDIG in Chapter 18). This strand emphasises the specific forms of knowledge production and circulation in each type. Another strand of discussion emphasises the networks of interactions between different groups. This strand follows the influential 'Knowledge systems for sustainable development' (Cash et al., 2003), which was cited in Chapters 2, 7 and 8 in WGII AR5; Cash et al. (2003) emphasise the usability and acceptability of scientific knowledge, and highlight the relations between knowledge producers and users. The discussion in Section 17.4.4 on knowledge as an enabling factor integrates these two strands of discussion of knowledge systems.

It was well established in AR5 and SRs that a component of knowledge systems for good climate decision-making is the production of 'information on climate, its impacts, potential risks, and vulnerability' which can 'be integrated into an existing or proposed decision-making context' (Jones et al., 2014: 200). Also important are two other components of knowledge: of response options and knowledge of other enabling conditions, particularly governance and finance, which were mentioned less frequently and more indirectly in AR5 and SR1.5, SROCC and SRCCL. Decision makers assess the feasibility of different alternatives (see Cross-Chapter Box FEASIB) and develop strategies for the implementation and modification of the alternative, requiring a level of knowledge of the governance, policy and finance landscapes at national (Tanner et al., 2019; Lopes et al., 2020; Roberts et al., 2020) and international scales (Woodruff, 2018).

Examples of the importance of these other two components—knowledge of response options and knowledge of enabling conditions—are provided by networks of cities, including internal institutional networks (Aylett, 2015), intermunicipal networks (e.g., those supported by Local Governments for Sustainability [ICLEI] and the international United Cities and Local Governments [UCLG] network), transnational municipal networks (e.g., 100 Resilient Cities, Asian Cities Climate Change Resilience Network [ACCCRN]) and city-to-city regional transdisciplinary learning networks (Ndebele-Murisa et al., 2020). These networks generate and exchange knowledge which can be critical to decision makers for understanding and evaluating the feasibility of different response options, identifying synergies across sectors and mainstreaming adaptation to climate change (Haupt et al., 2020). However, the question of how to finance such network activities remains under-studied (Bracking, 2021; See Box 17.3).

In addition to these general considerations of knowledge systems, research since AR5 has contributed to the understanding of specific types of knowledge. Scientific knowledge is thoroughly discussed in Chapter 1, especially in Section 1.3 'Understanding and Evaluating Climate Risk', which shows recent advances in the well-established IPCC categories of observation of past conditions and model-based projections of future conditions. We add here a consideration of a new area within scientific knowledge, artificial intelligence, which offers new methods for producing information that can be incorporated into knowledge systems.

Applying artificial intelligence (AI) to climate change is predominantly in the area of climate modelling and forecasting, inclusive of weather extremes (Monteleoni et al., 2013; Jones, 2017; Huntingford et al., 2019). Recent efforts conceptualise the potential uses of AI for mitigation and adaptation (Rolnick et al., 2019; Cheong et al., 2020b) in addition to forecasting (Rolnick et al., 2019; Chattopadhyay et al., 2020; Cheong et al., 2020b; Prabhat et al., 2021). There are very few cases to assess AI applications in these domains given that AI is a new field for climate change impact and adaptation. To this date, sectoral applications of AI relevant to climate change adaptation and risk reduction mainly have advanced in the areas of crop yields, early-warning systems and water management.

Cross-Chapter Box FINANCE: Finance for Adaptation and Resilience

Authors: Mark New (South Africa), Madeleine Rawlins (UK), David Viner (UK), Charlene Watson (UK), Lily Burge (UK), Lionel Mok (Canada), Lauren Arendse (South Africa), Vita Karoblyte (UK), Liane Schalatek (USA), Neha Rai (UK), Baysa Naran (Mongolia), So-Min Cheong (Republic of Korea), Nicoletta Giulivi (Italy/Guatemala).

Introduction

This Cross-Chapter Box reports on: (i) new evidence on the finance needed for adaptation and resilience, and uncertainties in these estimates; (ii) the emerging public and private climate finance architecture; (iii) the status of financing for AR, including sources, total flows, regional and sectoral distributions; (iv) equity considerations; (iv) opportunities and challenges for financing adaptation and resilience during and after the coronavirus disease 2019 (COVID-19) pandemic. This Cross-Chapter Box does not focus on finance for mitigation, which is covered in WGIII Chapter 15 (Kreibiel et al., 20122), nor the economic damages of climate change or financial aspects of Loss and Damage, which are covered in Cross-Working Group Box ECONOMIC (Chapter 16) and Cross-Chapter Box LOSS (this chapter), respectively.

Successive reports of the IPCC (Vellinga et al., 2001; Mimura et al., 2008; Yohe et al., 2008; Klein et al., 2014) and the AR6 Special Reports have noted the importance of finance as an enabler for adaptation, across both developed and developing nations. While the UNFCCC and the UNFCCC has yet to arrive at a formally agreed definition of climate finance, numerous overlapping have been suggested and reported (e.g., Falconer and Stadelmann, 2014; UNFCCC, 2014; Roberts and Weikmans, 2017; Munira et al., 2021). However, there is wide agreement across these definitions that climate finance refers to financial resources devoted to addressing climate change, both mitigation and adaptation to current and projected climate change, and that these resources can come from both public and private sources (high confidence). Climate finance includes, but in most definitions is not restricted to, international financial flows to developing countries. Finance can be delivered through a range of instruments including grants, concessional and non-concessional debt, and internal budget reallocations (high confidence) (Watson and Schalatek, 2019). Adaptation and resilience are often used interchangeably in climate finance discussions, although adaptation is a process, while resilience (to climate risk) is the ability to progress towards desired outcomes in the face of impacts from a changing climate (Section 1.2.1).

Box Cross-Chapter Box FINANCE.1 | The 100 Billion Climate Finance Commitment to Developing Countries

At the 16th session of the Conference of the Parties (COP16) in Copenhagen in 2009, developed country parties to the UNFCCC committed to a goal of jointly mobilising USD 100 billion yr^{-1} by 2020 to address the climate change needs of developing countries (UNFCCC, 2009). This was in response to a threat by developing countries to walk out of the negotiations, as they perceived developed country support to be lagging and lacking in ambition (Roberts et al., 2021). The commitment was formalised in the Cancun Agreements (Decision 1/CP.16) in 2010 and was re-affirmed as a key element of the Paris Agreement in 2015 (Article 9, paragraph 4). At the 26th session of the Conference of the Parties (COP26) in 2021, formal deliberations will begin on a new climate finance goal to be adopted in 2025; the current USD 100 billion target will serve as the annual minimum until 2025 (Chhetri et al., 2020).

The '100 Billion' does not represent the total need to respond to climate change in developing countries, nor the global cost across all countries, as is sometimes interpreted in the literature and media. As shown below in this Cross-Chapter Box, the estimated cost of adaptation for developing countries ranges from 15 to 411 billion USD yr^{-1} for climate change impacts out to 2030, with the majority of estimates being well above 100 billion.

Proposed sources for the developed country commitment included '*a wide variety of sources, public and private, bilateral and multilateral, including alternative sources of finance*' and several instruments including grants and loans. Nonetheless, there remain differences of opinion on the types of finance that should count towards this goal, with several issues identified (*high confidence*) (Bodnar et al., 2015; Bhattacharya et al., 2020; Roberts et al., 2021), including: (i) counting non-grant finance, such as market and concessional loans (public and private), where developing countries ultimately have to repay the investment; (ii) what is counted as 'climate' by different funders, especially when climate is not the prime objective; (iii) the extent to which some funds are 'new and additional' rather than a repurposing of development finance.

Progress towards the 100 Billion target has shown an upward trend over the last several years (*high confidence*), but will fall short in 2020, even when the most generous criteria are included (*high confidence*). In 2017/2018, the most recent year for which data have been comprehensively analysed, estimates using different (but overlapping) data sources and methods were in

Cross-Chapter Box FINANCE (continued)

the range 48–75 billion USD yr^{-1}, compared with 45–75 in 2015/2016 and 41–52 in 2013/2014 (Carty et al., 2020; SM17.3; CPI, 2020; OECD, 2020; UNFCCC, 2020). The distribution between adaptation and mitigation has remained strongly weighted towards mitigation, although the proportion allocated to adaptation has increased from 17–25% in 2013/2014 to 19–30% in 2017/2018 (*high confidence*). One analysis that excludes debt repayments indicates that the debt-adjusted flows are about half the total flows reported above, of which circa 31–33% was for adaptation between 2015/2016 and 2017/2018 (Carty et al., 2020).

Adaptation finance needs

Estimates of global, regional or national finance needs for adaptation and resilience vary depending on both analysis approach, the level of climate change, and the geographic and sectoral scope of analysis (*high confidence*) (UNEP, 2016; Chapagain et al., 2020; UNEP, 2020). Recent estimates have adopted one of main approaches: (i) aggregation of individual case studies, along with scaling to generate global or regional costs; (ii) analysis of NDC adaptation cost estimates (Weischer et al., 2016; Hallegatte et al., 2018); (iii) integrated assessment model simulation of impacts and adaptation costs (Markandya and González-Eguino, 2019; Chapagain et al., 2020).

All approaches suffer from limitations that can cause both over- and underestimates, including incomplete coverage of sectors and risks; inability to account for autonomous/unreported adaptation; incorrect cost estimations; soft and hard limits to adaptation; balance between adaptation, mitigation and residual cost; benefits and co-benefits on cost; and learning and innovation as climate change progresses (UNEP, 2020). Global or developing region estimates based on scaling NDC data is particularly uncertain, as most NDCs did not specify how the costs were calculated. Also, scaling from a relatively small set of NDCs with costs to the global scale is not particularly robust, indicating a need for more transparency and better guidance for calculating adaptation costs (Watkiss et al., 2015; Zhang and Pan, 2016; Hallegatte et al., 2018; African Development Bank, 2019).

Most estimates of adaptation cost in the literature are for developing countries. Chapagain et al. (2020) assessed various estimates of adaptation for developing countries, under different emissions scenarios for 2030 and 2050. The median estimates (and range) from these studies are 127 (15–411) and 295 (47–1088) billion USD yr^{-1} for climate change impacts out to 2030 and 2050, respectively (see SM17.3). All but one study report adaptation costs higher than the 70–100 billion estimated in 2010 by the World Bank (World Bank, 2010).

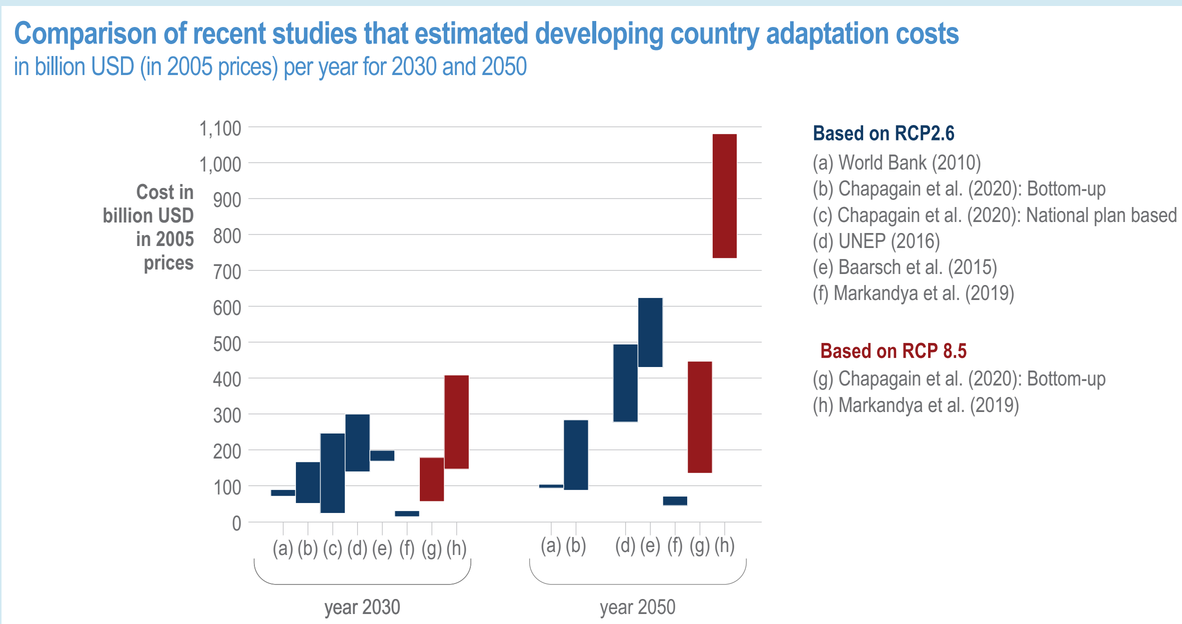

Figure Cross-Chapter Box FINANCE.1 | Comparison of recent studies that estimated developing country adaptation costs in billion USD (in 2005 prices) yr^{-1}, for 2030 and 2050. Figure based on Chapagain et al. (2020). Major studies are World Bank (2010), Chapagain et al. (2020), UNEP (2016), Baarsch et al. (2015) and Markandya and González-Eguino (2019). The solid-coloured bars are based on RCP2.6, and patterned bars are based on RCP 8.5; the width of the bars indicates the range of estimates (maximum and minimum) produced in each study.

Cross-Chapter Box FINANCE (continued)

The cost of adaptation for developed countries is rarely reported; most literature either reports a global cost or developing country costs, or costs for a specific country or sector. Baarsch et al. (2015), using an Integrated Assessment Model (IAM), report adaptation annual costs (2012 prices) in 2030 (and 2050) as 272 (660) billion globally and 205 (521) in developing countries only under the RCP2.6 scenario, indicating that developed country costs are around 25% (21%) of total cost.

In addition to global estimated adaptation costs, there are many studies that have focused on specific regions, countries or sectors, such as estimated adaptation cost for coastal environments, water-related infrastructure, urban infrastructure, agriculture and energy (UNEP, 2014; Watkiss et al., 2015; UNEP, 2016). Examples of such estimates are reported in various chapters in this report and summarised in SM17.3.

Estimating the benefit of adaptation, in terms of damage avoided, remains challenging. For example, Ricke et al. (2018) show that the social cost of carbon (monetary damage per tCO_2 emitted) varies by up to two orders of magnitude depending on country, socioeconomic scenario, damage function, total greenhouse gases (GHG) forcing, and local climate change. In addition, non-monetary benefits such as cultural identity, sacred places, human health and lives are often ignored (Tschakert et al., 2017; Serdeczny, 2019; see also Cross-Working Group Box ECONOMIC in Chapter 16; Cross-Chapter Box LOSS, this Chapter). Recent case studies and global level analyses continue to support the conclusion in IPCC AR5 WGII Chapter 17 (Chambwera et al., 2014) that the benefits of adaptation generally remain larger than the costs (*medium confidence*), but the cost–benefit ratio varies widely by context and assumptions (OECD, 2015; Global Commission on Adaptation, 2019; WRI, 2019)

The climate finance landscape

The adaptation and resilience finance landscape spans multiple sources, intermediaries, instruments and recipients, operating across global to sub-national scales (Buchner et al., 2019; Carter, 2020; Watson and Schalatek, 2021). Public finance is provided by national and sub-national governments and distributed directly by government or intermediaries such as development finance institutions and climate funds, either nationally or internationally. Private finance comes from five main sources: commercial financial institutions (banks), institutional investors (including asset managers, insurance companies and pension funds), other private equity (venture capital and infrastructure funds), non-financial corporations such as renewable energy or water companies, and individual households and communities. Across these different sources, the main instruments used are grants, concessional debt, market debt, internal budget allocation, insurance, as well as personal savings in households (*high confidence*). Public and private sources of funding can be blended into a single instrument, for example for insurance where public funds provide capital for both sovereign catastrophe instruments and micro-insurance (Jarzabkowski et al., 2019) or for concessional loans. Similarly, public finance is often ultimately derived from commercial debt instruments such as bonds.

International public climate finance

International public climate finance flows are realised through bilateral and multi-lateral channels (Watson and Schalatek, 2021) where contributions to these channels are received from Annex II and non-Annex I countries (UNFCCC SCF, 2018; Buchner et al., 2019). Annex II countries contribute as part of their commitments in the Paris Agreement, while non-Annex I countries commit climate finance through these channels on a voluntary basis (Pickering et al., 2015; Roberts and Weikmans, 2017; Egli and Stünzi, 2019). Bilateral intermediaries include development cooperation agencies and national development banks. These institutions often have long-standing development-cooperation experience, and offer climate change projects, facilities and financial instruments based on their differing mandates, structures and priorities (Atteridge et al., 2009; Buchner et al., 2019).

Multi-lateral channels include the UNFCCC financial mechanisms, such as the Green Climate Fund, and the multi-lateral development banks (MDBs), such as the World Bank. Both pool contributor resources before committing such resources for climate change projects and programmes. Funding through multi-lateral channels promotes recipient country engagement in the governance and prioritisation of funding decisions, with concurrent processes in the multi-laterals often existing to support country ownership of funded climate action (Ciplet et al., 2013; Ha et al., 2016).

There are five multi-lateral climate change funds of the UNFCCC and Paris Agreement financial mechanisms. There are further multi-lateral climate change funds that are not governed by the UNFCCC or Paris Agreement, the largest of which is the World Bank governed Climate Investment Funds (Watson and Schalatek, 2021). Some of the major multi-lateral climate change funds have been established with a specific focus on adaptation, while some bilateral donors have thematic or sectoral priorities. Multi-lateral climate change funds operate through accredited implementing entities. These have historically been multi-lateral in nature, such as the development banks, but recent years have seen a rise in the accreditation of national and regional institutions (UNFCCC SCF, 2018). In addition to programming funds

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Cross-Chapter Box FINANCE (continued)

from external sources, such as through the multi-lateral climate change funds, the MDBs also raise and programme their own climate finance (UNFCCC SCF, 2018; MDBs, 2019).

Several major multi-lateral climate change funds work through grant-only programmes, whereas others include concessional loan, equity and guarantee instruments. The broader suite of instruments used by the MDBs includes grant, investment loan, equity, guarantee, line of credit, policy-based financing and results-based financing (MDBs, 2019).

Public funding of a concessional nature that flows from Annex II to non-Annex I countries supports research and capacity building and can also facilitate private finance flows into climate action, with the intention to avoid creating a high debt burden in developing countries, in response to climate impacts for which they have little historic responsibility (Watson, 2016; Carter, 2020; Schalatek, 2020). Less concessional public finance flows include other official flows that are not developmental in nature and can be trade related, including, for example, export credits.

Critiques of the public climate finance architecture are aimed at the overlapping mandates of the institutions programming climate finance, particularly the multi-lateral climate funds, and the challenges in accessing funding (Nakhooda et al., 2014; Amerasinghe et al., 2017; Pickering et al., 2017). However, Pickering et al. (2017) further note that institutional fragmentation of climate finance could result in more flexibility, resilience and innovation. There have also been important governance changes leveraged by some of these funds and instruments, such as integration of gender considerations into projects (Schalatek, 2020).

Private financing of adaptation and resilience

There is an increasing focus on the role of the private sector to support large-scale financing of adaptation and resilience (UNEP, 2016; UNEP, 2018). To date, it has been difficult to track adaptation and resilience finance within the private sector (UNEP, 2016) as it is either not disclosed or not easily identifiable, since it is often built into capital and operating expenditure and is not a standalone investment. Several private mechanisms are emerging as important sources of climate finance (Gupta et al., 2014; Eccles and Krzus, 2018; Miller et al., 2019).

Green, social impact and resilience bonds are similar to traditional bonds—fixed-income financial instruments raised on commercial markets by companies, governments or financial institutions—but the proceeds are used to fund activities that have positive environmental, social or climate benefit (Tuhkanen, 2020). Green bonds align to voluntary principles, such as the Green Bond Principles set out by the International Capital Market Association, the Climate Bonds Initiative's Climate Resilience Principles (Sartzetakis, 2020). Given the voluntary nature and lack of standardisation of green bond principles, there are concerns around their additionality, and there is also a lack of data on how green bonds contribute to a scaling up of green projects (Dupre et al., 2018).

Green bond annual issuance reached 260 billion in 2019 (CBI, 2020), but as of 2018, only 3–5% (USD 12 billion) of green bond total proceeds can be explicitly traced to climate-resilience-related efforts (CBI, 2019). Examples of AR focused bonds include those issued by Fiji in 2017, dedicating 91% of spending to adaptation and resilience (Shukla and Peyraud, 2017; Ministry of Economy, 2019), and by the European Bank for Reconstruction and Development's 2019 Climate Resilience Bond for USD 700 million to finance climate-resilient infrastructure, commercial operations, agriculture or ecological systems (EBRD, 2019).

Dedicated investment vehicles are equity funds that are created to invest in products and services that enhance resilience and reduce risks. An example is the Climate Resilience and Adaptation Finance and Technology Transfer Facility that is proposed as a USD 500 million private equity fund to invest in companies providing climate resilience solutions for developing countries. Initial funding has been provided by donors (Miller et al., 2019).

Balance sheet finance occurs when an entity directly invests in resilience and adaptation rather than as a separate project. This source of funding may be from exiting reserves, re-allocation from other budget lines, or via external commercial finance, but the investment is financed by the firm rather than as a separate project (Gupta et al., 2014; Buchner et al., 2019).

Insurance can play an important role in managing residual climate risks at any given level of adaptation, but insurers can also be important r risk assessment and risk reduction as part of any insurance package (Jarzabkowski et al., 2019; Section 11.3.8.3). While traditional indemnity insurance is important for repair and rebuilding of damaged property and infrastructure, parametric insurance has become increasingly popular for supporting rapid post-disaster responses such as drought, hurricane damage and flooding. Examples include sovereign insurance facilities such as African Risk Capacity and the Caribbean Catastrophe Risk Insurance Facility (Broberg, 2019)

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Cross-Chapter Box FINANCE (continued)

as well as weather-index insurance targeted at individuals, especially in agriculture (Greatrex et al., 2015; Isakson, 2015; Surminski et al., 2016; Jensen and Barrett, 2017; Fischer, 2019). The role of insurance as a climate risk management option, as well as limitations, is covered in more depth in Section 17.2 and Cross-Chapter Box LOSS (this chapter).

Mainstreaming physical climate risks and resilience in the private sector

The data on tracked climate finance and green bond issuance for adaptation and resilience both show a substantial gap between the adaptation needs and the finance deployed. Scaling up these instruments is unlikely to close this gap given the challenges with financing adaptation projects, particularly from the private sector. There is therefore a need for more systematic action to manage climate risks and mainstream climate change considerations (Miller et al., 2019).

The financial case for mitigation investment can often be demonstrated through revenues from, for example, the sale of renewable electricity. On contrast, the benefits from investment in adaptation and resilience are typically considered in terms of avoided losses and cost benefit ratios. For example, the Global Commission on Adaptation (2019) estimates that the overall rate of return on investments in improved resilience is very high, with benefit–cost ratios ranging from 2:1 to 10:1, and in some cases even higher.

The private sector is becoming increasingly aware of the need to assess physical climate risks to avoid the long-term risks to assets and enhance climate resilience. The task force on climate-related financial disclosures (TCFD) is likely to create additional pressure from investors for companies to identify, manage and reduce risks from climate change (Eccles and Krzus, 2018; ERM and CBEY, 2018; Tuhkanen, 2020).

A key factor for the impact of the TCFD on mainstreaming of physical climate risks and demonstrating the case for investment in adaptation and resilience will be how investors systematically incorporate physical climate risks, adaptation and resilience into their investment decisions. The Coalition for Climate Resilient Investment (DFID et al., 2019) was established to look at this from the private sector viewpoint and is working to systematically incorporate resilience into cash flow modelling and asset valuation practices, so that investors may quantify the investment in resilience for an asset and the benefits associated with reduced costs and more reliable revenue streams.

Recent trends in climate finance flows

Considerable progress has been made in tracking climate finance since AR5, but substantial gaps remain, especially regarding domestic public finance and private sector balance sheet investment in adaptation (Section 17.5.1.5; CPI, 2020; Richmond et al., 2020). The best documented information comes from international climate funds, which provide detail at the project level. Most bilateral and multi-lateral investment institutions report on whether debt, grants and other instruments are for climate projects, but with less detail. Private finance is harder to track, as reporting is voluntary; even for green bonds, where certification identifies the range of sectors a bond aims to cover, reporting of how the bond is spent is infrequent.

The Climate Policy Initiative (CPI) has been tracking climate finance since 2009, allowing for trends to be assessed; however, trends reported are a function of both real changes in finance and changes in methods and information sources (Richmond et al., 2020). Total climate finance tracked by CPI has increased from USD 364 billion yr^{-1} in 2010/2011 to 579 billion in 2017/2018 (SM17.3). Tracked finance remained relatively constant from 2010/2011 to 2013/2014 but has increased steeply in more recent years. The proportion of finance allocated to adaptation has remained small throughout, between 4% and 8% (*high confidence*); a further 1–2% of global finance has been classified as 'multiple-objectives'. The large majority of tracked adaptation finance is from public sources (*high confidence*), with only 2% coming from private sources in 2017/2018 (CPI, 2020). This is at least partly because of the difficulty in demonstrating financial (as opposed to public good and avoided damages) return on investment for adaptation.

The majority of the most recently (2017/18) tracked adaptation and multiple-objective finance was supplied through public donors, largely through grants, concessional and non-concessional instruments (Figure FAR.1). Most finance (44.1%) was spent transregionally (allocated in specific projects to recipients in more than a single region). For regionally specific funding, Sub-Saharan Africa and South Asia, along with the Latin America and Caribbean region, received the largest gross amounts, although Oceania has received the greatest per-capita funding. The largest proportion of AR funding has been allocated to increasing the resilience of infrastructure, energy and the built environment, followed by agriculture, forestry and natural management, and then water and wastewater.

Across financial instruments, Sub-Saharan Africa received the highest relative proportion through grants (38%), followed by the Latin America and Caribbean region (23%), with other non-Organisation for Economic Co-operation and Development (OECD) regions receiving between 16% and 10% (SM17.3). Concessional debt as a proportion of the regional total varies from 84% in South Asia to as low as 29% in Latin America and Caribbean, which has the highest proportion of non-concessional debt (48%).

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Cross-Chapter Box FINANCE (continued)

Flow and distribution of globally tracked adaptation and resilience finance in 2018 from different sources, through different instruments into different sectors and regions

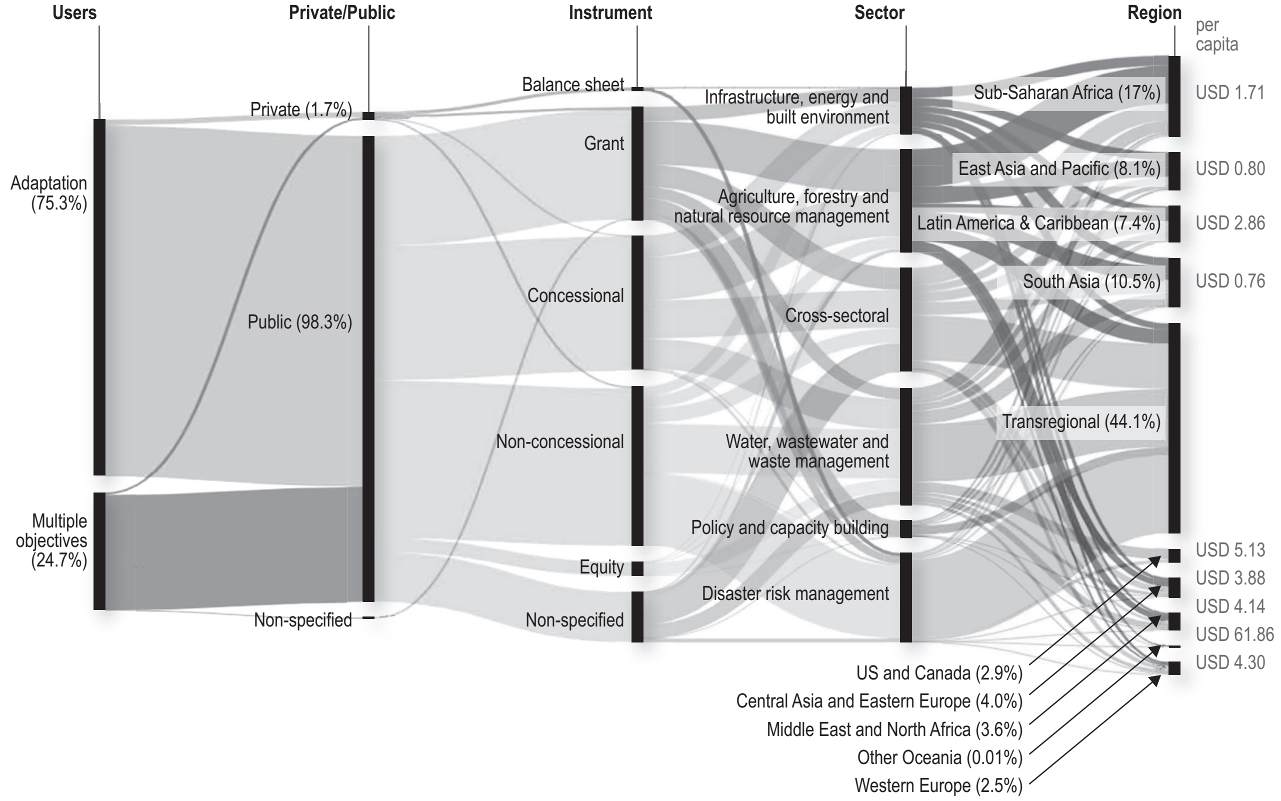

Figure Cross-Chapter Box FINANCE.2 | The flow and distribution of globally tracked adaptation and resilience finance in 2018 from different sources, through different instruments into different sectors and regions. Each strand shows the relative proportion of finance flowing from one category to another (for example, from private or public sources to different instruments). Categories from left to right are: (a) whether the finance is solely for adaptation or for adaptation and other objectives, including mitigation (multiple objectives); (b) whether the finance comes from public or private sources; (c) the financing instrument; (d) the broad sectoral allocation; (e) the geographical distribution of funding (proportion of total in % and per-capita allocation). Based on data collated by CPI (2020).

The importance of public and private finance for adaptation and resilience

Adaptation finance provided by international public mechanisms remains the core source of tracked flows in support of adaptation and resilience to developing countries (Micale et al., 2018; UNEP, 2018), although these public funds alone are insufficient to meet rapidly growing needs and constitute only a minority share of all public climate finance flows (UNEP, 2016; Global Commission on Adaptation, 2019).

Public mechanisms can play a role in leveraging private sector finance for adaptation by addressing real and perceived regulatory, cost and market barriers through blended finance approaches, public–private partnerships or innovative financial instruments and structuring in support of private sector requirements for risk management and guaranteed investment returns (Pillay et al., 2017; Miller et al., 2019).

There is growing agreement on the sectors (such as infrastructure, agriculture or water management) and approaches (contingency finance or insurance) where private sector adaptation investments alone, or leveraged by public mechanisms, might be best targeted, such as by reducing the risk of providing financial services for adaptation investments to domestic micro-, small and medium enterprises or agricultural smallholders, many of them women (Biagini and Miller, 2013; Chambwera et al., 2014; Pauw et al., 2016; Global Commission on Adaptation, 2019; Miller et al., 2019; Resurrección et al., 2019; Richmond et al., 2020). A remaining open question is how to allocate limited public adaptation funds in a way that is equitable, effective and efficient between mobilising private investments and safeguarding adequate financial support for necessary adaptation efforts, such as the provision of public goods, which the private sector will not invest in (Fankhauser and Burton, 2011; Abadie et al., 2013; Baatz, 2018; Omari-Motsumi et al., 2019).

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Cross-Chapter Box FINANCE (continued)

Many adaptation interventions in the most vulnerable countries, communities and people provide no adequate financial return on investments and can therefore can only be funded with highly concessional public finance. Grant support is most appropriate for measures such as capacity building, planning, public policy and regulatory reforms, disaster risk management and response, community engagement or support for social safety nets, and for addressing social vulnerabilities, including poverty or gender inequality, which constrain adaptation (Grasso, 2010a; Pillay et al., 2017; Agrawal et al., 2019; Buchner et al., 2019).

Access to adequate adaptation grant finance is further constrained because several public mechanisms provide grants only for the additional costs of adaptation measures compared with a development baseline in the absence of climate impacts. Calculating the incremental costs of adaptation measures imposes additional time and resource burden on the most vulnerable recipients, who are often faced with data gaps or technical capacity constraints (Chambwera et al., 2014; GCF, 2018; UNEP, 2018; Omari-Motsumi et al., 2019).

An exact delineation of respective costs for adaptation and development components is difficult and might be unsuitable as many adaptation measures are intrinsically linked to development. It may also prevent realising necessary synergies between both components (McGray et al., 2007; Smith et al., 2011; Denton et al., 2014; Resch et al., 2017; Micale et al., 2018).

Equality and fairness in climate finance

Climate finance literature recognises that poor and least developed households, communities and countries are most affected and marginalised by climate change, and least responsible for its causes, but receive relatively little financial support for adaptation (Chapters 15, 8; Olsson et al., 2014; Rozenberg and Hallegatte, 2015; Hallegatte et al., 2016; Rai and Fisher, 2017; Shakya and Byrnes, 2017).

While the gap between current financial flows to developing countries and their adaptation needs (see Box Cross-Chapter Box FINANCE.1) is a major factor undermining equity and fairness in financing, several other factors that can also affect fair and just financing in developing countries have been identified in recent literature (Klein et al., 2014; Colenbrander et al., 2018; Mfitumukiza et al., 2019; Khan et al., 2019a; Doshi and Garschagen, 2020). First, financing is skewed in favour of mitigation, and therefore towards fast-growing upper- and middle-income countries offering the biggest gains in emission reductions, especially in Southeast Asia, but also in Sub-Saharan Africa (Rai et al., 2016). Further, as much of current finance uses debt-based instruments, mitigation projects are further preferred as returns are more assured (Lee and Hong, 2018; Carty et al., 2020).

Second, the requirement of many funders for readiness and fiduciary capacity means that least developed countries (LDCs) have been less able to access finance, despite many support mechanisms being offered. Additionally, geopolitical preferences of some countries mean that some developing countries are preferred to others for bilateral funding (Doshi and Garschagen, 2020). This is exacerbated for private sector investment, where lower credit ratings make finance more expensive, and increasing understanding of exposure to physical climate risks could lead to 'capital flight' from most vulnerable countries (Global Commission on Adaptation, 2019; Miller et al., 2019; Cooper, 2020).

Third, within climate-vulnerable countries, very little is channelled to local communities who need it most; the few analyses available suggest that less than 10% of total climate finance supports decentralised actions (Rai et al., 2016; Soanes et al., 2017). Reasons include: (i) lack of consideration of procedural equity in programme design (Grasso, 2010b; Wang and Gao, 2018; Venn, 2019; Khan et al., 2019a); (ii) finance being managed by multi-lateral implementers, rather than agencies that are closer to local communities; (iii) the higher transaction costs of decentralised projects in low-income communities reduce their attractiveness to funders as well as the ability of local organisations to meet the fiduciary standards (Fonta et al., 2018; Omari-Motsumi et al., 2019).

It has been proposed that, as middle-income countries can leverage mitigation finance from the private sector, targeting scarce public finance towards LDCs and SIDS may be necessary to ensure sufficient funds reach these countries (Steele, 2015). Matching domestic climate spending with international support is one way to ensure LDCs get the funds they need (Grasso, 2010b; Bird, 2014). Targeting specific marginalised communities and women within countries can also help make climate finance more effective and fairer, such as the Asian Development Bank's efforts to make lending portfolios more inclusive and pro-poor (ADB, 2018).

Post-COVID recovery packages, debt relief and finance for adaptation and resilience

Recent literature has highlighted the opportunity that COVID recovery packages offer for environmentally sustainable, low-carbon and climate-resilient economic growth (Forster et al., 2020; Hepburn et al., 2020; Hanna et al., 2021). Assessment of whether this is indeed happening is limited, although the few available studies suggest that that this opportunity is not being realised in many nations (O'Callaghan and Murdock, 2021; VIVID Economics, 2021). One study of the Group of Twenty (G20) and 10 other nations suggested that

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Cross-Chapter Box FINANCE (continued)

stimulus packages would have net negative environmental impact in two-thirds of these countries (VIVID Economics, 2021), while another showed that around half of G20 recovery investment targeted at energy has had gone towards fossil fuels, rather than to cleaner energy sources (Dibley et al., 2021).

Concerns have also been raised about the interactions between debt service, COVID economic recession and post-COVID recovery in developing countries (Simmons et al., 2021; Volz et al., 2021). Debt service grows as a proportion of national budget during recession, reducing scope for investment in recovery, is a self-reinforcing cycle. It has been suggested that linking debt relief to Paris-aligned objectives can act as an additional source of climate finance (Fenton et al., 2014). The G20 has begun addressing this debt crisis through its Debt Service Suspension Initiative and the Common Framework for Debt Treatments (IMF, 2020). It has been suggested that these initiatives could be expanded to prioritise climate-focused debt-relief instruments and to include more countries (Steele and Patel, 2020; Volz et al., 2021). If debt relief is used to invest in national instrument for green and inclusive recovery, national ownership of the use of the finance can occur, avoiding some of the negative connotations of historical debt restructuring (Volz et al., 2021).

These sectoral advances using AI employ various learning techniques inclusive of supervised and unsupervised learning, multi-modal learning and transfer learning techniques to generate more accurate predictions than afforded by traditional climate projection methods (Cheong et al., 2020b; Camps-Valls et al., 2021). AI applications use finer-resolution data such as sub-daily weather-related data, remote and wearable sensor data, text data and real-time survey data. They are fed into neural networks and semi-/unsupervised learning to configure detailed and more precise predictions of climate change impact on crop yields (Crane-Droesch, 2018), early warning (Moon et al., 2019), impact of extreme heat on older adults (Cheong et al., 2020a), poverty in Africa (Oshri et al., 2018) and multi-scale water management combining blockchain technology with remote water sensors (Lin et al., 2018).

Indigenous knowledge and local knowledge are thoroughly covered in SROCC (Abram et al., 2019; IPCC, 2019c; IPCC, 2019d) and in Section 1.3.3. We here add relevant points to decision-making, and an additional form of knowledge, practitioner knowledge.

Indigenous knowledge and local knowledge are gaining recognition at multiple scales (Kleiche-Dray and Waast, 2016; David-Chavez and Gavin, 2018; Nakashima et al., 2018). Of note is their association with ecosystem-based adaptations, showcasing the long-term place-based knowledge of Indigenous Peoples (Johnson et al., 2015; Walshe and Argumedo, 2016; Carter, 2019; Mazzocchi, 2020). These knowledges and practices can be an important enabling condition in decision-making processes, complementing scientific information by identifying impacts (Fernández-Llamazares et al., 2017; Katz et al., 2020), emphasising values to consider (Huambachano, 2018), offering solutions (Chanza and de Wit, 2016; Cuaton and Su, 2020; Orlove et al., 2020), guiding land use and resource management (Brondízio et al., 2021) and filling gaps in scientific knowledge (Hiwasaki et al., 2014; Audefroy and Sánchez, 2017; Makondo and Thomas, 2018; Son et al., 2019; Latulippe and Klenk, 2020; Wheeler et al., 2020).

Practitioner knowledge—the pragmatic, practice-based knowledge that comes from the regular exercise of craft or professional work—was also acknowledged briefly in AR5 (Jones et al., 2014) and treated significantly in SROCC (Abram et al., 2019). Practitioner knowledge resembles local knowledge in that it is acquired through participation in activities, and yet it differs from local knowledge, which is often place-based and tied directly to specific landscapes and communities. Local knowledge typically covers a variety of environmental domains. Practitioner knowledge may be shared with people in different locations and is often more focused on a narrower set of work activities. Recent calls have recommended bringing practitioners more fully into the IPCC assessment process, to promote more effective decision-making (Howarth et al., 2018).

Practitioner knowledge makes significant contributions to decision-making by broadening the range of alternatives which are considered and by bringing in understandings of systems to the selection and implementation of alternatives. Such knowledge is applicable to a large number of domains, including biodiversity management (Tengö et al., 2014; Rathwell et al., 2015), and natural hazard risk management in urban settings, as reported in Denmark (Madsen et al., 2019), the USA (Matsler, 2019), Canada (Yumagulova and Vertinsky, 2019), Mexico (Aguilar-Barajas et al., 2019) and the Caribbean (Ramsey et al., 2019). Other contexts, all at regional scales, include watershed management in Peru (Ostovar, 2019), livestock management in Finland (Rasmus et al., 2020), agricultural adaptation in a context of water scarcity in Iran (Zarei et al., 2020) and the water–energy nexus in the USA (Gim et al., 2019).

Literature indicates the importance of effective governance for promoting integration of local and practitioner knowledge with scientific knowledge (*high confidence*). This integration is most extensive and promotes a wider consideration of alternatives, where governance arrangements promote ongoing exchanges of information and discussion of solutions, whether through formal mechanisms such as regional committees (Gim et al., 2019; Ostovar, 2019; Rasmus et al., 2020; Zarei et al., 2020) or informal mechanisms such as personal networks and local discussion groups (Madsen et al., 2019; Yumagulova and Vertinsky, 2019). Where such arrangements are absent, practitioner knowledge is side-lined from the formulation and implementation of decisions (Aguilar-Barajas et al., 2019; Matsler, 2019; Ramsey et al., 2019).

17.4.4.2 Co-production and Other Composite Knowledge Systems

There is strong evidence that composite knowledge systems—characterised by interactions between the producers and potential users of climate change information—can help facilitate climate-related decision-making (Prokopy and Power, 2015; Richards, 2018; Ramsey et al., 2019). Several institutional forms and structures have been created to link scientific knowledge, Indigenous knowledge, and local and practitioner knowledge to climate change decision-making.

17.4.4.2.1 Co-production

The co-production of knowledge by different actors provides important avenues for exchanging and integrating climate-related knowledge in decisions made across society (*high confidence*). Though many definitions of co-production have been offered in recent years (Bremer and Meisch, 2017; Vincent et al., 2018; Bremer et al., 2019; Harvey et al., 2019a), most describe a set of individuals or organisations who work together to generate a set of products that entail new knowledge products and that guide action (Miller and Wyborn, 2020). Some major forms of co-production include action research (Baztan et al., 2017; Laursen et al., 2018; Zanocco et al., 2018a), trans-disciplinarity (Howarth and Monasterolo, 2016; Wamsler, 2017; Lanier et al., 2018; Scott et al., 2018; Knapp et al., 2019; Young et al., 2019), rapid assessment processes (Atkinson et al., 2018b) and participatory integrated assessments (Howarth et al., 2018; Krkoška Lorencová et al., 2018; Bitsura-Meszaros et al., 2019; Carter et al., 2019a; Cremades et al., 2019; Leitch et al., 2019; Martínez-Tagüeña et al., 2020; Section 17.3.1.3.1).

Co-production promotes iterative dialogue, experimentation, the tailoring of knowledge to context, needs and priorities, and learning, often promoting integration of Indigenous knowledge, local knowledge and practitioner knowledge with scientific knowledge (*high confidence*). It generally entails long-lasting ties and fully inclusive partnerships between different parties (Kench et al., 2018). Governance measures and adequate financing can act as enablers of such co-production. This integration is most extensive, and promotes a wider consideration of alternatives where governance arrangements promote ongoing exchanges of information and discussion of solutions, whether through formal mechanisms such as regional committees (Gim et al., 2019; Ostovar, 2019; Rasmus et al., 2020; Zarei et al., 2020) or informal mechanisms such as personal networks and local discussion groups (Madsen et al., 2019; Yumagulova and Vertinsky, 2019). Where such arrangements are absent, practitioner knowledge is side-lined from the formulation and implementation of decisions (Orleans Reed et al., 2013; Aguilar-Barajas et al., 2019; Matsler, 2019; Ramsey et al., 2019).

An important mechanism of co-production is the boundary organisation, a knowledge-producing organisation composed of individuals who reflect different disciplines or knowledge systems and who represent different activities, sectors or forms of governance (Blades et al., 2016; Graham and Mitchell, 2016; Guido et al., 2016; Jeuring et al., 2019; Serrao-Neumann et al., 2020; Zarei et al., 2020). Boundary organisations themselves can be linked into boundary chains (Lemos et al., 2014; Meyer et al., 2015; Kirchhoff et al., 2015a; Pretorius et al., 2019; Daniels et al., 2020). When individuals and organisations from different disciplinary backgrounds and missions coordinate their activities informally, the resulting ties have been termed 'knowledge networks' (Ziaja and Fullerton, 2015; Brugger et al., 2016; Guido et al., 2016; Davies et al., 2018; Klenk, 2018; Muccione et al., 2019; Ziaja, 2019). When such networks interact with each other, the resulting associations have been called 'communities of practice', which can work to collectively shape information to shared contextual circumstances (Orsato et al., 2018; Wang et al., 2019b).

There is extensive evidence that co-production can generate useful climate knowledge (Djenontin and Meadow, 2018; Bisbal, 2019; Ryan and Bustos, 2019; Hewitt et al., 2020; Jack et al., 2020; Lavorel et al., 2020; Ruiz-Mallén, 2020) and that it can increase the likelihood that knowledge will be used in decision-making (Vogel et al., 2016; Prokopy et al., 2017; Skelton et al., 2017; Sylvester and Brooks, 2020). Co-production is not without its costs, since it requires more time, money, facilitation expertise and personal commitment from participants than more conventional modes of knowledge production (Lemos et al., 2018; Sletto et al., 2019; Wamsler et al., 2019; Blair et al., 2020). Some research has shown ways to decrease the costs of co-production for participants, such as funding and time to enable and sustain interactions and to build trust and legitimacy, or to create boundary organisations (Young et al., 2016; Klenk et al., 2017).

Co-production is supported by project cycles that provide for the involvement of stakeholders from the outset (Daly and Dilling, 2019; Brady and Leichenko, 2020); flexible research agendas that do not assume a climate related question (Daniels et al., 2020); support for interactivity and reflexivity (Araujo et al., 2020); and institutionalising incentives which address the different values, norms, perceptions and work patterns of scientists, policymakers and civil society representatives (Cvitanovic et al., 2015; Vincent et al., 2015; Bruno Soares and Dessai, 2016; Singh et al., 2017; Djenontin and Meadow, 2018; Norström et al., 2020; Turnhout et al., 2020). Certain roles, such as policy entrepreneurs (Tanner et al., 2019), embedded researchers (Pretorius et al., 2019) and knowledge brokers (Cvitanovic et al., 2015), can facilitate co-production.

17.4.4.2.2 Climate services

Climate services (refer to CWG Box on Climate Services) can be important enablers of climate risk management, provided they are credible, relevant and usable (*high confidence*), and will become increasingly important as human influence on weather and climate extremes grows across all regions (Chapter 11; Fischer et al., 2021; IPCC, 2021). Climate services are more effective and more widely used when they are tailored to specific decisions and decision makers (*high confidence*). Sustained iterative engagement between climate information users, producers and translators can improve the quality of the information and the decision-making and avoid maladaptation (*medium confidence*).

Historically, climate services have been organised by climate information providers, based in meteorological, hydrological and agricultural faculties and services, serving to improve through climate risk management, including the use of historical information, monitoring, seasonal forecasts and long-term climate projections (Hewitt et al., 2012; Blome, 2017; Bessembinder et al., 2019; Vaughan et al., 2019b).

Recent research on climate services shows that transdisciplinary knowledge co-production is a key enabler, starting to shift emphasis from the creation of climate services *products* to climate services *processes* (Vincent et al., 2018; Carter et al., 2019b; Daniels et al., 2020), potentially increasing uptake and sustainability (Norström et al., 2020). This shift is a result of the recognition of benefits which a co-production approach can offer, in addition to the provision of information; these additional benefits include building confidence, capacities, learning, knowledge, social capital, institutional capacity, stakeholder relationships, social networks, beneficial management practices and strengthened institutions (Bruno Soares and Dessai, 2016; Djenontin and Meadow, 2018; Bremer et al., 2019).

Cross-Chapter Box 12.2 in WGI AR6, 'Climate information for climate services', shows that users are widely distributed across civil society. Relevant users of climate services include humanitarian organisations (Coughlan de Perez and Mason, 2014; Harvey et al., 2019b), government offices (Mahon et al., 2019), international agencies (Perkins and Nachmany, 2019) and the private sector (Beckett, 2016; Hudson et al., 2019). Climate services currently exist at local, national, regional and international scales, at time scales which range from sub-seasonal to decadal and longer (White et al., 2017; Hewitt et al., 2020) and in a range of different sectors (Bruno Soares and Buontempo, 2019). Agriculture is the sector with the largest number of examples (Zebiak et al., 2015; Burke and Emerick, 2016; Cliffe et al., 2016; Haigh et al., 2018; Buontempo et al., 2020); others include health (Ghebreyesus et al., 2010; Ballester et al., 2016), forestry (Caurla and Lobianco, 2020), fisheries (Busch et al., 2016), disaster risk reduction (Street et al., 2019) and water resources management (van Vliet et al., 2015; Golding et al., 2019). Evaluations of the extent to which climate services are accessed, used and deliver benefits to decision makers remain in an initial stage (Perrels, 2020), though studies suggest that these contributions vary widely depending on context. A review of evaluation of weather and climate agricultural services in Africa, for instance, found that most farmers use climate services when they are available , but that on-farm outcomes varied, with some farmers experiencing yield losses and others gains upward of 60% (Vaughan et al., 2019a). Other studies express concern that large climate service projects have run for decades at significant expense, without adequate evaluation (Gerlak et al., 2020).

Recent reviews (Carr and Onzere, 2018; Hewitt et al., 2020) provide evidence that the use of climate services is affected by (a) the quality, reliability and skill of the climate information (Zebiak, 2019); (b) the fit, tailoring and contextualisation of that information with respect to the specific decision-making needs of particular users (Clarkson et al., 2019); (c) the mode and method by which the service is communicated (Golding et al., 2017); and (d) the characteristics of the users themselves, including the users' access to resources that would allow them to alter their decisions based on the information provided (Clarkson et al., 2019).

A related literature characterises the extent to which the development, reach and effectiveness of climate services is affected by factors that can be termed 'climate service governance' (Stegmaier et al., 2020). Elements of this governance include the arrangements by which those parties engage with each other (Vaughan et al., 2016; Daniels et al., 2020) and the financial arrangements, and associated responsibilities, which support the service (Lourenço et al., 2015; Bruno Soares and Buontempo, 2019). Though governance varies by context, evidence suggests that engaging a range of experts and potential users in the co-design and co-production of climate services increases the use and utility of services (Lemos et al., 2014; Pope et al., 2017; Masuda et al., 2018; Harvey et al., 2019b). However, some studies warn that, even with broad and inclusive participation, power differentials can create barriers to co-production, reducing the usefulness of information products (Alexander et al., 2020) and the neglect of non-meteorological sources of information which may also possess useful predictive power (Coughlan de Perez et al., 2019).

A small but growing number of papers consider the business models that support climate services, including, for instance, the role of open data (Iturbide et al., 2019; Chimani et al., 2020), the standards or institutional mandates by which users come to understand the credibility and legitimacy of certain services (Bruno Soares and Buontempo, 2019), and the role of public–private partnerships (Cortekar et al., 2020). While the commercialisation of climate services holds significant promise that more and more specifically targeted services will be provided, there is not yet agreement on which business models best support this in different contexts. There is also concern that commercialisation of climate services may disadvantage under-resourced actors at the expense of wealthier or more powerful ones (Webber, 2017; Webber and Donner, 2017; Cortekar et al., 2020). It has been noted that some climate services, such as weather forecasts and early warnings, are an example of a public good, best provided by public agencies (*high confidence*) (Sutter, 2013; Kitchell, 2016; Hansen et al., 2018).

17.4.4.2.3 Capacity and motivation within knowledge systems

Knowledge of climate change influences decision-making not only by providing information but also by increasing the motivation to act and by promoting behaviour change. Evidence from many sectors (including water (Section 4.5.2), ocean and coastal ecosystems (Section 3.6.2), and agriculture (Section 5.4.2) and regions (including Africa [Section 9.8.4], Asia [Section 10.4.6] and North America [Section 10.4.5] shows that building capacity (e.g., adaptive capacity, institutional capacity, education/training in human capacity) can support adaptation and limited governance capacity can constrain it (*high confidence*). An emerging area of research examines the contribution of building capacity within public and technical organisations and agencies to draw on Indigenous knowledge and local knowledge (Adger et al., 2017; Hochman et al., 2017; Bacud, 2018). A number of factors influence the effect of knowledge on motivation and behaviour change, including values and education.

Decision makers who shape options for managing climate risk can evaluate stakeholders' capacities and motivations to participate in the implementation process of these options. Stakeholder engagement in climate change risk management supports successful adaptation (Gray et al., 2014; Elsawah et al., 2015; Siders, 2017; Giordano et al., 2020).

Research in psychology and related fields shows that the cognitive mechanisms by which individuals and organisations process climate information influence this capacity, motivation and engagement (Grothmann and Patt, 2005; Grothmann et al., 2013; Masud et al., 2016; Nelson et al., 2016; Takahashi et al., 2016; Hügel and Davies, 2020; Grothmann and Michel, 2021).

The perception of climate change as a major threat that requires action has increased since AR5, reflecting both the growth of information about climate change and the processing of that information (Lee et al., 2015; Fagan and Huang, 2019). Global social movements play an important role in raising public awareness of climate urgency (Thackeray et al., 2020). Climate change concern plays an important role in decision-making outcomes which entail public participation (Lammel, 2015; Chiang, 2018; van Valkengoed and Steg, 2019; Arıkan and Günay, 2020). Nonetheless, public risk perception varies sharply on spatial and temporal scales, reflecting environmental changes, social influences (Kousser and Tranter, 2018; Rousseau and Deschacht, 2020), economic capacities (Arıkan and Günay, 2020) and culture (Noll et al., 2020), as well as individual characteristics (van Valkengoed and Steg, 2019). The importance of values and norms is demonstrated by recent research which highlights how intrinsic motivation (altruistic, self-transcendental and eco-centric values) (Corner et al., 2014; Braito et al., 2017; Xiang et al., 2019; Bouman et al., 2020) and extrinsic social motivation (e.g., economic gains and social desirability) (van Valkengoed and Steg, 2019) can drive action.

Recent research shows the importance of education as a predictor of risk perception, motivation and action. Education level is the strongest predictor of public awareness of climate change risk in a study across 119 countries of public awareness of climate change risk (Lee, 2015), though this relationship varies in different nations, and is influenced by mediating variables (Muttarak and Chankrajang, 2015; Blennow et al., 2016) (Ballew et al., 2020). Knowledge and awareness of climate change are correlated with the motivation to undertake action on climate change (Hornsey and Fielding, 2017). The integration of climate science in educational curricula has been shown to be effective (Hess and Maki, 2019; Molthan-Hill et al., 2019), including approaches such as integration of the complex system approach (Jacobson et al., 2017), experiential climate change education (Siegner, 2018), including climate games (O'Garra et al., 2021; Pfirman et al., 2021), massive open online courses and informal science learning centres (Geiger et al., 2017).

Attention to behavioural change of individuals has grown since AR5, including cases which address both adaptation and mitigation (e.g., dietary changes, modification of buildings, transport alternatives) (Azadi et al., 2019; Fischer, 2019; Willett et al., 2019; Sharifi, 2020; Sharifi, 2021). The interventions to promote behavioural change can be bottom-up, initiated by individuals, communities, non-governmental organisations or the private sector, or top-down, coming from governments at various levels (Robertson and Barling, 2015; Stern et al., 2016). They are supported by a number of mechanisms, including education, information strategies, and campaigns, financial incentives, regulatory processes and legislation (Rosenow et al., 2017; Creutzig et al., 2018; Carlsson et al., 2019). These behavioural changes contribute significantly to effective risk management.

17.4.5 Enabling Condition 4: Catalysing Conditions

A clear difference between enabling conditions and catalysing conditions is emerging in the climate mitigation literature (Hermwille et al., 2019; Michaelowa et al., 2021), with some examples in the adaptation literature as well (Madsen et al., 2019; Booysen et al., 2019a; Bolorinos et al., 2020). Though enabling conditions are necessary pre-conditions that allow response options to be formulated and implemented, their presence alone does not guarantee that these response options will occur in a timely fashion or at a scale commensurate with the risk, or even that they will occur at all. Catalysing conditions address this deficit in advancing action. They serve to overcome the inertia that often operates as a barrier to action and motivate individuals and organisations to initiate or accelerate action. Different forms of catalysing conditions, described below, lead individuals and organisations to weigh more seriously the costs of delaying action or keeping action at low levels. Catalysing conditions focus the attention of individuals and organisations on particular risks, leading actors to augment their decision-making processes and to allocate financial and social resources to respond to those risks. This attention and deliberation can lead to more frequent and potentially substantial adaptations, whether through more extensive action on existing forms of adaptation or through the adoption of entirely new adaptations (Bolorinos et al., 2020).

The first two catalysing conditions described below address the costs of delaying action. Urgency increases the awareness of individuals and organisations of such costs, while windows of opportunity, including extreme events, are time-bound periods during which certain actions are possible, but after which they are more difficult or impossible. The other two conditions stimulate new forms or levels of action by promoting or directing step changes from one policy or management regime to another (Solecki et al., 2017). Litigation over adaptation issues, for example, can open new lines of action or close off old ones, while catalysing agents advance action through a variety of means (e.g., communicating the urgency of climate action, revising agendas for action, expanding coalitions which undertake action). As detailed below, these four catalysing conditions can operate together as well as separately to promote more prompt and extensive adaptations.

17.4.5.1 Urgency

Urgency can catalyse action for individuals and organisations. A moderate level of urgency serves as an important driver of climate action, but both high and low levels of urgency impede response (*high confidence*). Wilson and Orlove (2021) review 5 experimental and 20 observational papers that examine the relationship between urgency and levels of response in climate decision-making, across a range of settings: from individuals and households to communities, managed ecosystems, sub-national regions and international river basin. Urgency in the papers is defined primarily through objective and subjective time pressure, including the recognition of the costs of delaying action and the importance of using windows of opportunity during which new forms and higher levels of response are possible. All the experimental papers and all but three of the observational papers provide support for an inverted U-shaped relationship between urgency and response intensity (including motivation and action), with

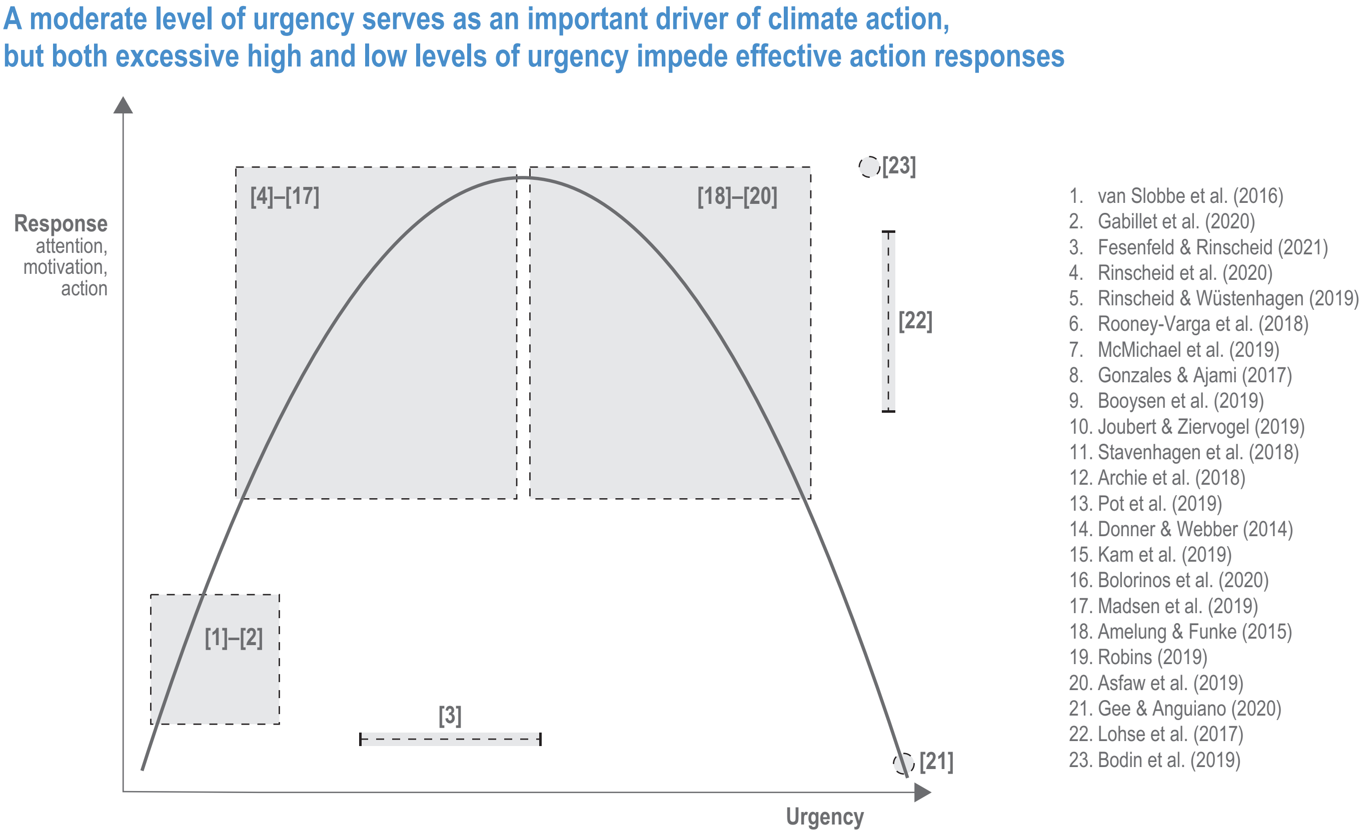

Figure 17.9 | A moderate level of urgency serves as an important driver of climate action, but both high and low levels of urgency impede response (derived from Wilson and Orlove, 2021).

higher levels of response at intermediate levels of urgency and lower levels of response at low or high levels of urgency (Figure 17.9). The general shape of this relationship also is supported for other decision domains by a well-established line of research within psychology (Heitz, 2014; Zakay, 2014; Prem et al., 2017).

The synthesis of the studies on urgency offers two central lessons for policymakers, community groups and others involved in addressing climate change. First, greater levels of response to climate change-induced challenges can be motivated by communication strategies that move decision makers from low to moderate levels of urgency (*high confidence*). In the case of drought, a number of studies show that urgent messages promote water conservation, especially when these messages are repeated, perceived as trustworthy and linked to concrete suggestions for action (Gonzales and Ajami, 2017; Joubert and Ziervogel, 2019; Kam et al., 2019; Booysen et al., 2019a; Booysen et al., 2019b; Bolorinos et al., 2020). These effects are also demonstrated in experimental studies of adaptation planning in contexts including European flood preparations (Madsen et al., 2019; Pot et al., 2019) and Pacific Island coastal planning (Donner and Webber, 2014).

Second, very high levels of urgency are a barrier to effective action (*medium confidence*) because last-minute actions to reduce risk during crises can create haste and panic, often leading to insufficient deliberation. In these cases, decision makers fail to consider a full range of alternative actions, make rash choices and poorly mobilise available resources (Asfaw et al., 2019; Robins, 2019; Gee, 2020). Given that climate decision makers in many regions and sectors are experiencing greater pressure to act, this finding suggests the existence of windows for planning and action during which climate risks have led to moderate levels of urgency, but before these risks have resulted in urgency exceeding some upper threshold (Section 17.4.5.2).

In addition, these studies point to potential weaknesses as well as strengths in strategic communication to modulate urgency. Such messages may instead lead to lower levels of response if they induce very high levels of urgency (Asfaw et al., 2019), though this effect may be somewhat mitigated by messages that simultaneously increase recipients' sense of self-efficacy or they are experienced in the specific risk domain discussed in the messages (Bodin et al., 2019). Future research on the relationships between urgency and effective risk management could help refine the measurement of urgency, how the relationship varies in different contexts, the role of different forms of messaging about urgency and action (Fesenfeld and Rinscheid, 2021), and the effects of urgency on decision-making by high-level decision makers within polities and by climate social movements.

17.4.5.2 Windows of Opportunity

Windows of opportunity are time-bounded periods during which conditions are present for advancing and often accelerating climate adaptation strategies. They can act as significant catalysing conditions for climate action and are connected to a range of possible outcomes from small incremental shifts to larger-scale more profound transformation adaptations (Novalia and Malekpour, 2020).

Windows can open because of extreme weather events (Birkmann and Fernando, 2008), political shifts, such as new institutions, new laws and regulations, and presence of a new policy entrepreneur or new policies (Haasnoot et al., 2013; Bell and Morrison, 2015), relevant and achievable policy goals, and emergence of new knowledge (Abunnasr et al., 2013), and close after the initial causes recede and become less efficacious. They also serve as focusing events whereby a coalition of groups address specific policy questions or response options (Rudel, 2019). Recognising that windows of opportunity often catalyse action does not mean that action outside such windows is insignificant or impossible.

Extreme events such as disasters often act as proximate drivers of windows of opportunity (Birkmann and Fernando, 2008; McSweeney and Coomes, 2011). Climate disasters in a specific location become significant windows for new debate, policymaking and financing (McSweeney and Coomes, 2011). Extreme events also can facilitate change at locations distant from the most impacted site when remote actors gain perspective on their own risks (Friedman et al., 2019; Solecki et al., 2019). Factors that facilitate extreme events driving proactive as opposed to reactive responses include access to relevant risk and vulnerability data, pre-existing experience with similar events, and appropriate governance (Brown et al., 2017a). Page and Dilling (2020) find that worldview or ideology plays a central role in sense-making and in shaping what organisational decision makers 'see' in terms of acceptable actions in response to an extreme event.

Significant variation is present across the mix and intensity of conditions that promote action through a window of opportunity. Capacity to respond to is a function of the presence of enabling conditions as well as tools and methods to aid decision-making (Shi et al., 2015). Political activism provides windows of opportunity for climate adaptation (Lauer and Eguavoen, 2016; see also Section 17.4.5.3.1).

Sudden shifts in institutions and legal framework can also catalyse climate action. For example, the year 2015 included a series of international frameworks such as the Sendai Framework for Disaster Risk Reduction 2015–2030 (van Niekerk et al., 2020; Hofmann, 2021), the 2030 Agenda for Sustainable Development, which established the Sustainable Development Goals (Sanchez Rodriguez et al., 2018), and the Paris Climate Agreement, which dramatically enhanced the promotion and implementation of altered the conditions under which climate adaptation occurred.

17.4.5.3 Climate Litigation on Adaptation

Litigation for Loss and Damage from climate change was first noted as a potential motivator for emissions reduction in AR4, and AR5 noted that litigation was pending but not tested and that, while legal systems were beginning to define the boundaries of responsibility for climate change, it was 'unclear liability exists'. The SR1.5 (IPCC, 2018a) reported, with *high confidence*, that litigation risks of government and business had increased, and the SRCCL (IPCC, 2019b) noted that recent developments in climate attribution improve the ability to detect human influence on climate and broaden liability.

Since AR5 there has been growing recognition of the potential of litigation for failure to take measures to adapt to climate change to drive climate risk management (Banda and Fulton, 2017; Peel et al., 2017; Bouwer, 2018). Litigation cases on adaptation and loss and damage account for about one-third of those covered in the literature (Setzer and Vanhala, 2019). Reasons for this growth are: (i) the growing gap between projected climate change impacts and current adaptation efforts (Stezer and Byrnes, 2019) and (ii) expanded legal duty of government, business and others to manage foreseeable harms (Marjanac and Patton, 2018). Climate change litigation is expanding geographically into the Americas, Asia (and the Pacific region) and Europe, with several cases brought in low- and middle-income countries (Stezer and Byrnes, 2019) (Table 17.6).

Lawsuits against private entities contribute to articulating climate change as a legal and financial risk (*medium confidence*) (Peel and Osofsky, 2015; Ganguly et al., 2018; McCormick et al., 2018; Peel and Osofsky, 2018). Even if unsuccessful, Estrin (2016) concludes they are important in underlining the high level of public concern.

Climate-related, legal, financial disclosure requirements are improving investment decision-making of corporations as well as augmenting *ex post* liability for failure to consider climate change risk in decision-making. Organisations are required to disclose governance around climate-related risks (impact of climate change on businesses, products, services, supply or value chain, adaptation and mitigation activities, investment in research and development and operations). This functions as a vehicle for identifying climate-related risk and the organisation's resilience strategy taking into consideration different climate- related scenarios including a 2°C or lower scenario (Sarra, 2018). Institutions such as the G20 (Carney, 2019), the American Bar Association (Brammer and Chakrabarti, 2019) and the European Commission (Zadek, 2018) have adopted or endorsed these standards.

17.4.5.4 Catalysing Agents

Individuals and organisations often serve as catalysing agents of climate risk decision-making. They promote greater levels of new forms of climate action by communicating the urgency of climate action and by developing coalitions which undertake action. Agents include individuals, organisations or collectives, or multiple organisations linked together.

17.4.5.4.1 Social movements and other mobilisations

Recent studies of climate-related social movements show that they can act as catalysing agents which promote action to manage climate-related risks (*medium confidence*). However, these studies use varying definitions of climate movements within the broader context of environmental movements. A prominent topic of research is the rapidity and the large scale of the proliferation of these movements around the world, primarily in urban settings but also in rural and Indigenous contexts (Claeys and Delgado Pugley, 2017).

Table 17.6 | Examples of types of climate-related litigation.

Litigation type	Detail and examples	Supporting literature
Challenge government decisions for not considering climate change risks	Challenging government or administrative planning decisions for failure to consider, or adequately address, climate change in relation to developing and protecting coastal zones, water-stressed regions, flood-prone areas or decisions affecting endangered species whose habitat is at risk. For example, the Victorian Civil and Administrative Tribunal in Australia rejected a planned housing project in a coastal area, citing the risks from climate change (Gippsland Coastal Bd. v. South Gippsland Sc & Ors (No2), 2008).	Banda and Fulton (2017); Peel et al. (2017); Bouwer (2018); Clarke and Hussain (2018)
Petitions to act	Constitutional petitions to force governments to take adaptation measures. As an example, in Leghari v. Pakistan a farmer initiated public interest litigation against federal and provincial governments for failure to develop climate change resilience through adaptation to floods, droughts and other impacts because it violated his rights to life and dignity. The High Court of Lahore found for Mr. Leghari and created a commission to develop and implement a wide range of adaptation actions.	Banda and Fulton (2017); Ashgar Leghari v. Federation of Pakistan (April 2015); Ashgar Leghari v. Federation of Pakistan (September 2015)
Regulatory proceedings	Environmental groups and city and state officials intervened in the application of the electric utility serving New York City, Consolidated Edison Company, to the New York State Public Service Commission for a rate increase. The intervenors argued that the company was not adequately preparing for flooding, heatwaves and other climate-related impacts. As a result, the Commission directed the company to undertake a study of its vulnerability to climate change, and write and implement a plan to address these risks.	Consolidated Edison Co. (2019)
Failure to act by public authorities	Liability of public authorities for failure to undertake necessary adaptation actions to avoid damage to life or property, especially where statutory framework is proven ineffective or out of step with international commitments; in some areas these are class action suits. An example is private lawsuits for failure of a built environment to consider adaptation needs in a built environment (energy efficiency works, overheating because of increased temperatures).	Banda and Fulton (2017); Peel et al. (2017); Bouwer (2018)
Failure by private sector to consider climate change adaptation in their business practice	Examples include: (i) a citizen suit against ExxonMobil for failure to adapt Everett Terminal to the impacts of climate change including increased precipitation, sea level rise and storm surges occurring with increasing frequency; (ii) a citizen suit against Shell Oil Products US alleging Shell failed to incorporate climate risks in its investment in a bulk storage and fuel terminal in Rhode Island, USA; (iii) shareholder action against ExxonMobil for failure to report climate risks or complying with recommendations to do so and for issuing misleading corporate disclosure relied on by investors; (iv) a suit brought an NGO, the Conservation Law Foundation, against Exxon Mobil alleging that the company had taken insufficient precautions to protect a major oil tank farm near Boston, USA, from coastal storms that are worsened by climate change, creating a danger of an oil spill into Boston Harbour. The U.S. Court of Appeals for the First Circuit ruled in 2021 that the lawsuit could proceed, and that the NGO could attempt to make out its case that Exxon Mobil should take greater precautions.; (v) government and citizen claims for public nuisance against fossil fuel companies for the costs of adaptation such as infrastructure to protect against sea level rise.	Benjamin (2017); Stezer and Byrnes (2019); Street and Jude (2019); Wasim (2019); Conservation Law Foundation v. Exxon Mobil Corporation (2021)
Youth public trust claims	Government inter-generational liability for inadequate climate change mitigation and adaptation efforts. Our Children's Trust (a non-profit organisation) and others brought an action against the USA and several executive branch individuals in 2015 claiming damages for their loss of the environment and the defendant's failure to preserve a habitable climate system by the governments' affirmative actions that actively cause and worsen the climate crisis. Similarly, a public trust claim could be brought in a coastal town for failure to adapt to climate change.	Schneider et al. (2017); Bouwer (2018)
Human rights claims	Human rights may be a powerful tool for organising and unifying adaptation decision-making, especially for the most vulnerable, through enforcement mechanisms of progressive realisation as well as *ex post* liability (Chapter 8). For example, a persons' right to food implores state parties to take necessary actions to alleviate hunger caused by climate change; during natural and other disasters, rights to water and life are impacted; sea level rise and storm surges impact many coastal settlements and the right to adequate housing and an adequate standard of living. This is in part due to increasing acceptance of the impact of climate change on health, livelihoods, shelter and fundamental rights.	Hall and Weiss (2012); Peel and Osofsky (2018); Setzer and Vanhala (2019); Stezer and Byrnes (2019)

These movements usually focus on climate mitigation but sometimes include adaptation. Their social bases include groups which had not previously been active in climate politics, notably children and youth, as well as sectors with long traditions of environmental activism, such as women and Indigenous Peoples (see Cross-Chapter Boxes GENDER and INDIG in Chapter 18). Much of the literature on youth movements traces the emergence of the movements themselves (Sanson et al., 2019; Treichel, 2020), their framings of climate change as a social justice issue (Holmberg and Alvinius, 2019) and their presence in demonstrations and on social media (Boulianne et al., 2020). Climate action catalysed by youth and other climate movements include visible international events such as the signing of Declaration on Children, Youth, and Climate Action at COP25 in Madrid 2019 (Han and Ahn, 2020), as well as national efforts, including lawsuits, and local events such as in tree-planting and waste reduction initiatives (Bandura and Cherry, 2019).

A recent review examines 2743 cases around the world of mobilisations for environmental justice causes (Scheidel et al., 2020); roughly half the cases occurred between 1970 and 2007, and half between 2008 and 2019. Of these environmental mobilisations, 17% are directly related to climate and energy, and others are related to climate-sensitive issues (15% for biomass and land use, 14% for water management). This study reports the proportion of positive outcomes for different strategies, defined as meeting the goals of the movements, which generally align with climate adaptation and sustainable resource management. These rates vary from 10% for negotiated solutions to 34% for court decisions.

It notes the corresponding higher rates of failure, as well as the costs borne by the movements, which include criminalisation (20% of cases), violence (18%) and assassination (13%). These costs are significantly higher for Indigenous communities that engage in these mobilisations.

At a global scale, climate movements succeeded in pressing for the greater recognition of the importance of Indigenous knowledge within international agreements (Tormos-Aponte and García-López, 2018) but did not achieve the major reforms of climate finance which they sought (Khan et al., 2019a); these differing outcomes reflect the sensitivity of the issues and the formation of coalitions which supported or opposed the movements. At national and local scales, one review of US cases reports limited effectiveness of climate movements because of the ability of governmental agencies to co-opt them (Pulido et al., 2016), while another review in Pakistan shows a number of successes, because the movements were able to build alliances with other public sector and community groups (Shawoo and McDermott, 2020).

17.4.5.4.2 Policy leaders and entrepreneurs

Policy leaders, often described as policy entrepreneurs within the scholarly literature, are individuals in positions of leadership who set agendas and build coalitions to drive decision-making processes, and hence can function as catalysers of climate adaptation (Petridou and Mintrom, 2020). Political leaders who have taken on climate change as a key policy issue function as policy entrepreneurs at international, national and sub-national levels. City officials, including mayors and other executives, often play the role of climate policy entrepreneurs, while the absence of effective leadership negatively affects adaptation success (Becker and Kretsch, 2019). Such entrepreneurs can be important forces for change in both reactive contexts following an extreme or focusing event and in proactive context. They can be effective especially in contexts where they navigate and link together formal and informal networks of complex climate governance systems (Tanner et al., 2019). Their capacity to act has been increased when they and their institutions are embedded within partnership networks (Bellinson and Chu, 2019). It is in these contexts that the leadership and position of a policy entrepreneur becomes even more catalytic when operating at the interface of formal and informal networks (Mintrom, 2019; Stone, 2019).

Sub-national actors and city officials including mayors and other executives are among the individuals most often described and assessed as climate policy entrepreneurs (Kalafatis and Lemos, 2017). City-level climate policy entrepreneurs often operate using their own experience, connections and persistence to address issues of importance to their constituency. Climate risk concerns are often inherently local, and in turn local decision makers perceive it as being appropriate to engage. Conversely, the absence of effective leadership negatively affects adaptation success (Kalafatis and Lemos, 2017; Becker and Kretsch, 2019). Urban climate policy entrepreneurs operate in four key spheres of policy development and implementation: attention and support seeking strategies; linking strategies (e.g., coalition building); relational management strategies (e.g., networking and trusting building); and arena strategies including timing (Brouwer and Huitema, 2018). The presence and operation of urban climate policy entrepreneurs is positively associated in settings with multiple jurisdictions and across differing spatial scales (Kalafatis and Lemos, 2017; Renner and Meijerink, 2018). It is in these contexts that their capacity to operate simultaneously at the interface of multiple networks is particularly valuable for promoting climate action. Urban climate policy entrepreneurs can directly engage with a range of constituent groups and offer and promote climate adaptation strategies that can have direct impact on the daily lives of these residents and their interests.

17.5 Adaptation Success and Maladaptation, Monitoring, Evaluation and Learning

17.5.1 Adaptation Success and Maladaptation

17.5.1.1 The Adaptation–Maladaptation Continuum

As evidence on adaptation implementation grows (Berrang-Ford et al., 2021; Eriksen et al., 2021), there is a need to examine the outcomes of adaptation (Ford et al., 2011) for effectiveness, adequacy and justice/equity in both outcomes and process, as well as synergies and trade-offs with mitigation, ecosystem functioning and other societal goals. There is also a growing recognition of the observed and potential negative consequences of some adaptation interventions, often referred to as maladaptation (Juhola et al., 2016; Magnan et al., 2016; Schipper, 2020; Eriksen et al., 2021). This section advances a new framing to allow for an improved assessment of the potential positive or negative outcomes of adaptation options, therefore allowing navigation of the adaptation–maladaptation continuum.

17.5.1.1.1 Defining and assessing success in adaptation vis a vis maladaptation

The highly contextual nature of adaptation, a multitude of applied definitions of adaptation (e.g., cost effectiveness versus outcomes), its overlaps with development interventions, and the long time horizons over which outcomes accrue, deter a universal definition of adaptation success (Dilling et al., 2019; Section 17.5.1.2; Owen, 2020; Singh et al., 2021). Moser and Boykoff (2013), Olazabal et al. (2019b) and Sherman and Ford (2013) suggest criteria against which successful adaptation could potentially be tracked. The literature is converging to suggest that successful adaptation broadly refers to actions and policies that effectively and substantially reduce climate vulnerability, and exposure to and/or impacts of climate risk (Noble et al., 2014; Juhola et al., 2016), while creating synergies to other climate-related goals, increasing benefits to non-climate-related goals (such as current and future economic, societal and other environmental goals) and minimise trade-offs (Grafakos et al., 2019) across diverse objectives, perspectives, expectations and values (Eriksen et al., 2015; Gajjar et al., 2019a; Owen, 2020) (*high confidence*).

Maladaptation refers to current or potential negative consequences of adaptation-related responses that lead to an increase in the climate vulnerability of a system, sector or group (Barnett and O'Neill, 2010) by exacerbating or shifting vulnerability or exposure now or in the future (Antwi-Agyei et al., 2014; Noble et al., 2014; Juhola et al., 2016; Magnan et al., 2020) and eroding sustainable development (Juhola et al., 2016). Conceptually, maladaptation differs from 'failed' or

Box 17.3 | Climate Risk Decision-Making in Settlements: From Incrementalism to Transformational Adaptation

Cities are important sites of experimentation where the integration and management of adaptation decision-making complexity often takes place. These actions provide early evidence of what aspects of complex climate risk management decision-making functions well, but also what does not work (Revi et al., 2020). Cities are seen as locales where case examples of transformative adaptation can be examined (Rosenzweig and Solecki, 2018; Vermeulen et al., 2018). Cities act as testbeds of how to integrate climate response into issues of equity, health, resource allocation and sustainability in ways that utilise innovative use of new and emerging decision-support tools, methods and protocols.

Risk management has been an integral part of the community development and settlement building process. Three key sets of drivers influence risk management decision-making in cities (Solecki et al., 2017). These include: (1) root, that is, cultural norms and social traditions; (2) context, that is, policy and governance conditions; and (3) proximate, that is, extreme events. Settlements have developed informal and formal strategies, including climate protection levels, to respond to local conditions of climate risk and hazards. In formal contexts, these strategies are contextualised in local climate change action plans (Araos et al., 2016a; Stults and Woodruff, 2017; Reckien et al., 2018a; Singh et al., 2021) and defined around a set of evaluation tools and methods and building codes, standards and regulations (see discussion in Section 17.4.4).

Climate change has begun to alter the environmental baseline of cities, changing their risk and hazard profiles. In recent years, national and local risk management can benefit from assessments of current decision-making strategies and from evaluations of opportunities for change in risk management policy. These changes can be adjustments of existing policies or transitions to a new policy for current (i.e., conditions already experienced by getting worse) or emerging risks (i.e., conditions not previously or widely experienced but now increasingly present).

With increasing impacts of climate change, settlements of all sizes are considering how to make their communities more resilient to climate risk (see Cross-Working Group Box URBAN in Chapter 6; Araos et al., 2016a; Araos et al., 2017; Reckien et al., 2018a). In many settlements, demands for heightened resiliency are being coupled with opportunities to enhance the social and economic equity and quality of life of residents. Transformational adaptation (transformational, as being outcome-oriented; Vermeulen et al., 2018) and associated adjustments to the urban risk management decision-making require an integration of climate resiliency pathways and conditions of sustainable development (Mendizabal et al., 2018). At the same time, growing conflict is present between requirements for greater resiliency and continued economic development, in particular in low-income environments (Ahenkan et al., 2020). Cities and their residents have the capacity to transform their own governance and decision-making systems (Birkmann et al., 2014; Chu, 2018; Romero-Lankao et al., 2018). Furthermore, cities have recognised the opportunity and demand to transform in order to be more ambitious (Mendizabal et al., 2018) and more successful, more equitable (Reckien et al., 2018b) and better able to connect the climate action to the sustainable development process (Singh et al., 2021).

In some cases, transformational adaptation is associated with large-scale, top-down, formal decision processes leading to significant policy shifts. For coastal cities, this might include actions to build massive flood protection systems (as opposed to simple increase of existing structures) (Albers et al., 2015; Hinkel et al., 2018; Ajibade, 2019; see also Section 2.3.5, Cross-Chapter Paper 2) or policies to encourage managed retreat from increasing at risk locations (Hino et al., 2017; Rulleau and Rey-Valette, 2017). In more extreme instances, the relocation of cities is presented as a possibility, such as planned for the city of Jakarta (Garschagen et al., 2018b). However, acceptability of top-down approaches to relocation are usually low, and bottom-up drivers of relocation are important, especially to avoid inequitable outcomes (Mach and Siders, 2021). Intensity of extreme events and changing risk perceptions and expectations of property prices have been identified as important behavioural drivers of voluntary relocation (de Koning et al., 2019; de Koning and Filatova, 2020). Yet, when not supported by equitable public adaptation policies, the transformational adaptation left to the influence of autonomous adaptation and market institutions alone leads to climate gentrification low-income households are priced out from the hazard-free zones (de Koning and Filatova, 2020).

These circumstances also have revealed potential advances in decision-making by encouraging greater participation, more effective generation and use of information and data, and more prominent inclusion of questions of social and economic equity (Ziervogel et al., 2017; Reckien et al., 2018b; Solecki et al., In Press). Adaptation planning and decision-making, in general, within cities has increasingly focused on actively engaging residents in participatory and neighbourhood scale co-production processes (Broto et al., 2015; Sarzynski, 2015; Wamsler, 2017; Foster et al., 2019). However, engaging residents in risk management and adaptation has not always led to transformative decision-making and resiliency, but can at times also reinforce existing maladaptive systems (D'Alisa and Kallis, 2016).

Box 17.3 (continued)

Now increasing amounts of data are being collected via surveys or in participatory settings next to advanced methods, such as using citizen science, big data and AI, to integrate these social dimensions of climate adaptation decisions in cities in formal models (Abebe et al., 2019; Taberna et al., 2020). Linking to social data on individual decisions, risk perceptions, social norms and governmental policy, advanced social models trace and quantify how adaptation in cities evolve and would cumulatively induce transformational change. Although wider application of these models is outstanding, there is opportunity to simulate and learn from the integration of social and behavioural data with political and cultural norms (de Koning and Filatova, 2020).

Although non-urban areas could in many instances act in the same way as urban areas, the density of people, assets, infrastructure and economical values drive cities to act as testbeds, implement adaptation and strive for resiliency. Cities are showcases for the larger environmental systems of governments that also support mitigation ambition of national actors and are therefore demanding to be recognised as valuable actors in the international negotiations, highlighting their contribution in emissions reductions (Chan et al., 2015; Hale, 2016), such as in the preparation for the first Global Stocktake of the Paris Agreement in 2023 (see Cross-Chapter Box PROGRESS in this Chapter).

'unsuccessful' adaptation (Schipper, 2020), which 'describes a failed adaptation initiative not producing any significant detrimental effect' (Magnan et al., 2016: 648). Several frameworks have been proposed to explain and better assess maladaptation (Hallegatte, 2009; Barnett and O'Neill, 2010; Magnan, 2014; Magnan et al., 2016; Gajjar et al., 2019b). To limit the risk of maladaptation, a common focus of these frameworks is on intentionally avoiding negative consequences of adaptation interventions, anticipating detrimental lock-ins and path dependence, and minimising spatio-temporal trade-offs/ dis-benefits.

The adaptation literature challenges the simplistic dichotomy of interventions being either successful or maladaptive (e.g., Moser and Boykoff, 2013; Singh et al., 2016; Magnan et al., 2020; Schipper, 2020). There is no clear-cut boundary between these two categories; rather, successful adaptation and maladaptation need to be considered as the two ends of a continuum of risk management strategies (Figure 17.10), emphasising that:

- no options are 'bad' or 'good' *a priori* with respect to reducing climate risk/vulnerability.
- positive and negative outcomes of adaptation depend on local context specificities (including the presence/absence of enabling conditions [1]), how adaptation is planned and implemented, who is judging the outcomes (i.e., adaptation decision maker, planner, implementer or recipient) and when adaptation outcomes are assessed.
- *ex ante* assessment of where options fall on the continuum can help anticipate maladaptive outcomes.

Along the adaptation–maladaptation continuum, adaptation options can score high or low on different outcome criteria identified in this section such as: benefits to the number of people, benefits to ecosystem services, equity outcomes (for marginalised ethnic groups, gender, low-income populations), transformational potential and contribution to GHG emission reduction (see SM 17.1 for full descriptions). Importantly, the outcome of the assessment, and consequently location of a given adaptation option along this continuum, is dynamic, depending on multiple components, including changes in the characteristics of climate hazards and the effects of iterative risk management. Unfortunately, this temporal dimension is understudied in the literature (including studying thresholds or speed), preventing advances on this specific point.

17.5.1.1.2 *Empirical evidence on success of adaptation vis a vis maladaptation*

Although the empirical evidence on current and potential successful adaptation and maladaptation remains small and fragmented (Magnan et al., 2020; Berrang-Ford et al., 2021; see Section 17.3.2 in this Chapter), the above framing allows for moving a step further in assessing the potential contribution of a wide range of adaptation-related options to success or maladaptation.

According to an assessment (Figure 17.11; see SM 17.1 for full descriptions) of maladaptation-relevant outcome dimensions, here called criteria, that is, benefits to people, benefits to ecosystem services, benefits to equity (marginalised ethnic groups, gender, low-income populations), transformational potential and contribution to GHG emission reduction, no option is located at one or the other end of the adaptation-maladaptation continuum (Figure 17.11, right panel), showing that all options have some maladaptation potential, that is, trade-offs (*very high confidence*). This is also shown by the wide confidence ranges of most options (right panel) signifying that most adaptation can be done in a way that involves a higher or a lower risk of maladaptation (*medium confidence*; see also Figure 17.3). The option of 'coastal infrastructure' signifies the highest risk for maladaptation. While it can be an efficient adaptation option in highly densely populated areas (Oppenheimer et al., 2019; CCP2.3), it has potential trade-offs for natural system functioning and human vulnerability over time. The options most widely associated with successful adaptation are 'nature restoration', 'social safety nets', 'change of farm/fishery practice' and 'change of diets/reducing food waste' (*high confidence*).

Some options show the dominant influence of certain criteria (Figure 17.11, central panel rows). For example, 'availability of health infrastructure' and 'access to health care' are dominated by the criterion

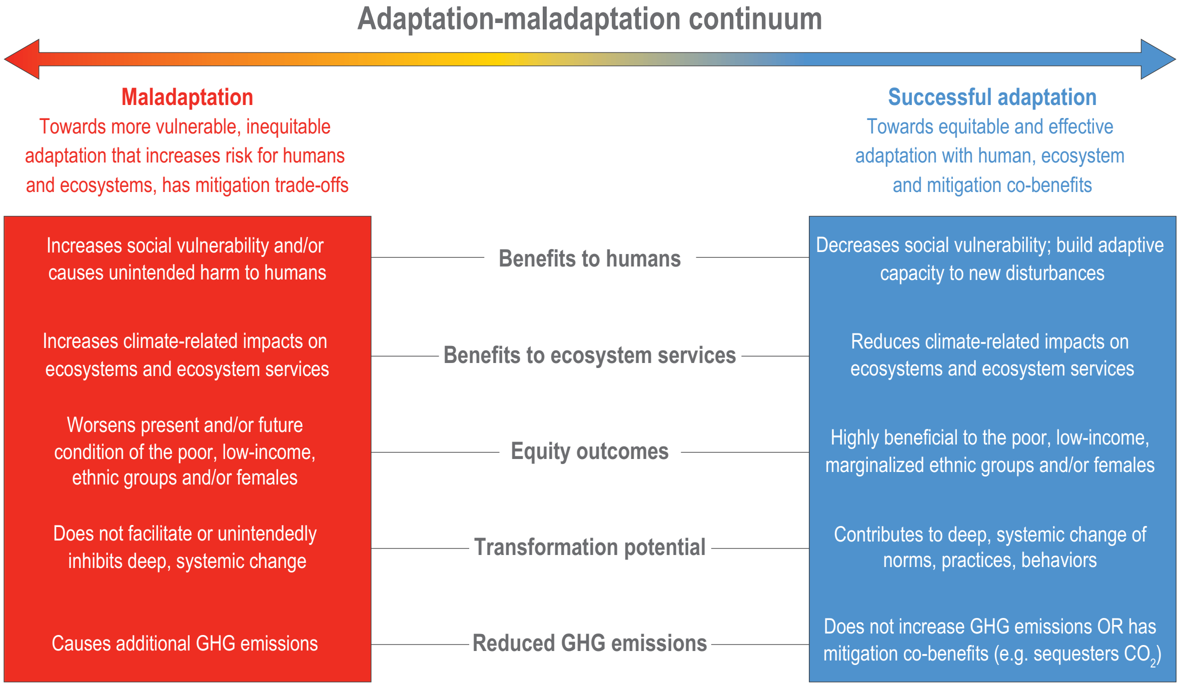

Figure 17.10 | Successful adaptation and maladaptation are conceptualised as the two end points of a continuum, with adaptation options being located along the continuum based on outcome criteria (how they benefit humans and ecosystems; how they contribute to or hinder equity goals; whether they enable transformative change to climatic risks; and synergies and trade-offs with climate mitigation). As indicated in SM 17.1 and Figure 17.10, adaptation options might rate largely positive and slightly negative across outcome criteria (tending towards successful adaptation), while other adaptation options might have small positive aspects and larger negative ones across different outcome criteria (tending towards maladaptation). The figure draws on Singh et al. (2016), Magnan et al. (2020) and Schipper (2020).

'greenhouse gas emissions'. Similarly, 'spatial planning' carries a high risk of disadvantages to marginalised ethnic and low-income groups. This means that these adaptations could be transformed into successful adaptations more easily than others, if attention is paid to the dominant criterion. For example, if health care could be provided with low GHG emissions, it would move closer towards successful adaptation (*high confidence*). For other options, the criteria's influence is more evenly distributed, as illustrated for the 'diversification of livelihoods' and the three options to address climate risks to peace and mobility, denoting multiple entry points to reduce the risk of maladaptive outcomes for these options.

Some criteria score highly across a number of options (Figure 17.11, central panel columns), showing that many adaptations do not pay attention to different trade-offs. For example, particular attention should be paid to prioritising benefits to low-income groups and leveraging the transformational potential of adaptation (having the largest number of large circles), that is, many evaluated options become maladaptive by exacerbating the vulnerability of low-income groups and by fortifying the status quo (*medium confidence*). On the contrary, most evaluated adaptation options are widely applicable across populations (benefits to humans) and deliver ecosystem services, while some also respect gender equity (largest number of small bubbles across options). Through these criteria, a number of adaptation options contribute to a higher potential for successful adaptation (*high confidence*).

The results displayed in Figure 17.11 are not rigorous predictions but illustrate the maladaptive potential of options based on a synthesis of literature from underlying WGII chapters and cross-chapter papers. This leads to findings for general situations, potentially obscuring critical contextual specificities which can mediate successful adaptation or maladaptation outcomes. In a certain context, Figure 17.11 will appear different. Moreover, the analysis is based on a static interpretation of adaptation outcomes, while risk and risk reduction are dynamic. The current, underlying literature does not help understanding the temporal dimension of the options, their flexibility or risk of lock-in, and related potential contribution to long-term maladaptation or successful adaptation. The added value of the analysis lies in the approach to assess the potential contribution to maladaptation or successful adaptation (via the seven criteria at the top of the figure), rather than in the final results themselves. This overview illustrates how, in a particular context and for particular groups of people, adaptation options and their location on the adaptation–maladaptation continuum can be assessed for a set of outcome dimensions, focusing on assessing potential contributions per and across criteria as well as per and across options (critical information to support the identification of adaptation pathways; Cross-Chapter Box DEEP in this Chapter).

17.5.1.1.3 Enabling successful adaptation and pre-empting maladaptation

Considering evidence on enabling successful adaptation in the sectoral (Chapters 2–8) and regional chapters (Chapters 9–15), four conditions stand out as particularly key to enabling adaptation success: recognitional equity and justice, including the integration of Indigenous and local communities and knowledge; procedural equity and justice; distributive equity and justice; and flexible and strong institutions that seek integration of climate risk management with

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https://doi.org/10.1017/9781009325844.026

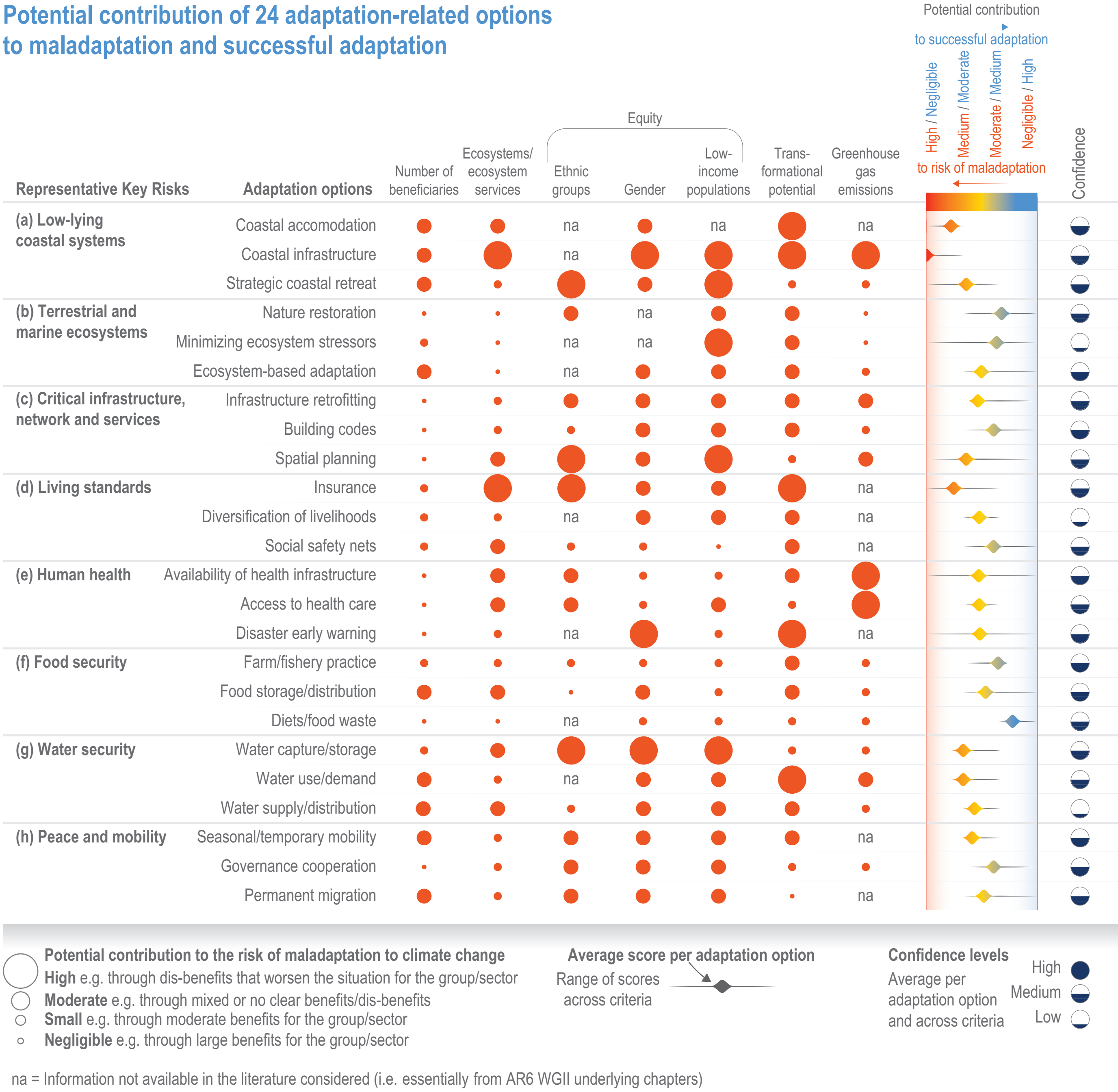

Figure 17.11 | The potential contribution of 24 adaptation-related options to maladaptation and successful adaptation. The figure builds on evidence provided in the underlying sectoral and regional chapters and the Cross-Chapter Papers (SM17.1) to map 24 adaptation options identified as relevant to the eight Representative Key Risks (see Section 16.5) onto the adaptation–maladaptation continuum. It assesses the potential contribution of each of these adaptation options to successful adaptation and the risk of maladaptation. The figure permits a review of options in multiple ways: (a) looking at adaptation options (first column), one can see which adaptation options score highest across the criteria (the central rows). Results by options show which ones carry the highest risk of maladaptation (largest circles per row); (b): looking at criteria (top centre), one can see which criteria seem to be most influential to contribute to maladaptation outcomes (largest circles per central column); (c) panel on the right: merging the scores of each adaptation option across criteria helps highlight whether the options are likely to end up as successful adaptation or maladaptation.

other policies and address long-term risk reduction goals (Table 17.7). For a wider discussion of enablers for adaptation and climate risk management, see Section 17.4.

Recognitional equity and justice: Recognitional justice focuses on inclusion and agency, that is, examining who is recognised as a legitimate actor and how their rights, needs and interests are acknowledged and incorporated into action (Singh et al., 2021).

A global assessment of 1682 papers on adaptation responses yields that low-income groups (*high agreement*, 37% of 1682 articles), women (*medium agreement*, 20% articles), Indigenous peoples

(10%), the elderly (8%), youths (5%), racial and ethnic minorities (4%), and migrants (4%) were the most frequently considered groups in adaptation responses. Individuals with disabilities are the least considered, with only 1% of articles including this group. There is a category of 'other' capturing characteristics of social disadvantage that are distinct from the categories above. This includes, for example, spatially marginalised populations (e.g., groups relegated to flood-prone or cyclone-prone areas) and groups marginalised due to marital status or assets (education, farm size and land tenure) (Araos et al., 2021).

Procedural equity and justice: Participation is employed to enable procedures that aim to redress power imbalances, which are assumed to be the root causes of vulnerability (i.e., the reasons that lead certain people and places to be differentially vulnerable to climate risks) (Tschakert and Machado, 2012; Shackleton et al., 2015; Schlosberg et al., 2017; Ziervogel et al., 2017). However, participation is often constrained by gender (Cross-Chapter Box GENDER in Chapter 18), social status, unequal citizenship (as concerns education, access to information, finance and media) (Wallimann-Helmer et al., 2019), entrenched political interests (Shackleton et al., 2015; Chu et al., 2017), power dynamics (Rusca et al., 2015; Taylor and Bhasme, 2018; Kita, 2019; Omukuti, 2020; Taylor and Bhasme, 2020) or institutional shortcomings (Nightingale, 2017, in Nepal), which allow the most powerful access to funding and reinforce marginalisation of the powerless (Schipper et al., 2014; Khatri, 2018; McNamara et al., 2020). Vulnerability is also sometimes used as a pretext to exclude groups from participation, often because vulnerable groups do not own land and lack legal status, time or the ability to commit labour or material inputs for adaptation, all drivers of vulnerability in the first place (Nyantakyi-Frimpong and Bezner Kerr, 2015; Camargo and Ojeda, 2017; Nagoda and Nightingale, 2017; Nightingale, 2017; Thomas and Warner, 2019; Mikulewicz, 2020).

Reporting from the global assessment of equity considerations in adaptation, procedural equity and justice was slightly more often mentioned (~52%) than not (~48%) (*medium agreement*). However, the robustness of the evidence on inclusion of vulnerable and marginalised groups in the planning of adaptation responses is low (63%) (*high agreement*). Only for ~6% of the articles that provide evidence for inclusion of vulnerable groups was the robustness of evidence high (*low agreement*). Globally, the categories of low income (~25%) and women (~13%) are most often included, although the robustness remains low. Most of the *robust evidence* comes from Africa and Asia, where adaptation responses mostly focus on low-income and women groups in the food (28%) and poverty (32%) sectors (*medium agreement*). With regard to other vulnerability categories, such as disabled populations, almost negligible evidence was found for the inclusion of this group, globally. There is also little reporting of procedural equity in community-based or ecosystem-based responses (Araos et al., 2021).

Distributive equity and justice: Attention to distributional equity and justice aims to ensure that adaptation interventions do not exacerbate inequities (Atteridge and Remling, 2018) and that the benefits and burdens of interventions are distributed fairly (Tschakert et al., 2013; Reckien et al., 2017; Reckien et al., 2018b; Pelling and Garschagen, 2019).

A global assessment of 1682 papers on adaptation (Araos et al., 2021) finds that about 60% of articles mentioned at least one vulnerable group being involved in the implementation of adaptation or targeted by it (*medium confidence*). Low-income groups (*high agreement*, 37% of 1682 articles) and women (*medium agreement*, 20% articles) are the most frequently mentioned. Particularly in sectors and regions that incorporated coping measures in their adaptation response (poverty, food, Africa, Asia, Central and South America), these groups are prevalent. In sectors where responses were more strategic or planned, such as in cities, terrestrial and water, in a larger proportion of articles (51%, 47% and 47% of articles, respectively) vulnerable groups were not frequently included in the response (*medium agreement*). There was also a stark difference in inclusion of marginalised and vulnerable groups between high-income and low-income countries or regions, with the majority of the responses from Australia, Europe and North America, not including marginalised groups (*high agreement* with 70%, 69% and 55% of articles, respectively), showing the need for increasing attention in particular on a cross-sectoral and cross-regional relation (Araos et al., 2021).

Flexible and strong institutions: There is *medium confidence* that flexible institutions can enable adoption of new adaptation measures or course-correct established ones based on ongoing monitoring and evaluation, which is key to avoiding potential maladaptation (e.g., Granberg and Glover, 2014, in Australia; Magnan et al., 2016; Torabi et al., 2018; Gajjar et al., 2019a, in India). Cross-sectoral, cross-jurisdictional and cross-spatial institutional frameworks enable successful adaptation by improving the ability of societies to respond to changes in their environment in a timely manner. The latter points to the vital role of monitoring and evaluation, as the tool to detect change in risk and vulnerability, together with environmental or societal conditions determining risk and the effectiveness, efficiency, adequacy or success of adaptation responses.

17.5.2 Adaptation Monitoring, Evaluation & Learning

17.5.2.1 Purpose of Monitoring and Evaluation

Adaptation responses have been observed in every region and across a wide variety of sectors (Section 16.3), but little evidence exists of their outcomes in terms of climate risk reduction (*high confidence*) (Section 1.4.3; Ford and Berrang-Ford, 2016; Tompkins et al., 2018; Berrang-Ford et al., 2021; Eriksen et al., 2021; UNEP, 2021a). To advance on that, the Paris Agreement is encouraging countries to engage in 'Monitoring and evaluating and learning from adaptation plans, policies, programmes and actions' (UN, 2015, Article 7.9d). Monitoring and evaluation (M&E) is the systematic process of collecting, analysing and using information to assess the progress of adaptation and evaluate its effects—for example, risk reduction outcomes, co-benefits and trade-offs—mostly during and after implementation (AR6 Glossary, Annex II). Distinctions between monitoring and evaluation typically view monitoring as a continuous process of tracking implementation and informing management to allow for corrective action including in situations of deep uncertainty (see Cross-Chapter Box DEEP in this Chapter), while evaluation is described as a more comprehensive assessment of achievements, unintended effects and lessons learned

Table 17.7 | Key factors that enable successful adaptation. The evidence and examples draw on the underlying sectoral and regional chapters as well as a synthesis of adaptation literature.

Enablers	What this enables	Key characteristics	Examples and traceability
Recognitional justice	Pluralising the ambit of who is 'counted' as vulnerable, drawing on multiple knowledge systems	– Focuses on inclusion and agency, i.e., who is recognised as a legitimate actor and how their rights, needs and interests are acknowledged and incorporated into adaptation (Chu and Michael, 2018; Singh et al., 2021). – Acknowledges how differential vulnerability to climate change stems from historical and structural inequalities, which can unevenly distribute adaptation benefits, especially for the poorest and the most marginalised (Tschakert and Machado, 2012; Shackleton et al., 2015; Schlosberg et al., 2017; Ziervogel et al., 2017; Eriksen et al., 2021). – Informs more equitable adaptation priorities (Ziervogel et al., 2017), legitimises adaptation actions (Myers et al., 2018; Ellis and Tschakert, 2019), supports inclusion of marginalised groups (Chu and Michael, 2018) (*medium confidence*).	– Co-production of knowledge and inclusion of Indigenous and local knowledge (Loboguerrero et al., 2018; Dannenberg et al., 2019, Cross-Chapter Box ILK; Ziervogel et al., 2019). – Co-production of knowledge and inclusion of marginalised groups across sectors, see, e.g., in the health sector (Chapter 7), food systems (Chapter 5) and fire management (Chapter 12).
Procedural justice	Differential participation and power for more inclusive adaptation planning and implementation	– Ensures that processes of representation and participation in adaptation planning, prioritisation and implementation are inclusive (Holland, 2017; Reckien et al., 2017; Reckien et al., 2018b) (*medium confidence*). – Enables adaptations to advance more quickly and generate higher levels of well-being (e.g., Dannenberg et al., 2019 comparing cases of strategic retreat), while also benefitting poorer households (Chu and Michael, 2018). – Higher participation can enable more legitimate outcomes, greater awareness about societal problems addressed, larger willingness for community cooperation, and increased individual behavioural change (Burton and Mustelin, 2013). – Participation in design and implementation of adaptation projects can be a critical element for avoiding maladaptive outcomes (Taylor, 2015; Nightingale, 2017; Forsyth, 2018; Mikulewicz, 2019).	– Participation of multiple stakeholders enables co-production of adaptation strategies and devolution of decision-making (Ziervogel, 2019) and often, if not always (D'Alisa and Kallis, 2016), a higher level of transformational adaptation (and more ambitious local mitigation goals) (Cattino and Reckien, in press). – Participatory processes can have more equitable outcomes as evidenced in informal settlements (Ziervogel, 2019, South Africa), small farmers (Loboguerrero et al., 2018, Colombia), migrants (Gajjar et al., 2019b, India) and deliberative dialogues (Ojha and et al., 2019). – But participation does not always address unequal power relations (e.g., Buggy and McNamara, 2016; Karlsson et al., 2017).
Distributive justice	Delivering adaptation for vulnerable groups and correcting structural vulnerabilities	– Ensures that adaptation interventions do not exacerbate inequities (Atteridge and Remling, 2018) and that the benefits and burdens of interventions are distributed fairly (Tschakert et al., 2013; Reckien et al., 2017; Reckien et al., 2018b; Pelling and Garschagen, 2019). – However, low levels of commitment to distributive justice, e.g., when justice is one of many goals of adaptation instead of the prime one, are insufficient to promote equitable distribution of benefits and harms (*medium evidence*, *high agreement*) (Anguelovski et al., 2016; Pulido et al., 2016; Weinstein et al., 2019; Shawoo and McDermott, 2020).	– Women and men have very different access to mobile phones, entailing lower responsiveness with climate services among women (Partey et al., 2020, across Africa). – Slow progress on prioritising distributional and procedural justice limits the expansion of adaptation funding to poorest and most vulnerable social groups and nations (Khan et al., 2019a). – Focusing only on distributive justice alone is less effective than a holistic integration of recognitional and procedural justice (*limited evidence*, *medium agreement*); e.g., only including poor households as recipients provides benefits to wealthier households, in sectors such as insurance for herders in Mongolia (Taylor, 2016b), urban water supply in Malawi (Rusca et al., 2017), informal urban settlements in Kenya (Pelling and Garschagen, 2019) and forest management in Cambodia (Work et al., 2019).
Flexible and strong institutions	Seeks policy integration and dynamic risk management, and accounts for long-term goals	– Institutional flexibility allows a society to respond quickly to the demands of a changing environment by developing new institutions or adjusting existing ones quickly (Davis, 2010); possibly avoiding lock-ins and addressing future climate risks (*very robust evidence*, *high agreement*) (Levi-Faur, 2012; Sherman and Ford, 2013; Boyd and Juhola, 2015; Magnan et al., 2016). – Stability (and familiarity) is often desired in governance arrangements, and balancing the need for stability with goals of flexibility without causing rigidity is key (Craig et al., 2017, in USA; Chapter 11). This is possible through deliberate, consultative changes that build awareness, develop shared norms, rules and goals, and develop inclusive decision-making processes (Chapter 3).	– Capacity building of adaptation funders, planners and implementers and re-orienting existing institutions to make decisions under uncertainty, institute long-term climate risk management that goes beyond typical political/planning cycles, and develop learning mechanisms between sectors, actors and projects needed (Moser and Boykoff, 2013; Granberg and Glover, 2014 in Australia; Boyd and Juhola, 2015 in cities; Ziervogel, 2019 in Africa and; Olazabal et al., 2019b in India; Chapter 3 Oceans; Chapter 10; Chapter 11; Chapter 12). – Flexible institutions enable adoption of new adaptation measures or course-correct based on ongoing M&E (e.g., Granberg and Glover, 2014 in Australia; Magnan et al., 2016; Torabi et al., 2018; Gajjar et al., 2019a in India) (*medium evidence*, *high agreement)*. – Sectoral or spatial policy integration (Chu et al., 2017; Section 17.6; Hino et al., 2017; Robinson and Wren, 2020); integration of jurisdictional frameworks of different agencies (Poesch et al., 2016; Chapter 5; Chapter 9); and adaptive and flexible legal systems which disaggregate socio-ecological systems into smaller components (Arnold and Gunderson, 2013; Wenta et al., 2019) are key enablers.

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carried out at certain point in time (OECD, 2002). M&E is an important part of the adaptation process (Figure 1.9). It can help to generate information on adaptation success or maladaptive outcomes.

M&E of adaptation is undertaken for different purposes, including: (1) understanding whether responses have achieved their intended objectives and contributed to a reduction in climate risks and vulnerability or to an increase of adaptive capacity and resilience, (2) informing ongoing implementation and future responses, and (3) providing upward and downward accountability (Preston et al., 2009; UNFCCC, 2010a; Pringle, 2011; Spearman and McGray, 2011). M&E is also commonly linked to learning (Section 17.5.2.7). By continuously monitoring implementation, for example, to assess whether adaptation is on track or needs to be accelerated, M&E can aid decision-making under uncertainty. Adaptation M&E is distinct from tracking financial flows related to adaptation since financial accounting does not provide information on implementation and outcomes (Section 17.5.2.5; Adaptation Partnership, 2012; World Bank Independent Evaluation Group, 2012).

17.5.2.2 Adaptation M&E Approaches

Adaptation M&E can be conducted for various purposes and in a wide variety of different contexts ranging from the local to the global level (McKenzie Hedger et al., 2008; UNFCCC, 2010a; Spearman and McGray, 2011). The context and specific purpose of M&E determine what information needs to be generated, and together with the available resources also determine the suitability of particular approaches and methods (Leiter, 2016; Leiter, 2017). Several frameworks and approaches have been proposed for M&E of adaptation and climate resilience (Bours et al., 2014d; Schipper and Langston, 2015; Adaptation Committee, 2016; ODI, 2016; Cai et al., 2018; Gregorowski et al., 2018), including sector-specific ones for agriculture (FAO, 2017; FAO, 2019a; FAO, 2019b), health (Ebi et al., 2018), ecosystem-based adaptation (Donatti et al., 2018; Donatti et al., 2020; GIZ, 2020) and cities (Section 6.4.6).

Adaptation M&E generally seeks to answer whether implementation is taking place and what effects it has (Figure 17.12). Accordingly, M&E can focus on the processes, activities and outputs or on their outcomes and ultimate impacts (Harley et al., 2008; Pringle, 2011; Ford et al., 2013). Most of the available guidance for the development of adaptation M&E systems is aimed at the household, local or project level (Pringle, 2011; Villanueva, 2012; Olivier et al., 2013; CARE, 2014; BRACED, 2015; Leiter, 2016; Jones, 2019b) with only limited guidance for national or cross-sectoral M&E systems (Price-Kelly et al., 2015) or frameworks that are applicable at different scales (Brooks et al., 2014). The available guidebooks take users through a series of steps which are synthesised in Figure 17.12.

The majority of adaptation M&E efforts have so far focused on processes and outputs rather than on achieved outcomes such as climate risks, vulnerability, well-being or development (Droesch et al., 2008; GIZ and Adelphi, 2017; UNDP Cambodia, 2014; Fawcett et al., 2017) (*high confidence*) or use a combination thereof (Brooks et al., 2011; Brooks et al., 2014). Newly emerging approaches include perception-based measurements and the use of data collected via mobile phones (Jones et al., 2018; Jones, 2019a), which can be collected frequently (Clare et al., 2017a; Knippenberg et al., 2019; Jones and Ballon, 2020). Such advances call into question the common reliance on 'objective' indicators defined from an external perspective. Instead, they suggest that multiple complementary approaches combined with higher-frequency data collection produce a more elaborate picture of the effects of adaptation and resilience responses (Jones and d'Errico, 2019; Knippenberg et al., 2019; Singh et al., 2019; Jones, 2019a; see Cross-Chapter Box PROGRESS in this Chapter) (*medium confidence*).

Central to designing, monitoring and evaluating adaptation responses is outlining how activities are expected to lead to intended objectives, for example, via a theory of change (Bours et al., 2014c; Oberlack and al., 2019). Theories of change or similar change models provide a basis to decide what to measure, but more attention needs to be paid to how theories of change are constructed and who is involved (Mason and Barnes, 2007; Forsyth, 2018). Participatory approaches can support understanding how climate risks affect the respective population, how these risks interact with social and cultural processes, and how responses could most effectively address climate risks (Conway et al., 2019). Inclusive M&E systems can facilitate ownership and enhance the meaningfulness and usability of the generated information (CARE, 2014; Faulkner et al., 2015). Meaningfulness is not associated with a particular approach or method but depends on whether the chosen M&E design fits the M&E purpose and the information needs of the intended audience (Fisher et al., 2015; Leiter, 2017). Effective communication of M&E findings and feedback into decision-making processes is essential to achieve the respective M&E purpose and facilitate learning (Section 17.5.2.7).

17.5.2.3 Adaptation Indicators and Indices

A set of all-purpose and globally applicable standard indicators that could comprehensively measure adaptation does not exist (*high confidence*) (IPCC, 2014; Leiter and Pringle, 2018). A wide variety of indicators have been used to assess adaptation and its results (CARE, 2010; Harvey et al., 2011; Lamhauge et al., 2013; Brooks et al., 2014; Hammill et al., 2014b; Mäkinen et al., 2018; HM Government, 2019). Literature has also noted unrealistic expectations of what indicators can accomplish. For instance, decisions involving competing political interests would not be adequately informed through simple indicators; and learning requires knowledge of how and why change has happened, something that indicators often do not capture (Hinkel, 2011; Bours et al., 2014b). Indicators can also become misguided incentives and might steer attention away from what matters (Leiter and Pringle, 2018; Hallegatte and Engle, 2019; Klonschinski, 2021). Surveys, scorecards, interviews and focus groups are alternative methods of gaining insights on adaptation progress (Brooks et al., 2014; Porter et al., 2015; Das, 2019; McNamara et al., 2020).

The difficulties of assessing adaptation and an emphasis on short-term results have contributed to the common practice of relying on easily quantifiable indicators rather than assessing actual changes, that is, outcomes and impacts (World Bank Independent Evaluation Group, 2012; Fisher et al., 2015). In fact, indicators used by international climate funds largely measure outputs which provide little evidence of the actual effectiveness of adaptation, that is, its outcomes and impacts (GCF Independent Evaluation Unit, 2018; Leiter et al., 2019; Pauw et al., 2020).

https://doi.org/10.1017/9781009325844.026

Adaptation monitoring, evaluation (M&E) and learning as part of the adaptation process

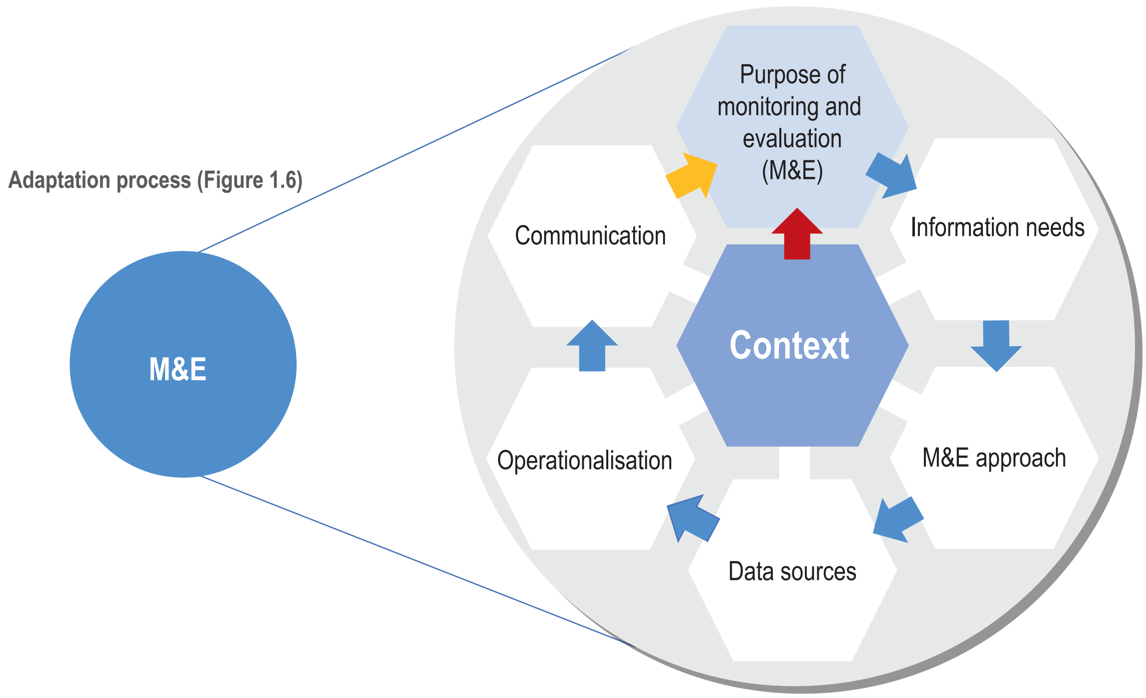

Figure 17.12 | Adaptation M&E and learning as part of the adaptation process (based on Hammill et al., 2014a; Price-Kelly et al., 2015; Leiter, 2016). This figure shows the main steps involved in developing an adaptation M&E system where the context informs the purpose of M&E, which in turn determines the information needs. To achieve the M&E purposes, the chosen approach and data sources need to be able to generate the needed information, which needs to be communicated in a suitable way to the target audiences.

Indices, the combination of multiple indicators into a single score, are common products of risk and vulnerability assessments to compare countries or other entities, often in the form of rankings or maps (Preston et al., 2011; Reckien, 2018; de Sherbinin and et al., 2019). They can indicate changes in vulnerability over time within their respective conceptualisation of vulnerability or risk. The construction of indices, including indicator selection, their weighting, normalisation and data sources, has a profound impact on their scores (Reckien, 2018). Research has consistently found large discrepancies between country vulnerability rankings (Brooks et al., 2005; Eriksen and Kelly, 2007; Leiter et al., 2017b; Visser et al., 2020). Reviews of vulnerability and resilience indices identified 'substantial conceptual, methodological and empirical weaknesses' (Füssel, 2010: 8) and a widespread lack of validation (Cai et al., 2018). Using countries as a unit of analysis also masks significant sub-national variation (Otto et al., 2015; Mohammadpour et al., 2019). Individual indices therefore 'fail to convene a robust guidance for policy makers' (Muccione et al., 2017: 4) and should not present the sole basis for policy decisions (Brooks et al., 2005; Leiter and Pringle, 2018). Due to their limitations (Singh et al., 2017), the OECD suggests that indices are primarily used for 'initiating discussion and stimulating public interest' (OECD, 2008: 13).

17.5.2.4 Empirical Evidence of National Adaptation M&E Systems

Tracking the implementation of national adaptation plans is essential for understanding their effectiveness, that is, the progress made in addressing climate risks, and can support assessing the success of adaptation and the risk of maladaptation. Over 60 countries have developed or started developing national adaptation M&E systems, although less than half are yet reporting on implementation (Leiter, 2021b; Table 17.8). Country-specific adaptation M&E systems vary considerably regarding their legal mandate, purpose, content, involved actors and types of reporting (Hammill et al., 2014a; EEA, 2015; Leiter, 2015; Leiter et al., 2017a; EEA, 2020). In most cases, they focus primarily on monitoring implementation rather than assessing outcomes, although some are linked to national climate risk or vulnerability assessments (e.g., in Germany and the UK) (EEA, 2018). At least 15 countries have published evaluations of national adaptation plans which help inform the development of successive adaptation plans or strategies (Table 17.8). Nevertheless, there is only limited empirical evidence of the ability of M&E systems to facilitate action or increase the level of ambition of revised policies. More research is needed to determine the quality of national adaptation M&E systems and how well they support the policy cycle.

Under the Paris Agreement, countries are encouraged to provide information on adaptation, including its adequacy and effectiveness (Möhner et al., 2017; Adaptation Committee, 2021). National adaptation M&E systems can inform both national as well as international reporting and contribute to the Global Stocktake (see Cross-Chapter Box PROGRESS in this Chapter; Craft and Fisher, 2015; Leiter et al., 2017a). Guidance for and examples of national adaptation progress assessments are provided by Price-Kelly et al. (2015), Brooks et al. (2014), Brooks et al. (2019), EEA (2015), GIZ (2017), Karani (2018) and van Rüth and Schönthaler (2018). Global assessments of adaptation progress have so far often focused on adaptation planning and, to a lesser extent, implementation, while evidence of the collective effect of adaptation globally remains limited (*high confidence*) (UNEP, 2021a; Cross-Chapter Box PROGRESS in this Chapter).

17.5.2.5 Challenges of Assessing Adaptation

To date, literature has largely focused on aspects prior to implementation such as assessments of climate vulnerability and risks or appraisals of adaptation options (Sietsma et al., 2021; Cross-Chapter Box Adaptation). To understand adaptation progress, the assessment of implemented adaptation actions and their outcomes requires more attention (*very high confidence*) (Cross-Chapter Box PROGRESS in this Chapter).

Outcomes on risk reduction are typically expressed in ways that are specific to the respective sector or context (e.g., as agricultural yields, health benefits or reduced water stress) highlighting that 'adaptation has no common reference metrics in the same way that tonnes of GHGs or radiative forcing values are for mitigation' (IPCC, 2014: 856). Assessments of adaptation progress therefore need to specify what they are measuring and how they are measuring it. The way adaptation is conceptualised, for example as a continuum between successful adaptation and maladaptation (Section 17.1.1), and the way adaptation is framed, for example as a technical challenge or a political process (Juhola et al., 2011; Bassett and Fogelman, 2013; Eriksen et al., 2015), shape the understanding of progress and its subsequent measurement (Singh et al., 2021).

Furthermore, people can be differently affected even in the same location owing to, among others, differential vulnerability among the population (Reckien and Petkova, 2019; Thomas et al., 2019). Different views and values can also affect what it means to adapt (Few et al., 2021). Assessments of adaptation progress therefore need to be transparent and reflective about how they define and measure adaptation and account for culturally and geographic contingent concepts of what it means to adapt in light of the global diversity of livelihoods and concepts.

The lack of knowledge on adaptation progress is associated with further measurement challenges, including that avoided impacts are difficult to measure and that risk levels change over time, meaning what is effective today may not be effective in the future (Brooks et al., 2011; Pringle, 2011; Spearman and McGray, 2011; Villanueva, 2012; Bours et al., 2014a). Moreover, adaptation is embedded in complex political and social realities where power and politics shape outcomes and where simplistic views of how adaptation would take place may be ill-conceived (Nightingale, 2017; Mikulewicz, 2018; Mikulewicz, 2020). In practice, this means that theories of change of adaptation projects may miss important causes of risks and could subsequently lead to inaccurate assessments (Forsyth, 2018). Measuring adaptation is therefore a matter of understanding drivers of vulnerability and risk and of designing responses and M&E systems accordingly (UNFCCC, 2019a, section V).

The importance of context and the dependence on viewpoints make comparative assessments of adaptation across nations, regions or responses challenging. Comparison requires a consistent conceptualisation of adaptation, comparable units of analysis and access to relevant data sets (Ford et al., 2015; Ford and Berrang-Ford, 2016). Comparative adaptation policy assessments to date often lack clarity in concepts and explanatory variables (Dupuis and Biesbroek, 2013; Biesbroek R, 2018a). The trade-off between standardisation and context specificity also complicates attempts to aggregate adaptation progress across scales to the national or global level (Leiter and Pringle, 2018; Cross-Chapter Box PROGRESS in this Chapter).

17.5.2.6 Tracking Adaptation Finance

Adaptation finance tracking is capturing the financial flows associated with adaptation. It can indicate how much is being spent on adaptation, where funds are going to and whether spending matches allocated budgets. Thus, adaptation finance tracking can provide useful information for decision-making, but it does not provide information on the achievements resulting from the invested funds. Accordingly, it can complement, but not substitute, M&E of actions and outcomes. Adaptation finance tracking can be applied domestically (Guzmán et al., 2017; Guzmán et al., 2018) as well as internationally, for instance by developed countries to report on the goal to mobilise USD 100 billion yr^{-1} by 2020 in climate finance (UNFCCC SCF, 2018). Data on adaptation finance can be used alongside information on planning and implementation to assess adaptation progress (UNEP, 2021a).

Tracking adaptation finance requires defining what counts as adaptation. Different definitions can lead to large variations in the estimated amount of adaptation finance (Donner et al., 2016; Hall, 2017). A further challenge is how to account for adaptation that is mainstreamed, that is, where adaptation-specific investments form only part of a larger programme or budget line, or where actions contribute to adaptation without being labelled as adaptation. These challenges limit the direct comparability between adaptation and mitigation finance (UNFCCC, 2019a). In fact, tracking adaptation finance differs from tracking mitigation finance since activities cannot be *a priori* assumed to constitute adaptation but instead have to be assessed for their linkage to climate risks in a particular context (MDBs & IDFC, 2018). Methods for adaptation finance tracking continue to be further developed aiming at better comparability and completeness (Richmond and Hallmeyer, 2019; Richmond et al., 2021).

Various methods are used to track adaptation finance, which makes comparisons between adaptation finance figures challenging (UNFCCC SCF, 2018; Weikmans and Roberts, 2019). For example, multi-lateral development banks use a different methodology than countries do under the OECD Development Assistance Committee (DAC) (Box 17.4; MDBs, 2019). One of the differences concerns the treatment of partially adaptation-relevant projects, namely whether only parts or the full amount of a given project volume are counted as adaptation finance (see, e.g., MDBs, 2019). Under the OECD DAC methodology, countries often use a fixed percentage (e.g., 50% of the total project value), whereas the MDB methodology attempts for a project-specific estimation of the adaptation-relevant proportion (MDBs & IDFC, 2018). Another aspect is whether tracking distinguishes between financial instruments, such as grants or loans. Different accounting rules can lead to large differences in reported amounts of adaptation finance and to a lack of comparability between providers (Weikmans and Roberts, 2019). Studies identified an over-reporting (i.e., counting non-adaptation-related finance) by a factor of two to three, which suggests the need for a more consistent and transparent accounting system (Weikmans et al., 2017; CARE, 2021).

Table 17.8 | Countries in different stages of developing or operating a national adaptation M&E system as of 1 August 2021 (Source: Leiter, 2021b). Countries can appear twice if they have published both a progress report and an evaluation.

	National adaptation M&E system		
	Stage	**Definition**	**Country**
Under development	Early stage	Tangible steps have been undertaken to develop a national adaptation M&E system, for example a stocktake of relevant existing data sources and engagement with stakeholders on the objectives of the M&E system	Benin, Cook Islands, Jordan, Paraguay, Sri Lanka, Uganda
	Advanced stage	Details of the adaptation M&E system have been developed, including, for instance, institutional arrangements, indicators and data sources, but it has not yet been applied	Albania, Bulgaria, Cameroon, Canada, Colombia, Ethiopia, Fiji, Grenada, Indonesia, Moldova, Morocco, Mozambique, Nauru, Peru, Rwanda, Senegal, St. Lucia, St. Vincent and the Grenadines, Suriname, Thailand, Togo, Tonga, Turkey, Vietnam
In operation	Adaptation progress report published	A progress report on the implementation of the national adaptation plan or strategy has been published	Austria, Belgium (Flanders), Brazil, Burkina Faso, Cambodia, Chile, Cyprus, France, Germany, Japan, Kenya, Kiribati, Lithuania, Mexico, the Netherlands (Delta Programme), Norway, Portugal, Slovakia, Spain, South Africa, South Korea, Switzerland, UK
	Evaluation published	An evaluation of the implementation of the national adaptation plan or strategy has been undertaken and published	Belgium, Cambodia, Chile, Czech Republic, Finland, France, Germany, Ireland, Mexico, the Netherlands, Philippines, South Korea, Spain, Switzerland, UK

Cross-Chapter Box PROGRESS | Approaches and Challenges to Assess Adaptation Progress at the Global Level

Authors: Matthias Garschagen (Germany), Timo Leiter (Germany/UK), Robbert Biesbroek (the Netherlands), Alexandre K. Magnan (France), Diana Reckien (the Netherlands/Germany), Mark New (South Africa), Lea Berrang-Ford (UK/Canada), So Min Cheong (Republic of Korea), Lisa Schipper (Sweden/USA), Robert Lempert (USA).

This Cross-Chapter Box responds to a growing demand for assessing global climate change adaptation progress, which currently faces the challenge of lacking consensus on how adaptation progress at this level can be tracked (*high confidence*). The box therefore assesses the rationale and methodological approaches for understanding adaptation progress globally across sectors and regions. It discusses strengths and weaknesses of existing approaches and sources of information, with a view towards informing the first Global Stocktake of the Paris Agreement in 2023.

Rationale for assessing adaptation progress at the global level

Global assessments of adaptation are expected to help answer key questions of climate policy (Ford et al., 2015; UNEP, 2017; Adaptation Committee, 2021) (*limited evidence*, *high agreement*), including: Do the observed, collective investments in adaptation lead humanity to being better able to avoid or reduce the negative consequences from climate change? Where is progress being made, and what gaps remain in the global adaptation response to climate risks?

While more than 170 countries have policies that address adaptation (Nachmany et al., 2019b; Section 17.4.2), very few have operational frameworks to track and evaluate implementation and results (Leiter, 2021a; Section 17.5.2.4). In Europe, for example, most countries have adopted a national adaptation plan or strategy, but only few are tracking whether ambitions are realised (EEA, 2020; Section 13.11.2). Moreover, climate risks are interconnected across scales, regions and sectors (Eakin et al., 2009; Challinor et al., 2017; Cross-Chapter Box INTERREG in Chapter 16; Hedlund et al., 2018) (*high confidence*), complicating causal attribution. National assessments of progress usually do not assess private sector and non-governmental adaptation and barely account for climate risks that transcend across borders, for example through supply chains or shared ecosystems (EEA, 2018; Benzie and Persson, 2019). In addition, adaptation action in one place or time can potentially lead to negative effects elsewhere (externalities) (Magnan and Ribera, 2016; Atteridge and Remling, 2018; 17.5.1). Hence, determining the collective adequacy and effectiveness (see Figure 1.7 in Chapter 1) of adaptation responses is different from simple aggregates of national and sub-national information (UNEP, 2017).

Assessing global progress on adaptation is therefore of high relevance to the scientific community, policymakers and other actors. Global assessments serve different information needs than local assessments, and their meaningfulness depends on the chosen approaches and their limitations. Aggregated global assessments of adaptation progress are therefore not meant to substitute place-specific ones but to complement them to enhance the knowledge base on adaptation beyond actions by or within individual countries. The Paris Agreement stipulates a Global Stocktake to be undertaken every 5 years to assess the collective progress towards its long-term goals, including

Cross-Chapter Box PROGRESS (continued)

on adaptation (UNFCCC, 2015, Article 14). Yet very few scientific studies have addressed the adaptation-specific aspects of the Global Stocktake (Craft and Fisher, 2018; Tompkins et al., 2018), and there are different views and options on how assessing global progress could take place (*high confidence*).

Considerations in designing global adaptation assessments

A number of key considerations for the design of global adaptation assessment approaches are discussed in the literature (Ford and Berrang-Ford, 2016; Berrang-Ford et al., 2017). Some of these involve trade-offs, such as global applicability versus context specificity, for which there is no simple solution. Design considerations directly depend on the objectives of global adaptation assessments, which can differ between actors and can include, for example, providing transparency, enabling accountability, understanding effectiveness or guiding policy development (Section 17.5.2.1). The underlying objectives determine the suitability of approaches and the data requirements.

Comparability

Global assessments may have the objective to compare adaptation over time and across sectors and regions (Ford et al., 2015). Such comparison requires a consistent definition of concepts (Hall, 2017; Berrang-Ford et al., 2019) and the identification of variables that are both generic enough to be applicable from one context to another and specific enough to illustrate national circumstances. To date, finding such balance has proven to be challenging (Dupuis and Biesbroek, 2013). The context dependence of adaptation outcomes poses limits for meaningful comparisons. Even people exposed to the same climate hazard may be differentially affected due to varying levels of vulnerability and resilience (Jones et al., 2018; Thomas et al., 2019), meaning that perceptions on adaptation outcomes can also differ (Jones and d'Errico, 2019).

Aggregation

The aggregation of data from local or regional to global scales can take different forms ranging from qualitative synthesis to quantitative aggregation, which may involve condensing a diverse set of variables into a single score (Leiter, 2015; Section 17.5.2.3). In contrast to climate change mitigation, adaptation does not have a global reference metric against which adaptation levels could be assessed to identify progress or gaps. Experience from the Global Environment Facility, for example, has shown that mechanical aggregation based on standardised indicators fails to capture what makes the greatest difference on the ground (Chen and Uitto, 2014).

Results: Input, process, output or outcome

Adaptation progress at any spatial scale can in principle be assessed in terms of input (e.g., resources spent), process (i.e., the way adaptation is organised), output (i.e., adaptation capacities and actions) and outcomes (i.e., actual changes induced) (Section 17.5.2.2). Due to the challenges inherent in measuring adaptation outcomes (Sections 16.3, 17.5.1 and 17.5.2.5), most global assessments to date have focused on outputs, such as whether countries have adopted adaptation plans (Berrang-Ford et al., 2021; UNEP, 2021a) (*high confidence*). Understanding the effectiveness of adaptation responses globally requires a way to conceptualise and capture outcomes, for example in terms of effective climate risk reduction, while avoiding simplifications that mask maladaptation at the global level, such as where climate risks are shifted to other countries, sectors or population groups (Cross-Chapter Box INTERREG in Chapter 16, Section 17.5.1).

Data

Global assessments typically require global availability of consistent data, be they quantitative or qualitative, which has proven to be a constraining factor for attempts to assess global adaptation (*high confidence*). For example, many countries face difficulties in reporting adequately on progress in implementing the Sendai Framework and risk-related SDGs (UNDRR, 2019: vi). The availability of data also influences which variables can be eventually selected in an assessment. This limitation can affect the ability to meet the initial objectives and lead to biases in the framing and interpretation of assessment outcomes. For some variables, an alternative to relying on nationally provided data can be to develop new global data sets (Magnan and Chalastani, 2019) or utilise data from Earth Observation (Andries et al., 2018). Adaptation is hence faced with a dilemma between globally available yet generic data and regionally or locally more detailed yet patchy data (*high confidence*).

Assessment of existing approaches to assess adaptation progress at the global level

Only few global assessments of adaptation progress across sectors have been undertaken to date (*high confidence*). They focus, for example, on whether countries have progressed their adaptation policies and actions over time (Lesnikowski et al., 2015; Nachmany et al., 2019b), the extent of implemented adaptation globally (Leiter, 2021a; Leiter, 2021b), and the type and actors of responses (Berrang-Ford et al., 2021), evidence for reduced vulnerability to climate-related hazards (Formetta and Feyen, 2019; UNDRR, 2019) or adaptation planning in cities across the globe (Araos et al., 2016a; Reckien et al., 2018a; Olazabal et al., 2019a). Each of these assessments draws

https://doi.org/10.1017/9781009325844.026

Cross-Chapter Box PROGRESS (continued)

on different approaches and data, and all have particular potential but also limitations (Table Cross-Chapter Box PROGRESS.1) (*high confidence*). The application of differing approaches shows that there is no single 'best' approach or data source to assess global progress on adaptation (*high confidence*). Existing global assessments have provided valuable insights into the extent and types of responses and their level of planning and implementation (Section 16.3.2.4). However, they do not provide comprehensive and robust answers so far on whether climate risk and vulnerability have been reduced (Berrang-Ford et al., 2021) (*high confidence*). As a result, combining different approaches and integrating data on climate risk levels, policy measures, implemented actions and their effects on climate risk reduction is currently regarded as the most robust approach (Berrang-Ford et al., 2019) (*medium evidence*, *high agreement*).

Table Cross-Chapter Box PROGRESS.1 | Key approaches and data sources used for global adaptation assessments.

Approach/data source	Potential added value	Limitations
Systematic assessment of adaptation responses reported in academic literature (e.g., systematic reviews, evidence synthesis, meta-analysis, large-*n* comparative studies) Examples: Berrang-Ford, 2011, Global Adaptation Mapping Initiative, Berrang-Ford et al. (2021)	Provides an indication of the status, trends and gaps in adaptation responses	Not a representative sample; biased towards responses published in scientific literature; excludes grey literature; some topics and regions not well covered; challenges in terms of comparability and aggregation; inconsistency in definitions and use of concepts; English language bias
Self-reported progress documents by countries (e.g., National Communications, Biennial Transparency Reports or domestic progress and evaluation) Examples: Gagnon-Lebrun and Agrawala (2007); Lesnikowski et al. (2015); Lesnikowski et al. (2016); Leiter (2021a)	Context-specific information; official government documents enable assessments of national progress	May only be available every few years; content is sensitive to political and policy changes; possible bias towards positive examples; challenges in terms of comparability and aggregation; inconsistency in definitions and use of concepts
Self-reported information from the private sector (e.g., information on actions taken in response to climate risks within the context of climate-related financial disclosure or in company reports). Examples: Committee on Climate Change (2017); Street and Jude (2019); UNFCCC (2021), responses reported under Climate-related Financial Disclosure	Provides an indication of the status, trends and gaps in adaptation responses by the private sector; complements information published in the scientific literature; could enable better understanding of supply chain risks	Sample biased towards larger companies; challenges in terms of comparability and aggregation; potential inconsistencies in definitions and use of concepts
Project documents and evaluations (e.g., from climate funds or implementing organisations) Examples: Leiter (2021b); Eriksen et al. (2021)	Detailed information on context, intended or achieved results and activities	Actual implementation can differ from what was proposed; fragmented picture of local/regional actions; results may be challenging to aggregate; challenges in terms of comparability and aggregation; inconsistency in definitions and use of concepts
Existing global data sets of mostly quantitative indicators Examples: United Nations (UN, 2016a; UN, 2016b; UN, 2019; UNDRR, 2019)	Comparable information based on globally defined indicators	Global data availability constrains indicator choice; reporting burden for new indicators; trade-off between global applicability and national circumstances; usefulness and meaningfulness of global indicators is contested (Leiter and Pringle, 2018; Lyytimäki et al., 2020; Pauw et al., 2020).
Tracking financial flows Examples: CPI (2019), OECD (2018a), MDBs (2019)	Comparable data on financial flows directed at adaptation; standardised methodologies (e.g., OECD RIO markers; climate finance tracking method of multi-lateral development banks; Section 17.5.2.6; Cross-Chapter Box FINANCE in this Chapter)	No information about implementation of measures and their adaptation effect (Eriksen et al, 2021), i.e., it tracks inputs, not outputs or outcomes; inconsistency in what gets counted as adaptation finance (Donner et al., 2016; Doshi and Garschagen, 2020); evidence of over-reporting (Michaelowa and Michaelowa, 2011; Weikmans et al., 2017)

Conclusion—Combining approaches for assessing adaptation progress at the global level

Understanding to what extent the world is on track to adapt to climate change impacts and risks globally is a pressing question in scientific and policy communities, especially in light of the Global Stocktake under the Paris Agreement. Important considerations for a robust assessment framework (e.g., consistency), as well as the associated scientific challenges (e.g., aggregation, externalities, breadth versus depth of data) and the role of underlying objectives (e.g., on the contested issue of comparability) are increasingly understood (*high confidence*). There is also a growing and diverse body of information on adaptation progress, although most assessments of global progress undertaken to date focus on processes and outputs (e.g., policies and plans) rather than outcomes (i.e., risk reduction). A variety of approaches and data sources are employed, such as systematic reviews of observed adaptation, formal communications by Parties to the UNFCCC, and

Cross-Chapter Box PROGRESS (continued)

project documents to international funding agencies. Novel approaches, including big data tools (Ford et al., 2016; Biesbroek et al., 2020), are also being explored but still have to prove their practical value. Each approach and source of information can contribute additional knowledge, but also demonstrates limitations, so that there is no single 'best' approach (*high confidence*). Yet, to date, the international community has not sufficiently explored the relative strengths and weaknesses of different approaches and their applicability and, therefore, their potential synergies in complementing each other. Triangulated assessments have only rarely been applied (*high confidence*) due to multiple conceptual and methodological challenges, despite their potential for increasing the robustness of knowledge. One overarching conclusion of this Cross-Chapter Box therefore is that the combination of different approaches will provide a more comprehensive picture of global adaptation progress than is currently available from individual approaches (*limited evidence*, *high agreement*).

Box 17.4 | The Rio Markers Methodology to Track Climate Finance

The OECD Development Assistance Committee (DAC) introduced a methodology to track the amount of bilateral official development assistance (ODA) that is targeting climate change mitigation and/or adaptation. It distinguishes whether activities have adaptation as a 'principal' objective (score '2'), as a 'significant' objective (score '1') or as not targeting it (score '0') (OECD, 2016). The associated project value is counted in full, in part, or not counted as adaptation finance, respectively. Countries count the volume of partial adaptation projects (score '1') to a different extent, which limits comparability and can lead to over-reporting (OECD, 2019). The first data on this 'adaptation marker' became available in 2012 for the financial flows of 2010. It forms the basis for developed countries' reporting to the UNFCCC Secretariat on their financial commitments towards developing countries (Weikmans and Roberts, 2019).

While a guidebook with requirements for adaptation as a principle or significant objective has been developed (OECD, 2016), several studies have shown that OECD DAC donors tend to overestimate the number of activities in their portfolio that genuinely have adaptation objectives (Michaelowa and Michaelowa, 2011; Weikmans et al., 2017; CARE, 2021). Hence, the amount of adaptation finance from public sources may be lower than reported. The use of just three categories leads to a broad range of the extent of adaptation being concentrated in the middle category ('significant objective'). Accordingly, the category 'principle objective adaptation' provides a more robust predictor of the relevance of an activity to adaptation (Donner et al., 2016).

Good coverage of adaptation finance data exists around international public finance flows, predominantly official development assistance flows from OECD DAC members and from multi-lateral development banks. Less data exist around domestic public finance and private finance flows to adaptation activities, but data sources continue to be further expanded, for example through climate change expenditure tagging and city-level data (Weikmans et al., 2017; UNFCCC SCF, 2018; Richmond et al., 2021). Recent estimates of adaptation finance are provided in UNFCCC SCF (2018), Macquarie et al. (2020) and Cross-Chapter Box FAR in this Chapter.

17.5.2.7 Evaluation and Learning

Most adaptation M&E frameworks and tools proposed to date refer to monitoring rather than evaluation (*high confidence*) (Adaptation Committee, 2016). Evaluations are envisioned to go beyond monitoring by examining how and why results have been achieved and what could be improved (Brousselle and Buregeya, 2018; Vähämäki and Verger, 2019). Evaluations of adaptation outcomes are still rare, particularly quantitative impact evaluations (Weldegebriel and Prowse, 2013; Das, 2019; Béné et al., 2020). Impact evaluations of adaptation need to address several methodological as well as practical challenges (Dinshaw et al., 2014; Fisher et al., 2015; Béné et al., 2017; Puri et al., 2020). Different types of evaluations are appropriate for different evaluation questions (Silvestrini et al., 2015). Evaluations of the available evidence of effective adaptation, in particular topics or sectors, have emerged more recently, for instance on mainstreaming (Runhaar et al., 2018) and agricultural climate services (Vaughan et al., 2019a). Impact evaluations of capacity building measures are important because capacity building is assumed to lead to adaptation, but its actual effects are seldom examined (Mortreux and Barnett, 2017; Alpizar F and Meiselman, 2019). If well designed and utilised for learning, evaluations can play an important role in improving adaptation responses (Hildén, 2011).

Learning requires information about how and why change occurred and what experiences have been made (Feinstein, 2012). M&E is frequently associated with learning, but it is rarely made explicit how learning is supposed to take place (Armitage et al., 2008; Baird et al., 2015; Borras and Hølund, 2015). The design of adaptation M&E systems can support learning by gathering relevant information and disseminating it in a way that is accessible and effectively linked to decision-making processes (Spearman and McGray, 2011; Villanueva, 2012; Fisher et al., 2015). Options include institutionalised feedback mechanisms, peer learning and knowledge sharing events, a learning culture and ways to gather in-depth insights beyond indicators (ibid; Oswald and Taylor, 2010). Since AR5, adaptation programmes and funds such as the BRACED programme, the Adaptation Fund, the Climate Investment Funds and the Green Climate Fund have created knowledge-sharing units and provide resources to support learning activities (BRACED, 2015; Roehrer and Kouadio, 2015; Adaptation Fund, 2016; Leavy et al., 2018; CIF, 2020; Puri et al., 2020), but there is little information about their longer-term effectiveness.

17.6 Managing and Adapting to Climate Risks for Climate Resilient Development

Actions to ameliorate a climate risk have consequences beyond the immediate effects on exposure or vulnerability to a hazard. They may aim to combat many risks, could adversely interact with other risks and actions, or may be nested within a suite of actions across many risks. Some actions may have negative consequences for climate resilient development. In this broader context, the effectiveness of adaptations for supporting climate resilient development is now better articulated (Box 17.1). Importantly, adaptations need to be designed to not only combat current and future climate risks but also ensure that they do not lock in undesirable pathways in the future as risks develop and change (*very high confidence*) (Sections 17.2, 17.3.1, 17.5). Effective management of climate risks will therefore be dependent on satisfactorily managing current climate risks (Boxes 17.1, 17.2, 17.5), coupled with assessing prognoses for future climate risks, and developing responses in advance for reducing those risks to tolerable residual levels (*very high confidence*) (Sections 1.4, 1.6, 16.6, 17.2, Box 16.1; e.g., water risks, Section 4.7.1). The dynamic nature of risk (Viner et al., 2019; Simpson et al., 2021; Sections 16.3, 16.6) also means that the contribution of current adaptations to ameliorating future risks needs to be regularly reviewed (*high confidence*) (Section 17.5.2). Across the Working Group II report are examples of how managing adaptations to ameliorate climate risks can negatively or positively affect sustainable development, thereby impacting the potential for climate resilient development discussed in Chapter 18. Drawing on the assessment of sectoral and regional chapters in this report, this section examines three broad components for orienting decision-making for climate adaptation towards climate resilient development.

17.6.1 Need for Integrated Risk Management

The complex, interacting and compounding nature of climate risks means that single risks cannot be managed in isolation (*very high confidence*) (Section 16.5, Figure 16.11; Section 17.3.2; Nhamo et al., 2018), including accounting for potential risks arising from adaptations (Simpson et al., 2021). Regional examples of needs for cross-sectoral integrated management include the water–energy–food nexus in Africa (Section 10.5.1), Asia (Section 10.6.3), Australasia (Section 11.6), Europe (Section 13.2.2) and North America (Table 14.8), and ecosystem-oriented adaptations and/or nature-based solutions, in Africa (Section 9.6.5), Asia (Section 10.4.2), Australasia (Box 11.4, Section 11.3.5), Central and South America (Section 12.5.1), Europe (Section 13.3.2), North America (Section 14.6.1, Box 14.3) and Small Islands (Section 15.5.4). The cross-sectoral interactions within humans systems, including impacts on cities, settlements and infrastructure, are reflected in those subjects as well as for health in Africa (Section 9.10.2), Asia (Section 10.4.5), Australasia (Section 11.3.6), Central and South America (Section 12.5.6), Europe (Section 13.7.2), North America (Section 14.6.1) and Small Islands (Section 15.6.2), and poverty and livelihoods in Africa (Section 9.11.3), Asia (Sections 10.4.5, 10.5), Australasia (Section 11.4), Central and South America (Section 12.5.7), Europe (Section 13.8.2), North America (Section 14.6.1) and Small Islands (Section 15.3.4).

These examples demonstrate that the emergence of climate risks can be at different rates and different time horizons, and the interactions between risks vary from region to region (*very high confidence*). The need to manage these risks in an integrated manner is readily identified in the water–energy–food nexus (Box 9.5). However, in terms of climate resilient development, the need for integration is demonstrated by the diverse and interacting impacts of climate risks on ecosystems (Sections 2.7, 3.6), cities (Sections 6.2.3, 6.2.4, Boxes 6.2, 6.3), health (Section 7.4), and poverty and livelihoods (Section 8.6).

17.6.2 Strategies for Managing a Portfolio of Climate Risks

Since WGII AR5, new methods for simultaneously considering multiple societal and sectoral objectives, climate risks and adaptation options have emerged (Section 17.3.2; Adam et al., 2014; Hadka et al., 2015; Garner et al., 2016; Rosenzweig et al., 2017; Giupponi and Gain, 2017a; Stelzenmuller et al., 2018; Marchau et al., 2019), including methods for accounting for different sources of uncertainty and types of risk (Section 17.3.1; Giupponi and Gain, 2017a). Different decision-making approaches can be complementary (*high confidence*) (Section 17.3.1; Kwakkel et al., 2016), and multiple approaches will likely be necessary in managing the risks across sectors, over different spatial scales, and over short to long time scales (*medium confidence*) (Cross-Chapter Box PROGRESS in this Chapter; Girard et al., 2015; Rouillard and Spray, 2016).

Deciding on which adaptations to adopt when managing climate risks inevitably needs examination of trade-offs in outcomes (*very high confidence*) (Sections 17.3.1, 17.5.1; Cross-Chapter Box FEASIB in Chapter 18). A current difficulty with integrated assessments is to develop a set of metrics that are appropriately scaled for the different sectors or outcomes to be compared (e.g., Sections 12.5.2.6, 17.3.1, 17.5.2; Cross-Chapter Box PROGRESS in this Chapter). For climate resilient development, dimensions of poverty, equity, justice and health need to be factored into analyses (Boxes 17.1, 17.5), many of which are difficult to quantify (*high confidence*) (Section 18.2.4). Moreover, uncertainties on the interactions within and between sectors can make trade-off analyses uneven in their precision across sectors and uncertain as to the outcome of an implemented adaptation (*medium confidence*) (Sections 4.7.2, 17.4, 17.5).

Expertise and resources for using tools and approaches for integrated risk management vary between the developed and developing countries (*high confidence*) (e.g., Section 4.7.2). Exploration of adaptation scenarios can be derived from Earth System Models (*high confidence*) (e.g., Sections 4.7.1.2, 11.7.3.1). However, the feasibility of possible adaptations and the degree to which they are likely to be effective (Box 17.1) will require further exploration as success will depend on appropriate enabling conditions, including institutional support and capacity, available financial resources and knowledge, and suitable conditions for stakeholder participation (*high confidence*) (Section 17.4). The current levels of uncertainty surrounding the effectiveness of many adaptation options (Section 17.5.2; Cross-Chapter Box PROGRESS in this Chapter) means that decision-making approaches applicable to deep uncertainty (Cross-Chapter Box DEEP in this Chapter; Section 17.3.1) will apply in many if not most cases (*medium confidence*). An early step in identifying suitable integrated pathways for managing climate risks, establishing 'no regrets' anticipatory options in a timely manner, and avoiding path dependencies is to jointly map the steps for adapting to sectoral risks and determine suitable ways to avoid maladaptations arising (*high confidence*) (Section 17.3.1, Cross-Working Group Box URBAN in Chapter 6 and Cross-Chapter Boxes DEEP in this Chapter). The application of Dynamic Adaptive Pathway planning has been successfully used in this way in Australasia (Section 11.7.3) and Europe (Sections 13.6.2.2, 13.10.2) (Lawrence et al., 2019a; Haasnoot et al., 2020a). Current experience suggests that synergies between sectors can save resources and effort (*limited evidence*) (Section 13.11.2). Iterative processes can then enhance adaptation programmes by including more detailed modelling, and updated knowledge as the experience is acquired (Section 17.3.1).

17.6.3 Mainstreaming Climate Risk Management in Support of Climate Resilient Development

This chapter has assessed and detailed a number of decision-making tools (Section 17.3) and enabling mechanisms and catalysing conditions (Section 17.4) that could be used in mainstreaming the management of climate risk and adaptation in the sustainable development of communities, different sectors and nations. Since AR5, the challenges facing the management of climate risks have been articulated (Adger et al., 2018; Balasubramanian, 2018), and greater clarity on the steps that could be taken to better mainstream adaptation has been developed (*high confidence*) (Cuevas, 2016; Giupponi and Gain, 2017a; Gomez-Echeverri, 2018; Sanchez Rodriguez et al., 2018). Nevertheless, the choice of decision processes is recognised as being dependent on a variety of local factors influencing development (Ayers et al., 2014; Szabo et al., 2016).

Adaptation strategies or plans, some of which incorporate elements of climate resilient development, have been developed in many jurisdictions from local (Cuevas, 2016; Araos et al., 2016a; Reckien et al., 2018a; Göpfert et al., 2019) to provincial/state (Warnken and Mosadeghi, 2018) to national governments (Markolf et al., 2015; CSIRO, 2018; Warnken and Mosadeghi, 2018; Brown et al., 2018a; Table 17.8). National Adaptation Plans have been a requirement under the UNFCCC and establish the general approach taken by nations for adapting to climate change (Woodruff and Regan, 2019). Integrated risk assessments and adaptation processes are being developed but with much less experience evident in their implementation (*high confidence*) (Wise et al., 2014; Woodruff and Stults, 2016; Brown et al., 2018a).

National Adaptation Plans (NAPs) submitted to the UNFCCC have been reviewed for quality by Woodruff and Regan (2019). In their review, Woodruff and Regan used a number of indicators grouped within established 'quality principles'. They found that the plans were more oriented at the strategic level or at the level of specific projects rather than identifying methods for resolving cross-sectoral or cross-jurisdictional interactions or issues (*medium confidence*). A key recommendation from their review and supported by other studies (e.g., Abutaleb et al., 2018) is that plans would be improved greatly by having inputs from multiple government agencies and multiple sectors (*medium confidence*), which could provide the basis for planning and review of integrated adaptation. Also, the plans need greater attention to implementation (Sections 9.4.1, 11.8, 13.11.2), and the identification of metrics by which success (Section 17.5.1) and performance can be measured (Cross-Chapter Box PROGRESS in this Chapter), a common issue for adaptation planning generally (e.g., Sections 12.5.2.6, 17.5).

Hence, satisfactorily managing intersecting climate risks in different settings, of which RKRs provide examples, is central to achieving sustainable development (*high confidence*) (Section 16.6.4), requiring integrated risk management within and across regions, jurisdictions, sectors and ecosystems (*high confidence*) (see CCP5.4.2, CCP5.4.3). Iterative processes will enable measuring progress and updating adaptation at a satisfactory rate, to account for the different needs within regions and across sectors at different times (*high confidence*). The degree to which equity and justice will be achieved will be determined by the participatory processes in deciding on suitable adaptation options, the investment in the adaptation processes and the coordination and collaboration built among institutions and people across regions (*high confidence*).

Frequently Asked Questions

FAQ 17.1 | Which guidelines, instruments and resources are available for decision makers to recognise climate risks and decide on the best course of action?

Guidelines, instruments and resources to identify options for managing risks, and support decisions on the most suitable course of actions to take, can be collectively referred to as decision-support frameworks. These can include data services, decision-support tools, processes for making decisions and methods for monitoring and evaluating progress and success. Data services enable the identification, location and timing of risks that could manifest with negative impacts, as well as potential opportunities. Often, these are termed 'climate services' and assist with mapping hazards and how they are changing. Decision-support tools range from qualitative approaches to determining overlap of areas of concern with those hazards in the future, to more quantitative and dynamic simulation approaches that enable dynamic stress-testing of adaptation options and strategies to determine if proposed plans for adapting to the future could be successful. An important consideration is whether options for risk management or capitalisation on opportunities will limit options and flexibility for responding to unforeseen events in the future. If these options have a negative effect on other areas of concern, then they could be identified in these planning scenarios as maladaptations, and therefore avoided.

A great challenge for decision makers is how to choose effective options when the future is uncertain. Uncertainty can arise not just in the statistical error of the magnitude of risk but also in the nature and consequence of risk from uncertainty about mechanisms that link areas of concern to hazards, uncertainty in the decision processes themselves and so on. Methods are available to help develop no-regret options, commonly referred to as decision-making under conditions of deep uncertainty'.

Decision-support frameworks are most successful when they are iterative, integrative and consultative. Rather than a single decision be made, and an action taken, there are processes for making the best decision possible, then monitoring progress towards delivering a successful outcome. Given a set of suitable indicators with regular monitoring, decisions can be revised, updated or changed as the future unfolds and foundations for the original decision tested. This is important because climate responses need to be initiated well in advance of them being needed due to the time required to implement suitable responses. These forward-looking approaches allow errors to occur and corrections made before problems arise. They also enable action to be taken without having to wait for the circumstances to arise, which if this were to occur could result in only limited reactions being available and the outcomes then dependent upon recovery from events rather than proactive planning and avoidance of events. Integrated approaches to risk management are available to help manage portfolios of interacting risks, including the potential for compounding and cascading risks when climate-related events arise.

Managing uncertainty with forward-looking processes needs to be more deliberative and oriented towards building trust in a collaborative process. Building relationships through informal, bottom-up processes enables this to occur. Top-down planning processes are important for ensuring that the management of risks and opportunities do not end up with maladaptations and that the approaches are equitable and proportional to that which is needed to manage the risks.

Frequently Asked Questions

FAQ 17.2 | What financing options are available to support adaptation and climate resilience?

What do we mean by 'climate finance'?

The UNFCCC has no formally agreed upon definition of climate finance. The current IPCC definition is: '*the financial resources devoted to addressing climate change by all public and private actors from global to local scales, including international financial flows to developing countries to assist them in addressing climate change*' (see Annex II: Glossary).

What needs to be financed?

Financial resources might be needed for a range of adaptation and resilience building activities. These include research, education and capacity building; development of laws, regulations and standards; provision of climate services and other information; reducing the vulnerability of existing assets, activities and services; and ensuring future development—such as new infrastructure, settlements, health services and business activities—is climate resilient. Finance is also needed to recover and rebuild from the damage of climate hazards that cannot be completely avoided through adaptation. Adaptation actions can be undertaken by many different actors, alone or in partnership, including national and sub-national governments, public and private utilities, businesses of varying size, communities, households and individuals.

Table FAQ17.2.1 | Examples of adaptation and resilience activities that might need to be financed

Training of agricultural extension officers so that their advice to small-holder farmers can support implementation of climate adapted agriculture. Additional financial support is needed for the costs of farmers transitioning to climate-resilient agricultural practices.	A new urban development requires higher standards (and up-front costs) for buildings, roads, stormwater systems and water re-use and to be resilient to expected changes in heavy rainfall, runoff, temperature and water supply reliability.
A water utility requires capital expenditure to increase supply through a desalination plant and to reduce leakage from its reticulation system in response to a scenario of reduced surface water availability and an increase in customers.	A catastrophe risk insurance facility is established to provide post-disaster (drought, hurricane, flooding, pest outbreaks) recovery finance to national governments. The facility requires capital to be able to underwrite the insurance products it offers.

How much finance is needed?

The amount of adaptation finance depends on global, regional and local factors, including: the amount and timing of global warming, and how this translates into impacts and adaptation needs across the world; the levels of adaptation already in place; the type of risk being adapted to; and the adaptation options being chosen, including whether the adaptation required is incremental or transformational.

The most-mentioned figure for finance need is the developed countries' commitment to provide USD 100 billion per year by 2020 to support developing countries' efforts in mitigation and adaptation. Negotiations will start in 2021 on updating this amount for 2025. While sometimes thought to represent the actual cost of responding to climate change in developing countries, this is not the case. More recent estimates of the global cost of adaptation by 2030 across developed and developing countries range between about USD 80 and 300 billion per year.

What types of finance are available?

Four main types (or instruments) of finance are currently being used to support adaptation. These different types are not mutually exclusive; grants can be combined with loans to provide blended finance.

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Box FAQ 17.2 (continued)

Table FAQ17.2.2 | The main instruments through which adaptation is being financed.

Grants provide finance without any repayment requirements. Most grants for adaptation have been provided by multi-lateral funds such as the Green Climate Fund or a fund managed by a single OECD country such as Germany's International Climate Initiative. Some countries have national climate or environment funds that provide grants for their own climate adaptation actions. Grants are also provided by philanthropic foundations and sometimes by companies as part of their environmental and social responsiveness mandate.	**Concessional loans** require partial repayment of the finance provided. These involve either capital repayment coupled to below-market interest rates or capital repayment only. Concessional finance is almost entirely provided through multi-lateral development banks such as the World Bank. This finance is particularly important for developing countries where market interests are high due to poor credit ratings or other risk factors, or where the return on investment is too low make a commercial loan viable.
Non-concessional loans (or debts) are commercial instruments, where capital repayment and market interest rates apply. These may be provided through development banks or private banks. Green bonds are a relatively new form of market loan, designed to meet climate and other environmental sustainability criteria in terms of how the proceeds are used. In recent years, green bonds have offered better interest than ordinary bonds owing to oversubscription by investors who are looking to move towards environmentally sustainable investment portfolios.	**Budget re-allocation** does not require raising of new finance; rather, it involves moving funds already secured away from other purposes towards adaptation. In government, this might involve re-allocation towards flood defence. In the private sector, a company might move budget from marketing, research and development, or perhaps dividends, towards increasing the climate resilience of operation, infrastructure or their value chain.

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Where are different types of finance most useful?

Grants are useful for a range of adaptation actions where it is hard to generate a financial return. These include capacity-building activities, piloting new adaptation innovations, high-risk investment settings or projects where there are considerable non-financial benefits. In contrast, loans and other debt instruments can often support larger investments, for example for scaling out of successful pilot projects or for building adaptation and resilience into general development investment. To date, a large proportion of international climate finance for adaptation in developing countries, especially in Sub-Saharan Africa and Oceania, has been grant led, sourced from OECD public funds, indicating that in many instances financing via loans is either considered too risky by the commercial investment sector or it has been hard to demonstrate sufficient return on investment.

Distribution of adaptation finance across different regions and different types of finance in 2015–2016

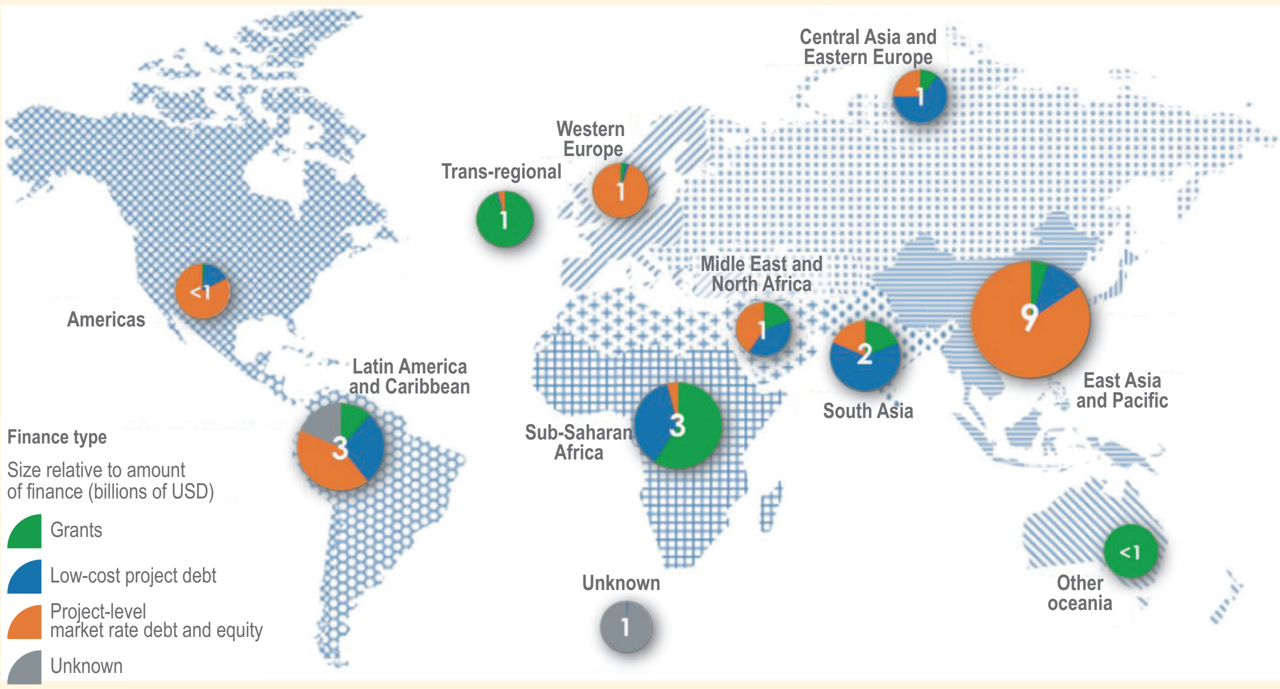

Figure FAQ17.2.1. | The distribution of adaptation finance across different regions and different types of finance in 2015–2016, as tracked by the Climate Policy Initiative. The size of each circle represents the amount of finance, with amount in billions USD superimposed.

Frequently Asked Questions

FAQ 17.3 | Why is adaptation planning along a spectrum from incremental to transformational adaptation important in a warming world?

In a warming world, incremental adaptation, that is, proven standard measures of adaptation, will not always suffice to adjust to the negative impacts from climate change leading to substantial residual risks and, in some cases, the breaching of adaptation limits; transformational adaptation, involving larger system-wide change (as compared with in-system change), will increasingly be necessary as a complement for helping individuals and communities to cope with climate change. As an example of incremental adaptation, a farmer may decide to use drought-tolerant crops to deal with increasing occurrences of heatwaves. With further warming and increases in heatwaves and drought, however, the impacts of climate change may necessitate the consideration of system-wide change, such as moving to an entirely new agricultural system in areas where the climate is no longer suitable for current practices, or switching to livestock rearing. Where on-site adaptation becomes infeasible and pull factors exist, the farming households may decide to seek employment in other sectors, which may also lead to migration for work. As another example, physical protection through sea walls to stop coastal flooding is a proven adaptation measure. With further projected flooding due to increasing sea level rise attributable to climate change transformational city planning, that would systemically change how flood water is managed throughout the whole city, potentially requiring deeper institutional, structural and financial support. Also, the deliberate relocation of settlements (managed retreat) is seeing attention in the face of increasingly severe coastal or riverine flooding in some regions. While transformational adaptation is increasingly being considered in theory and planning, implementation is only beginning to see attention.

Frequently Asked Questions

FAQ 17.4 | Given the existing state of adaptation, and the remaining risks that are not being managed, who bears the burden of these residual risks around the world?

A warming climate brings along increasing risks, part of which can be reduced or insured. What remains is called residual risks and needs to be retained by households, the private and public sectors. People living in conflict-affected areas benefit only marginally from adaptation investments by governments, private sector or other institutions. These people bear most of the changing climate risks themselves. Higher-income countries generally have invested heavily in structural adaptation to make sure people are not exposed to extreme events (e.g., dykes) and have developed a variety of private or public insurance systems to finance the risk of the most rare or extreme events. In other, middle- or lower-income countries, these very extreme events are less likely to be insured, and the impacts are borne by the most vulnerable people. Absent risk reduction or insurance, coping with residual risks generally means reducing consumption (e.g., food) or drawing down assets (selling machinery, houses, etc.), which all can bring along longer-term adverse developmental implications. Adaptation investments in low-income countries tend to focus more heavily on increasing capacity and reducing vulnerability; people remain exposed to the changing climate risks and bear the burden of reacting and responding.

Frequently Asked Questions

FAQ 17.5 | How do we know whether adaptation is successful?

Adaptation aims to reduce exposure and vulnerability to climate change by responding to dynamic and multi-scalar combinations of climatic risks. What might be seen as successful at one scale or at one point in time might not be at another, particularly if climate risks continue to rise. Moreover, the benefits of adaptation interventions may not reach all intended beneficiaries or everyone affected by climate impact and risk, causing different people to have different views on how successful adaptation has been.

There is, therefore, no universal way to measure adaptation success, but there is *high agreement* that success is associated with a reduction of climate risks and vulnerabilities (for humans and ecosystems) and an equitable balancing of synergies and trade-offs across diverse objectives, perspectives, expectations and values. Adaptation that is successful is also commonly expected to be inclusive of different socioeconomic groups, especially the most vulnerable, and to be based on flexible and integrative planning processes that take into account different climate scenarios.

Conceptually, the opposite of successful adaptation is maladaptation, that is, when adaptation responses produce unintended negative side effects such as exacerbating or shifting vulnerability, increasing risk for certain people or ecosystems, or increasing greenhouse gas emissions. Among the adaptation options assessed in this report (Figure FAQ17.5.1), physical infrastructure along coasts (e.g., sea walls) has the highest risk for maladaptation over time through negative side effects on ecosystem functioning and coastal livelihood opportunities. However, such adaptations may appear valuable in the short and even longer term for already densely populated urban coasts, demonstrating that an adaptation can be differently judged based on the context it is implemented in (Figure FAQ17.5.1). Many other adaptation options have a larger potential to contribute to successful adaptation (Figure FAQ17.5.1), such as nature restoration, providing social safety nets and changing diets/minimising food waste.

Assessments of adaptation need to be transparent about how they are measuring success. Monitoring and Evaluation (M&E) can be used to track progress and evaluate success and to identify if course corrections during adaptation implementation are needed to achieve the envisaged objectives. Given the diversity of adaptation actions and contexts, no one-size-fits-all approach to M&E and no common reference metrics for adaptation exist. To date, assessments of progress of adaptation have often focused on processes and outputs (i.e., actions taken, such as adaptation plans adopted) that are easier to measure than the effects of these actions in terms of long-term reduction of risks and vulnerabilities. However, knowledge about the outcomes in terms of reducing climate risk, impact and vulnerability is critically required to know if adaptation has been successful.

Tracking progress, in particular outcomes and impacts of adaptation, involves a number of challenges. First, to determine progress over time, risk and vulnerability assessments need to be repeated at least once after starting an adaptation process. This is rarely done, as it demands resources that are usually not factored into the adaptation response. Second, attributing changes in climate risks and vulnerabilities to the adaptation response is often difficult due to other influencing factors, such as socioeconomic development over time. Expected causal relationships between responses and their outcomes should already be outlined during the adaptation planning phase, for example by mapping the way from activities to outcomes, and they should be monitored during implementation. Third, as adaptation can occur in multiple forms and target multiple temporal and spatial scales, the engagement of a diversity of stakeholders is vital to understanding how responses enable adaptation and adaptation success across vulnerable groups. Although stakeholder engagement can be time intensive and costly, in particular when reaching out to populations that are usually not part of policy and planning processes, it can support evaluating co-benefits and trade-offs of adaptation responses. Consideration and analysis of co-benefits and trade-offs along with a focus on short, medium and long time horizons of adaptation goals, which is usually possible through flexible and strong institutions, facilitate successful adaptation and reduce the likelihood of maladaptation.

Box FAQ 17.5 (continued)

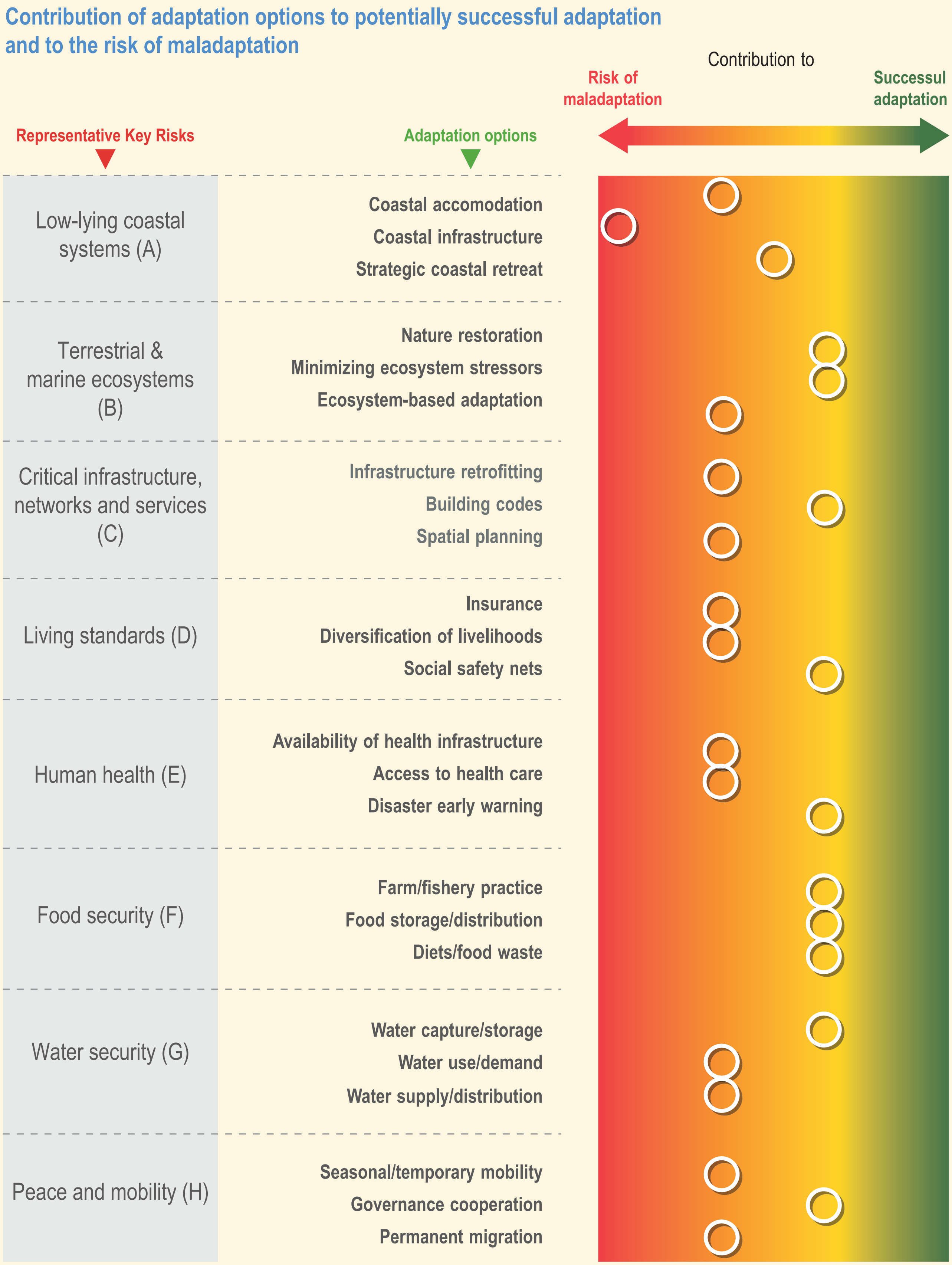

Figure FAQ17.5.1 | Contribution of adaptation options to potentially successful adaptation and to the risk of maladaptation. Note: A similar figure is part of Section 17.5.1.

References

Abadie, L.M., I. Galarraga and D. Rübbelke, 2013: An analysis of the causes of the mitigation bias in international climate finance. *Mitig. Adapt. Strateg. Glob. Change*, **18**(7), 943–955, doi:10.1007/s11027-012-9401-7.

Abbas, A. and R. Howard, 2015: *Foundations of Decision Analysis*. Pearson Education Limited, Harlow, UK.

Abebe, Y.A., et al., 2019: Flood risk management in Sint Maarten – a coupled agent-based and flood modelling method. *J. Environ. Manag.*, **248**, doi:10.1016/j.jenvman.2019.109317.

Abram, N., J.-P. Gattuso, A. Prakash, L. Cheng, M.P. Chidichimo, S. Crate, H. Enomoto, M. Garschagen, N. Gruber, S. Harper, E. Holland, R.M. Kudela, J. Rice, K. Steffen, and K. von Schuckmann, 2019: Framing and Context of the Report Supplementary Material. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.- O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Abunnasr, Y., E.M. Hamin and E. Brabec, 2013: Windows of opportunity: addressing climate uncertainty through adaptation plan implementation. *J. Environ. Plan. Manag.*, **58**(1), 135–155, doi:10.1080/09640568.2013.849233.

Abutaleb, K.A.A., A.H.E.-S. Mohammed and M.H.M. Ahmed, 2018: Climate change impacts, vulnerabilities and adaption measures for Egypt's Nile delta. *Earth Syst. Environ.*, **2**(2), 183–192, doi:10.1007/s41748-018-0047-9.

Ackermann, F., 2012: Problem structuring methods 'in the Dock': arguing the case for Soft OR. *Eur J Oper Res*, **219**(3), 652–658, doi:10.1016/j.ejor.2011.11.014.

Adam, J.C., et al., 2014: BioEarth: Envisioning and developing a new regional earth system model to inform natural and agricultural resource management. *Clim Change*, **129**(3-4), 555–571, doi:10.1007/s10584-014-1115-2.

Adams, H., S. Blackburn and N. Mantovani, 2021: Psychological resilience for climate change transformation: relational, differentiated and situated perspectives. *Curr. Opin. Environ. Sustain.*, **50**, 303–309.

Adaptation Committee, 2016: *Inventory of Ongoing Monitoring and Evaluation Work of Adaptation Prepared under the Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change*, accessed 31 March 2022, https://unfccc.int/files/adaptation/groups_committees/adaptation_committee/application/pdf/ac10_5b_m_and_e_.pdf. (Note by the secretariat, **16**).

Adaptation Committee, 2021: *Approaches to Reviewing the Overall Progress Made in Achieving the Global Goal on Adaptation*. Technical Paper. UNFCCC Secretariat, Adaptation Committee, Bonn.

Adaptation Fund, 2016: *Knowledge Management Strategy & Action Plan*, accessed 31 March 2022, https://www.adaptation-fund.org/document/knowledge-management-strategy-action-plan/.

Adaptation Partnership, 2012: *Tracking successful adaptation – smart monitoring for good results*. Results report.Federal Ministry for Economic Cooperation and Development (BMZ), accessed 31 March 2022, https://www.adaptationcommunity.net/publications/tracking-successful-adaptation-workshop-report-2012/.

ADB, 2018: *Strategy 2030: Achieving a Prosperous, Inclusive, Resilient, and Sustainable Asia and the Pacific*. Asian Development Bank, Philippines, ISBN 978-9292612856.

Adger, W.N., I. Brown and S. Surminski, 2018: Advances in risk assessment for climate change adaptation policy. *Philos. Trans. A. Math. Phys. Eng. Sci.*, **376**(2121), 20180106, doi:10.1098/rsta.2018.0106.

Adger, W.N., C. Butler and K. Walker-Springett, 2017: Moral reasoning in adaptation to climate change. *Environ. Polit.*, **26**(3), 371–390, doi:10.1080/09644016.2017.1287624.

Adnan, M.S.G., A.Y.M. Abdullah, A. Dewan and J.W. Hall, 2020: The effects of changing land use and flood hazard on poverty in coastal Bangladesh. *Land Use Policy*, **99**, 104868, doi:10.1016/j.landusepol.2020.104868.

Aerts, J.C.J.H., et al., 2018a: Pathways to resilience: adapting to sea level rise in Los Angeles. *Ann. N.Y. Acad. Sci.*, **1427**(1), 1–90, doi:10.1111/nyas.13917.

Aerts, J.C.J.H., et al., 2018b: Integrating human behaviour dynamics into flood disaster risk assessment. *Nat. Clim. Change*, **8**(3), 193–199, doi:10.1038/s41558-018-0085-1.

African Development Bank, 2019: *Analysis of Adaptation Components in African Nationally Determined Contributions (NDCs)*. African Ndc Hub Secretariat, accessed 31 March 2022, https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/Analysis_of_Adaptation_Components_in_African_NDCs_2019.pdf.

Agrawal, A., et al., 2019: *Climate Resilence through Social Protection*. Background Paper for Global Commission on Adaptation. IIED, Rotterdam and Washington, D.C.

Aguilar-Barajas, I., N.P. Sisto, A.I. Ramirez and V. Magaña-Rueda, 2019: Building urban resilience and knowledge co-production in the face of weather hazards: flash floods in the Monterrey Metropolitan Area (Mexico). *Environ. Sci. Policy*, **99**, 37–47, doi:10.1016/j.envsci.2019.05.021.

Ahenkan, A., D.N. Chutab and E.K. Boon, 2020: Mainstreaming climate change adaptation into pro-poor development initiatives: evidence from local economic development programmes in Ghana. *Clim. Dev.*, **13**(7), 603–615.

Ahmad, B., A. Bukhari and B. Cheema, 2019: Generation of Cressman Interpolated High-resolution Gauge-based Gridded Observations (CIHGGO) for climatic variables using in-situ data over Pakistan. *Eur. J. Sci. Explor.*, **2**(4), 7.

Ahmad, S.K. and F. Hossain, 2020: Maximizing energy production from hydropower dams using short-term weather forecasts. *Renew. Energy*, **146**, 1560–1577, doi:10.1016/j.renene.2019.07.126.

Ahmed, I., et al., 2019: Opportunities and challenges of compliance to safe building codes: Bangladesh and Nepal. *APN Sci. Bull.*

Ajibade, I., 2019: Planned retreat in Global South megacities: disentangling policy, practice, and environmental justice. *Clim. Chang.*, **157**(2), 299–317.

Ajibade, I. and M. Egge, 2019: SDGs and climate change adaptation in Asian megacities: synergies and opportunities for transformation. In: *Achieving the Sustainable Development Goals*. Routledge, London pp. 100–116. ISBN 978-0429029622.

Alam, A.S.A. F., et al., 2020a: Agriculture insurance for disaster risk reduction: a case study of Malaysia. *Int. J. Disaster Risk Reduct.*, **47**, 101626, doi:10.1016/j.ijdrr.2020.101626.

Albers, R., et al., 2015: Overview of challenges and achievements in the climate adaptation of cities and in the Climate Proof Cities program. Build. Environ., **83**, 1–10.

Albuja, S. and I.C. Adarve, 2011: Protecting people displaced by disasters in the context of climate change: challenges from a mixed conflict/disaster context. *Tulane Environ. Law J.*, **24**(2), 239–252.

Aleksandrova, M. and C. Costella, 2021: Reaching the poorest and most vulnerable: addressing loss and damage through social protection. *Curr. Opin. Environ. Sustain.*, **50**, 121–128.

Alessa, L., et al., 2016: The role of Indigenous science and local knowledge in integrated observing systems: moving toward adaptive capacity indices and early warning systems. *Sustain. Sci.*, **11**(1), 91–102.

Alexander, S., et al., 2020: Development of an interdisciplinary, multi-method approach to seasonal climate forecast communication at the local scale. *Clim. Change*, **162**(4), 2021–2042, doi:10.1007/s10584-020-02845-9.

Alexeeff, S.E., G.G. Pfister and D. Nychka, 2016: A Bayesian model for quantifying the change in mortality associated with future ozone exposures under climate change. *Biometrics*, **72**(1), 281–288, doi:10.1111/biom.12383.

Ali, A. and O. Erenstein, 2017: Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. *Clim. Risk Manag.*, **16**, 183–194, doi:10.1016/j.crm.2016.12.001.

Ali, S., S. Zhang and T. Yue, 2020: Environmental and economic assessment of rainwater harvesting systems under five climatic conditions of Pakistan. *J. Clean. Prod*, **259**, 120829–120829.

Allen, T., P. Heinrigs and I. Heo, 2018: *Agriculture, Food and Jobs in West Africa*. West African Papers (OECD) eng no. 14.

Alpizar, F., Bernedo Del Carpio, M., Ferraro, P.J. and Meiselman, B.S., 2019: The impacts of a capacity-building workshop in a randomized adaptation project. *Nat. Clim. Change*, **9**, 587–591.

Amerasinghe, N., J. Thwaites, G. Larsen and A. Ballesteros, 2017: *Future of the Funds: Exploring the Architecture of Multilateral Climate Finance*. World Resources Institute, Washington D.C., ISBN 978-1569739150. 100 pp.

Andrianarimanana, D., 2015: The role of inter-household transfers in coping with post-disaster losses in Madagascar. In: *Disaster Risk Financing and Insurance: Issues and results* [Clarke, D., A. d. Janvry, E. Sadoulet and E. Skoufias)].

Andries, A., et al., 2018: Translation of earth observation data into sustainable development indicators: an analytical framework. *Sustain. Dev.*, **27**(3), 366–376.

Anguelovski, I., et al., 2016: Equity impacts of urban land use planning for climate adaptation. *J. Plan. Educ. Res.*, **36**(3), 333–348, doi:10.1177/0739456x16645166.

Anguita Olmedo, C. and P. González Gómez del Miño, 2019: El Sahel: dimensión transfronteriza y dinámicas geopolíticas. *Geopol. Rev. Stud. Sobre Espac. Poder*, **10**(2), 281–303.

Annan, F. and W. Schlenker, 2015: Federal crop insurance and the disincentive to adapt to extreme heat. *Am. Econ. Rev.*, **105**(5), 262–266.

Antwi-Agyei, P., A.J. Dougill and L.C. Stringer, 2014: Barriers to climate change adaptation: evidence from northeast Ghana in the context of a systematic literature review. *Clim. Dev.*, **7**(4), 297–309, doi:10.1080/17565529.2014.951013.

Aragòn-Correa, J.A., A.A. Marcus and D. Vogel, 2019: The effects of mandatory and voluntary regulatory pressures on firms' environmental strategies: a review and recommendations for future research. *Acad. Manag. Ann.*, **14**(1), 339–365, doi:10.5465/annals.2018.0014.

Araos, M., et al., 2021: Equity in human adaptation-related responses: A systematic global review, *One Earth*, **4**(10), 1454–1467, doi:10.1016/j.oneear.2021.09.001

Araos, M., et al., 2016a: Climate change adaptation planning in large cities: A systematic global assessment. *Environ. Sci. Policy*, **66**, 375–382.

Araos, M., et al., 2017: Climate change adaptation planning for Global South megacities: the case of Dhaka. *J. Environ. Policy Plan.*, **19**(6), 682–696, doi:10.1080/1523908X.2016.1264873.

Araujo, J., B. Harvey and Y. Huang, 2020: *A critical reflection on learning from the FCFA programme. Future Climate for Africa*, accessed 31 March 2022, https://media.africaportal.org/documents/a_critical_reflection_on_learning_from_the_fcfa_programme_CuvAQxO.pdf.

Argyris, N. and S. French, 2017: *Behavioural Issues and Impacts in Nuclear Emergency Decision Support*, 180–193.

Arias, P., et al., 2021: *Technical Summary* Climate Change. Cambridge University Press, Cambridge.

Arıkan, G. and Günay, D., 2021: Public attitudes towards climate change: A cross-country analysis. *Br. J. Polit. Int. Relat.,* **23**(1), 158-174. doi:10.1177/1369148120951013.

Armitage, D., M. Marschkeb and R. Plummer, 2008: Adaptive co-management and the paradox of learning. *Glob. Environ. Chang.*, **18**, 86–98.

Arnold, C.A. and L. Gunderson, 2013: Adaptive law and resiliencer. *Environ. Law Report. Univ. Louisv. Sch. Law Leg. Stud. Res. Pap. Ser.*, **43**(4), 10426–10443.

Asfaw, H.W., S. Lake First, T.K. McGee and A.C. Christianson, 2019: Evacuation preparedness and the challenges of emergency evacuation in Indigenous communities in Canada: the case of Sandy Lake First Nation, Northern Ontario. *Int. J. Dis. Risk Reduct.*, **34**, 55–63, doi:10.1016/j.ijdrr.2018.11.005.

v. Ashgar Leghari, 2015: *Federation of Pakistan, L. H. C*., accessed 31 March 2022, http://climatecasechart.com/climate-change-litigation/non-us-case/ashgar-leghari-v-federation-of-pakistan/

Åström, H.L.A., et al. (ed.), 2014 *Describing concurrent flood hazards in a risk assessment decision framework using a bayesian network methodology*. 13th International Conference on Urban Drainage. IWA Publishing, London. 90 pp.

Atkinson, G., N.A. Braathen, B. Groom and S. Mourato, 2018a: *Cost-benefit analysis and the environment: further developments and policy use, Organisation for Economic Co-operation and Development*. OECD, Paris, France, accessed 31 March 2022, https://www.oecd.org/governance/cost-benefit-analysis-and-the-environment-9789264085169-en.htm.

Atkinson, R., T. Dörfler and E. Rothfuß, 2018b: Self-organisation and the co-production of governance: the challenge of local responses to climate change. *Polit. Gov.*, **6**(1), 169–179, doi:10.17645/pag.v6i1.1210.

Atteridge, A. and E. Remling, 2018: Is adaptation reducing vulnerability or redistributing it? *Wiley. Interdiscip. Rev. Clim. Change.*, **9**(1), 1–16.

Atteridge, A., et al., 2009: *Bilateral finance institutions and climate change: a mapping of climate portfolios*. Stockholm Environment Institute, Stockholm, ISBN 978-9186125202.

Atun, R., et al., 2015: Health-system reform and universal health coverage in Latin America. *Lancet*, **385**(9974), 1230–1247.

Audefroy, J.F. and B.N.C. Sánchez, 2017: Integrating local knowledge for climate change adaptation in Yucatán, Mexico. *Int. J. Sustain. Built Environ.*, **6**(1), 228–237, doi:10.1016/j.ijsbe.2017.03.007.

Averchenkova, A., 2019: *Legislating for a low carbon and climate resilient transition: learning from international experiences*. vol. Elcano Policy Paper. Real Instituto Elcano, Madrid, accessed 31 March 2022, https://www.realinstitutoelcano.org/en/policy-paper/legislating-for-a-low-carbon-and-climate-resilient-transition-learning-from-international-experiences/

Averchenkova, A., S. Fankhauser and J.J. Finnegan, 2021: The impact of strategic climate legislation: evidence from expert interviews on the UK Climate Change Act. *Clim. Policy*, **21**(2), 251–263, doi:10.1080/14693062.2020.1819190.

Averchenkova, A. and L. Guzman, 2018: *Mexico's General Law on Climate Change: Key Achievements and Challenges Ahead* Environment, G. R. I. o. C. C. a. t. London School of Economics and Political Science, London.

Averchenkova, A. and S. Matikainen, 2017: Climate legislation and international commitments. In: *Trends in Climate Change Legislation*. Edward Elgar Publishing, Massachusetts, USA., pp. 193–208. ISBN 978-1786435781.

Ayers, J., et al., 2014: Mainstreaming climate change adaptation into development in Bangladesh. *Clim. Dev.*, **6**(4), 293–305, doi:10.1080/17565529.2014.977761.

Aylett, A., 2015: Institutionalizing the urban governance of climate change adaptation: results of an international survey. *Urban Clim.*, **14**, 4–16, doi:10.1016/j.uclim.2015.06.005.

Azadi, Y., M. Yazdanpanah and H. Mahmoudi, 2019: Understanding smallholder farmers' adaptation behaviors through climate change beliefs, risk perception, trust, and psychological distance: Evidence from wheat growers in Iran. *J. Environ. Manag.*, **250**, 109456, doi:10.1016/j.jenvman.2019.109456.

Azhoni, A., S. Jude and I. Holman, 2018: Adapting to climate change by water management organisations: enablers and barriers. *J. Hydrol. Reg. Stud.*, **559**, 736–748, doi:10.1016/j.jhydrol.2018.02.047.

Baarsch, F., et al., 2015: *Impacts of Low Aggregate INDCs Ambition*.

Baatz, C., 2018: Climate Adaptation Finance and Justice. A Criteria-Based Assessment of Policy Instruments. *Analyse Krit.*, **40**(1), 73–106, doi:10.1515/auk-2018-0004.

2018: Integration of Indigenous and Scientific Knowledge in Disaster Risk Reduction: Resilience Building of a Marginalized Sampaguita Growing Community in the Philippines. *Procedia Eng*, 511–518.

Baffoe, G. and H. Matsuda, 2017: An empirical assessment of households livelihood vulnerability: the case of rural Ghana. *Soc. Indic. Res.*, **140**(3), 1225–1257, doi:10.1007/s11205-017-1796-9.

Bahri, T., et al., 2021: *Adaptive management of fisheries in response to climate change*. FAO Fisheries and Aquaculture Technical Paper, No. 667. FAO, Rome. 301 pp.

Baird, J., R. Plummer, C. Haug and D. Huitema, 2015: Learning effects of interactive decision-making processes for climate change adaptation. *Glob. Environ. Chang.*, **27**, 51–63.

Baker, E. and S. Solak, 2011: Climate change and optimal energy technology R&D policy. *Eur. J. Oper Res.*, **213**(2), 442–454, doi:10.1016/j.ejor.2011.03.046.

Balasubramanian, M., 2018: Climate change, famine, and low-income communities challenge Sustainable Development Goals. *Lancet Planet. Health*, **2**(10), e421–e422, doi:10.1016/s2542-5196(18)30212-2.

Ballester, J., R. Lowe, P.J. Diggle and X. Rodó, 2016: Seasonal forecasting and health impact models: challenges and opportunities. *Ann. N.Y. Acad. Sci.*, **1382**, 8.

Ballew, M.T., et al., 2020: Does socioeconomic status moderate the political divide on climate change? The roles of education, income, and individualism. *Glob. Environ. Chang.*, **60**, doi:10.1016/j.gloenvcha.2019.102024.

Banda, M.L. and C.S. Fulton, 2017: Litigating Climate Change in National Courts: Recent Trends and Developments in Global Climate Law. *Environ. Law Report. Univ. Louisv. Sch. Law Leg. Stud. Res. Pap. Ser.*, **47**(2), 10121.

Bandura, A. and L. Cherry, 2019: Enlisting the power of youth for climate change. *Am. Psychol.*, doi:10.1037/amp0000512.

Barbeaux, S.J., K. Holsman and S. Zador, 2020: Marine heatwave stress test of ecosystem-based fisheries management in the gulf of alaska pacific cod fishery. *Front. Mar. Sci.*, **7**, 703.

Barnard, P., R. Altwegg, I. Ebrahim and L.G. Underhill, 2017: Early warning systems for biodiversity in southern Africa–How much can citizen science mitigate imperfect data? *Biol. Conserv.*, **208**, 183–188.

Barnett, J., et al., 2014: A local coastal adaptation pathway. *Nat. Clim. Chang.*, **4**(12), 1103–1108, doi:10.1038/nclimate2383.

Barnett, J. and S. O'Neill, 2010: Maladaptation. *Glob. Environ. Chang.*, **2**(20), 211–213.

Basher, R., 2006: Global early warning systems for natural hazards: systematic and people-centred. *Philos. Trans. A. Math. Phys. Eng. Sci.*, **364**(1845), 2167–2182, doi:10.1098/rsta.2006.1819.

Bassett, T.J. and C. Fogelman, 2013: Déjà vu or something new? The adaptation concept in the climate change literature. *Geoforum*, **48**, 42–53.

Basupi, L.V., C.H. Quinn and A.J. Dougill, 2019: Adaptation strategies to environmental and policy change in semi-arid pastoral landscapes: evidence from Ngamiland, Botswana. *J. Arid Environ.*, **166**, 17–27, doi:10.1016/j.jaridenv.2019.01.011.

Batisha, A. F., 2015: Implementing fuzzy decision making technique in analyzing the Nile Delta resilience to climate change. *Alex. Eng. J.*, **54**(4), 1043–1056, doi:10.1016/j.aej.2015.05.019.

Bauch, C.T., R. Sigdel, J. Pharaon and M. Anand, 2016: Early warning signals of regime shifts in coupled human-environment systems. *Proc. Natl. Acad. Sci. U. S. A.*, **113**(51), 14560–14567, doi:10.1073/pnas.1604978113.

Baudoin, M.-A., et al., 2016: From top-down to "community-centric" approaches to early warning systems: exploring pathways to improve disaster risk reduction through community participation. *Int. J. Disaster Risk Sci.*, **7**(2), 163–174, doi:10.1007/s13753-016-0085-6.

Baur, E., R. Schnarwiler, A. Prystav and L. Sundermann, 2018: *Disaster Risk Financing: Smart Solutions for the Public Sector. Closing the Protection Gap*. SwissRe, Zurich.

Baztan, J., et al., 2017: Life on thin ice: insights from Uummannaq, Greenland for connecting climate science with Arctic communities. *Polar Sci.*, **13**, 100–108, doi:10.1016/j.polar.2017.05.002.

Becker, A. and E. Kretsch, 2019: The leadership void for climate adaptation planning: case study of the port of providence (Rhode Island, United States). *Front. Earth Sci.*, **7**, 29.

Beckett, V., 2016: *Insuring the Geopolitics of Climate Change*. *ReActions*, London.

Bedelian, C. and J.O. Ogutu, 2017: Trade-offs for climate-resilient pastoral livelihoods in wildlife conservancies in the Mara ecosystem, Kenya. *Pastoralism*, **7**(1), 10, doi:10.1186/s13570-017-0085-1.

Bedford, T., S. French and E. Atherton, 2005: Supporting ALARP decision making by cost benefit analysis and multiattribute utility theory. *J. Risk Res.*, **8**(3), 207–223, doi:10.1080/1366987042000192408.

Behzadian, M., R.B. Kazemzadeh, A. Albadvi and M. Aghdasi, 2010: PROMETHEE: A comprehensive literature review on methodologies and applications. *Eur. J. Oper Res.*, **200**(1), 198–215, doi:10.1016/j.ejor.2009.01.021.

Belčáková, I., M. Świąder and M. Bartyna-Zielińska, 2019: The green infrastructure in cities as A tool for climate change adaptation and mitigation: slovakian and polish experiences. *Atmosphere*, **10**(9), 552.

Bell, J. and T. Morrison, 2015: A Comparative Analysis of the Transformation of Governance Systems: Land-Use Planning for Flood Risk. *J. Environ. Policy Plan.*, **17**(4), 516–534, doi:10.1080/1523908x.2014.986567.

Bell, M.L., et al., 2001: An evaluation of multi-criteria methods in integrated assessment of climate policy. *J. Multi Crit. Decis. Anal.*, **10**(5), 229–256, doi:10.1002/mcda.305.

Bellinson, R. and E. Chu, 2019: Learning pathways and the governance of innovations in urban climate change resilience and adaptation. *J. Environ. Policy Plan.*, **21**(1), 76–89, doi:10.1080/1523908x.2018.1493916.

Belton, V. and T. Stewart, 2002: *Multiple Criteria Decision Analysis: An Integrated Approach*. Kluwer Academic Publishers, Boston.

Bendoly, E. and S. Clark, 2016: *Visual Analytics for Management: Translational Science and Applications in Practice*. Taylor & Francis, New York, ISBN 978-1315640891.

Béné, C., et al., 2017: Squaring the circle: reconciling the need for rigor with the reality on the ground in resilience impact assessment. *World Dev*, **97**, 212–231.

Béné, C., S. Devereux and R. Sabates-Wheeler, 2012: Shocks and social protection in the horn of Africa: analysis from the productive safety net programme in Ethiopia. *IDS Work. Pap.*, **2012**(395), 1–120, doi:10.1111/j.2040-0209.2012.00395.x.

Béné, C., A. Riba and D. Wilson, 2020: Impacts of resilience interventions – evidence from a quasi-experimental assessment in Niger. *Int. J. Dis. Risk Reduct.*, **43**, 101390, doi:10.1016/j.ijdrr.2019.101390.

Benjamin, L., 2017: The duty of due consideration in the anthropocene: climate risk and English directorial duties. *Carbon Clim. Law Rev.*, **11**(2), 90–99.

Benzie, M. and A. Persson, 2019: Governing borderless climate risks: moving beyond the territorial framing of adaptation. *Int. Environ. Agree.*, **19**, 369–393.

Berrang-Ford, L., et al., 2019: Tracking global climate change adaptation among governments. *Nat. Clim. Chang.*, **9**, 440–449.

Berrang-Ford, L., et al., 2014: What drives national adaptation? A global assessment. *Clim. Change*, **124**(1-2), 441–450, doi:10.1007/s10584-014-1078-3.

Berrang-Ford, L., et al., 2021: A systematic global stocktake of evidence on human adaptation to climate change. Nat. Clim. Change, **11**, 989–1000, doi: 10.1038/s41558-021-01170-y.

Berrang-Ford, L., et al., 2017: *Towards the assessment of global adaptation progress*. United Nations Environment Programme (UNEP), Nairobi, Kenya, 35–47.

Bessembinder, J., et al., 2019: Need for a common typology of climate services. *Clim. Serv.*, **16**, 100135, doi:10.1016/j.cliser.2019.100135.

Betzold, C. and I. Mohamed, 2017: Seawalls as a response to coastal erosion and flooding: a case study from Grande Comore, Comoros (West Indian Ocean). *Reg. Environ. Chang.*, **17**(4), 1077–1087.

Beunen, R. and J.J. Patterson, 2019: Analysing institutional change in environmental governance: Exploring the concept of 'institutional work. *J. Environ. Plan. Manag.*, **62**(1), 12–29.

Beven, K.J., et al., 2018a: Epistemic uncertainties and natural hazard risk assessment – Part 1: A review of different natural hazard areas. *Nat. Hazards Earth Syst. Sci.*, **18**(10), 2741–2768, doi:10.5194/nhess-18-2741-2018.

Beven, K.J., et al., 2018b: Epistemic uncertainties and natural hazard risk assessment – Part 2: What should constitute good practice? *Nat. Hazards Earth Syst. Sci.*, **18**(10), 2769–2783, doi:10.5194/nhess-18-2769-2018.

Bhattacharya, A., et al., 2020: *Delivering on the $100 billion climate finance commitment and transforming climate finance*. Independent Expert Group on Climate Finance, https://www.un.org/sites/un2.un.org/files/100_billion_climate_finance_report.pdf. Accessed 2021.

Bhave, A.G., D. Conway, S. Dessai and D.A. Stainforth, 2016: Barriers and opportunities for robust decision making approaches to support climate change adaptation in the developing world. *Clim. Risk Manag.*, **14**, 1–10, doi:10.1016/j.crm.2016.09.004.

Bhave, A.G., D. Conway, S. Dessai and D.A. Stainforth, 2018: Water resource planning under future climate and socioeconomic uncertainty in the Cauvery river basin in Karnataka, India. *Water Resour. Res.*, **54**(2), 708–728, doi:10.1002/2017wr020970.

Biagini, B., et al., 2014: A typology of adaptation actions: A global look at climate adaptation actions financed through the Global Environment Facility. *Glob. Environ. Chang.*, **25**(1), 97–108, doi:10.1016/j.gloenvcha.2014.01.003.

Biagini, B. and A. Miller, 2013: Engaging the private sector in adaptation to climate change in developing countries: importance, status, and challenges. *Clim. Dev.*, **5**(3), 242–252, doi:10.1080/17565529.2013.821053.

Bianco, G.B., 2020: Climate change adaptation, coffee, and corporate social responsibility: challenges and opportunities. *Int. J. Corp. Soc. Responsib.*, **5**(1), 3, doi:10.1186/s40991-020-00048-0.

Biehl, L.L., L. Zhao, C.X. Song and C.G. Panza, 2017: Cyberinfrastructure for the collaborative development of U2U decision support tools. *Clim. Risk Manag.*, **15**(C), 90–108, doi:10.1016/j.crm.2016.10.003.

Biermann, F. and I. Boas, 2017: Towards a global governance system to protect climate migrants: taking stock. In: *Research Handbook on Climate Change, Migration and the Law*. Edward Elgar Publishing, Massachusetts, USA.

Biesbroek, G.R., et al., 2010: Europe adapts to climate change: comparing national adaptation strategies. *Glob. Environ. Change*, **20**(3), 440–450, doi:10.1016/j.gloenvcha.2010.03.005.

Biesbroek, R., Berrang-Ford, L., Ford, J.D., Tanabe, A., Austin, S.E. and Lesnikowski, A., 2018: Data, concepts and methods for large-n comparative climate change adaptation policy research: A systematic literature review. *Wiley. Interdiscip. Rev. Clim. Change.*, **9**(6), e548.

Bird, N., 2014: *Fair share: climate finance to vulnerable countries. Briefing Papers*. Overseas Development Institute, accessed 31 March 2022, , https://odi.org/en/publications/fair-share-climate-finance-to-vulnerable-countries/.

Birkmann, J. and N. Fernando, 2008: Measuring revealed and emergent vulnerabilities of coastal communities to Tsunami in Sri Lanka. *Disasters*, **32**(1), 82–105, doi:10.1111/j.1467-7717.2007.01028.x.

Birkmann, J., M. Garschagen and N. Setiadi, 2014: New challenges for adaptive urban governance in highly dynamic environments: Revisiting planning systems and tools for adaptive and strategic planning. *Urban Clim.*, **7**, 115–133.

Birkmann, J. and T. Welle, 2015: Assessing the risk of loss and damage: exposure, vulnerability and risk to climate-related hazards for different country classifications. *Int. J. Glob. Warming*, **8**(2), 191–212.

Bisbal, G.A., 2019: Practical tips to establish an actionable science portfolio for climate adaptation. *Sci. Public Policy*, **46**(1), 148–153, doi:10.1093/scipol/scy070.

Bitsura-Meszaros, K., E. Seekamp, M. Davenport and J.W. Smith, 2019: A PGIS-based climate change risk assessment process for outdoor recreation and tourism dependent communities. *Sustainability*, **11**(12), 3300, doi:10.3390/su11123300.

Blades, J.J., et al., 2016: Forest managers' response to climate change science: evaluating the constructs of boundary objects and organizations. *For. Ecol. Manag.*, **360**, 376–387, doi:10.1016/j.foreco.2015.07.020.

Blair, B., O.A. Lee and M. Lamers, 2020: Four paradoxes of the user–provider interface: a responsible innovation framework for sea ice services. *Sustainability*, **12**(2), 448, doi:10.3390/su12020448.

Blennow, K., J. Persson, E. Persson and M. Hanewinkel, 2016: Forest owners' response to climate change: University education trumps value profile. *PLoS ONE*, **11**(5), doi:10.1371/journal.pone.0155137.

Bloemen, P.J.T.M., et al., 2019: DMDU into practice: adaptive delta management in the Netherlands. In: *Decision Making under Deep Uncertainty: From Theory to Practice* [Marchau, V.A.W.J., W.E. Walker, P.J.T.M. Bloemen and S.W. Popper(eds.)]. Springer International Publishing, Cham, pp. 321–351. ISBN 978-3030052522.

Blome, T.H.A.M.-C.M.J.D., 2017: *IInnovation in Climate Services and Capacity Building*. Conference report: Fifth International Conference on Climate Services (ICCS5, Cape Town, South Africa, February 28 - March 2 2017.

Blühdorn, I. and M. Deflorian, 2019: The collaborative management of sustained unsustainability: on the performance of participatory forms of environmental governance. *Sustainability*, **11**(4), 1189.

Boardman, A.E., D.H. Greenberg, A.R. Vining and D.L. Weimer, 2017: *Cost-benefit analysis: concepts and practice*. Cambridge University Press, Cambridge.

Bobadoye, A., W. Ogara, G. Ouma and J. Onono, 2016: Assessing climate change adaptation strategies among rural Maasai pastoralist in Kenya. *Am. J. Rural. Dev.*, **4**(6), 120–128.

Boda, C., et al., 2020: *Framing Loss and Damage from Climate Change as the Failure of Sustainable Development*.

Bodin, Ö., 2017: Collaborative environmental governance: achieving collective action in social-ecological systems. *Science*, **357**(6352), eaan1114, doi:10.1126/science.aan1114.

Bodin, Ö., et al., 2019: Working at the "speed of trust": pre-existing and emerging social ties in wildfire responder networks in Sweden and Canada. *Reg Environ Change*, **19**(8), 2353–2364, doi:10.1007/s10113-019-01546-z.

Bodnar, P., J. Brown and S. Nakhooda, 2015: *What Counts: Tools to Help Define and Understand Progress Towards the $100 Billion Climate Finance Commitment*. Climate Policy Initiative, World Resources Institute and Overseas Development Institute, accessed 31 March 2022, https://www.wri.org/research/what-counts-tools-help-define-and-understand-progress-towards-100-billion-climate-finance.

Bolorinos, J., N.K. Ajami and R. Rajagopal, 2020: Consumption change detection for urban planning: monitoring and segmenting water customers during drought. *Water Resour. Res.*, **56**(3), e2019WR025812, doi:10.1029/2019wr025812.

Bonczek, R.H., C.W. Holsapple and A.B. Whinston, 2014: *Foundations of Decision Support Systems*. Academic Press, Massachusetts, USA, pp. 412. ISBN 978-1483236391.

Booysen, M.J., M. Visser and R. Burger, 2019a: Temporal case study of household behavioural response to Cape Town's "Day Zero" using smart meter data. *Water Res.*, **149**, 414–420, doi:10.1016/j.watres.2018.11.035.

Booysen, M.J., B. Wijesiri, C. Ripunda and A. Goonetilleke, 2019b: Fees and governance: Towards sustainability in water resources management at schools in post-apartheid South Africa. *Sustain. Cities Soc.*, **51**, 101694, doi:10.1016/j.scs.2019.101694.

Boran, I., 2017: Two concepts of wrongful harm: a conceptual map for the warsaw international mechanism for loss and damage. *Ethics Policy Environ.*, **20**(2), 195–207.

Bordner, A.S., C.E. Ferguson and L. Ortolano, 2020: Colonial dynamics limit climate adaptation in Oceania: perspectives from the Marshall Islands. *Glob. Environ. Chang.*, **61**, 102054.

Borgomeo, E., J.W. Hall and M. Salehin, 2017: Avoiding the water-poverty trap: insights from a conceptual human-water dynamical model for coastal Bangladesh. *Int. J. Water Resour. Dev.*, **34**(6), 900–922, doi:10.1080/07900627.2017.1331842.

Borgomeo, E., et al., 2016: Trading-off tolerable risk with climate change adaptation costs in water supply systems. *Water Resour. Res.*, **52**(2), 622–643, doi:10.1002/2015wr018164.

Borgonovo, E. and E. Plischke, 2016: Sensitivity analysis: a review of recent advances. *Eur. J. Oper Res.*, **248**(3), 869–887.

Borras, S. and S. Hølund, 2015: Evaluation and policy learning: the learners' perspective. *Eur. J. Polit. Res.*, **54**, 99–120.

Bosomworth, K., P. Leith, A. Harwood and P.J. Wallis, 2017: What's the problem in adaptation pathways planning? The potential of a diagnostic problem-structuring approach. *Environ. Sci. Policy*, **76**, 23–28, doi:10.1016/j.envsci.2017.06.007.

Boston, J., A. Panda and S. Surminski, 2021: Designing a funding framework for the impacts of slow-onset climate change—insights from recent experiences with planned relocation. *Curr. Opin. Environ. Sustain.*, **50**, 159–168.

Boulianne, S., M. Lalancette and D. Ilkiw, 2020: "School strike 4 climate": social media and the international youth protest on climate change. *Media Commun.*, **8**(2), 208–218.

Bouman, T., et al., 2020: When worry about climate change leads to climate action: How values, worry and personal responsibility relate to various climate actions. *Glob. Environ. Chang.*, **62**, 102061, doi:10.1016/j.gloenvcha.2020.102061.

Bourne, A., et al., 2016: A socio-ecological approach for identifying and contextualising spatial ecosystem-based adaptation priorities at the sub-national level. *PLoS ONE*, **11**(5), e155235, doi:10.1371/journal.pone.0155235.

Bours, D., C. McGinn and P. Pringle, 2014a: *Guidance note 1: twelve reasons why climate change adaptation M&E is challenging*, accessed 31 March 2022, https://www.ukcip.org.uk/wp-content/PDFs/MandE-Guidance-Note1.pdf.

Bours, D., C. McGinn and P. Pringle, 2014b: *Guidance Note 2: Selecting Indicators for Climate Change Adaptation Programming*, accessed 31 March 2022, https://ukcip.ouce.ox.ac.uk/wp-content/PDFs/MandE-Guidance-Note2.pdf.

Bours, D., C. McGinn and P. Pringle, 2014c: *Guidance Note 3: Theory of Change Approach to Climate Change Adaptation Programming* SEA Change CoP and UKCIP, accessed 31 March 2022, https://www.ukcip.org.uk/wp-content/PDFs/MandE-Guidance-Note3.pdf.

Bours, D., C. McGinn and P. Pringle, 2014d: Monitoring and Evaluation for Climate Change Adaptation and Resilience: A Synthesis of Tools, Frameworks and Approaches – 2nd edition. SEA Change Community of Practice and United Kingdom Climate Impacts Programme (UKCIP), accessed 31 March 2022, https://ukcip.ouce.ox.ac.uk/wp-content/PDFs/SEA-Change-UKCIP-MandE-review-2nd-edition.pdf

Bouwer, K., 2018: The unsexy future of climate change litigation. *J. Environ. Law.*, **30**(3), 483–506, doi:10.1093/jel/eqy017.

Bouyssou, D., et al., 2006: *Evaluation and Decision Models with Multiple Criteria: Stepping stones for the analyst* International Series in Operations Research & Management Science. Springer, Berlin Heidelberg. 445 pp.

Bouyssou, D., et al., 2012: *Aiding decisions with multiple criteria: essays in honor of Bernard Roy*. Springer, Berlin Heidelberg.

Bowen, T., et al., 2020: *Adaptive Social Protection: Building Resilience to Shocks* International Development in Focus. The World Bank, Washington, D.C., ISBN 978-1464815751. 152 pp.

Bowyer, P., S. Bender, D. Rechid and M. Schaller, 2014: *Adapting to Climate Change: Methods and Tools for Climate Risk Management*, 124.

Boyd, E., et al., 2017: A typology of loss and damage perspectives. *Nat. Clim. Change*, **7**(10), 723.

Boyd, E. and S. Juhola, 2015: Adaptive climate change governance for urban resilience. *Urban Stud.*, **52**(7), 1234–1264.

BRACED, 2015: *BRACED Programme Monitoring & Evaluation (M&E) Guidance Notes*, accessed 31 March 2022, http://www.braced.org/resources/i/braced-monitoring-evaluation-guidance-notes/.

Bracking, S.L.N., 2021: Climate Finance Governance: Fit for Purpose? *WIREs Clim. Chang.*, doi:10.1002/WCC.709.

Brady, M.B. and R. Leichenko, 2020: The impacts of coastal erosion on Alaska's North Slope communities: a co-production assessment of land use damages and risks. *Polar Geogr.*, 1–21, doi:10.1080/1088937x.2020.1755907.

Braito, M.T., et al., 2017: Human-nature relationships and linkages to environmental behaviour. *Environ. Values*, **26**(3), 365–389, doi:10.3197/096327117x14913285800706.

Brammer, R.F. and P. Chakrabarti, 2019: Scitech and the task force on climate-related financial disclosures. *Scitech Lawyer Chic.*, **15**(4), 14–17.

Bremer, S. and S. Meisch, 2017: Co-production in climate change research: reviewing different perspectives. *Wiley Interdiscip. Rev. Clim. Chang.*, **8**(6), e482, doi:10.1002/wcc.482.

Bremer, S., et al., 2019: Toward a multi-faceted conception of co-production of climate services. *Clim. Serv.*, **13**, 42–50, doi:10.1016/j.cliser.2019.01.003.

Broberg, M., 2019: Parametric loss and damage insurance schemes as a means to enhance climate change resilience in developing countries. *Clim. Policy*, **20**(6), 693–703, doi:10.1080/14693062.2019.1641461.

Broberg, M. and B.M. Romera, 2020: Loss and damage after Paris: more bark than bite? *Clim. Policy*, **20**(6), 661–668, doi:10.1080/14693062.2020.1778885.

Brondízio, E.S., et al., 2021: Locally based, regionally manifested, and globally relevant: indigenous and local knowledge, values, and practices for nature. *Annu. Rev. Environ. Resour.*, doi:10.1146/annurev-environ-012220-012127.

Brooks, N., W.N. Adger and P.M. Kelly, 2005: The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Glob. Environ. Chang.*, **15**, 151–163.

Brooks, N., et al., 2019: *Framing and tracking 21st century climate adaptation: monitoring, evaluation and learning for Paris, the SDGs and beyond*. IIED Working Paper.

Brooks, N., et al., 2011: *Tracking adaptation and measuring development*. IIED Working Paper No. 1. International Institute for Environment and Development (IIED), London, UK.

Brooks, N., et al., 2014: *Tracking adaptation and measuring development: a step-by-step guide*. International Institute for Environment and Development (IIED), London.

Broto, V.C., E. Boyd and J. Ensor, 2015: Participatory urban planning for climate change adaptation in coastal cities: lessons from a pilot experience in Maputo, Mozambique. *Curr. Opin. Environ. Sustain.*, **13**, 11–18.

Brousselle, A. and J.M. Buregeya, 2018: Theory-based evaluations: framing the existence of a new theory in evaluation and the rise of the 5th generation. *Evaluation*, **24**(2), 153–168.

Brouwer, S. and D. Huitema, 2018: Policy entrepreneurs and strategies for change. *Reg. Environ. Change*, **18**(5), 1259–1272, doi:10.1007/s10113-017-1139-z.

Brown, C., et al., 2019: Decision Scaling (DS): Decision Support for Climate Change. In: *Decision Making under Deep Uncertainty From Theory to Practice* [Marchau, V.A.W.J., W.E. Walker, P.J.T.M. Bloemen and S.W. Popper(eds.)]. Springer International Publishing, Cham, pp. 255–287. ISBN 978-3030052515.

Brown, K., et al., 2018: Turning risk assessment and adaptation policy priorities into meaningful interventions and governance processes. *Philos. Trans. A. Math. Phys. Eng. Sci.*, **376**(2121), doi:10.1098/rsta.2017.0303.

Brown, K., et al., 2018a: Turning risk assessment and adaptation policy priorities into meaningful interventions and governance processes. *Philos. Trans. A. Math. Phys. Eng. Sci.*, **376**(2121), 20170303, doi:10.1098/rsta.2017.0303.

Brown, K., L. Naylor and T. Quinn, 2017a: Making space for proactive adaptation of rapidly changing coasts: a windows of opportunity approach. *Sustainability*, **9**(8), doi:10.3390/su9081408.

Brugger, J., A. Meadow and A. Horangic, 2016: Lessons from first-generation climate science integrators. *Bull. Am. Meteorol. Soc.*, **97**(3), 355–366, doi:10.1175/bams-d-14-00289.1.

Bruno Soares, M. and Buontempo, C. 2019: Challenges to the Sustainability of Climate Services in Europe. *Wiley Interdisciplinary Reviews: Climate Change*, **10**(4), p.e587.

Bruno Soares, M. and Dessai, S., 2016: Barriers and enablers to the use of seasonal climate forecasts amongst organisations in Europe. *Clim. Change*, **137**(1), 89–103, doi:10.1007/s10584-016-1671-8.

Buchner, B., et al., 2019: *Global Landscape of Climate Finance 2019*. Climate Policy Initiative, London, accessed 31 March 2022, https://www.climatepolicyinitiative.org/wp-content/uploads/2019/11/2019-Global-Landscape-of-Climate-Finance.pdf.

Buggy, L. and K.E. McNamara, 2016: The need to reinterpret "community" for climate change adaptation: a case study of Pele Island, Vanuatu. *Clim. Dev.*, **8**(3), 270–280.

Buontempo, C., et al., 2020: Fostering the development of climate services through Copernicus Climate Change Service (C3S) for agriculture applications. *Weather. Clim. Extrem.*, **27**, 100226, doi:10.1016/j.wace.2019.100226.

Burke, M. and K. Emerick, 2016: Adaptation to climate change: evidence from US agriculture. *Am. Econ. J. Econ. Policy*, **8**(3), 106–140, doi:10.1257/pol.20130025.

Burstein, F. and C.W. Holsapple, 2008: *Handbook on Decision Support Systems 1: Basic Themes*. International Handbooks on Information Systems. Springer-Verlag, Berlin Heidelberg, ISBN: 3540487166, 9783540487166.

Burthe, S.J., et al., 2016: Do early warning indicators consistently predict nonlinear change in long-term ecological data? *J. Appl. Ecol.*, **53**(3), 666–676, doi:10.1111/1365-2664.12519.

Burton, I., O.P. Dube, D. Campbell-Lendrum, I. Davis, R.J.T. Klein, J. Linnerooth-Bayer, A. Sanghi, and F. Toth, 2012: Managingthe risks: international level and integration across scales. In: *Managing the Risks of Extreme Events and Disasters toAdvance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of theIntergovernmental Panel on Climate Change (IPCC).. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 393–435.

Burton, P. and J. Mustelin, 2013: Planning for climate change: is greater public participation the key to success? *Urban Policy Res.*, **31**(4), 399–415, doi:10.1080/08111146.2013.778196.

Busch, D.S., et al., 2016: Climate science strategy of the US National Marine Fisheries Service. *Mar. Policy.*, **74**, 58–67, doi:10.1016/j.marpol.2016.09.001.

Butler, J.R.A., et al., 2016: Priming adaptation pathways through adaptive co-management: design and evaluation for developing countries. *Clim. Risk Manag.*, **12**(C), 1–16, doi:10.1016/j.crm.2016.01.001.

Buurman, J. and V. Babovic, 2016: Adaptation Pathways and Real Options Analysis: an approach to deep uncertainty in climate change adaptation policies. *Policy Soc.*, **35**(2), 137–150.

Cai, H., et al., 2018: A synthesis of disaster resilience measurement methods and indices. *Int. J. Dis. Risk Reduct.*, **31**, 844–855.

Calliari, E., O. Serdeczny and L. Vanhala, 2020: Making sense of the politics in the climate change loss & damage debate. *Glob. Environ. Chang.*, **64**, 102133.

Calliari, E., S. Surminski and J. Mysiak, 2019: The Politics of (and behind) the UNFCCC's Loss and Damage Mechanism. In: *Loss and Damage from Climate Change. Concepts, Methods and Policy Options* [Mechler, R., et al.(ed.)]. Springer, Cham, pp. 155–178.

Calvello, M., et al., 2015: The Rio de Janeiro early warning system for rainfall-induced landslides: analysis of performance for the years 2010–2013. *Int. J. Dis. Risk Reduct.*, **12**, 3–15.

Camargo, A. and D. Ojeda, 2017: Ambivalent desires: State formation and dispossession in the face of climate crisis. *Polit. Geogr.*, **60**, 57–65.

Camps-Valls, G., D. Tuia, X.X. Zhu and M. Reichstein, 2021: *Deep learning for the Earth Sciences: a comprehensive approach to remote sensing, climate science and geosciences*. John Wiley & Sons, Hoboken, ISBN 978-1119646143.

CARE, 2010: *Framework of Milestones and Indicators for Community-Based Adaptation*, accessed 31 March 2022, https://careclimatechange.org/wp-content/uploads/2015/04/CBA_Framework.pdf.

CARE, 2014: *Participatory Monitoring, Evaluation, Reflection and Learning for Community-based Adaptation: A revised manual for local practitioners,* accessed 31 March 2022, http://www.careclimatechange.org/files/2014_PMERL.pdf.

CARE, 2021: *Climate Adaptation Finance – Fact or Fiction?* Centre, C. C. a. R. I., accessed 31 March 2022, https://careclimatechange.org/climate-adaptation-finance-fact-or-fiction/.

Carlsson, F., C. Gravert, O. Johansson-Stenman and V. Kurz, 2019: *Nudging as an Environmental Policy Instrument*. University of Gothenburg, Department of Economics, accessed 31 March 2022, https://ideas.repec.org/p/hhs/gunwpe/0756.html.

Carney, M., 2019: Fifty Shade of Green: The world needs a new, sustainable financial system to stop runaway climate change. *Int. Monet. Fund*, 12–15.

Carr, E.R. and S.N. Onzere, 2018: Really effective (for 15% of the men): lessons in understanding and addressing user needs in climate services from Mali. *Clim. Risk Manag.*, **22**, 82–95, doi:10.1016/j.crm.2017.03.002.

Carter, L., 2019: Traditional Ecological Knowledge in Climate Change. In: *Indigenous Pacific Approaches to Climate Change*, pp. 25–38. ISBN 9783319964386978331996 4393.

Carter, L., 2020: *The Ecosystem of Private Investment in Climate Action*. Invest4Climate Knowledge Series. United Nations Development Programme, New York, USA.

Carter, N.A., et al., 2019a: Lessons Learned through Research Partnership and Capacity Enhancement in Inuit Nunangat. *Arctic*, **72**(4), 381–403, doi:10.14430/arctic69507.

Carter, S., et al., 2019b: *Co-production of African weather and climate services*. Africa, W., A. Climate Information Services for and f. Future Climate, accessed 31 March 2022, https://futureclimateafrica.org/coproduction-manual.

Carty, T., J. Kowalzig and B. Zagema, 2020: *Climate Finance Shadow Report 2020: Assessing Progress Towards the $100 billion Commitment*. Oxfam International, Oxford, ISBN 978-1787486621.

Cash, D.W., et al., 2003: Knowledge systems for sustainable development. *Proc. Natl. Acad. Sci.*, **100**(14), 8086–8091, doi:10.1073/pnas.1231332100.

Catenacci, M. and C. Giupponi, 2013: Integrated assessment of sea-level rise adaptation strategies using a Bayesian decision network approach. *Environ. Model. Softw.*, **44**, 87–100, doi:10.1016/j.envsoft.2012.10.010.

Cattino, M. and D. Reckien, 2021: Does public participation lead to more ambitious and transformative local climate change planning? *Curr. Opin. Environ. Sustain.* **52**, 100–110.

Caurla, S. and A. Lobianco, 2020: Estimating climate service value in forestry: The case of climate information on drought for maritime pine in Southwestern France. *Clim. Serv.*, **17**, 100106, doi:10.1016/j.cliser.2019.100106.

CBI, 2019: *Climate Resilience Principles: A framework for assessing climate resilience investments*. Initiative, C. B, accessed 31 March 2022, https://www.climatebonds.net/files/page/files/climate-resilience-principles-climate-bonds-initiative-20190917-.pdf.

CBI, 2020: *Green Bonds Global State of the Market 2019*. Initiative, C. B, accessed 31 March 2022, https://www.climatebonds.net/files/reports/cbi_sotm_2019_vol1_04d.pdf.

Ceccato, P., et al., 2018: Data and tools to integrate climate and environmental information into public health. *Infect Dis. Poverty*, **7**(1), 126, doi:10.1186/s40249-018-0501-9.

Challinor, A.J., W.N. Adger and T.G. Benton, 2017: Climate risks across borders and scales. *Nat. Clim. Change*, **7**(9), 621–623.

Challinor, A.J., et al., 2018: Transmission of climate risks across sectors and borders. *Philos. Trans. Royal Soc. A Math. Phys. Eng. Sci.*, **376**(2121), 20170301, doi:10.1098/rsta.2017.0301.

Chambwera, M., G. Heal, C. Dubeux, S. Hallegatte, L. Leclerc, A. Markandya, B.A. McCarl, R. Mechler, and J.E. Neumann, 2014: Economics of adaptation. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 945–977. ISBN 978-1107058071.

Chan, S., et al., 2015: Reinvigorating international climate policy: a comprehensive framework for effective nonstate action. *Glob Policy*, **6**(4), 466–473.

Chandra, A., et al., 2017: Gendered vulnerabilities of smallholder farmers to climate change in conflict-prone areas: a case study from Mindanao, Philippines. *J. Rural. Stud.*, **50**, 45–59.

Chantarat, S., A.G. Mude, C.B. Barrett and M.R. Carter, 2013: Designing index-based livestock insurance for managing asset risk in northern Kenya. *J. Risk Insur.*, **80**(1), 205–237, doi:10.1111/j.1539-6975.2012.01463.x.

Chanza, N. and A. de Wit, 2016: Enhancing climate governance through indigenous knowledge: case in sustainability science. *S. Afr. J. Sci.*, **112**(3/4), 35–37, doi:10.17159/sajs.2016/20140286.

Chapagain, D., F. Baarsch, M. Schaeffer and S. D'Haen, 2020: Climate change adaptation costs in developing countries: insights from existing estimates. *Clim. Dev.*, doi:10.1080/17565529.2020.1711698.

Chattopadhyay, A., E. Nabizadeh and P. Hassanzadeh, 2020: Analog Forecasting of Extreme-Causing Weather Patterns Using Deep Learning. *J. Adv. Model. Earth Syst.*, **12**(2), doi:10.1029/2019MS001958.

Chen, C., et al., 2016: Measuring the adaptation gap: A framework for evaluating climate hazards and opportunities in urban areas. *Environ. Sci. Policy*, **66**, 403–419.

Chen, S. and J.I. Uitto, 2014: *Small grants, big impacts: aggregation challenges* Uitto, J. I. Routledge, London and New York, 105–122.

Cheong, S.-M., C. Bautista and L. Ortiz, 2020a: Sensing physiological change and mental stress in older adults from hot weather. *IEEE Access*, **8**, 70171–70181, doi:10.1109/access.2020.2982153.

Cheong, S.-M., et al. (ed.), *AI for Climate Change Adaptation*. 2020 Annual Meeting, Washington State Convention Center. American Association for the Advancement of Science. Washington, D.C.

Chhetri, R.P., et al., 2020: *CFAS Policy Brief: Options for the post-2025 climate finance goal*. Climate Finance Advisory.https://cfas.info/en/publication/options-post-2025-climate-finance-goal. Accessed 2021 . (20 pp).

Chiang, Y.-C., 2018: Exploring community risk perceptions of climate change-A case study of a flood-prone urban area of Taiwan. *Cities*, **74**, 42–51.

Chimani, B., et al., 2020: Compilation of a guideline providing comprehensive information on freely available climate change data and facilitating their efficient retrieval. *Clim. Serv.*, **19**, 100179, doi:10.1016/j.cliser.2020.100179.

Chu, E., I. Anguelovski and D. Roberts, 2017: Climate adaptation as strategic urbanism: assessing opportunities and uncertainties for equity and inclusive development in cities. *Cities*, **60**(A), 378–387, doi:10.1016/j.cities.2016.10.016.

Chu, E. and K. Michael, 2018: Recognition in urban climate justice: marginality and exclusion of migrants in Indian cities. *Environ. Urban.*, **31**(1), 139–156, doi:10.1177/0956247818814449.

Chu, E.K., 2018: Urban climate adaptation and the reshaping of state–society relations: The politics of community knowledge and mobilisation in Indore, India. *Urban Stud.*, **55**(8), 1766–1782.

CIF, 2020: *Evaluation and Learning Special Initiative: FY20 Annual Report and FY21 Work Plan* Document Joint CTF-SCF/TFC.22/5.

Ciplet, D., J.T. Roberts and M. Khan, 2013: The politics of international climate adaptation funding: justice and divisions in the greenhouse. *Glob. Environ. Polit.*, **13**(1), 49–68, doi:10.1162/GLEP_a_00153.

Ciullo, A., et al., 2020: Efficient or fair? Operationalizing ethical principles in flood risk management: a case study on the Dutch-German rhine. *Risk. Anal.*, **40**(9), 1844–1862.

Claeys, P. and D. Delgado Pugley, 2017: Peasant and indigenous transnational social movements engaging with climate justice. *Can. J. Dev. Stud.*, **38**(3), 325–340, doi:10.1080/02255189.2016.1235018.

Clare, A., S. Fankhauser and C. Gennaioli, 2017b: The national and international drivers of climate change legislation. In: *Trends in Climate Change Legislation* [Averchenkova, A., S. Fankhauser and M. Nachmany)](eds.)]. Edward Elgar Publishing, Cheltenham, UK, pp. 19–36. ISBN 978-1786435781.

Clare, A., R. Graber, L. Jones and D. Conway, 2017a: Subjective measures of climate resilience: What is the added value for policy and programming? *Glob. Environ. Chang.*, **46**(9), 17–22.

Clarke, D., A. de Janvry, E. Sadoulet and E. Skoufias (eds.), *Disaster Risk Financing and Insurance: Issues and Results*. Report on a workshop held at the Ferdi on June.

Clarke, D. and O. Mahul, 2011: *Disaster Risk Financing and Contingent Credit: a Dynamic Analysis*. World Bank Policy Research Working Paper, Vol. 5693.

Clarke, M. and T. Hussain, 2018: Climate change litigation: A new class of action. *White Case*, 8., accessed 31 March 2022, https://www.whitecase.com/publications/insight/climate-change-litigation-new-class-action.

Clarkson, G., et al., 2019: An investigation of the effects of PICSA on smallholder farmers' decision-making and livelihoods when implemented at large scale – The case of Northern Ghana. *Clim. Serv.*, **14**, 1–14, doi:10.1016/j.cliser.2019.02.002.

Cliffe, N., et al., 2016: Developing the capacity of farmers to understand and apply seasonal climate forecasts through collaborative learning processes. *J. Agric. Educ. Ext.*, **22**(4), 311–325, doi:10.1080/1389224X.2016.1154473.

Codjoe, S.N., et al., 2020: Impact of extreme weather conditions on healthcare provision in urban Ghana. *Soc. Sci. Med.*, **258**, 113072.

Coirolo, C., S. Commins, I. Haque and G. Pierce, 2013: Climate change and social protection in Bangladesh: are existing programmes able to address the impacts of climate change? *Dev. Policy Rev.*, **31**(S2), o74–o90, doi:10.1111/dpr.12040.

Coleman, J.C. and M. Sandhu, 1965: Intelligence level and background factors in learning disorders. *Psychol. Rep.*, **17**(1), 69–70, doi:10.2466/pr0.1965.17.1.69.

Colenbrander, S., D. Dodman and D. Mitlin, 2018: Using climate finance to advance climate justice: the politics and practice of channelling resources to the local level. *Clim. Policy*, **18**(7), 902–915, doi:10.1080/14693062.2017.1388212.

Collins M., M. Sutherland, L. Bouwer, S.-M. Cheong, T. Frölicher, H. Jacot Des Combes, M. Koll Roxy, I. Losada, K. McInnes, B. Ratter, E. Rivera-Arriaga, R.D. Susanto, D. Swingedouw, and L. Tibig, 2019: Extremes, Abrupt Changes and Managing Risk. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Colloff, M.J., et al., 2017: An integrative research framework for enabling transformative adaptation. *Environ. Sci. Policy*, **68**(C), 87–96, doi:10.1016/j.envsci.2016.11.007.

Committee on Climate Change, 2017: *Adaptation Reporting Power: second round review*, accessed 31 March 2022, https://d423d1558e1d71897434.b-cdn.net/wp-content/uploads/2017/03/Adaptation-Reporting-Power-Second-round-review-Committee-on-Climate-Change-March-2017.pdf.

Connolly, J.J.T. and I. Anguelovski, 2021: Three histories of greening and whiteness in American cities. *Front. Ecol. Evol.*, **9**(101), doi:10.3389/fevo.2021.621783.

Conservation Law Foundation v. Exxon Mobil Corporation, 2021: *Conservation Law Foundation v. Exxon Mobil Corporation*. http://climatecasechart.com/climate-change-litigation/wp-content/uploads/sites/16/case-documents/2021/20210701_docket-20-1456_opinion.pdf.

Consolidated Edison Co., C. C. V. S, 2019: *Consolidated Edison Co., C. C. V. S*., accessed 9 September 2021, https://www.coned.com/-/media/files/coned/documents/our-energy-future/our-energy-projects/climate-change-resiliency-plan/climate-change-vulnerability-study.pdf.

Conway, D., et al., 2019: The need for bottom-up assessments of climate risks and adaptation in climate-sensitive regions. *Nat. Clim. Chang.*, **9**(7), 503–511.

Cooper, R., 2020: *Risk of Capital Flight due to a Better Understanding of Climate Change Risks*. K4D Helpdesk, **Report 727**.Institute of Development Studies, Brighton, UK, https://gsdrc.org/publications/risk-of-capital-flight-due-to-a-better-uunderstanding-of-climate-change/.

Cornell, S., et al., 2013: Opening up knowledge systems for better responses to global environmental change. *Environ. Sci. Policy*, **28**, 60–70, doi:10.1016/j.envsci.2012.11.008.

Corner, A., E. Markowitz and N. Pidgeon, 2014: Public engagement with climate change: the role of human values. *Wiley Interdiscip. Rev. Clim. Chang.*, **5**(3), 411–422, doi:10.1002/wcc.269.

Cortekar, J., M. Themessl and K. Lamich, 2020: Systematic analysis of EU-based climate service providers. *Clim. Serv.*, **17**, 100125, doi:10.1016/j.cliser.2019.100125.

Cosens, B.A., et al., 2017: The role of law in adaptive governance. *Ecol. Soc. A J. Integr. Sci. Resil. Sustain.*, **22**(1), 1.

Coughlan de Perez, E. and S.J. Mason, 2014: Climate information for humanitarian agencies: some basic principles. *Earth Perspect.*, **1**(1), 1–6, doi:10.1186/2194-6434-1-11.

Coughlan de Perez, E., et al., 2019: From rain to famine: assessing the utility of rainfall observations and seasonal forecasts to anticipate food insecurity in East Africa. *Food Sec.*, **11**(1), 57–68, doi:10.1007/s12571-018-00885-9.

Coughlan de Perez, E., et al., 2015: Forecast-based financing: an approach for catalyzing humanitarian action based on extreme weather and climate forecasts. *Nat. Hazards Earth Syst. Sci.*, **15**(4), 895–904, doi:10.5194/nhess-15-895-2015.

CPI, 2019: *Global Landscape of Climate Finance 2019*. Initiative, C. P., accessed 31 March 2022, https://climatepolicyinitiative.org/wp-content/uploads/2019/11/2019-Global-Landscape-of-Climate-Finance.pdf.

CPI, 2020: *Updated View of the Global Landscape of Climate Finance 2019*. Rob Macquarie, Baysa Naran, Paul Rosane, Matthew Solomon, Cooper Wetherbee.Climate Policy, I., London, https://www.climatepolicyinitiative.org/publication/updated-view-on-the-global-landscape-of-climate-finance-2019. Accessed 2021.

Craft, B. and S. Fisher, 2015: *National Experiences Can Inform a Global Goal for Climate Change Adaptation*. IIED Briefing, International Institute for Environment and Development (IIED), London.

Craft, B. and S. Fisher, 2018: Measuring the adaptation goal in the global stocktake of the Paris Agreement. *Clim. Policy*, **18**(9), 1203–1209, doi:10.1080/14693062.2018.1485546.

Craig, R.K. (ed.), *'Stationarity is Dead' - Long Live Transformation: Five Principles for Climate Change Adaptation Law*.

Craig, R.K., et al., 2017: Balancing stability and flexibility in adaptive governance: an analysis of tools available in US environmental law. *Ecol. Soc. J. Integr. Sci. Resil. Sustain.*, **22**(2), 1.

Crain, C.M., K. Kroeker and B.S. Halpern, 2008: Interactive and cumulative effects of multiple human stressors in marine systems. *Ecol. Lett.*, **11**(12), 1304–1315, doi:10.1111/j.1461-0248.2008.01253.x.

Crane-Droesch, A., 2018: Machine learning methods for crop yield prediction and climate change impact assessment in agriculture. *Environ. Res. Lett.*, **13**(11), 114003, doi:10.1088/1748-9326/aae159.

Crawley, H. and D. Skleparis, 2018: Refugees, migrants, neither, both: categorical fetishism and the politics of bounding in Europe's 'migration crisis'. *J. Ethn. Migr. Stud.*, **44**(1), 48–64.

Cremades, R., et al., 2019: Ten principles to integrate the water-energy-land nexus with climate services for co-producing local and regional integrated assessments. *Sci. Total Environ.*, **693**, 133662, doi:10.1016/j.scitotenv.2019.133662.

Creutzig, F., et al., 2018: Towards demand-side solutions for mitigating climate change. *Nat. Clim. Change*, **8**(4), 260–263, doi:10.1038/s41558-018-0121-1.

CSIRO, 2018: *Climate Compass: A Climate Risk Management Framework for Commonwealth Agencies*. CSIRO, Australia.

Cuaton, G.P. and Y. Su, 2020: Local-indigenous knowledge on disaster risk reduction: Insights from the Mamanwa indigenous peoples in Basey, Samar after Typhoon Haiyan in the Philippines. *Int. J. Dis. Risk Reduct.*, **48**, 101596, doi:10.1016/j.ijdrr.2020.101596.

Cuevas, S.C., 2016: The interconnected nature of the challenges in mainstreaming climate change adaptation: evidence from local land use planning. *Clim. Change*, **136**(3-4), 661–676, doi:10.1007/s10584-016-1625-1.

Cummins, J.D. and O. Mahul, 2009: *Catastrophe risk financing in developing countries: principles for public intervention*. World Bank Publications, Washington, D.C., ISBN 978-0821377369.

Cvitanovic, C., et al., 2015: Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: A review of knowledge and research needs. *Ocean. Coast. Manag.*, **112**, 25–35, doi:10.1016/j.ocecoaman.2015.05.002.

Cvitanovic, C., et al., 2019: Maximising the benefits of participatory climate adaptation research by understanding and managing the associated challenges and risks. *Environ. Sci. Policy*, **94**, 20–31, doi:10.1016/j.envsci.2018.12.028.

D'Alisa, G. and G.A. Kallis, 2016: Political ecology of maladaptation: Insights from a Gramscian theory of the State. *Glob. Environ. Chang.*, **38**, 230–242.

Dalkir, K., 2005: *Knowledge Management in Theory and Practice*. Elsevier Butterworth–Heinemann, Oxford, ISBN 978-0750678643.

Daly, M. and L. Dilling, 2019: The politics of "usable" knowledge: examining the development of climate services in Tanzania. *Clim. Change*, **157**(1), 61–80, doi:10.1007/s10584-019-02510-w.

Daniels, E., et al., 2020: Refocusing the climate services lens: Introducing a framework for co-designing "transdisciplinary knowledge integration processes" to build climate resilience. *Clim. Serv.*, **19**, 100181, doi:10.1016/j.cliser.2020.100181.

Dannenberg, A.L., H. Frumkin, J.J. Hess and K.L. Ebi, 2019: Managed retreat as a strategy for climate change adaptation in small communities: public health implications. *Clim. Chang.*, **153**(1), 1–14.

Daron, J., 2015: Challenges in using a Robust Decision Making approach to guide climate change adaptation in South Africa. *Clim. Change*, **132**(3), 459–473.

Daron, J., et al., 2021: Integrating seasonal climate forecasts into adaptive social protection in the Sahel. *Clim. Dev.*, **13**(6), 543–550.

Das, S., 2019: Evaluating climate change adaptation through evacuation decisions: a case study of cyclone management in India. *Clim. Change*, **152**, 291–305.

David-Chavez, D.M. and M.C. Gavin, 2018: A global assessment of Indigenous community engagement in climate research. *Environ. Res. Lett.*, **13**(12), 123005, doi:10.1088/1748-9326/aaf300.

Davies, K., et al., 2018: Navigating collaborative networks and cumulative effects for Sustainable Seas. *Environ. Sci. Policy*, **83**, 22–32, doi:10.1016/j.envsci.2018.01.013.

Davis, L.S., 2010: Institutional flexibility and economic growth. *J. Comp. Econ.*, **38**(3), 306–320.

de Bruin, K., et al., 2009: Adapting to climate change in The Netherlands: an inventory of climate adaptation options and ranking of alternatives. *Clim. Change*, **95**(1-2), 23–45, doi:10.1007/s10584-009-9576-4.

de Coninck, H., A. Revi, M. Babiker, P. Bertoldi, M. Buckeridge, A. Cartwright, W. Dong, J. Ford, S. Fuss, J.-C. Hourcade, D. Ley, R. Mechler, P. Newman, A. Revokatova, S. Schultz, L. Steg, and T. Sugiyama, 2018: Strengthening and Implementing the Global Response. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. ISBN 978-9291691517 In press.

De Gregorio Hurtado, S., et al., 2015: Understanding how and why cities engage with climate policy: an analysis of local climate action in Spain and Italy. *Tema J. Land Use Mobil. Environ.*, 23–46, doi:10.6092/1970-9870/3649.

de Koning, K. and T. Filatova, 2020: Repetitive floods intensify outmigration and climate gentrification in coastal cities. *Environ. Res. Lett.*, **15**(3), 34008, doi:10.1088/1748-9326/ab6668.

de Koning, K., T. Filatova, A. Need and O. Bin, 2019: Avoiding or mitigating flooding: bottom-up drivers of urban resilience to climate change in the USA. *Glob. Environ. Chang.*, **59**, 101981, doi:10.1016/j.gloenvcha.2019.101981.

de Ruig, L.T., et al., 2019: An economic evaluation of adaptation pathways in coastal mega cities: an illustration for Los Angeles. *Sci. Total Environ.*, **678**, 647–659, doi:10.1016/j.scitotenv.2019.04.308.

de Sherbinin, A., et al., 2019: Climate vulnerability mapping: a systematic review and future prospects. *Wiley. Interdiscip. Rev. Clim. Change.*, **10**(5), e600–e600.

De Smet, Y. and K. Lidouh (eds.), 2013: *An introduction to multicriteria decision aid: The PROMETHEE and GAIA methods*. In European Business Intelligence Summer School, Springer, Berlin, Heidelberg, pp. 150–176.

DeCaro, D.A., et al., 2017: Legal and institutional foundations of adaptive environmental governance. *Ecol. Soc.*, **22**(1), 32, doi:10.5751/ES-09036-220132.

Denton, F., T.J. Wilbanks, A.C. Abeysinghe, I. Burton, Q. Gao, M.C. Lemos, T. Masui, K.L. O'Brien, and K. Warner, 2014: Climate-resilient pathways: adaptation, mitigation, and sustainable development. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1101–1131.

Desai, B., et al., 2021: Addressing the human cost in a changing climate. *Science*, **372**(6548), 1284–1287.

Deubelli, T. and K. Venkateswaran, 2021: *Transforming Resilience-Building today for Sustainable Futures Tomorrow: Insights from the Forthcoming Book "Transformation and Disaster Resilience"*. IIASA Working Paper.

Dewi, N., K. Kusnandar and E. Rahayu, 2018: Risk mitigation of climate change impacts on rice farming through crop insurance: an analysis of farmer's willingness to participate (a case study in Karawang Regency, Indonesia). *IOP Conf. Series: Earth Environ. Sci.*, **200**, 12059, doi:10.1088/1755-1315/200/1/012059.

DFID, WEF, WTW, GCA and Coalition for Climate Resilient Investment (CCRI) (eds.), 2019: *UN Climate Action Summit Call to Action: Resilence & Adptation Initiatives, Global Resilience Partnership*.

Dias, L., A. Morton and J. Quigley, 2018: *Elicitation of Preferences and Uncertainty: Processes and Procedures*. Springer, Berlin Heidelberg.

Dibley, A., T. Wetzer and C. Hepburn, 2021: National COVID debts: climate change imperils countries' ability to repay. *Nature*, **592**, 184–187.

Dickey-Collas, M., 2014: Why the complex nature of integrated ecosystem assessments requires a flexible and adaptive approach. *ICES J. Mar. Sci.*, **71**(5), 1174–1182, doi:10.1093/icesjms/fsu027.

Dilling, L., et al., 2015: The dynamics of vulnerability: why adapting to climate variability will not always prepare us for climate change. *Wiley. Interdiscip. Rev. Clim. Change.*, **6**(4), 413–425.

Dilling, L., et al., 2019a: Is adaptation success a flawed concept? *Nat. Clim. Chang.*, **9**, 572–574.

Dinshaw, A., et al., 2014: *Monitoring and evaluation of climate change adaptation: methodological approaches*. OECD environment working papers. OECD Publishing, Paris, ISBN 19970900.

Djalante, R., C. Holley and F. Thomalla, 2011: Adaptive governance and managing resilience to natural hazards. *Int. J. Disaster Risk Sci.*, **2**(4), 1–14, doi:10.1007/s13753-011-0015-6.

Djenontin, I.N.S. and A.M. Meadow, 2018: The art of co-production of knowledge in environmental sciences and management: lessons from international practice. *Environ. Manag.*, **61**(6), 885–903, doi:10.1007/s00267-018-1028-3.

Donatti, C., et al., 2020: Indicators to measure the climate change adaptation outcomes of ecosystem-based adaptation. *Clim. Change*, **158**, 413–433.

Donatti, C., et al., 2018: Guidelines for designing, implementing and monitoring ecosystem-based adaptation interventions. *Conserv. Int.*

Donner, S.D., M. Kandlikar and S. Webber, 2016: Measuring and tracking the flow of climate change adaptation aid to the developing world. *Environ. Res. Lett.*, **11**(5), 54006.

Donner, S.D. and S. Webber, 2014: Obstacles to climate change adaptation decisions: a case study of sea-level rise and coastal protection measures in Kiribati. *Sustain. Sci.*, **9**(3), 331–345, doi:10.1007/s11625-014-0242-z.

Doshi, D. and M. Garschagen, 2020: Understanding adaptation finance allocation: which factors enable or constrain vulnerable countries to access funding? *Sustainability*, **12**(10), doi:10.3390/su12104308.

Doukas, H. and A. Nikas, 2020: Decision support models in climate policy. *Eur J Oper Res*, **280**(1), 1–24, doi:10.1016/j.ejor.2019.01.017.

Douville, H., K. Raghavan, J. Renwick, R.P. Allan, P.A. Arias, M. Barlow, R. Cerezo-Mota, A. Cherchi, T.Y. Gan, J. Gergis, D. Jiang, A. Khan, W. Pokam Mba, D. Rosenfeld, J. Tierney, and O. Zolina, 2021: Water Cycle Changes. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. University Press, Cambridge.

Droesch, A.C., et al., 2008: *A Guide to the Vulnerability Reduction Assessment*. UNDP Working Paper, United Nations Development Programme, Community-Based Adaptation Programme.

Dupre, S., T. Posey, T. Wang and T. Jamison, 2018: *Shooting for the Moon in a Hot Air Balloon? Measuring How Green Bonds Contribute to Scaling up Investments in Green Projects* Initiative, D. I.

Dupuis, J. and R. Biesbroek, 2013: Comparing apples and oranges: the dependent variable problem in comparing and evaluating climate change adaptation policies. *Glob. Environ. Chang.*, **23**(6), 1476–1487, doi:10.1016/j.gloenvcha.2013.07.022.

Durbach, I. and T.J. Stewart, 2020a: Probability and Beyond: Including Uncertainties in Decision Analysis. In: *Behavioral Operational Research*. Springer International Publishing, Berlin Heidelberg, pp. 75–91. ISBN 978-3030254049.

Durbach, I.N., 2014: Outranking under uncertainty using scenarios. *Eur. J. Oper. Res.*, **232**(1), 98–108, doi:10.1016/j.ejor.2013.06.041.

Durbach, I.N. and T.J. Stewart, 2020b: *Probability and Beyond: Including Uncertainties in Decision Analysis*. Springer, Berlin Heidelberg, 75–91.

Eakin, H., A. Winkels and J. Sendzimir, 2009: Nested vulnerability: exploring cross-scale linkages and vulnerability teleconnections in Mexican and Vietnamese coffee systems. *Environ. Sci. Policy*, **12**, 398–412.

Ebi, K.L., et al., 2018: Monitoring and evaluation indicators for climate change-related health impacts, risks, adaptation, and resilience. *Int. J. Environ. Res. Public Health*, **15**(9), doi:10.3390/ijerph15091943.

Ebi, K.L., J.J. Hess and T.B. Isaksen, 2016: Using uncertain climate and development information in health adaptation planning. *Curr. Envir. Health Rep.*, **3**(1), 99–105.

Ebi, K.L. and E.V. Prats, 2015: Health in national climate change adaptation planning. *Ann. Glob. Health.*, **81**(3), 418–426, doi:10.1016/j.aogh.2015.07.001.

EBRD, 2019: *Framework for Environmental Sustainability Bonds*. Development, E. B. f. R. a., London.

Eccles, R.G. and M.P. Krzus, 2018: Why companies should report financial risks from climate change. *MIT Sloan Manage. Rev.*, **59**(3).

Eckersley, R., 2015: The common but differentiated responsibilities of states to assist and receive 'climate refugees. *Eur. J. Polit. Theory*, **14**(4), 481–500.

Eckstein, D., M. Winges, V. Künzel and L. Schäfer, 2019: *Global Climate Risk Index 2020: Who Suffers Most from Extreme Weather Events? Wether-Related Loss Events in 2018 and 1999 to 2018*. Germanwatch Nord-Süd Initiative eV., Bonn, ISBN 978-3943704778.

EEA, *National monitoring, reporting and evaluation of climate change adaptation in Europe*, accessed 31 March 2022, https://www.eea.europa.eu/publications/national-monitoring-reporting-and-evaluation.

EEA, 2018: *National climate change vulnerability and risk assessments in Europe*, accessed 31 March 2022, https://www.eea.europa.eu/publications/national-climate-change-vulnerability-2018.

EEA, 2020: *Monitoring and evaluation of national adaptation policies throughout the policy cycle*, accessed 31 March 2022, https://www.eea.europa.eu/publications/national-adaptation-policies.

Egli, F. and A. Stünzi, 2019: A dynamic climate finance allocation mechanism reflecting the Paris Agreement. *Environ. Res. Lett.*, **14**(11), 114024, doi:10.1088/1748-9326/ab443b.

Eguiluz, V.M., J. Fernandez-Gracia, X. Irigoien and C.M. Duarte, 2016: A quantitative assessment of Arctic shipping in 2010-2014. *Sci Rep*, **6**, 30682, doi:10.1038/srep30682.

El-Zein, A. and F.N. Tonmoy, 2015: *Assessment of Vulnerability to Climate Change Using a Multi-Criteria Outranking Approach with Application to Heat Stress in Sydney*, 207–217.

Ellis, N.R. and P. Tschakert, 2019: Triple-wins as pathways to transformation? A critical review. *Geoforum*, **103**, 167–170, doi:10.1016/j.geoforum.2018.12.006.

Elmi, O.H. and D. Minja, 2019: Effects of hunger safety net program on livelihood improvement in Wajir County, Kenya. *Int. Acad. J. Law Soc.*, **1**(2), 435–449.

Elsawah, S., et al., 2015: A methodology for eliciting, representing, and analysing stakeholder knowledge for decision making on complex socio-ecological systems: from cognitive maps to agent-based models. *J. Environ. Manag.*, **151**, 500–516.

England, M.I., et al., 2018: Climate change adaptation and cross-sectoral policy coherence in southern Africa. *Reg. Environ. Change*, **18**(7), 2059–2071, doi:10.1007/s10113-018-1283-0.

Engler, J.O., D.J. Abson and H. von Wehrden, 2019: Navigating cognition biases in the search of sustainability. *Ambio*, **48**(6), 605–618, doi:10.1007/s13280-018-1100-5.

Eriksen, S., et al., 2021: Adaptation interventions and their effect on vulnerability in developing countries: help, hindrance or irrelevance? *World Dev.*, **141**, 105383.

Eriksen, S.H. and P.M. Kelly, 2007: Developing credible vulnerability indicators for climate adaptation policy assessment. *Mitig. Adapt. Strat. Glob. Change*, **12**, 495–524.

Eriksen, S.H., A.J. Nightingale and H. Eakin, 2015: Reframing adaptation: the political nature of climate change adaptation. *Glob. Environ. Chang.*, **35**, 523–533.

ERM and CBEY, 2018: *Investors Push the Pace of Climate Risk Financial Disclosures* Cort, T. and J. Stacey. Environmental Resources Management and Yale Center for Business and the Environment.

Ernst, K.M. and B.L. Preston, 2017: Adaptation opportunities and constraints in coupled systems: evidence from the U.S. energy-water nexus. *Environ. Sci. Policy*, **70**, 38–45, doi:10.1016/j.envsci.2017.01.001.

Escarcha, J.F., J.A. Lassa, E.P. Palacpac and K.K. Zander, 2020: Livelihoods transformation and climate change adaptation: the case of smallholder water buffalo farmers in the Philippines. *Environ. Dev.*, **33**, 100468.

Esteban, M., et al., 2017: Awareness of coastal floods in impoverished subsiding coastal communities in Jakarta: tsunamis, typhoon storm surges and dyke-induced tsunamis. *Int. J. Disaster Risk Reduct.*, **23**, 70–79, doi:10.1016/j.ijdrr.2017.04.007.

Esteve, P., C. Varela-Ortega and T.E. Downing, 2018: A stakeholder-based assessment of barriers to climate change adaptation in a water-scarce basin in Spain. *Reg. Environ. Change*, **18**(8), 2505–2517.

Estrin, D., 2016: *Limiting Dangerous Climate Change: The Critical Role of Citizen Suits and Domestic Courts—Despite the Paris Agreement*. CIGI Papers Series, **No. 101**.Centre for International Governance Innovation, Ontario, Canda, accessed 31 March 2022, https://www.cigionline.org/publications/limiting-dangerous-climate-change-critical-role-citizen-suits-and-domestic-courts.

Etongo, D., V. Amelie, A. Pouponneau and W.L. Filho, 2021: Identifying and Overcoming Barriers to Climate Change Adaptation in the Seychelles. In: *African Handbook of Climate Change Adaptation* [Oguge, N., D. Ayal, L. Adeleke and I. da Silva)](eds.)]. Springer International Publishing, Cham, pp. 2675–2692. ISBN 978-3030451066.

Fagan, M. and C. Huang, 2019: *A look at how people around the world view climate change*. Pew Research Center, accessed 31 March 2022, https://policycommons.net/artifacts/616841/a-look-at-how-people-around-the-world-view-climate-change/1597536/.

Falconer, A. and M. Stadelmann, 2014: What is climate finance? Definitions to improve tracking and scale up climate finance. Climate Policy Initiative, London, accessed 30 January 2022, http://climatepolicyinitiative.org/wp-content/uploads/2014/07/Brief-on-Climate-Finance-Definitions.pdf.

Fankhauser, S., A. Averchenkova and J. Finnegan, 2018: *10 years of the UK Climate Change Act*. Grantham Research Institute on Climate Change and the Environment, accessed 31 March 2022, http://www.lse.ac.uk/GranthamInstitute/publication/10-years-climate-change-act.

Fankhauser, S. and I. Burton, 2011: Spending adaptation money wisely. *Clim. Policy*, **11**(3), 1037–1049.

Fankhauser, S., C. Gennaioli and M. Collins, 2014: *Domestic dynamics and international influence: What explains the passage of climate change legislation?* Centre for Climate Change Economics and Policy Working Paper, Vol. 156.

FAO, 2017: *Tracking Adaptation in Agricultural Sectors. Climate Change Adaptation Indicators*. Food and Agriculture Organization of the United Nations, Rome.

FAO, 2019a: *Operational Guidelines for the Design, Implementation and Harmonization of Monitoring and Evaluation Systems for Climate-Smart Agriculture*. Food and Agriculture Organization of the United Nations, Rome.

FAO, 2019b: *Strengthening Monitoring and Evaluation for Adaptation Planning in the Agriculture Sectors*. Nations, F. a. A. O. o. t. U, Rome.

Fatorić, S., R. Morén-Alegret, R.J. Niven and G. Tan, 2017: Living with climate change risks: stakeholders' employment and coastal relocation in mediterranean climate regions of Australia and Spain. *Environ. Syst. Decis.*, **37**(3), 276–288.

Faulkner, L., J. Ayers and S. Huq, 2015: Meaningful measurement for community-based adaptation. *N. Direct. Eval.*, **147**, 89–104.

Fawcett, D., T. Pearce, J.D. Ford and L. Archer, 2017: Operationalizing longitudinal approaches to climate change vulnerability assessment. *Glob. Environ. Change*, **45**, 79–88.

Feinstein, O., 2012: Evaluation as a learning tool. *N. Direct. Eval.*, **134**, 103–112.

Fekete, J.-D. and R. Primet, 2016: *Progressive Analytics: A Computation Paradigm for Exploratory Data Analysis*.

Fenton, A., et al., 2014: Debt relief and financing climate change action. *Nature Clim Change*, **4**(8), 650–653.

Fernández-Llamazares, Á., et al., 2017: An empirically tested overlap between indigenous and scientific knowledge of a changing climate in Bolivian Amazonia. *Reg. Environ. Change*, **17**(6), 1673–1685, doi:10.1007/s10113-017-1125-5.

Ferretti, F., A. Saltelli and S. Tarantola, 2016: Trends in sensitivity analysis practice in the last decade. *Sci. Total. Environ.*, **568**, 666–670.

Fesenfeld, L.P. and A. Rinscheid, 2021: Emphasizing urgency of climate change is insufficient to increase policy support. *One Earth*, **4**(3), 411–424, doi:10.1016/j.oneear.2021.02.010.

Few, R., et al., 2021: Culture as a mediator of climate change adaptation: neither static nor unidirectional. *Wiley Interdiscip. Rev. Clim. Chang.*, **12**(1), e687.

Field, J. and I. Kelman, 2018: The impact on disaster governance of the intersection of environmental hazards, border conflict and disaster responses in Ladakh, India. *Int. J. Disaster Risk Reduct.*, **31**, 650–658.

Figueira, J.R., V. Mousseau and B. Roy, 2016: Electre Methods. In: *Multiple Criteria Decision Analysis*. Springer, New York, pp. 155–185. ISBN 978-1493930937.

Filho, L. and J. Nalau, 2018: *Limits to Climate Change Adaptation*. Springer, Berlin Heidelberg, ISBN 978-3319645995.

Fischer, A.P., 2019: Characterizing behavioral adaptation to climate change in temperate forests. *Landsc. Urban Plan.*, **188**, 72–79, doi:10.1016/j.landurbplan.2018.09.024.

Fischer, E.M., S. Sippel and R. Knutti, 2021: Increasing probability of record-shattering climate extremes. *Nat. Clim. Chang.*, **11**(8), 689–695, doi:10.1038/s41558-021-01092-9.

Fischhoff, B., 2015: *The Realities of Risk-Cost-Benefit Analysis*. aaa6516 pp.

Fisher, S., et al., 2015: Evaluating climate change adaptation: learning from methods in international development. *N. Direct. Eval.*, **147**, 13–35.

Fisichelli, N.A., S.G., G.W. Schuurman, W.B. Monahan and P.S. Ziesler, 2015: Protected area tourism in a changing climate: Will visitation at US national parks warm up or overheat? *Plos One*, **10**(6), e128226.

Fonta, W.M., E.T. Ayuk and T. van Huysen, 2018: Africa and the Green Climate Fund: current challenges and future opportunities. *Clim. Policy*, **18**(9), 1210–1225, doi:10.1080/14693062.2018.1459447.

Ford, J. and L. Berrang-Ford, 2016: The 4Cs of adaptation tracking: consistency, comparability, comprehensiveness, coherency. *Mitig. Adapt. Strateg. Glob. Change*, **21**, 839–859.

Ford, J.D., et al., 2015: Adaptation tracking for a post-2015 climate agreement. *Nat. Clim. Change*, **5**(11), 967–969, doi:10.1038/nclimate2744.

Ford, J.D., et al., 2013: How to track adaptation to climate change: a typology of approaches for national-level application. *Ecol. Soc.*, **18**(3), doi:10.5751/es-05732-180340.

Ford, J.D., L. Berrang-Ford and J. Paterson, 2011: A systematic review of observed climate change adaptation in developed nations. *Clim. Change*, **106**(2), 327–336, doi:10.1007/s10584-011-0045-5.

Formetta, G. and L. Feyen, 2019: Empirical evidence of declining global vulnerability to climate-related hazards. *Glob. Environ. Change.*, **57**, 101920, doi:10.1016/j.gloenvcha.2019.05.004.

Forster, P.M., et al., 2020: Current and future global climate impacts resulting from COVID-19. *Nat. Clim. Change*, **10**(10), 913–919, doi:10.1038/s41558-020-0883-0.

Forsyth, T., 2018: Is resilience to climate change socially inclusive? Investigating theories of change processes in Myanmar. *World Dev.*, **111**, 13–26, doi:10.1016/j.worlddev.2018.06.023.

Foster, S., et al., 2019: New York city panel on climate change 2019 report chapter 6: community-based assessments of adaptation and equity. *Ann. N. Y. Acad. Sci.*, **1439**(1), 126–173, doi:10.1111/nyas.14009.

Fox-Kemper, B., H.T. Hewitt, C. Xiao, G. Aðalgeirsdóttir, S.S. Drijfhout, T.L. Edwards, N.R. Golledge, M. Hemer, R.E. Kopp, G. Krinner, A. Mix, D. Notz, S. Nowicki, I.S. Nurhati, L. Ruiz, J.-B. Sallée, A.B.A. Slangen, and Y. Yu, 2021: Ocean, Cryosphere and Sea Level Change. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press., Cambridge.

French, S., 1995: Uncertainty and imprecision: modelling and analysis. *J. Oper. Res. Soc.*, **46**(1), 70–79, doi:10.1057/jors.1995.8.

French, S., 2003: Modelling, making inferences and making decisions: the roles of sensitivity analysis. *Top*, **11**(2), 229–251, doi:10.1007/bf02579043.

French, S., 2013: Cynefin, statistics and decision analysis. *J Oper Res Soc*, **64**(4), 547–561, doi:10.1057/jors.2012.23.

French, S., 2015: Cynefin: uncertainty, small worlds and scenarios. *J. Oper. Res. Soc.*, **66**, 1635–1645.

French, S., 2020a: *Decision support tools for complex decisions under uncertainty*, 2nd edn., 34.

French, S., 2021: From soft to hard elicitation. *J Oper Res Soc*, 1–17, doi:10.1080/01605682.2021.1907244.

French, S. and N. Argyris, 2018: *Decision Analysis and Political Processes*, 208–222.

French, S., S. Haywood, D. Oughton and C. Turcanu, 2020: Different types of uncertainty in nuclear emergency management. *Radioprotection*, **55**, S175–S180.

French, S., A.J. Maule and K.N. Papamichail, 2009: *Decision behaviour, analysis and support*. Cambridge University Press, Cambridge.

Frerks, G., D. Hilhorst and G. Bankoff, 2004: *Mapping vulnerability: disasters, development and people*. Earthscan, London, GB.

Friedman, E., R. Breitzer and W. Solecki, 2019: Communicating extreme event policy windows: discourses on Hurricane Sandy and policy change in Boston and New York City. *Environ. Sci. Policy*, **100**, 55–65, doi:10.1016/j.envsci.2019.06.006.

Fulton, E. and J. Link, 2014: Modeling Approaches for Marine Ecosystem-Based Management. In: *Marine Ecosystem-Based Management* [Fogarty, M.J. and J.J. McCarthy(eds.)] Vol.16, Harvard University Press, Cambridge, USA.

Fulton, E.A., 2021: Opportunities to improve ecosystem-based fisheries management by recognizing and overcoming path dependency and cognitive bias. *Fish Fish.*, **22**(2), 428–448, doi:10.1111/faf.12537.

Fulton, E.A., et al., 2019: Ecosystems say good management pays off. *Fish Fish.*, **20**(1), 66–96, doi:10.1111/faf.12324.

Fünfgeld, H., K. Lonsdale and K. Bosomworth, 2018: Beyond the tools: supporting adaptation when organisational resources and capacities are in short supply. *Clim. Change*, **153**(4), 625–641, doi:10.1007/s10584-018-2238-7.

Funk, C., et al., 2019: Recognizing the famine early warning systems network: over 30 years of drought early warning science advances and partnerships promoting global food security. *Bull. Am. Meteorol. Soc.*, **100**(6), 1011–1027, doi:10.1175/bams-d-17-0233.1.

Füssel, H.M., 2010: Review and quantitative analysis of indices of climate change exposure, adaptive capacity, sensitivity, and impacts. Background note of the 2010 world development report. *Dev. Clim. Chang.*

Gagnon-Lebrun, F. and S. Agrawala, 2007: Implementing adaptation in developed countries: an analysis of progress and trends. *Clim. Policy*, **7**(5), 392–408.

Gajjar, S.P., G. Jain, K. Michael and C. Singh, 2019b: Entrenched Vulnerabilities: Evaluating Climate Justice Across Development and Adaptation Responses in South India. In: *Climate Futures: Reimagining Global Climate Justice*. Zed Books, London.

Gajjar, S.P., C. Singh and T. Deshpande, 2019a: Tracing back to move ahead: a review of development pathways that constrain adaptation futures. *Clim. Dev.*, **11**(3), 223–237.

Gall, M., 2015: The suitability of disaster loss databases to measure loss and damage from climate change. *Int. J. Glob. Warming*, **8**(2), 170–190.

Gallardo-Albarrán, D., 2020: Sanitary infrastructures and the decline of mortality in Germany, 1877–1913. *Econ. Hist. Rev.*, **73**(3), 730–757, doi:10.1111/ehr.12942.

Ganguly, G., J. Setzer and V. Heyvaert, 2018: If at first you don't succeed: suing corporations for climate change. *Oxford J Legal Studies*, **38**(4), 841–868, doi:10.1093/ojls/gqy029.

Garcia-Portela, L., 2020: Moral responsibility for climate change loss and damage: a response to the excusable ignorance objection. *Teorema Int. J. Philos.*, **1**(39).

Gardiner, E.P., D.D. Herring and J.F. Fox, 2018: The U.S. Climate resilience toolkit: evidence of progress. *Clim Change*, **153**(4), 477–490, doi:10.1007/s10584-018-2216-0.

Garner, G., P. Reed and K. Keller, 2016: Climate risk management requires explicit representation of societal trade-offs. *Clim Change*, **134**(4), 713–723, doi:10.1007/s10584-016-1607-3.

Garschagen, M., et al., 2021: The consideration of future risk trends in national adaptation planning: conceptual gaps and empirical lessons. *Clim. Risk Manag.*, **34**, 100357, https://doi.org/10.1016/j.crm.2021.100357.

17

Garschagen, M., G.A.K. Surtiari and M. Harb, 2018b: Is Jakarta's new flood risk reduction strategy transformational? *Sustainability*, **10**(8), 2934.

Gautier, D., B. Locatelli, C. Corniaux and V. Alary, 2016: Global changes, livestock and vulnerability: the social construction of markets as an adaptive strategy. *Geogr J*, **182**(2), 153–164.

GCF, *Approach and scope for providing support to adaptation activities – Addendum I: The GCF's approach to adaptation: analysis and implications for the Fund*. Meeting of the Board. Manama, Bahrain, Green Climate Fund.

GCF Independent Evaluation Unit, 2018: *The IEU's independent review of the GCF's results management framework*. accessed 31 March 2022,. https://ieu.greenclimate.fund/evaluation/rmf2018.

Gee, A., 2020: *Fire in Paradise : an American tragedy* Anguiano, D. 1st edn., W. W. Norton & Company, New York, ISBN 97813240051481324005149.

Geere, J.-A.L. and P.R. Hunter, 2020: The association of water carriage, water supply and sanitation usage with maternal and child health. A combined analysis of 49 multiple indicator cluster surveys from 41 countries. *Int. J. Hyg. Environ. Health*, **223**(1), 238–247.

Geiger, N., J.K. Swim, J. Fraser and K. Flinner, 2017: Catalyzing public engagement with climate change through informal science learning centers. *Sci. Commun.*, **39**(2), 221–249, doi:10.1177/1075547017697980.

Gelman, A., 2003: A Bayesian formulation of exploratory data analysis and goodness-of-fit testing. *Int. Stat. Rev.*, **71**(2), 369–382, doi:10.1111/j.1751-5823.2003.tb00203.x.

Gelman, A., et al., 2013: *Bayesian Data Analysis*. Chapman and Hall, London.

Gelman, A. and C. Hennig, 2017: Beyond subjective and objective in statistics. *J. Royal Stat. Soc. Ser. A*, **180**(4), 967–1033, doi:10.1111/rssa.12276.

Geneletti, D. and L. Zardo, 2016: Ecosystem-based adaptation in cities: an analysis of European urban climate adaptation plans. *Land Use Policy*, **50**, 38–47, doi:10.1016/j.landusepol.2015.09.003.

Gerlak, A.K., et al., 2020: The Gnat and the Bull Do Climate Outlook Forums Make a Difference? *Bull. Am. Meteorol. Soc.*, **101**(6), E771–E784, doi:10.1175/bams-d-19-0008.1.

Gerrard, M.B. and K. Fischer, 2012: The law adaptation to climate change: United States and International aspects. *Am. Bar Assoc. Nat. Resour. Law Sect.*, **161438696X**.

Gervásio, H. and L. Simões da Silva, 2012: A probabilistic decision-making approach for the sustainable assessment of infrastructures. *Expert Syst Appl*, **39**(8), 7121–7131, doi:10.1016/j.eswa.2012.01.032.

Gewirtzman, J., et al., 2018: Financing loss and damage: reviewing options under the Warsaw International Mechanism. *Clim. Policy*, **18**(8), 1076–1086.

Ghebreyesus, T.A., et al., 2010: *Using climate information in the health sector*. Field Actions Science Reports.

Giffin, A.L., et al., 2020: Marine and coastal ecosystem-based adaptation in Asia and Oceania: review of approaches and integration with marine spatial planning. *Pac. Conserv. Biol.*, **27**(2), 104–117, doi:10.1071/PC20025.

Gil, J.D., et al., 2018: Tradeoffs in the quest for climate smart agricultural intensification in Mato Grosso, Brazil. *Environ. Res. Lett.*, **13**(6), 64025.

Gilbuena, R., et al., 2013: Environmental impact assessment using a utility-based recursive evidential reasoning approach for structural flood mitigation measures in Metro Manila, Philippines. *J. Environ. Manag.*, **131**, 92–102, doi:10.1016/j.jenvman.2013.09.020.

Gim, C., C.A. Miller and P.W. Hirt, 2019: The resilience work of institutions. *Environ. Sci. Policy*, **97**, 36–43, doi:10.1016/j.envsci.2019.03.004.

Giordano, R., et al., 2020: Enhancing nature-based solutions acceptance through stakeholders' engagement in co-benefits identification and trade-offs analysis. *Sci. Total. Environ.*, **713**, 136552.

Gippsland Coastal Bd. v. South Gippsland Sc & Ors (No2), 2008, **VCAT 1545**.

Girard, C., et al., 2015: Integrating top–down and bottom–up approaches to design global change adaptation at the river basin scale. *Glob. Environ. Chang.*, **34**, 132–146, doi:10.1016/j.gloenvcha.2015.07.002.

Giupponi, C., M. E. Borsuk, B.J.M. de Vries and K. Hasselmann, 2013: Innovative approaches to integrated global change modelling. *Environ. Model. Softw.*, **44**, 1–9, doi:10.1016/j.envsoft.2013.01.013.

Giupponi, C. and A.K. Gain, 2017a: Integrated spatial assessment of the water, energy and food dimensions of the Sustainable Development Goals. *Reg. Environ. Change*, **17**(7), 1881–1893, doi:10.1007/s10113-016-0998-z.

GIZ, 2017: *Factsheets of national adaptation monitoring and evaluation systems*, accessed 9 September 2021, hhttps://www.adaptationcommunity.net/monitoring-evaluation/national-level-adaptation/.

GIZ, 2020: *Guidebook for Monitoring and Evaluating Ecosystem-based Adaptation Interventions*, accessed 9 September 2021, https://www.adaptationcommunity.net/download/ME-Guidebook_EbA.pdf.1.

GIZ and Adelphi, 2017: *The vulnerability sourcebook: concept and guidelines for standardised vulnerability assessments*, accessed 9 September 2021,. https://www.adaptationcommunity.net/download/va/vulnerability-guides-manuals-reports/vuln_source_2017_EN.pdf.

Global Commission on Adaptation, 2019: *Adapt Now : A Global Call for Leadership on Climate Resilience*. Institute, W. R, Washington, DC. https://openknowledge.worldbank.org/handle/10986/32362.

Godden, L., 2012: *Legal Frameworks for Local Adaptation in Australia: The Role of Local Government in Water Governance in a Climate Change Era*, 325–388.

Golding, N., C. Hewitt and P. Zhang, 2017: Effective engagement for climate services: Methods in practice in China. *Clim. Serv.*, **8**, 72–76, doi:10.1016/j.cliser.2017.11.002.

Golding, N., et al., 2019: Co-development of a seasonal rainfall forecast service: Supporting flood risk management for the Yangtze River basin. *Clim. Risk Manag.*, **23**, 43–49, doi:10.1016/j.crm.2019.01.002.

Goldstein, A., W.R. Turner, J. Gladstone and D.G. Hole, 2019: The private sector's climate change risk and adaptation blind spots. *Nat. Clim. Chang.*, **9**(1), 18–25, doi:10.1038/s41558-018-0340-5.

Gomez-Echeverri, L., 2018: Climate and development: enhancing impact through stronger linkages in the implementation of the Paris Agreement and the Sustainable Development Goals (SDGs). *Philos. Trans. Ser. A Math. Phys. Eng. Sci.*, **376**(2119), 20160444, doi:10.1098/rsta.2016.0444.

Gonzales, P. and N. Ajami, 2017: Social and structural patterns of drought-related water conservation and rebound. *Water Resour. Res.*, **53**(12), 10619–10634, doi:10.1002/2017wr021852.

Goodwin, P. and G. Wright, 2014: *Decision Analysis for Management Judgment*, 5th edn., John Wiley & Sons Inc, New York, ISBN 978-1118740736.

Göpfert, C., C. Wamsler and W. Lang, 2019: A framework for the joint institutionalization of climate change mitigation and adaptation in city administrations. *Mitig. Adapt. Strateg. Glob. Change*, **24**(1), doi:10.1007/s11027-018-9789-9.

Gorddard, R., et al., 2016: Values, rules and knowledge: Adaptation as change in the decision context. *Environ. Sci. Policy*, **14629011**, 60–69.

Government of Sweden, 2017: *Swedish National Strategy for Climate Change Adaptation*. Government Proposition 2017/18:163, accessed 4 April 2022, https://www.smhi.se/polopoly_fs/1.168045!/National%20Strategy%20for%20Climate%20Change%20Adaptation.pdf.

Government of the Commonwealth of Dominica, 2018: *Commonwealth of Dominica Climate Resilience Act 16 of 2018*, accessed 4 April 2022, https://observatoriop10.cepal.org/es/node/427#:~:text=Resilience%20Act%20(No.-,16%20of%202018),the%20first%20climate%20resilient%20nation.

Govindan, K. and M.B. Jepsen, 2016: ELECTRE: A comprehensive literature review on methodologies and applications. *Eur. J. Oper. Res.*, **250**(1), 1–29, doi:10.1016/j.ejor.2015.07.019.

Grafakos, S., et al., 2019: Analytical framework to evaluate the level of integration of climate adaptation and mitigation in cities. *Clim. Change*, **154**(1), 87–106.

Graham, A. and C.L. Mitchell, 2016: The role of boundary organizations in climate change adaptation from the perspective of municipal practitioners. *Clim. Change*, **139**(3), 381–395, doi:10.1007/s10584-016-1799-6.

Granberg, M. and L. Glover, 2014: Adaptation and maladaptation in Australian national climate change policy. *J. Environ. Policy Plan.*, **16**(2), 147–159.

Grasso, M., 2010a: An ethical approach to climate adaptation finance. *Glob. Environ. Chang.*, **20**(1), 74–81, doi:10.1016/j.gloenvcha.2009.10.006.

Grasso, M., 2010b: Justice in Funding Adaptation under the International Climate Change Regime. *Marco Grasso*, doi:10.1007/978-90-481-3439-7_1.

Gray, S., et al., 2014: Are coastal managers detecting the problem? Assessing stakeholder perception of climate vulnerability using Fuzzy Cognitive Mapping. *Ocean. Coast. Manag.*, **94**, 74–89.

Greatrex, H., et al., 2015: *Scaling up Index Insurance for Smallholder Farmers: Recent Evidence and Insights*.

Gregorowski, R., A. Dorgan and C. Hutchings, 2018: *Resilience Measurement-MEL Approaches in Practice* Resilience Measurement Evidence & Learning Community of Practice.

Gregory, R., et al., 2012: *Structured Decision Making: A Practical Guide to Environmental Management Choices*. Wiley-Backwell, New Jersey, USA, ISBN 978-1444333411.

Grothmann, T., K. Grecksch, M. Winges and B. Siebenhüner, 2013: Assessing institutional capacities to adapt to climate change: integrating psychological dimensions in the Adaptive Capacity Wheel. *Nat. Hazards Earth Syst. Sci.*, **13**(12), 3369–3384.

Grothmann, T. and T.A. Michel, 2021: Participation for building urban climate resilience? Results from four cities in Germany. In: *Building Resilience to Natural Hazards in the Context of Climate Change*. Springer, Berlin Heidelberg, pp. 173–208.

Grothmann, T. and A. Patt, 2005: Adaptive capacity and human cognition: the process of individual adaptation to climate change. *Glob. Environ. Chang.*, **15**(3), 199–213.

Groutsis, D., D. van den Broek and W.S. Harvey, 2015: Transformations in network governance: the case of migration intermediaries. *J. Ethn. Migr. Stud.*, **41**(10), 1558–1576.

Groves, D.G., E. Molina-Perez, E. Bloom and J.R. Fischbach, 2019: Robust Decision Making (RDM): Application to Water Planning and Climate Policy. In: *Decision Making under Deep Uncertainty: From Theory to Practice* [Marchau, V.A.W.J., W.E. Walker, P.J.T.M. Bloemen and S.W. Popper(eds.)]. Springer International Publishing, Cham, pp. 135–163. ISBN 978-3030052522.

Grynning, S., et al., 2020: Climate adaptation in maintenance operation and management of buildings. *Buildings*, **10**(6), 107.

Guido, Z., et al., 2016: Connecting climate information producers and users: boundary organization, knowledge networks, and information brokers at caribbean climate outlook forums. *Weather. Clim. Soc.*, **8**(3), 285–298, doi:10.1175/wcas-d-15-0076.1.

Guillén Bolaños, T., M. Máñez Costa and U. Nehren, 2018: Development of a prioritization tool for climate change adaptation measures in the forestry sector. In: *Economic tools and methods for the analysis of global change impacts on agriculture and food security*, pp. 165–177.

Gunawan, S. and S. Azarm, 2005: *Multi-Objective Robust Optimization Using a Sensitivity Region Concept*, 50–60.

Gupta S., J. Harnisch, D. C. Barua, L. Chingambo, P. Frankel, R. J. Garrido Vázquez, L. Gómez-Echeverri, E. Haites, Y. Huang, R. Kopp, B. Lefèvre, H. Machado-Filho, and E. Massetti, 2014: Cross-cutting Investment and Finance Issues. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Inter-governmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1207–1246. ISBN 978-1107058217.

Gustafson, S., A.J. Cadena and P. Hartman, 2016: Adaptation planning in the Lower Mekong Basin: merging scientific data with local perspective to improve community resilience to climate change. *Clim. Dev.*, **10**(2), 152–166, doi:10.1080/17565529.2016.1223593.

Gutjahr, W.J. and A. Pichler, 2016: *Stochastic Multi-Objective Optimization: A Survey on Non-Scalarizing Methods*, 475–499.

Guzmán, S., T. Guillén and J. Manda, 2018: *A Review of Domestic Data Sources for Climate Finance Flows in Recipient Countries*. GFLAC, U., accessed 4 April 2022, https://www.adaptation-undp.org/resources/reports-and-publications-relevance-country-teams/review-domestic-data-sources-climate.

Guzmán, S., et al., 2017: *Toward Climate Finance Reporting Systems in Latin America. Toward Implementation: The 2017 AdaptationWatch Report*. Adams, K. and D. Falzon, accessed 4 April 2022, http://ow.ly/S3Be30gWJ9S.

Ha, S., T. Hale and P. Ogden, 2016: Climate Finance in and between Developing Countries: An Emerging Opportunity to Build On. *Glob. Policy*, **7**(1), 102–108, doi:10.1111/1758-5899.12293.

Haasnoot, M., et al., 2020a: Defining the solution space to accelerate climate change adaptation. *Reg. Environ. Change*, **20**(2), doi:10.1007/s10113-020-01623-8.

Haasnoot, M., et al., 2020b: Adaptation to uncertain sea-level rise; how uncertainty in Antarctic mass-loss impacts the coastal adaptation strategy of the Netherlands. *Environ. Res. Lett.*, **15**(3), 34007, doi:10.1088/1748-9326/ab666c.

Haasnoot, M., J.H. Kwakkel, W.E. Walker and J. ter Maat, 2013: Dynamic adaptive policy pathways: a method for crafting robust decisions for a deeply uncertain world. *Glob. Environ. Chang.*, **23**(2), 485–498, doi:10.1016/j.gloenvcha.2012.12.006.

Haasnoot, M., S. van't Klooster and J. van Alphen, 2018: Designing a monitoring system to detect signals to adapt to uncertain climate change. *Glob. Environ. Change*, **52**, 273–285, doi:10.1016/j.gloenvcha.2018.08.003.

Haasnoot, M., et al., 2019: Investments under non-stationarity: economic evaluation of adaptation pathways. *Clim. Change*, **161**(3), 451–463, doi:10.1007/s10584-019-02409-6.

Hadka, D., J. Herman, P. Reed and K. Keller, 2015: An open source framework for many-objective robust decision making. *Environ. Model. Softw.*, **74**, 114–129, doi:10.1016/j.envsoft.2015.07.014.

Haigh, T., et al., 2018: Provision of climate services for agriculture: public and private pathways to farm decision-making. *Bull. Am. Meteorol. Soc.*, **99**(9), 1781–1790, doi:10.1175/bams-d-17-0253.1.

Hale, T., 2016: "All hands on deck": the Paris agreement and nonstate climate action. *Glob. Environ. Polit.*, **16**(3), 12–22.

Hall, J.W., H. Harvey and L.J. Manning, 2019: Adaptation thresholds and pathways for tidal flood risk management in London. *Clim. Risk Manag.* **24**, 42–58.

Hall, J.W., et al., 2012: Robust climate policies under uncertainty: a comparison of robust decision making and info-gap methods. *Risk Anal.*, **32**(10), 1657–1672, doi:10.1111/j.1539-6924.2012.01802.x.

Hall, M.J. and D.C. Weiss, 2012: Avoiding adaptation apartheid: climate change adaptation and human rights law. *Yale J. Int. Law*, **37**(2), 309.

Hall, N., 2017: What is adaptation to climate change? Epistemic ambiguity in the climate finance system. *Int. Environ. Agreements Polit. Law Econ.*, **17**(1), 37–53, doi:10.1007/s10784-016-9345-6.

Hallegatte, S., 2009: Strategies to adapt to an uncertain climate change. *Glob. Environ. Chang.*, **19**(2), 240–247.

Hallegatte, S., et al., 2016: *Shock Waves: Managing the Impacts of Climate Change on Poverty* Climate Change and Development. The World Bank, Washington D.C., ISBN 978-1464806735. 224 pp.

Hallegatte, S., et al., 2018: *The Economics (and Obstacles to) aligning Development and Climate Change Adaptation*. Global Commission on Adaptation. Rotterdam and Washington, D.C., accessed 9 September 2021, https://gca.org/wp-content/uploads/2018/10/18_WP_GCA_Economics_1001_final.pdf.

Hallegatte, S. and N.L. Engle, 2019: The search for the perfect indicator: reflections on monitoring and evaluation of resilience for improved climate risk management. *Clim. Risk Manag.*, **23**, 1–6, doi:10.1016/j.crm.2018.12.001.

Hallegatte, S., et al., 2012: *Investment Decision Making Under Deep Uncertainty : Application to Climate Change*. World Bank, Washington, DC.

Hammill, A., et al., 2014b: *Repository of Adaptation Indicators: real case examples from national Monitoring and Evaluation Systems*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Bonn.

Hammill, A., et al., 2014a: *Monitoring and evaluating adaptation at aggregated levels: a comparative analysis of ten systems*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Han, H. and S.W. Ahn, 2020: Youth mobilization to stop global climate change: narratives and impact. *Sustainability*, **12**(10), doi:10.3390/su12104127.

Hanea, A., G.F. Nane, T. Bedford, et al., 2021: *Expert Judgement in Risk and Decision Analysis*. Springer, Cham.

Hanna, R., Y. Xu and D.G. Victor, 2021: After COVID-19, green investment must deliver jobs to get political traction. *Nature*, **582**, 178–180.

Hansen, J., et al., 2018: Strengthening climate services for the food security sector. *WMO Bull.*, **67**(2), 20–26.

Haque, A.N., 2016: Application of multi-criteria analysis on climate adaptation assessment in the context of least developed countries. *J. Multi Crit. Decis. Anal.*, **23**(5-6), 210–224, doi:10.1002/mcda.1571.

Harley, M., L. Horrocks, N. Hodgson and J. Van Minnen, 2008: *Climate Change Vulnerability and Adaptation Indicators*.

Harrison, P.A., R.W. Dunford, I.P. Holman and M.D.A. Rounsevell, 2016: Climate change impact modelling needs to include cross-sectoral interactions. *Nature Clim Change*, **6**(9), 885–890, doi:10.1038/nclimate3039.

Harvey, A., et al., 2011: *Provision of Research to Identify Indicators for the Adaptation Sub-Committee*.

Harvey, B., L. Cochrane and M. Van Epp, 2019a: Charting knowledge co-production pathways in climate and development. *Environ. Policy Gov.*, **29**(2), 107–117, doi:10.1002/eet.1834.

Harvey, B., L. Jones, L. Cochrane and R. Singh, 2019b: The evolving landscape of climate services in sub-Saharan Africa: what roles have NGOs played? *Clim Change*, **157**(1), 81–98, doi:10.1007/s10584-019-02410-z.

Haße, C. and C. Kind, 2018: Updating an existing online adaptation support tool: insights from an evaluation. *Clim. Change*, **153**(4), 559–567, doi:10.1007/s10584-018-2166-6.

Haupt, W., L. Chelleri, S. van Herk and C. Zevenbergen, 2020: City-to-city learning within climate city networks: definition, significance, and challenges from a global perspective. *Int. J. Urban Sustain. Dev.*, **12**(2), 143–159, doi:10.1080/19463138.2019.1691007.

Hedlund, J., S. Fick, H. Carlsen and M. Benzie, 2018: Quantifying transnational climate impact exposure: new perspectives on the global distribution of climate risk. *Glob. Environ. Chang.*, **52**, 75–85.

Heidrich, O., et al., 2016: National climate policies across Europe and their impacts on cities strategies. *J. Environ. Manag.*, **168**, 36–45, doi:10.1016/j.jenvman.2015.11.043.

Heitz, R.P., 2014: The speed-accuracy tradeoff: history, physiology, methodology, and behavior. *Front. Neurosci.*, doi:10.3389/fnins.2014.00150.

Helmrich, A.M. and M.V. Chester, 2020: Reconciling complexity and deep uncertainty in infrastructure design for climate adaptation. *Sustain. Resilient Infrastruct,* **7** (2) 83–99*.*

Hepburn, C., et al., 2020: Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change? *Oxf. Rev. Econ. Policy*, **36**(Supplement_1), S359–S381.

Herington, J., 2017: Climate-related insecurity, loss and damage. *Ethics Policy Environ.*, **20**(2), 184–194.

Hermans, L.M., M. Haasnoot, J. ter Maat and J.H. Kwakkel, 2017: Designing monitoring arrangements for collaborative learning about adaptation pathways. *Environ. Sci. Policy*, **69**, 29–38, doi:10.1016/j.envsci.2016.12.005.

Hermwille, L., A. Siemons, H. Förster and L. Jeffery, 2019: Catalyzing mitigation ambition under the Paris Agreement: elements for an effective Global Stocktake. *Clim. Policy*, **19**(8), 988–1001.

Herron, H., et al., 2015: *Addressing Climate Change within Disaster Risk Management* A Practical Guide for IDB Project Preparation Environmental Safeguards Unit TECHNICAL NOTE N◦ IDB-TN-806. Banco Interamericano de Desarrollo, Washington, DC.

Hess, D.J. and A. Maki, 2019: Climate change belief, sustainability education, and political values: assessing the need for higher-education curriculum reform. *J Clean Prod*, **228**, 1157–1166, doi:10.1016/j.jclepro.2019.04.291.

Hewitt, C., S. Mason and D. Walland, 2012: The global framework for climate services. *Nat. Clim. Change*, **2**(12), 831–832, doi:10.1038/nclimate1745.

Hewitt, C.D., et al., 2020: The process and benefits of developing prototype climate services—examples in China. *J. Meteorol. Res.*, **34**(5), 893–903, doi:10.1007/s1335102000426.

Highfield, W.E. and S.D. Brody, 2017: Determining the effects of the FEMA Community Rating System program on flood losses in the United States. *Int. J. Dis. Risk Reduct.*, **21**, 396–404, doi:10.1016/j.ijdrr.2017.01.013.

Hildén, M., 2011: The evolution of climate policies: the role of learning and evaluations. *J. Clean. Prod.*, **19**(16), 1798–1811.

Hilhorst, D., 2003: Responding to disasters. Diversity of bureaucrats, technocrats and local people. *Int. J. Mass. Emerg. Disasters*, **21**(1), 37–56.

Hinkel, J., 2011: 'Indicators of vulnerability and adaptive capacity': towards a clarification of the science–policy interface. *Glob. Environ. Chang.*, **21**, 198–208.

Hinkel, J., et al., 2018: The ability of societies to adapt to twenty-first-century sea-level rise. *Nat. Clim. Change*, **8**(7), 570–578.

Hino, M., C.B. Field and K.J. Mach, 2017: Managed retreat as a response to natural hazard risk. *Nat. Clim. Change*, **7**, 364, doi:10.1038/nclimate3252.

Hiwasaki, L., E. Luna, Syamsidik and R. Shaw, 2014: Process for integrating local and indigenous knowledge with science for hydro-meteorological disaster risk reduction and climate change adaptation in coastal and small island communities. *Int. J. Disaster Risk Reduct.*, **10**, 15–27, doi:10.1016/j.ijdrr.2014.07.007.

HM Government, 2019: *Number of people whose resilience has been improved as a result of ICF*, accessed 4 April 2022, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/835527/KPI-4-number-people-resilience-improved1.pdf.

Hochman, Z., et al., 2017: Smallholder farmers managing climate risk in India: 1. Adapting to a variable climate. *Agric. Syst.*, **150**, 54–66, doi:10.1016/j.agsy.2016.10.001.

Hochrainer-Stigler, S., R. Mechler, G. Pflug and K. Williges, 2014: Funding public adaptation to climate-related disasters. Estimates for a global fund. *Glob. Environ. Chang.*, **25**, 87–96.

Hock, R., G. Rasul, C. Adler, B. Cáceres, S. Gruber, Y. Hirabayashi, M. Jackson, A. Kääb, S. Kang, S. Kutuzov, Al. Milner, U. Molau, S. Morin, B. Orlove, and H. Steltzer, 2019: High Mountain Areas. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Hofmann, S.Z., 2021: 100 Resilient Cities program and the role of the Sendai framework and disaster risk reduction for resilient cities. *Prog. Dis. Sci.*, **11**, 100189.

Holland, B., 2017: Procedural justice in local climate adaptation: political capabilities and transformational change. *Environ. Polit.*, **26**(3), 391–412.

Hollowed, A.B., et al., 2020: *Integrated Modeling to Evaluate Climate Change Impacts on Coupled Social-Ecological Systems in Alaska*.

Holmberg, A. and A. Alvinius, 2019: Children's protest in relation to the climate emergency: a qualitative study on a new form of resistance promoting political and social change. *Childhood*, **27**(1), 78–92, doi:10.1177/0907568219879970.

Holsapple, C., M. Sena and W. Wagner, 2019: The perceived success of ERP systems for decision support. *Inf. Technol. Manag.*, **20**(1), 1–7, doi:10.1007/s10799-017-0285-9.

Holsman, K.K., et al., 2019: *Towards Climate Resiliency in Fisheries Management*, 1368–1378.

Holtzman, S., 1989: *Intelligent Decision Systems*. Addison-Wesley, Reading, MA.

17

Hornsey, M.J. and K.S. Fielding, 2017: Attitude roots and Jiu Jitsu persuasion: understanding and overcoming the motivated rejection of science. *Am. Psychol.*, **72**(5), 459–473, doi:10.1037/a0040437.

Hossain, P., F. Ludwig and R. Leemans, 2018: Adaptation pathways to cope with salinization in south-west coastal region of Bangladesh. *Ecol. Soc.*, **23**, doi:10.5751/es-10215-230327.

Howarth, C. and I. Monasterolo, 2016: Understanding barriers to decision making in the UK energy-food-water nexus: the added value of interdisciplinary approaches. *Environ. Sci. Policy*, **61**, 53–60, doi:10.1016/j.envsci.2016.03.014.

Howarth, C., S. Morse-Jones, K. Brooks and A.P. Kythreotis, 2018: Co-producing UK climate change adaptation policy: an analysis of the 2012 and 2017 UK Climate Change Risk Assessments. *Environ. Sci. Policy*, **89**, 412–420, doi:10.1016/j.envsci.2018.09.010.

Howell, S., et al., 2001: *Real Options - Evaluating Corporate Investment Opportunities in a Dynamic World* Financial Times. Prentice Hall, London.

Hssaisoune, M., et al., 2020: Moroccan groundwater resources and evolution with global climate changes. *Geosciences*, **10**(2), doi:10.3390/geosciences10020081.

Huambachano, M., 2018: Enacting food sovereignty in Aotearoa New Zealand and Peru: revitalizing Indigenous knowledge, food practices and ecological philosophies. *Agroecol. Sustain. Food Syst.*, **42**(9), 1003–1028, doi:10.1080/21683565.2018.1468380.

Hudson, P., W.J.W. Botzen and J.C.J.H. Aerts, 2019: Flood insurance arrangements in the European Union for future flood risk under climate and socioeconomic change. *Glob. Environ. Chang.*, **58**, 101966, doi:10.1016/j.gloenvcha.2019.101966.

Hudson, P., W.W. Botzen, L. Feyen and J.C. Aerts, 2016: Incentivising flood risk adaptation through risk based insurance premiums: trade-offs between affordability and risk reduction. *Ecol. Econ.*, **125**, 1–13.

Hügel, S. and A.R. Davies, 2020: Public participation, engagement, and climate change adaptation: A review of the research literature. *Wiley Interdiscip. Rev. Clim. Chang.*, **11**(4), e645.

Huggel, C., I. Wallimann-Helmer, D. Stone and W. Cramer, 2016: Reconciling justice and attribution research to advance climate policy. *Nat. Clim. Change*, **6**(10), 901.

Huntingford, C., et al., 2019: Machine learning and artificial intelligence to aid climate change research and preparedness. *Environ. Res. Lett.*, **14**(12), doi:10.1088/1748-9326/ab4e55.

Hurlbert, M., J. Krishnaswamy, E. Davin, F.X. Johnson, C.F. Mena, J. Morton, S. Myeong, D. Viner, K. Warner, A. Wreford, S. Zakieldeen, Z. Zommers, 2019: Risk Management and Decision making in Relation to Sustainable Development. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

Hyde, K., H.R. Maier and C. Colby, 2003: Incorporating uncertainty in the PROMETHEE MCDA method. *J. Multi Crit. Decis. Anal.*, **12**(4-5), 245–259, doi:10.1002/mcda.361.

Ianelli, J., K.K. Holsman, A.E. Punt and K. Aydin, 2016: Multi-model inference for incorporating trophic and climate uncertainty into stock assessments. *Deep. Sea Res. Part Ii: Top. Stud. Oceanogr.*, **134**, 379–389, doi:10.1016/j.dsr2.2015.04.002.

ICRC, 2016: *Protracted conflict and humanitarian action: some recent ICRC experiences*. Cross, I. C. o. t. R, Geneva.

IMF, 2020: *World Economic Outlook October 2020: Executive Summary. COVID 19: Debt Service Suspension Initiative*. World Bank, Washington, D.C., 26

INC, 1991: *Vanuatu: Draft annex relating to Article 23 (Insurance) for inclusion in the revised single text on elements relating to mechanisms (A/AC.237/WG.II/Misc.13)*. Intergovernmental Negotiating Committee for a Framework Convention on Climate Change, Working Group II, Geneva.

Insuresilience Global Partnership, 2018: *The Insuresilience Global Partnership*. InsuResilience Secretariat, Bonn.

Iooss, B. and A. Saltelli, 2017: Introduction to Sensitivity Analysis. In: *Handbook of Uncertainty Quantification* [Ghanem, R., D. Higdon and H. Owhadi (eds.)]. Springer International Publishing, Berlin Heidelberg.

IPCC, 2012: *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA. 582 pp.

IPCC, 2014: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of theIntergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 1132 pp.

IPCC, 2018a: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Zhai, P., H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor and T. Waterfield, V Masson-Delmotte (eds.)]. In press.

IPCC, 2018b: Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

IPCC, 2019a: Annex I: Glossary. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley (eds.)]. In press.

IPCC, 2019b: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

IPCC, 2019c: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

IPCC, 2019d: Summary for Policymakers. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge. In Press.

Isakson, S.R., 2015: Derivatives for development? Small-farmer vulnerability and the financialization of climate risk management. *J. Agrar. Chang.*, **15**(4), 569–580, doi:10.1111/joac.12124.

Iturbide, M., et al., 2019: The R-based climate4R open framework for reproducible climate data access and post-processing. *Environ. Model. Softw.*, **111**, 42–54, doi:10.1016/j.envsoft.2018.09.009.

Iyahen, E. and J. Syroka, 2018: Managing Risks from Climate Change on the African Continent: The African Risk Capacity (ARC) as an Innovative Risk Financing Mechanism. *Resilience*. Elsevier, pp. 243–252, https://doi.org/10.1016/B978-0-12-811891-7.00020-7.

Jack, C.D., R. Jones, L. Burgin and J. Daron, 2020: Climate risk narratives: an iterative reflective process for co-producing and integrating climate knowledge. *Clim. Risk Manag.*, **29**, 100239, doi:10.1016/j.crm.2020.100239.

Jacobson, M.J., et al., 2017: Designs for learning about climate change as a complex system. *Learn. Instr.*, **52**, 1–14, doi:10.1016/j.learninstruc.2017.03.007.

Jafino, B.A., J.H. Kwakkel and B. Taebi, 2021: Enabling assessment of distributive justice through models for climate change planning: A review of recent advances and a research agenda. *Wiley Interdiscip. Rev. Clim. Chang.*, **12** (4) e721.

Jäger, W.S., et al., 2018: A Bayesian network approach for coastal risk analysis and decision making. *Coast. Eng.*, **134**, 48–61, doi:10.1016/j.coastaleng.2017.05.004.

James, R.A., et al., 2019: Attribution: How Is It Relevant for Loss and Damage Policy and Practice? In: *Loss and Damage from Climate Change*. Springer, Berlin Heidelberg, pp. 113–154.

Jarzabkowski, P., et al., 2019: *Insurance for Climate Adaptation*. Background Paper for the Global Commission on Adaptation.Global Commission on, A, Rotterdam and Washington, DC, www.gca.org. Accessed 2020.

Jashapara, A., 2011: *Knowledge management : an integrated approach*. Pearson/Financial Times/Prentice Hall, Harlow, Essex; New York, ISBN 97802737281910273728199.

Jaspars, S. and D. Maxwell, 2009: Food Security and Livelihoods Programming in Conflict: a Review. In: *HPN Network Paper-Humanitarian Practice Network, Overseas Development Institute*, Vol. 65.

Jensen, N. and C. Barrett, 2017: Agricultural index insurance for development. *Appl. Econ. Perspect. Policy.*, **39**(2), 199–219.

Jeuring, J., M. Knol-Kauffman and A. Sivle, 2019: *Toward Valuable Weather and Sea-Ice Services for the Marine Arctic: Exploring User–Producer Interfaces of the Norwegian Meteorological Institute*.

Jobbins, G., et al., 2015: To what end? Drip irrigation and the water–energy–food nexus in Morocco. *Int. J. Water Resour. Dev.*, **31**(3), 393–406, doi:10.1080/07900627.2015.1020146.

Johnson, J.T., et al., 2015: Weaving Indigenous and sustainability sciences to diversify our methods. *Sustain. Sci.*, **11**(1), 1–11, doi:10.1007/s11625-015-0349-x.

Jones, L., 2019a: Resilience isn't the same for all: Comparing subjective and objective approaches to resilience measurement. *Wiley. Interdiscip. Rev. Clim. Change.*, **10**(1), 1–19.

Jones, L., 2019b: *A how-to guide for subjective evaluations of resilience*. accessed 4 April 2022, https://www.researchgate.net/publication/336375851_A_how_to_guide_for_subjective_evaluations_of_resilience.

Jones, L. and P. Ballon, 2020: Tracking changes in resilience and recovery after natural hazards: insights from a high-frequency mobile-phone panel survey. *Glob. Environ. Chang.*, **62**, 102–153.

Jones, L. and M. d'Errico, 2019: Whose resilience matters? Like-for-like comparison of objective and subjective evaluations of resilience. *World Dev.*, **124**.

Jones, L., E. Samman and P. Vinck, 2018: Subjective measures of household resilience to climate variability and change: insights from a nationally representative survey of Tanzania. *Ecol. Soc.*, **23**, 1–1.

Jones, N., 2017: How machine learning could help to improve climate forecasts. *Nature*, **548**(7668), 379–379, doi:10.1038/548379a.

Jones, R.N., A. Patwardhan, S.J. Cohen, S. Dessai, A. Lammel, R.J. Lempert, M.M.Q. Mirza, and H. von Storch, 2014: Foundations for decision making. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of theIntergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 195–228.

Jongman, B., 2018: Effective adaptation to rising flood risk. *Nat. Commun.*, **9**(1), 1986, doi:10.1038/s41467-018-04396-1.

Jost, C., et al., 2015: Understanding gender dimensions of agriculture and climate change in smallholder farming communities. *Clim. Dev.*, **8**(2), 133–144, doi:10.1080/17565529.2015.1050978.

Joubert, L. and G. Ziervogel, 2019: *Day Zero: One City's Response to a Record-Breaking Drought*. Cape Town, accessed 4 April 2022, http://dayzero.org.za/.

Juhola, S., E. Glaas, B.-O. Linnér and T.-S. Neset, 2016: Redefining maladaptation. *Environ. Sci. Policy*, **55**, 135–140, doi:10.1016/j.envsci.2015.09.014.

Juhola, S., E.C.H. Keskitalo and L. Westerhoff, 2011: Understanding the framings of climate change adaptation across multiple scales of governance in Europe. *Environ. Polit.*, **20**(4), 445–463.

Jurt, C., et al., 2015: Cultural values of glaciers. In: *The High-Mountain cryosphere: Environmental Changes and Human Risks*. Cambridge University Press, Cambridge, pp. 90–106.

Kakinuma, K., et al., 2020: Flood-induced population displacements in the world. *Environ. Res. Lett.*, **15**(12), 124029, doi:10.1088/1748-9326/abc586.

Kalafatis, S.E. and M.C. Lemos, 2017: The emergence of climate change policy entrepreneurs in urban regions. *Reg. Environ. Change*, **17**(6), 1791–1799, doi:10.1007/s10113-017-1154-0.

Kam, J., K. Stowers and S. Kim, 2019: Monitoring of drought awareness from Google trends: a case study of the 2011–17 California drought. *Weather. Clim. Soc.*, **11**(2), 419–429, doi:10.1175/wcas-d-18-0085.1.

Karani, I., 2018: *Development of National and Sub-National Adaptation Metrics: Lessons from Kenya*. UNEP DTU Partnership, Copenhagen.

Karlsson, L., A.J. Nightingale, L.O. Naess and J. Thompson, 2017: *Triple wins or 'triple faults'? Analysing policy discourses on climate-smart agriculture (CSA)*), accessed 4 April 2022, https://hdl.handle.net/10568/80746.

Karlsson, M. and E.L. Mclean, 2020: Caribbean small-scale fishers' strategies for extreme weather events: lessons for adaptive capacity from the dominican republic and Belize. *Coast. Manag.*, **48**(5), 456–480.

Katz, E., A. Lammel and M.-P. Bonnet, 2020: Climate Change in a Floodplain of the Brazilian Amazon: Scientific Observation and Local Knowledge. In: *Changing Climate, Changing Worlds: Local Knowledge and the Challenges of Social and Ecological Change* [Welch-Devine, M., A. Sourdril and B.J. Burke(eds.)]. Springer International Publishing, Cham, pp. 123–144. ISBN 978-3030373122.

Keeney, R.L., 1992: *Value-Focused Thinking: A Path to Creative Decisionmaking*. Harvard University Press, Massachusetts, USA

Keeney, R.L., 2012: *Value-Focused Brainstorming*, 303–313.

Keeney, R.L. and H. Raiffa, 1993: *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. Cambridge University Press, Cambridge.

Keisler, J., D.A. Turcotte, R. Drew, et al., 2014: *Value-Focused Thinking for Community-Based Organizations: Objectives and Acceptance in Local Development*, 221–256.

Kempa, L., L. Zamarioli, W.P. Pauw and C. Çevik, 2021: *Financing Measures to Avert, Minimise and Address Loss and Damage: Options for the Green Climate Fund* paper, F. S.-U. C. r.

Kench, P.S., et al., 2018: Co-creating resilience solutions to coastal hazards through an interdisciplinary research project in New Zealand. *J. Coast. Res.*, **85**, 1496–1500, doi:10.2112/SI85-300.1.

Khan, M., et al., 2019a: Twenty-five years of adaptation finance through a climate justice lens. *Clim Change*, **161**(2), 251–269, doi:10.1007/s10584-019-02563-x.

Khatri, D., 2018: *Climate and Development at the third Pole: Dynamics of Power and Knowledge Reshaping Community Forest Governance in Nepal*. Swedish University of Agricultural Sciences, Uppsala, Sweden.

Khonje, M., J. Manda, A.D. Alene and M. Kassie, 2015: Analysis of adoption and impacts of improved maize varieties in eastern Zambia. *World Dev.*, **66**, 695–706, doi:10.1016/j.worlddev.2014.09.008.

Kim, H., D.W. Marcouiller and K.M. Woosnam, 2020: Coordinated planning effort as multilevel climate governance: Insights from coastal resilience and climate adaptation. *Geoforum*, **114**, 77–88, doi:10.1016/j.geoforum.2020.05.023.

Kim, Y. and E.-S. Chung, 2013: Fuzzy VIKOR approach for assessing the vulnerability of the water supply to climate change and variability in South Korea. *Appl. Math. Model.*, **37**(22), 9419–9430, doi:10.1016/j.apm.2013.04.040.

Kirchhoff, C.J., M.C. Lemos and S. Kalafatis, 2015a: Creating synergy with boundary chains: Can they improve usability of climate information? *Clim. Risk Manag.*, **9**(C), 77–85, doi:10.1016/j.crm.2015.05.002.

Kita, S.M., 2019: Barriers or enablers? Chiefs, elite capture, disasters, and resettlement in rural Malawi. *Disasters*, **43**(1), 135–156, doi:10.1111/disa.12295.

Kitchell, E., 2016: Information sharing and climate risk management among Senegalese agropastoralists. *Clim. Dev.*, **8**(2), 158–168, doi:10.1080/17565529.2015.1034225.

Klamroth, K., J.D. Knowles, G. Rudolph and M.M. Wiecek (eds.), *Personalized Multiobjective Optimization: An Analytics Perspective (Dagstuhl Seminar 18031)*. Dagstuhl Reports. Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik, Dagstuhl, Germany, 33–99.

Kleiche-Dray, M. and R. Waast, 2016: *Indigenous Knowledge in Mexico: Between Environmentalism and Rural Development*, 86–110.

Klein, R.J., et al., 2017: *Advancing climate adaptation practices and solutions: emerging research priorities*. Stockholm Environment Institute. Stockholm, Sweden.

Klein, R.J.T., G.F. Midgley, B.L. Preston, M. Alam, F.G.H. Berkhout, K. Dow and M.R. Shaw, 2014: Adaptation opportunities, constraints, and limits. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability.Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of theIntergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 899–943. 4 pp.

Klein, R.J.T., et al., 2007: Inter-relationships between adaptation and mitigation. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson(eds.)]. Cambridge University Press, Cambridge, United Kingdom, pp. 745–777. ISBN 978-0521880107.

Klenk, N., 2018: From network to meshwork: becoming attuned to difference in transdisciplinary environmental research encounters. *Environ. Sci. Policy*, **89**, 315–321, doi:10.1016/j.envsci.2018.08.007.

Klenk, N., A. Fiume, K. Meehan and C. Gibbes, 2017: Local knowledge in climate adaptation research: moving knowledge frameworks from extraction to co-production. *WIREs Clim. Chang.*, **8**(5), e475, doi:10.1002/wcc.475.

Klonschinski, A., 2021: Universal metrics for climate change adaptation finance? A cautionary tale. *Sustainability*, **13**(16), 9428.

Kloos, J., N. Gebert, T. Rosenfeld and F. Renaud, 2013: *Climate change, water conflicts and human security*. Regional assessment and policy guidelines for the Mediterranean, Middle East and Sahel. CLICO final report. UNited Nations University–Institute for Environment and Human Security (Report, 10. updated on, **8**(27), 2013.

Knapp, C.N., et al., 2019: Placing transdisciplinarity in context: a review of approaches to connect scholars, society and action. *Sustainability*, **11**(18), 4899, doi:10.3390/su11184899.

Knippenberg, E., N. Jensen and M. Constas, 2019: Quantifying household resilience with high frequency data: temporal dynamics and methodological options. *World Dev*, **121**, 1–15.

Koerth, J., A.T. Vafeidis and J. Hinkel, 2017: Household-level coastal adaptation and its drivers: a systematic case study review. *Risk Anal.*, **37**(4), 629–646, doi:10.1111/risa.12663.

Kolen, B. and I. Helsloot, 2014: Decision-making and evacuation planning for flood risk management in the Netherlands. *Disasters*, **38**(3), 610–635.

Kolstad C., K. Urama, J. Broome, A. Bruvoll, M. Cariño Olvera, D. Fullerton, C. Gollier, W. M. Hanemann, R. Hassan, F. Jotzo, M. R. Khan, L. Meyer, and L. Mundaca, 2014: Social, Economic and Ethical Concepts and Methods. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovern-mental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Konidari, P. and D. Mavrakis, 2007: A multi-criteria evaluation method for climate change mitigation policy instruments. *Energy Policy*, **35**(12), 6235–6257, doi:10.1016/j.enpol.2007.07.007.

Kool, R., J. Lawrence, M. Drews and R. Bell, 2020: Preparing for sea-level rise through adaptive managed retreat of a New Zealand stormwater and wastewater network. *Infrastructures*, **5**(11), 92.

Korhonen, P.J. and J. Wallenius, 2020: *Making Operations More Efficient*. Springer, Cham, 131–139.

Kousser, T. and B. Tranter, 2018: The influence of political leaders on climate change attitudes. *Glob. Environ. Chang.*, **50**, 100.

Kreibich, H., et al., 2017: Adaptation to flood risk: Results of international paired flood event studies. *Earths Future*, **5**(10), 953–965, doi:10.1002/2017ef000606.

Krishnapillai, M., 2018: Enhancing Adaptive Capacity and Climate Change Resilience of Coastal Communities in Yap. In: *Climate Change Impacts and Adaptation Strategies for Coastal Communities* [Leal Filho, W.(ed.)]. Springer International Publishing, Cham, pp. 87–118. ISBN 978-3319707037.

Krkoška Lorencová, E., et al., 2018: Participatory climate change impact assessment in three Czech cities: the case of heatwaves. *Sustainability*, **10**(6), 1906.

Kuipers, E., 2019: *Using disaster response to the 2017 Mocoa mudslide to build legitimacy in the post-Acuerdo de Paz context*. Erasmus University, Rotterdam.

Kumar, A., et al., 2017: A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. *Renew. Sustain. Energy Rev.*, **69**, 596–609, doi:10.1016/j.rser.2016.11.191.

Kunreuther H., S. Gupta, V. Bosetti, R. Cooke, V. Dutt, M. Ha-Duong, H. Held, J. Llanes-Regueiro, A. Patt, E. Shittu, and E. Weber, 2014: Integrated Risk and Uncertainty Assessment of Climate Change Response Policies. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cam-bridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kwakkel, J., 2020: Is real options analysis fit for purpose in supporting climate adaptation planning and decision-making? *WIREs Clim. Chang.*, **11**, doi:10.1002/wcc.638.

Kwakkel, J.H., 2017: The Exploratory Modeling Workbench: An open source toolkit for exploratory modeling, scenario discovery, and (multi-objective) robust decision making. *Environ. Model. Softw.*, **96**, 239–250, doi:10.1016/j.envsoft.2017.06.054.

Kwakkel, J.H., M. Haasnoot and W.E. Walker, 2014: Developing dynamic adaptive policy pathways: a computer-assisted approach for developing adaptive strategies for a deeply uncertain world. *Clim. Change*, **132**(3), 373–386, doi:10.1007/s10584-014-1210-4.

Kwakkel, J.H., M. Haasnoot and W.E. Walker, 2016: Comparing robust decision-making and dynamic adaptive policy pathways for model-based decision support under deep uncertainty. *Environ. Model. Softw.*, **86**, 168–183, doi:10.1016/j.envsoft.2016.09.017.

Lal, P.N., T. Mitchell, P. Aldunce, H. Auld, R. Mechler, A. Miyan, L.E. Romano, and S. Zakaria, 2012: National systems formanaging the risks from climate extremes and disasters. In: *Managing the Risks of Extreme Events and Disasters to AdvanceClimate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of theIntergovernmental Panel on Climate Change (IPCC) [Field, C., et al.(ed.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 339–392.

Lalou, R., B. Sultan, B. Muller and A. Ndonky, 2019: Does climate opportunity facilitate smallholder farmers' adaptive capacity in the Sahel? *Palgrave Commun.*, **5**(1), 81, doi:10.1057/s41599-019-0288-8.

Lama, P.D., 2018: Gendered consequences of mobility for adaptation in small island developing states: case studies from Maafushi and Kudafari in the Maldives. *Isl. Stud. J.*, **13**(2), 111–128.

Lamhauge, N., E. Lanzi and S. Agrawala, 2013: The use of indicators for monitoring and evaluation of adaptation: lessons from development cooperation agencies. *Clim. Dev.*, **5**(3), 229–241, doi:10.1080/17565529.2013.801824.

Lammel, A., 2015: *Climate change. From perception to action* Les Notes de la Fondation d'Ecologie Politique.

Landauer, M., S. Juhola and J. Klein, 2019: The role of scale in integrating climate change adaptation and mitigation in cities. *J. Environ. Plan. Manag.*, **62**(5), 741–765, doi:10.1080/09640568.2018.1430022.

Lanier, A.L., et al., 2018: Facilitating integration in interdisciplinary research: lessons from a south florida water, sustainability, and climate project. *Environ. Manage.*, **62**(6), 1025–1037, doi:10.1007/s00267-018-1099-1.

Larson, K., D. White, P. Gober and A. Wutich, 2015: Decision-making under uncertainty for water sustainability and urban climate change adaptation. *Sustainability*, **7**(11), 14761–14784.

Latulippe, N. and N. Klenk, 2020: Making room and moving over: knowledge co-production, indigenous knowledge sovereignty and the politics of global environmental change decision-making. *Curr. Opin. Environ. Sustain.*, **42**, 7–14, doi:10.1016/j.cosust.2019.10.010.

Lauer, H. and I. Eguavoen, 2016: Mainstreaming Climate Change Adaptation into Development in the Gambia: A Window of Opportunity for Transformative Processes? In: *Innovation in Climate Change Adaptation* [Leal Filho, W.(ed.)]. Springer International Publishing, Cham, pp. 87–98. ISBN 978-3319258140.

Laursen, S., et al., 2018: Collaboration across worldviews: managers and scientists on Hawai'i island utilize knowledge coproduction to facilitate climate change adaptation. *Environ. Manag.*, **62**(4), 619–630, doi:10.1007/s00267-018-1069-7.

Lavorel, S., B. Locatelli, M.J. Colloff and E. Bruley, 2020: Co-producing ecosystem services for adapting to climate change. *Philos. Trans. Biol. Sci.*, **375**(1794), 20190119, doi:10.1098/rstb.2019.0119.

Lawrence, J., et al., 2019b: *A Practice Brief: Adaptation Transition at the Coast*.

Lawrence, J., et al., 2018: National guidance for adapting to coastal hazards and sea-level rise: anticipating change, when and how to change pathway. *Environ. Sci. Policy*, **82**, 100–107.

Lawrence, J. and M. Haasnoot, 2017: What it took to catalyse uptake of dynamic adaptive pathways planning to address climate change uncertainty. *Environ. Sci. Policy*, **68**, 47–57, doi:10.1016/j.envsci.2016.12.003.

Lawrence, J., et al., 2019: Dynamic Adaptive Policy Pathways (DAPP): From Theory to Practice. In: *Decision Making under Deep Uncertainty: from theory to practice* [Marchau, V., W.E. Walker, P. Bloemen and S.W. Popper)](eds.)]. Springer, Berlin Heidelberg, pp. 187–199. ISBN 978-3030052515.

Lawrence, J., et al., 2019a: From theory to practice: a timeline of interventions by a change agent with the developers and users of Dynamic Adaptive Policy Pathways (DAPP). In: *Decision Making under Deep Uncertainty: From Theory to Practice* [Marchau, V., W. Walker and P. Bloeman(eds.)]. Springer International Publishing, Cham.

Le Cozannet, G., J.-C. Manceau and J. Rohmer, 2017: Bounding probabilistic sea-level projections within the framework of the possibility theory. *Environ. Res. Lett.*, **12**, 14012, doi:10.1088/1748-9326/aa5528.

Leavy, J., E. Boydell, S. McDowell and B. Sladkova, 2018: *Resilience Results. Braced Final Evaluation. Synthesis Paper*, accessed 4 April 2022, https://itad.com/wp-content/uploads/2018/09/BRCJ6513-Final-Evaluation-report-1709-WEB.pdf.

Leck, H. and D. Roberts, 2015: What lies beneath: understanding the invisible aspects of municipal climate change governance. *Curr. Opin. Environ. Sustain.*, **13**, 61–67, doi:10.1016/j.cosust.2015.02.004.

Lee, K.W. and M. Hong, 2018: Relative Effectiveness of Various Development Finance Flows: A Comparative Study. *KDI J Econ. Policy*, **40**(3), 91–115, doi:10.23895/kdijep.2018.40.3.91.

Lee, M. and B. Tansel, 2013: Water conservation quantities vs customer opinion and satisfaction with water efficient appliances in Miami, Florida. *J. Environ. Manage*, **128**, 683–689, doi:10.1016/j.jenvman.2013.05.044.

Lee, S.Y., 2015: *Motivations for local resistance in international peacebuilding*. Taylor & Francis, London, 1437–1452.

Lee, T.M., et al., 2015: Predictors of public climate change awareness and risk perception around the world. *Nat. Clim. Change*, **5**(11), 1014–1020, doi:10.1038/nclimate2728.

Leitch, A.M., et al., 2019: Co-development of a climate change decision support framework through engagement with stakeholders. *Clim. Change*, **153**(4), 587–605, doi:10.1007/s10584-019-02401-0.

Leiter, T., 2015: Linking monitoring and evaluation of adaptation to climate change across scales: avenues and practical approaches. *N. Dir. Evaluat.*, **2015**(147), 117–127, doi:10.1002/ev.20135.

Leiter, T., 2016: *Key considerations for monitoring and evaluation of community-based adaptation to climate change: lessons from experience* Atela, J. and others. African Centre for Technology Studies Press, Nairobi, Kenya.

Leiter, T., 2017: *The Adaptation M&E Navigator. A decision support tool for the selection of suitable approaches to monitor and evaluate adaptation to climate change* Uitto, J., J. Puri and R. D. van den Berg. Springer, Berlin Heidelberg, 327–341.

Leiter, T., 2021a: *Progress in implementing adaptation: insights from project proposals and scientific literature* UNEP. Adaptation Gap Report 2020. United Nations Environment Programme (UNEP), Nairobi, Kenya, 33–40.

Leiter, T., 2021b: Do governments track the implementation of national climate change adaptation plans? An evidence-based global stocktake of monitoring and evaluation systems. *Environ. Sci. Policy,* **125**, 179–188.

Leiter, T., et al., 2017a: *Country-Specific Assessments of Adaptation Progress*. United Nations Environment Programme (UNEP), Nairobi, Kenya, 23–33.

Leiter, T., et al., 2019: *Adaptation metrics: Current landscape and evolving practices. Background paper for the Global Commission on Adaptation*, accessed 4 April 2022, https://cdn.gca.org/assets/2019-09/AdaptationMetrics.pdf.

Leiter, T., et al., 2017b: *Can climate vulnerability and risk be measured through global indices? Policy Brief*. Accessed 4 April 2022, http://www.adaptationcommunity.net/wp-content/uploads/2017/09/Measuring-vulnerability-through-global-indices-Policy-Brief-GIZ-2017.pdf.

Leiter, T. and P. Pringle, 2018: *Pitfalls and potential of measuring adaptation through adaptation metrics* L. Christiansen, G. M. and P. Naswa. UNEP DTU Partnership, Copenhagen, 29–48.

Lemmen, D.S., F.J. Warren, T.S. James and C.S.L. Mercer Clarke, 2016: *Canada's Marine Coasts in a Changing Climate*. Government of Canada, Ottawa, accessed 4 April 2022, https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/files/pdf/NRCAN_fullBook%20%20accessible.pdf . (274 pp).

Lemos, M.C., et al., 2018: To co-produce or not to co-produce. *Nat. Sustain.*, **1**(12), 722–724, doi:10.1038/s41893-018-0191-0.

Lemos, M.C., et al., 2014: Moving climate information off the shelf: boundary chains and the role of RISAs as adaptive organizations. *Weather. Clim. Soc.*, **6**(2), 273–285, doi:10.1175/wcas-d-13-00044.1.

Lempert, R., 2019: Robust decision making (RDM). In: *Decision Making under Deep Uncertainty: from theory to practice* [Marchau, V., W.E. Walker, P. Bloemen and S.W. Popper)](eds.)]. Springer, Berlin Heidelberg, pp. 23–51. ISBN 978-3030052515.

Lempert, R., S. Popper, S. Bankes and S.C. Rand, 2003: *Shaping the Next One Hundred Years: New Methods for Quantitative Long-Term Policy Analysis*. ISBN 978-0833032751.

Lempert, R.J. and D.G. Groves, 2010: Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American west. *Technol. Forecast. Soc. Chang.*, **77**(6), 960–974, doi:10.1016/j.techfore.2010.04.007.

Lempert, R.J. and S. Turner, 2021: Engaging multiple worldviews with quantitative decision support: a robust decision-making demonstration using the lake model. *Risk Anal.*, **41**(6), 845–865.

Lesnikowski, A., et al., 2015: National-level progress on adaptation. *Nat. Clim. Change*, **6**(3), 261–264, doi:10.1038/nclimate2863.

Lesnikowski, A., et al., 2016: What does the Paris Agreement mean for adaptation? *Clim. Policy*, **17**(7), 825–831, doi:10.1080/14693062.2016.1248889.

Lesnikowski, A., J.D. Ford, R. Biesbroek and L. Berrang-Ford, 2019: A policy mixes approach to conceptualizing and measuring climate change adaptation policy. *Clim. Change*, **156**(4), 447–469, doi:10.1007/s10584-019-02533-3.

Levi-Faur, D., 2012: *From "Big Government" to "Big Governance"?* Levi-Faur, D. Oxford University Press, New York, United States.

Li, X., et al., 2017: Patterns of herders' adaptation to changes in social–ecological systems across northern China's grasslands over the past three decades. *Rangel. J.*, **39**(4), 317–328.

Limthongsakul, S., V. Nitivattananon and S.D. Arifwidodo, 2017: Localized flooding and autonomous adaptation in peri-urban Bangkok. *Environ. Urban.*, **29**(1), 51–68, doi:10.1177/0956247816683854.

Lin, Y.-P., J. Petway, W.-Y. Lien and J. Settele, 2018: Blockchain with artificial intelligence to efficiently manage water use under climate change. *Environments*, **5**(3), 34, doi:10.3390/environments5030034.

Lincke, D. and J. Hinkel, 2018: Economically robust protection against 21st century sea-level rise. *Glob. Environ. Change*, **51**, 67–73, doi:10.1016/j.gloenvcha.2018.05.003.

Linnerooth-Bayer, J. and S. Hochrainer-Stigler, 2015: Financial instruments for disaster risk management and climate change adaptation. *Clim. Change*, **133**(1), 85–100.

Linnerooth-Bayer, J., et al., 2019: Insurance as a Response to Loss and Damage? In: *Loss and Damage from Climate Change*. Springer, Berlin Heidelberg, pp. 483–512.

Loboguerrero, A.M., et al., 2018: Bridging the gap between climate science and farmers in Colombia. *Clim. Risk Manag.*, **22**, 67–81.

Lonsdale, K., P. Pringle and B. Turner, 2015: *Transformative adaptation: what it is, why it matters and what is needed*. UK Climate Impacts Programme, Oxford, UK.

Lopes, J., et al., 2020: Determinants of Foreign Investment and International Aid for Meeting the Sustainable Development Goals in Africa: A Visual Cognitive Review of the Literature. In: *Sustainability Challenges in Sub-Saharan Africa I*. Springer, Spingapore, pp. 161–187. ISBN 978-9811544576.

Lourenço, T.C., R. Swart, H. Goosen and R. Street, 2015: The rise of demand-driven climate services. *Nat. Clim. Change*, **6**(1), 13–14, doi:10.1038/nclimate2836.

Lumbroso, D., E. Brown and N. Ranger, 2016: Stakeholders' perceptions of the overall effectiveness of early warning systems and risk assessments for weather-related hazards in Africa, the Caribbean and South Asia. *Nat. Hazards*, **84**(3), 2121–2144, doi:10.1007/s11069-016-2537-0.

Lwasa, S., 2015: A systematic review of research on climate change adaptation policy and practice in Africa and South Asia deltas. *Reg. Environ. Change*, **15**(5), 815–824.

Lyytimäki, J., et al., 2020: Risks of producing and using indicators of sustainable development goals. *Sustain. Dev.* **28**(6), 1528–1538.

MacAskill, M., K. Bykvist and T. Ord, 2020: *Moral uncertainty*. Oxford University Press, Oxford, ISBN 978-0198722274.

Mach, K.J., et al., 2019: Climate as a risk factor for armed conflict. *Nature*, **571**(7764), 193–197, doi:10.1038/s41586-019-1300-6.

Mach, K.J., M.D. Mastrandrea, P.T. Freeman and C.B. Field, 2017: Unleashing expert judgment in assessment. *Glob. Environ. Chang. Policy Dimensions*, **44**, 1–14, doi:10.1016/j.gloenvcha.2017.02.005.

Mach, K.J. and A. Siders, 2021: Reframing strategic, managed retreat for transformative climate adaptation. *Science*, **372**(6548), 1294–1299.

MacLeod, D., et al., 2021: Are Kenya meteorological department heavy rainfall advisories useful for forecast-based early action and early preparedness for flooding? *Nat. Hazards Earth Syst. Sci.*, **21**(1), 261–277, doi:10.5194/nhess-21-261-2021.

Macquarie, R., et al., 2020: *Updated view on the Global Landscape of Climate Finance*. Initiative, C. P., accessed 4 April 2022, https://www.climatepolicyinitiative.org/wp-content/uploads/2020/12/Updated-View-on-the-2019-Global-Landscape-of-Climate-Finance-1.pdf.

Madsen, H.M., P.S. Mikkelsen and A. Blok, 2019: Framing professional climate risk knowledge: extreme weather events as drivers of adaptation innovation in Copenhagen, Denmark. *Environ. Sci. Policy*, **98**, 30–38, doi:10.1016/j.envsci.2019.04.004.

Magnan, A., 2014: Avoiding maladaptation to climate change: towards guiding principles. *Surv. Perspect. Integrating Environ. Soc.*, (7.1.).

Magnan, A.K. and S. Chalastani, 2019: *Towards a Global Adaptation Progress Tracker: first thoughts* Iddri.

Magnan, A.K. and T. Ribera, 2016: Global adaptation after Paris. *Science*, **352**(6291), 1280–1282, doi:10.1126/science.aaf5002.

Magnan, A.K., et al., 2016: Addressing the risk of maladaptation to climate change. *Wiley Interdiscip. Rev. Clim. Change*, **7**(5), 646–665, doi:10.1002/wcc.409.

Magnan, A.K., E.L.F. Schipper and V.K. Duvat, 2020: Frontiers in climate change adaptation science: advancing guidelines to design adaptation pathways. *Curr. Clim. Change Rep.*, **6**(4), 166–177.

Mahon, R., et al., 2019: Fit for purpose? Transforming national meteorological and hydrological services into national climate service centers. *Clim. Serv.*, **13**, 14–23, doi:10.1016/j.cliser.2019.01.002.

Mäkinen, K., et al., 2018: *Indicators for Adaptation to Climate Change at National Level - Lessons from Emerging Practice in Europe*.

Makondo, C.C. and D.S. Thomas, 2018: Climate change adaptation: Linking indigenous knowledge with western science for effective adaptation. *Environ. Sci. Policy*, **88**, 83–91.

Manocha, N. and V. Babovic, 2017: Development and valuation of adaptation pathways for storm water management infrastructure. *Environ. Sci. Policy*, **77**, 86–97, doi:10.1016/j.envsci.2017.08.001.

Marchau, V.A., W.E. Walker, P.J. Bloemen and S.W. Popper, 2019: *Decision making under deep uncertainty: from theory to practice*. Springer Nature, Berlin Heidelberg.

Mard, J., G. Di Baldassarre and M. Mazzoleni, 2018: Nighttime light data reveal how flood protection shapes human proximity to rivers. *Sci. Adv.*, **4**(8), eaar5779, doi:10.1126/sciadv.aar5779.

Marjanac, S. and L. Patton, 2018: Extreme weather event attribution science and climate change litigation: an essential step in the causal chain? *J. Energy Nat. Resour. Law*, **36**(3), 265–298, doi:10.1080/02646811.2018.1451020.

Markandya, A. and M. González-Eguino, 2019: Integrated Assessment for Identifying Climate Finance Needs for Loss and Damage: A Critical Review. In: *Loss and Damage from Climate Change: Concepts, Methods and Policy Options* [Mechler, R., L.M. Bouwer, T. Schinko, S. Surminski and J. Linnerooth-Bayer(eds.)]. Springer International Publishing, Cham, pp. 343–362. ISBN 978-3319720265.

Markl-Hummel, L. and J. Geldermann, 2014: A local-level, multiple criteria decision aid for climate protection. *Euro J. Decis. Process.*, **2**(1), 121–152, doi:10.1007/s40070-013-0011-8.

Markolf, S.A., K. Klima and T.L. Wong, 2015: Adaptation frameworks used by US decision-makers: a literature review. *Environ. Syst. Decis.*, **35**(4), 427–436, doi:10.1007/s10669-015-9572-3.

Marktanner, M., E. Mienie and L. Noiset, 2015: From armed conflict to disaster vulnerability. *Dis. Prev. Manag. Int. J.*, **24**(1), 53–69, doi:10.1108/dpm-04-2013-0077.

Martinez-Diaz, L., L. Sidner and J. McClamrock, 2019: *The future of disaster risk pooling for developing countries: Where do we go from here?* World Resources Institute, Washington DC.

Martínez-Tagüeña, N., et al., 2020: *Conservation and Development in the Biosphere Reserve of Mapimí: A Transdisciplinary and Participatory Project to Understand Climate Change Adaptation*. Springer Climate. 163 pp.

Marttunen, M., J. Lienert and V. Belton, 2017: Structuring problems for multi-criteria decision analysis in practice: a literature review of method combinations. *Eur. J. Oper. Res.*, **263**(1), 1–17, doi:10.1016/j.ejor.2017.04.041.

Mason, P. and M. Barnes, 2007: Constructing Theories of Change. Methods and Sources. *Evaluation*, **13**(2), 151–170.

Mastrandrea, M.C., et al., 2010: *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties*, accessed 4 April 2022, https://www.ipcc.ch/site/assets/uploads/2017/08/AR5_Uncertainty_Guidance_Note.pdf.

Mastrandrea, M.D. and K.J. Mach, 2011: Treatment of uncertainties in IPCC Assessment Reports: past approaches and considerations for the Fifth Assessment Report. *Clim. Change*, **108**(4), 659–673.

Masud, M.M., et al., 2016: Climate change issue and theory of planned behaviour: relationship by empirical evidence. *J. Clean. Prod.*, **113**, 613–623, doi:10.1016/j.jclepro.2015.11.080.

Masuda, Y.J., et al., 2018: Innovation diffusion within large environmental NGOs through informal network agents. *Nat. Sustain.*, **1**(4), 190–197, doi:10.1038/s41893-018-0045-9.

Matheny, J.G., 2007: Reducing the risk of human extinction. *Risk Anal. Int. J.*, **27**(5), 1335–1344.

Matsler, A.M., 2019: Making 'green' fit in a 'grey' accounting system: the institutional knowledge system challenges of valuing urban nature as infrastructural assets. *Environ. Sci. Policy*, **99**, 160–168, doi:10.1016/j.envsci.2019.05.023.

Mayer, B., 2016: The relevance of the no-harm principle to climate change law and politics. *Asia Pac. J. Environ. Law*, **19**, 79–104.

Mayer, B., 2017: Migration in the UNFCCC workstream on loss and damage: an assessment of alternative framings and conceivable responses. *Transnatl. Environ. Law*, **6**(1), 107–129.

Mazzocchi, F., 2020: A deeper meaning of sustainability: insights from indigenous knowledge. *Anthropocene Rev.*, **7**(1), 77–93, doi:10.1177/2053019619898888.

McCormick, S., et al., 2018: Strategies in and outcomes of climate change litigation in the United States. *Nat. Clim. Change*, **8**(9), 829–833, doi:10.1038/s41558-018-0240-8.

McDonald, J. and M.C. Styles, 2014: Legal strategies for adaptive management under climate change. *J. Environ. Law*, **26**(1), 25–53.

McGray, H., et al., 2007: *Weathering the Storm: Options for Framing Adaptation and Development*. WRI Report. World Resources Institute, Washington, D.C.

McKenzie Hedger, M.M.M.T., et al., 2008: *Evaluation of Adaptation to Climate Change from a Development Perspective, Desk Review*.

McNamara, K.E., R. Bronen, N. Fernando and S. Klepp, 2018: The complex decision-making of climate-induced relocation: adaptation and loss and damage. *Clim. Policy*, **18**(1), 111–117.

McNamara, K.E., et al., 2020: An assessment of community-based adaptation initiatives in the Pacific Islands. *Nat. Clim. Chang.*, **10**(7), 628–639.

McNamara, K.E. and G. Jackson, 2019: Loss and damage: A review of the literature and directions for future research. *Wiley Interdiscip. Rev. Clim. Chang.*, **10**(2), 1–16.

McSweeney, K. and O.T. Coomes, 2011: Climate-related disaster opens a window of opportunity for rural poor in northeastern Honduras. *Proc. Natl. Acad. Sci.*, **108**(13), 5203, doi:10.1073/pnas.1014123108.

MDBs, 2019: *Joint report on Multilateral Development Banks' Climate Finance 2019*, accessed 4 April 2022, https://publications.iadb.org/publications/english/document/2019-Joint-Report-on-Multilateral-Development-Banks-Climate-Finance.pdf.

MDBs and IDFC, 2018: *Lessons Learned from Three Years of Implementing the MDB-IDFC COMMON PRINCIPLES FOR CLIMATE CHANGE ADAPTATION FINANCE TRACKING*, accessed 4 April 2022, https://www.ebrd.com/documents/climate-finance/lessons-learned-from-three-years-of-implementing-the-mdbidfc-common-principles-for-climate-change-adaptation-finance-tracking.pdf?blobnocache=true.

Mechler, R., et al., 2014: Managing unnatural disaster risk from climate extremes. *Nat. Clim. Change*, **4**(4), 235–237, doi:10.1038/nclimate2137.

Mechler, R., et al., 2019: *Loss and damage from climate change: concepts, methods and policy options*. Springer Nature, Berlin Heidelberg.

Mechler, R., et al., 2019: Science for loss and damage. Findings and propositions. In: *Loss and Damage from Climate Change*. Springer, Berlin Heidelberg, pp. 3–37.

Mechler, R. and T.M. Deubelli, 2021: Finance for loss and damage: a comprehensive risk analytical approach. *Curr. Opin. Environ. Sustain.*, **50**, 185–196.

Mechler, R., S. Hochrainer-Stigler and J. Linnerooth-Bayer, 2006: *Public sector financial vulnerability to disasters*.

Mechler, R. and T. Schinko, 2016: Identifying the policy space for climate loss and damage. *Science*, **354**(6310), 290, doi:10.1126/science.aag2514.

Mehling, M., 2015: The comparative law of climate change: a research agenda. *Rev. Eur. Comp. Int. Environ. Law*, **24**(3), 341–352.

Melbourne-Thomas, J., et al., 2017: Integrated modelling to support decision-making for marine social–ecological systems in Australia. *ICES J. Mar. Sci.*, **74**(9), 2298–2308, doi:10.1093/icesjms/fsx078.

Melia, N., K. Haines and E. Hawkins, 2016: Sea ice decline and 21st century trans-Arctic shipping routes. *Geophys. Res. Lett.*, **43**(18), 9720–9728, doi:10.1002/2016gl069315.

Mena, R. and D. Hilhorst, 2020: The (im)possibilities of disaster risk reduction in the context of high-intensity conflict: the case of Afghanistan. *Environ. Hazards*, 1–21, doi:10.1080/17477891.2020.1771250.

Mendizabal, M., et al., 2018: Stimulating urban transition and transformation to achieve sustainable and resilient cities. *Renew. Sustain. Energy Rev.*, **94**, 410–418.

Mendoza, G., et al., 2018: *Climate Risk Informed Decision Analysis (CRIDA): collaborative water resources planning for an uncertain future*. UNESCO Publishing, accessed 4 April 2022, https://agwaguide.org/docs/CRIDA_Nov_2018.pdf.

Meredith, M.P., et al., 2019: Polar Regions. In: *The Ocean and Cryosphere in a Changing Climate: Summary for Policymakers*. Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 203–320. https://doi.org/10.1017/9781009157964.005

Mesquita, P.S. and M. Bursztyn, 2016: Integration of social protection and climate change adaptation in Brazil. *Br. Food J.*, **118**(12), 3030–3043, https://doi.org/10.1108/BFJ-02-2016-0082.

17

Meyer, R., S. McAfee and E. Whiteman, 2015: How California is mobilizing boundary chains to integrate science, policy and management for changing ocean chemistry. *Clim. Risk Manag.*, **9**, 50–61, doi:10.1016/j.crm.2015.04.002.

Mfitumukiza, D., et al., 2019: *Scaling local and community-based adaptation*. Background Paper for Global Commission on Adaptation.

Micale, V., B. Tonkonogy and F. Mazza, 2018: *Understanding and Increasing Finance for Climate Adaptation in Developing Countries*. Initiative, C. P, https://climatepolicyinitiative.org/our-work/publications. Accessed 2019.

Michaelowa, A. and K. Michaelowa, 2011: Coding error or statistical embellishment? The political economy of reporting climate aid. *World Dev.*, **39**(11), 2010–2020.

Michaelowa, A., K. Michaelowa, I. Shishlov and D. Brescia, 2021: Catalysing private and public action for climate change mitigation: the World Bank's role in international carbon markets. *Clim. Policy*, **21**(1), 120–132.

Michailidou, A.V., C. Vlachokostas and N. Moussiopoulos, 2016: Interactions between climate change and the tourism sector: multiple-criteria decision analysis to assess mitigation and adaptation options in tourism areas. *Tour. Manag.*, **55**, 1–12, doi:10.1016/j.tourman.2016.01.010.

Mikulewicz, M., 2018: Politicizing vulnerability and adaptation: on the need to democratize local responses to climate impacts in developing countries. *Clim. Dev.*, **10**(1), 18–34.

Mikulewicz, M., 2019: Thwarting adaptation's potential? A critique of resilience and climate resilient development. *Geoforum*, **104**, 267–282.

Mikulewicz, M., 2020: Disintegrating labour relations and depoliticised adaptation to climate change in rural São Tomé and Príncipe. *Area*, 1–9, doi:10.1111/area.12630.

Miller, A., S. Swann, S. Cheng and A. Eil, 2019: *Driving Finance Today for the Climate Resilient Society of Tomorrow: for Global Comission on Adaptation*. Climate Finance Advisors, Unepfi.

Miller, C.A. and C. Wyborn, 2020: Co-production in global sustainability: histories and theories. *Environ. Sci. Policy*, **113**, 88–95, doi:10.1016/j.envsci.2018.01.016.

Millington, N. and S. Scheba, 2021: Day zero and the infrastructures of climate change: water governance, inequality, and infrastructural politics in cape town's water crisis. *Int. J. Urban Reg. Res.*, **45**(1), 116–132.

Mimet, A., et al., 2020: Contribution of private gardens to habitat availability, connectivity and conservation of the common pipistrelle in Paris. *Landsc. Urban Plan.*, **193**, 103671, doi:10.1016/j.landurbplan.2019.103671.

Mimura, N., et al., 2008: *Small islands*. Cambridge University Press, Cambridge, UK, 681–716.

Mimura, N., R.S. Pulwarty, D.M. Duc, I. Elshinnawy, M.H. Redsteer, H.Q. Huang, J.N. Nkem, and R.A. SanchezRodriguez, 2014: Adaptation planning and implementation. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 869–898.

Ministry of Economy, 2019: *The Fiji Sovereign Green Bond 2019 Update*. Ministry of Economy, Suva, Fiji, accessed 4 April 2022, https://www.rbf.gov.fj/wp-content/uploads/2020/03/Fiji-Sovereign-Green-Bond-Impact-Report-2019.pdf.

Mintrom, M., 2019: *Policy Entrepreneurs and Dynamic Change. Elements in Public Policy*. Cambridge University Press, Cambridge, accessed 4 April 2022, https://www.cambridge.org/core/elements/policy-entrepreneurs-and-dynamic-change/AA75C2D1EA0ADD4C43C1C5987E84280F.

Mohammadpour, P., T. Mahjabin, J. Fernandez and C. Grady, 2019: From national indices to regional action—an analysis of food, energy, water security in Ecuador, Bolivia, and Peru. *Environ. Sci. Policy*, **101**, 291–301.

Möhner, A., T. Leiter and T. Kato, 2017: *Adaptation in the Paris Agreement and provisions for review and reporting*. United Nations Environment Programme (UNEP), Nairobi, Kenya.

Molthan-Hill, P., N. Worsfold, G.J. Nagy and L. Filho, 2019: *Climate Change Education for Universities: A conceptual Framework from an International Study (Book Review)*.

Monteleoni, C., G.A. Schmidt and S. McQuade, 2013: Climate Informatics: accelerating discovering in climate science with machine learning. *Comput. Sci. Eng.*, **15**(5), 32–40, doi:10.1109/mcse.2013.50.

Moon, S.-H., Y.-H. Kim, Y.H. Lee and B.-R. Moon, 2019: Application of machine learning to an early warning system for very short-term heavy rainfall. *J. Hydrol.*, **568**, 1042–1054, doi:10.1016/j.jhydrol.2018.11.060.

Morgan, E.A., J. Nalau and B. Mackey, 2019: Assessing the alignment of national-level adaptation plans to the Paris Agreement. *Environ. Sci. Policy*, **93**, 208–220, doi:10.1016/j.envsci.2018.10.012.

Mortreux, C. and J. Barnett, 2017: Adaptive capacity: exploring the research frontier. *Wiley. Interdiscip. Rev. Clim. Change.*, **8**(e467).

Mortreux, C., et al., 2018: Political economy of planned relocation: a model of action and inaction in government responses. *Glob. Environ. Chang.*, **50**, 123–132, doi:10.1016/j.gloenvcha.2018.03.008.

Moser, S.C. and M.T. Boykoff, 2013: Climate change and adaptation success: the scope of the challenge. In: *Successful adaptation to climate change*. Routledge, Routledge, Oxford, UK, pp. 25–58.

Muccione, V., S.K. Allen, C. Huggel and J. Birkmann, 2017: *Differentiating Regions for Adaptation Financing: the Role of Global Vulnerability and Risk Distributions*.

Muccione, V., et al., 2019: *Joint Knowledge Production in Climate Change Adaptation Networks*. doi:10.1016/j.cosust.2019.09.011.

Mugambiwa, S.S., 2018: Adaptation measures to sustain indigenous practices and the use of indigenous knowledge systems to adapt to climate change in Mutoko rural district of Zimbabwe. *Jamba*, **10**(1), 388, doi:10.4102/jamba.v10i1.388.

Müller, B., L. Johnson and D. Kreuer, 2017: Maladaptive outcomes of climate insurance in agriculture. *Glob. Environ. Chang.*, **46**, 23–33, doi:10.1016/j.gloenvcha.2017.06.010.

Munira, S., R. Bashar, T. H. Easher and M. R. Khan, 2021: Climate Finance in the UNFCCC Negotiations: Bridging Gaps with Lessons Learnt. In: Climate Change in Bangladesh: A Cross-Disciplinary Framework [Jakariya, M. and M. N. Islam (eds.)]. Springer International Publishing, Cham, pp. 1–24. ISBN 978-3-030-75825-7.

Mustelin, J. and J. Handmer, 2013: Triggering transformation: managing resilience or invoking real change. *Proc. Transform. A Chang. Clim.*, 19–21.

Muttarak, R. and T. Chankrajang, 2015: *Who is concerned about and takes action on climate change? Gender and education divides among Thais*. Yearbook of Population Research, Vienna, 193–220.

Mycoo, M. A., 2017: Beyond 1.5°C: vulnerabilities and adaptation strategies for Caribbean Small Island Developing States. *Reg Environ Change*, **18**(8), 2341–2353, doi:10.1007/s10113-017-1248-8.

Myers, R., et al., 2018: Messiness of forest governance: how technical approaches suppress politics in REDD+ and conservation projects. *Glob. Environ. Chang.*, **50**, 314–324, doi:10.1016/j.gloenvcha.2018.02.015.

Nachmany, M., A. Abeysinghe and S. Barakat, 2017: Climate change legislation in the least developing countries. *Trends Clim. Chang. Legislation*, **59**, https://doi.org/10.4337/9781786435781.

Nachmany, M., R. Byrnes and S. Surminski, 2019a: *National laws and policies on climate change adaptation: a global review*. Policy Publication, Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy, London, accessed 4 April 2022, https://www.lse.ac.uk/granthaminstitute/publication/national-laws-and-policies-on-climate-change-adaptation-a-global-review/.

Nachmany, M., R. Byrnes and S. Surminski, 2019b: *Policy Brief: National Laws and Policies on Climate Change Adaptation: a Global Review*. Grantham

Research Institute on Climate Change and the Environment, London School of Economics and Political Science, London.

Nachmany, M., et al., 2015: *The 2015 global climate legislation study: a review of climate change legislation in 99 countries: summary for policy-makers*.

Nachmany, M. and J. Setzer, 2018: *Global trends in climate change legislation and litigation: 2018 snapshot*. Policy Publication, Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy, London, accessed 4 April 2022, https://www.lse.ac.uk/granthaminstitute/publication/global-trends-in-climate-change-legislation-and-litigation-2018-snapshot/.

Nagle Alverio, G., S.H. Hoagland, E. Coughlan de Perez and K.J. Mach, 2021: The role of international organizations in equitable and just planned relocation. *J Environ Stud Sci*, 1–12, doi:10.1007/s13412-021-00698-x.

Nagoda, S. and A.J. Nightingale, 2017: Participation and power in climate change adaptation policies: vulnerability in food security programs in Nepal. *World Dev*, **100**, 85–93.

Nakashima, D., I. Krupnik and J.T. Rubis, 2018: *Indigenous Knowledge for Climate Change Assessment and Adaptation*. Cambridge University Press, Cambridge, ISBN 978-1107137882.

Nakhooda, S., et al., 2014: *Climate Finance: is it making a difference? A review of the effectiveness of Multilateral Climate Funds*. Overseas Development Institute, London, UK, ISBN 20527209.

Nawrotzki, R.J. and J. DeWaard, 2018: Putting trapped populations into place: Climate change and inter-district migration flows in Zambia. *Reg. Environ. Change*, **18**(2), 533–546.

Ndebele-Murisa, M.R., et al., 2020: City to city learning and knowledge exchange for climate resilience in southern Africa. *PLoS ONE*, **15**(1), doi:10.1371/journal.pone.0227915.

Neely, J.E. and R. de Neufville, 2001: Hybrid real options valuation of risky product development projects. *Int. J. Technol.*, **1**, 29–46, doi:10.1504/ijtpm.2001.001743.

Neise, T. and J. Revilla Diez, 2019: Adapt, move or surrender? Manufacturing firms' routines and dynamic capabilities on flood risk reduction in coastal cities of Indonesia. *Int. J. Dis. Risk Reduct.*, **33**, 332–342, doi:10.1016/j.ijdrr.2018.10.018.

Nelson, H.W., T.B. Williamson, C. Macaulay and C. Mahony, 2016: Assessing the potential for forest management practitioner participation in climate change adaptation. *For. Ecol. Manag.*, **360**, 388–399.

Mann, N., P. Grifman and J. Finzi Hart, 2017: The stakes are rising: lessons on engaging coastal communities on climate adaptation in southern California. *Cities Environ.*, **10**(2), 6.

Ng, A.K.Y., et al., 2018: Implications of climate change for shipping: opening the Arctic seas. *WIREs Clim. Chang.*, **9**(2), e507, doi:10.1002/wcc.507.

Nhamo, L., et al., 2018: The water-energy-food nexus: climate risks and opportunities in southern Africa. *Water*, **10**(5), 567–567, doi:10.3390/w10050567.

Nightingale, A.J., 2017: Power and politics in climate change adaptation efforts: struggles over authority and recognition in the context of political instability. *Geoforum*, **84**, 11–20.

Nikas, A., H. Doukas and L. Martínez López, 2018: A group decision making tool for assessing climate policy risks against multiple criteria. *Heliyon*, **4**(3), e588, doi:10.1016/j.heliyon.2018.e00588.

Noble, I.R., S. Huq, Y.A. Anokhin, J. Carmin, D. Goudou, F.P. Lansigan, B. Osman-Elasha and A. Villamizar, 2014: Adaptation needs and options. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 833–868. ISBN 978-1107058071.

Noll, B., T. Filatova and A. Need, 2020: How does private adaptation motivation to climate change vary across cultures? Evidence from a meta-analysis. *Int. J. Dis. Risk Reduct.*, **46**, 101615, doi:10.1016/j.ijdrr.2020.101615.

Nordlander, L., M. Pill and B.M. Romera, 2020: Insurance schemes for loss and damage: fools' gold? *Clim. Policy*, **20**(6), 704–714.

Norström, A.V., et al., 2020: Principles for knowledge co-production in sustainability research. *Nat. Sustain.*, **3**(3), 182–190, doi:10.1038/s41893-019-0448-2.

Novalia, W. and S. Malekpour, 2020: Theorising the role of crisis for transformative adaptation. *Environ. Sci. Policy*, **112**, 361–370, doi:10.1016/j.envsci.2020.07.009.

Núñez Collado, J.R. and H.-H. Wang, 2020: Slum upgrading and climate change adaptation and mitigation: lessons from Latin America. *Cities*, **104**, 102791, doi:10.1016/j.cities.2020.102791.

Nyantakyi-Frimpong, H. and K. Bezner, 2015: A political ecology of high-input agriculture in northern Ghana. *Afr. Geogr. Rev.*, **34**(1), 13–35.

O'Garra, T., et al., 2021: Impact of gameplay vs. reading on mental models of social-ecological systems: a fuzzy cognitive mapping approach. *Ecol. Soc.*, **26**(2), doi:10.5751/ES-12425-260225.

O'Brien, K., M. Pelling, A. Patwardhan, S. Hallegatte, A. Maskrey, T. Oki, U. Oswald-Spring, T. Wilbanks, and P.Z. Yanda, 2012: Toward a sustainable and resilient future. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, New York, NY, USA, pp. 437–486.

O'Callaghan, B.J. and E. Murdock, 2021: *Are We Building Back Better? Evidence from 2020 and Pathways for Inclusive Green Recovery Spending*. Programme, U. N. E.Oxford & Nairobi, https://www.unep.org/resources/publication/are-we-building-back-better-evidence-2020-and-pathways-inclusive-green. Accessed 2021.

Oberlack, C. and al e, 2019: Theories of change in sustainability science. Understanding how change happens. *Gaia*, **28**(2), 106–111.

Oberlack, C. and K. Eisenack, 2014: Alleviating barriers to urban climate change adaptation through international cooperation. *Glob. Environ. Chang.*, **24**, 349–362, doi:10.1016/j.gloenvcha.2013.08.016.

OCHA, 2011: *Humanitarian Action Plan for the Conflict-Affected Provinces of Mindanao*. United Nations, New York.

ODI, 2016: *Analysis of Resilience Measurement Frameworks and Approaches*.

OECD, 2002: *Glossary of Key Terms in Evaluation and Results Based Management*. Publications, O, Paris.

OECD, 2008: *Handbook on Constructing Composite Indicators. Methodology and User Guide*. OECD, Joint Research Centre of the European Commission, Paris.

OECD, 2015: Overview of costs and benefits of adaptation at national and regional scale. In: *Climate Change Risks and Adaptation: LInking Policy and Economics*. OCED Publishing, Paris, pp. 37–75.

OECD, 2016: *Converged Statistical Reporting Directives for the Creditor Reporting System (CRS) and the Annual DAC Questionnaire*, accessed 4 April 2022, https://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/DCDDAC(2016)3FINAL.pdf.

OECD, 2019: *Results of the first survey on coefficients that Members apply to the Rio marker data when reporting to the UN Conventions on Climate Change and Biodiversity*, accessed 4 April 2022, https://one.oecd.org/document/DCD/DAC/STAT(2020)41/en/pdf.

OECD, 2020: *Climate Finance Provided and Mobilised by Developed Countries in 2013-18*. Publishing, O, Paris, https://doi.org/10.1787/f0773d55-en. Accessed 2021.

Ohunakin, O.S., M.S. Adaramola, O.M. Oyewola and R.O. Fagbenle, 2014: Solar energy applications and development in Nigeria: drivers and barriers. *Renew. Sustain. Energy Rev.*, **32**, 294–301.

17

Ojha, et al., 2019: Improving science-policy interface: Lessons from the policy lab methodology in Nepal's community forest governance. *For. Policy Econ.*, 101997, https://doi.org/10.1016/j.forpol.2019.101997.

Olazabal, M., et al., 2019a: A cross-scale worldwide analysis of coastal adaptation planning. *Environ. Res. Lett.*, **14**(12), 124056–124056.

Olazabal, M., et al., 2019b: Are local climate adaptation policies credible? A conceptual and operational assessment framework. *Int. J. Urban Sustain. Dev.*, **11**(3), 277–296, doi:10.1080/19463138.2019.1583234.

Olivier, J., T. Leiter and J. Linke, 2013: *Adaptation Made to Measure: a Guidebook to the Design and Results-Based Monitoring of Climate Change Adaptation Projects*, 2nd edn., Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Bonn.

Olsson, L., M. Opondo, P. Tschakert, A. Agrawal, S.H. Eriksen, S. Ma, L.N. Perch, and S.A. Zakieldeen, 2014: Livelihoods and poverty. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global andSectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IntergovernmentalPanel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 793–832. ISBN 978-1107058071.

Omari-Motsumi, K., M. Barnett and L. Schalatek, 2019: *Broken Connections and Systemic Barriers: Overcoming the Challenge of the 'Missing Middle' in Adaptation Finance*. Background Paper for Global Comission on Adaptation, accessed 4 April 2022, https://us.boell.org/en/2020/01/10/broken-connections-and-systemic-barriers-overcoming-challenge-missing-middle-adaptation.

Omukuti, J., 2020: Challenging the obsession with local level institutions in country ownership of climate change adaptation. *Land Use Policy*, **94**, 104525–104525.

Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, 2019: Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Orleans Reed, S., et al., 2013: "Shared learning" for building urban climate resilience-experiences from Asian cities. *Environ. Urban.*, **25**(2), 393–412, doi:10.1177/0956247813501136.

Orlove, B., R. Shwom, E. Markowitz and S.-M. Cheong, 2020: Climate decision-making. *Annu. Rev. Environ. Resour.*, **45**(1), 271–303, doi:10.1146/annurev-environ-012320-085130.

Orsato, R.J., J.G. Ferraz de Campos and S.R. Barakat, 2018: Social learning for anticipatory adaptation to climate change: evidence from a community of practice. *Organ. Environ.*, doi:10.1177/1086026618775325.

Oshri, B., et al., 2018: *Infrastructure Quality Assessment in Africa using Satellite Imagery and Deep Learning*. In Proceedings of the 24th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining (pp. 616–625), https://doi.org/10.1145/3219819.3219924.

Ostovar, A.L., 2019: Investing upstream: watershed protection in Piura, Peru. *Environ. Sci. Policy*, **96**, 9–17, doi:10.1016/j.envsci.2019.02.005.

Oswald, K. and P. Taylor, 2010: A learning approach to monitoring and evaluation. *IDS Bull.*, **41**(6), 115–120.

Otto, F.E., et al., 2020: Towards an inventory of the impacts of human-induced climate change. *Bull. Am. Meteorol. Soc.*, **101**(11), e1972–e1979.

Otto, I.M., et al., 2015: Socio-economic data for global environmental change research. *Nat. Clim. Change*, **5**(6), 503–506.

Owen, G., 2020: What makes climate change adaptation effective? A systematic review of the literature. *Glob. Environ. Chang.*, **62**, 102071, https://doi.org/10.1016/j.gloenvcha.2020.102071.

Pace, M.L., S.R. Carpenter and J.J. Cole, 2015: With and without warning: managing ecosystems in a changing world. *Front. Ecol. Environ.*, **13**(9), 460–467, doi:10.1890/150003.

Page, E.A. and C. Heyward, 2017: Compensating for climate change loss and damage. *Polit. Stud.*, **65**(2), 356–372.

Page, R. and L. Dilling, 2020: How experiences of climate extremes motivate adaptation among water managers. *Clim. Change*, **161**(3), 499–516, doi:10.1007/s10584-020-02712-7.

Paleari, S., 2019: Disaster risk insurance: A comparison of national schemes in the EU-28. *Int. J. Dis. Risk Reduct.*, **35**, 101059, doi:10.1016/j.ijdrr.2018.12.021.

Palutikof, J.P., R.B. Street and E.P. Gardiner, 2019a: Decision support platforms for climate change adaptation: an overview and introduction. *Clim Change*, **153**(4), 459–476, doi:10.1007/s10584-019-02445-2.

Palutikof, J.P., R.B. Street and E.P. Gardiner, 2019b: Looking to the future: guidelines for decision support as adaptation practice matures. *Clim. Change*, **153**(4), 643–655.

Pandey, C.L. and R.M. Bajracharya, 2017: Climate adaptive water management practices in small and midsized cities of Nepal: case studies of Dharan and Dhulikhel. *Sustain. J. Rec.*, **10**(5), 300–307, doi:10.1089/sus.2017.0008.

Papathanasiou, J., N. Ploskas and I. Linden, 2016: *Real-World Decision Support Systems: Case Studies* Integrated Series in Information Systems. 1st edn., Springer International Publishing, Cham, 327.

Parding, K.M., et al., 2020: GCMeval – An interactive tool for evaluation and selection of climate model ensembles. *Clim. Serv.*, **18**, 100167, doi:10.1016/j.cliser.2020.100167.

Park, S.E., et al., 2012: Informing adaptation responses to climate change through theories of transformation. *Glob. Environ. Chang.*, **22**(1), 115–126, doi:10.1016/j.gloenvcha.2011.10.003.

Parnell, G.S., D.W. Hughes, R.C. Burk, et al., 2013: *Invited Review—Survey of Value-Fcused thinking: Applications, Research Developments and Areas for Future Research*, 49–60.

Partey, S.T., et al., 2020: Gender and climate risk management: evidence of climate information use in Ghana. *Clim. Change*, **158**(1), 61–75.

Partzsch, L., 2020: *Alternatives to Multilateralism: New Forms of Social and Environmental Governance* Earth System Governance. MIT Press, Massachusetts, USA, ISBN 978-0262539227.

Pauw, P.W., C. Grüning and C. Menzel, 2020: *Number of beneficiaries as an indicator for adaptation: do the numbers add up?* GCF Monitor. FS-UNEP Collaboration Centre of the Frankfurt School of Finance and Management, Frankfurt.

Pauw, W.P., R.J.T. Klein, P. Vellinga and F. Biermann, 2016: Private finance for adaptation: do private realities meet public ambitions? *Clim. Change*, **134**(4), 489–503, doi:10.1007/s10584-015-1539-3.

Pearce, D., G. Atkinson and S. Mourato, 2006: Cost-benefit analysis and the environment: recent developments. *Benefits Transf.*, doi:10.1787/9789264010055-en.

Pedrycz, W., P. Ekel and R. Parreiras, 2011: *Fuzzy Multicriteria Decision-Making : Models, Methods and Applications*. Wiley, Chichester, West Sussex, U.K, ISBN 978-0470682258. 360 pp.

Peduzzi, P., 2017: Flooding: prioritizing protection? *Nat. Clim. Change*, **7**(9), 625.

Peel, J., H. Osofsky and A. Foerster, 2017: Shaping the 'next generation' of climate change litigation in Australia. *Melb. Univ. Law. Rev.*, **41**, 793–844.

Peel, J. and H.M. Osofsky, 2015: *Climate Change Litigation: Regulatory Pathways to Cleaner Energy*. Cambridge Studies in International and Comparative Law. Cambridge University Press, Cambridge, ISBN 978-1107036062.

Peel, J. and H.M. Osofsky, 2018: A rights turn in climate change litigation? *Transnatl. Environ. Law*, **7**(1), 37–67, doi:10.1017/s2047102517000292.

Pelling, M. and M. Garschagen, 2019: Put equity first in climate adaptation. *Nature*, **569**(7756), 327–329, doi:10.1038/d41586-019-01497-9.

Perkins, R. and M. Nachmany, 2019: 'A very human business'—Transnational networking initiatives and domestic climate action. *Glob. Environ. Chang.*, **54**, 250–259, doi:10.1016/j.gloenvcha.2018.11.008.

Perrels, A., 2020: Quantifying the uptake of climate services at micro and macro level. *Clim. Serv.*, **17**, 100152, doi:10.1016/j.cliser.2020.100152.

Peters, B.G., 2018: *Policy problems and policy design*. Edward Elgar Publishing, Cheltenham, United Kingdom, ISBN 978-1786431356.

Peters, K., et al., 2019: *Double Vulnerability: The Humanitarian Implications of Intersecting Climate and Conflict Risk*. ODI, London.

Peterson, T.R. and J.L. Thompson, 2020: *Environmental Risk Communication: Responding to Challenges of Complexity and Uncertainty*. Routledge, Oxford, United Kingdom, 591–606.

Petridou, E. and M. Mintrom, 2020: A research agenda for the study of policy entrepreneurs. *Policy Stud. J.*, doi:10.1111/psj.12405.

Pfirman, S., et al., 2021: "Stickier" learning through gameplay: An effective approach to climate change education. *J. Geosci. Educ.*, **69**(2), 192–206, doi:10.1080/10899995.2020.1858266.

Phan, T.D., et al., 2019: *Applications of Bayesian Networks as Decision Support Tools for Water Resource Management under Climate Change and Socio-Economic Stressors: A Critical Appraisal*, 26–42.

Pickering, J., C. Betzold and J. Skovgaard, 2017: Special issue: managing fragmentation and complexity in the emerging system of international climate finance. *Int. Environ. Agreements Polit. Law Econ.*, **17**(1), 1–16, doi:10.1007/s10784-016-9349-2.

Pickering, J., F. Jotzo and P.J. Wood, 2015: Sharing the global climate finance effort fairly with limited coordination. *Glob. Environ. Polit.*, **15**(4), 39–62, doi:10.1162/GLEP_a_00325.

Piggott, J.J., C.R. Townsend and C.D. Matthaei, 2015: Reconceptualizing synergism and antagonism among multiple stressors. *Ecol. Evol.*, **5**(7), 1538–1547, doi:10.1002/ece3.1465.

Pijnenburg, A., T. Gammeltoft-Hansen and C. Rijken, 2018: Controlling migration through international cooperation. *Eur. J. Migr. Law*, **20**(4), 365–371.

Pill, M., 2021: Linking solidarity funds and philanthropic giving to finance loss and damage from climate change related slow-onset events. *Curr. Opin. Environ. Sustain.*, **50**, 169–174, doi:10.1016/j.cosust.2021.04.003.

Pillay, K., S. Aakre and A. Torvanger, 2017: *Mobilizing Adaptation Finance in Developing Countries*. Vol. 2. Center for International Climate Research (CICERO), Olso, Norway.

Poesch, M.S., et al., 2016: Climate change impacts on freshwater fishes: a Canadian perspective. *Fisheries*, **41**(7), 385–391.

Pope, E.C.D., C. Buontempo and T. Economou, 2017: Quantifying how user-interaction can modify the perception of the value of climate information: A Bayesian approach. *Clim. Serv.*, **6**(C), 41–47, doi:10.1016/j.cliser.2017.06.006.

Porter, J.J., D. Demeritt and S. Dessai, 2015: The right stuff? informing adaptation to climate change in British Local Government. *Glob. Environ. Chang.*, **35**, 411–422, doi:10.1016/j.gloenvcha.2015.10.004.

Porter, J.J., S. Dessai and E.L. Tompkins, 2014: What do we know about UK household adaptation to climate change? A systematic review. *Clim. Change*, **127**(2), 371–379, doi:10.1007/s10584-014-1252-7.

Posner, R.A., 2004: *Catastrophe: risk and response*. Oxford University Press, Oxford, ISBN 978-0195178135.

Pot, W.D., A. Dewulf, G.R. Biesbroek and S. Verweij, 2019: What makes decisions about urban water infrastructure forward looking? A fuzzy-set qualitative comparative analysis of investment decisions in 40 Dutch municipalities. *Land Use Policy*, **82**, 781–795, doi:10.1016/j.landusepol.2018.12.012.

Prabhat, et al., 2021: ClimateNet: An expert-labeled open dataset and deep learning architecture for enabling high-precision analyses of extreme weather. *Geosci. Model Dev.*, **14**(1), 107–124, doi:10.5194/gmd-14-107-2021.

Prem, R., S. Ohly, B. Kubicek and C. Korunka, 2017: Thriving on challenge stressors? Exploring time pressure and learning demands as antecedents of thriving at work. *J. Organiz. Behav.*, **38**(1), 108–123, doi:10.1002/job.2115.

Preston, B., E.J. Yuen and R.M. Westaway, 2011: Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks. *Sustain. Sci.*, **6**, 177–202.

Preston, B.L., R. Westaway, S. Dessai and T.F. Smith (eds.), *Are we adapting to climate change? Research and methods for evaluating progress*. 89th American Meteorological Society Annual Meeting: Fourth Symposium on Policy and Socio-Economic Research, Phoenix, AZ, 1–15.

Pretorius, C., 2017: Exploring procedural decision support systems for wicked problem resolution. *South Afr. Comput. J.*, **29**(1), 191–219, doi:10.18489/sacj.v29i1.448.

Pretorius, L., et al., 2019: *An Embedded Researcher Approach to Integrate Climate Information into Decision Making in Southern African Cities: Lessons from FRACTAL*. FRACTAL Working Paper, **8**, Future Climate for Africa.

Price-Kelly, H., T. Leiter, J. Olivier and D. Hammill, 2015: *Developing national adaptation monitoring and evaluation systems: a guidebook*, accessed 4 April 2022, https://www.adaptationcommunity.net/monitoring-evaluation/national-level-adaptation/.

Pringle, P., 2011: *AdaptME Toolkit: Adaptation Monitoring and Evaluation*. United Kingdom Climate Impacts Programme (UKCIP).

Prober, S.M., et al., 2017: Informing climate adaptation pathways in multi-use woodland landscapes using the values-rules-knowledge framework. *Agric. Ecosyst. Environ.*, **241**, 39–53, doi:10.1016/j.agee.2017.02.021.

Prokopy, L.S., et al., 2017: Useful to usable: developing usable climate science for agriculture. *Clim. Risk Manag.*, **15**(C), 1–7, doi:10.1016/j.crm.2016.10.004.

Prokopy, L.S. and R. Power, 2015: Envisioning new roles for land-grant university extension: lessons learned from climate change outreach in the midwest. *J. Ext.*, **53**(6).

Pulido, L., E. Kohl and N.M. Cotton, 2016: State regulation and environmental justice: the need for strategy reassessment. *Capitalism Nat. Social.*, **27**(2), 12–31, doi:10.1080/10455752.2016.1146782.

Pulver, S., 2011: Corporate Responses. In: *The Oxford Handbook of Climate Change and Society* [Dryzek, J.S., R.B. Norgaard and D. Schlosberg)](eds.)]. Oxford University Press, New York.

Puri, J., A. Rastogi, M. Prowse and S. Asfaw, 2020: Good will hunting: challenges of theory-based impact evaluations for climate investments in a multilateral setting. *World Dev*, **127**, 104784, doi:10.1016/j.worlddev.2019.104784.

Qiao, X.-J., A. Kristoffersson and T.B. Randrup, 2018: Challenges to implementing urban sustainable stormwater management from a governance perspective: a literature review. *J. Clean. Prod.*, **196**, 943–952, doi:10.1016/j.jclepro.2018.06.049.

Quinn, J., et al., 2017: Public health crisis: the need for primary prevention in failed and fragile states. *Cent. Eur. J. Public Health*, **25**(3), 171–176.

Radel, C., B. Schmook, L. Carte and S. Mardero, 2018: Toward a political ecology of migration: land, labor migration, and climate change in northwestern Nicaragua. *World Dev.*, **108**, 263–273.

Rahman, M.H., et al., 2020: Climate Resilient Cotton Production System: A Case Study in Pakistan. In: *Cotton Production and Uses: Agronomy, Crop Protection, and Postharvest Technologies* [Ahmad, S. and M. Hasanuzzaman(eds.)]. Springer, Singapore, pp. 447–484. ISBN 978-9811514722.

Rai, N., S. Best and M. Soanes, 2016: *Unlocking climate finance for decentralised energy access*. Working Paper, IIED. ISBN 978-1784313593.

Rai, N. and S. Fisher, 2017: *The Political Economy of Low Carbon Resilient Development: planning and implementation*. Routledge, Oxford, United Kingdom, ISBN 978-1138393431.

Ramsey, M.M., et al., 2019: Overcoming barriers to knowledge integration for urban resilience: a knowledge systems analysis of two-flood prone communities in san Juan, puerto Rico. *Environ. Sci. Policy*, **99**, 48–57, doi:10.1016/j.envsci.2019.04.013.

Ranabhat, S., et al., 2018: Policy coherence and interplay between climate change adaptation policies and the forestry sector in Nepal. *Environ. Manage.*, **61**, doi:10.1007/s00267-018-1027-4.

Ranger, N., T. Reeder and J. Lowe, 2013: Addressing 'deep' uncertainty over long-term climate in major infrastructure projects: four innovations of the Thames Estuary 2100 Project. *Euro J. Decis. Process.*, **1**(3), 233–262, doi:10.1007/s40070-013-0014-5.

Rao, N., et al., 2020: Managing risk, changing aspirations and household dynamics: Implications for wellbeing and adaptation in semi-arid Africa and India. *World Dev.*, **125**, 104667.

Rasel, H., M. Hasan, B. Ahmed and M. Miah, 2013: Investigation of soil and water salinity, its effect on crop production and adaptation strategy. *Int. J. Water Resour. Environ. Eng.*, **5**(8), 475–481.

Rasmus, S., et al., 2020: Climate change and reindeer management in Finland: co-analysis of practitioner knowledge and meteorological data for better adaptation. *Sci. Total. Environ.*, **710**, doi:10.1016/j.scitotenv.2019.136229.

Rathwell, K.J., D. Armitage and F. Berkes, 2015: Bridging knowledge systems to enhance governance of the environmental commons: A typology of settings. *Int. J. Commons*, **9**(2), 851–880, doi:10.18352/ijc.584.

Raz, T. and E. Micheal, 2001: Use and benefit of tools for project risk management. *Int. J. Proj. Manag.*, **19**(1), 9–17.

Reckien, D., 2014: Weather extremes and street life in India—Implications of Fuzzy Cognitive Mapping as a new tool for semi-quantitative impact assessment and ranking of adaptation measures. *Glob. Environ. Chang.*, **26**, 1–13.

Reckien, D., 2018: What is in an index? Construction method, data metric, and weighting scheme determine the outcome of composite social vulnerability indices in New York City. *Reg. Environ. Change*, **18**(5), 1439–1451.

Reckien, D., et al., 2017: Climate change, equity and the Sustainable Development Goals: an urban perspective. *Environ. Urban.*, **29**(1), 159–182.

Reckien, D., J. Flacke, M. Olazabal and O. Heidrich, 2015: The influence of drivers and barriers on urban adaptation and mitigation plans-an empirical analysis of European cities. *PLoS ONE*, **10**(8), e135597, doi:10.1371/journal.pone.0135597.

Reckien, D. and M.K.B. Luedeke, 2014: The social dynamics of suburbanization: insights from a qualitative model. *Environ. Plan. A*, **46**(4), 980–1000, doi:10.1068/a4639.

Reckien, D., et al., 2018b: Equity, environmental justice, and urban climate change. In: *Climate change and cities: Second assessment report of the urban climate change research network*, pp. 173–224.

Reckien, D. and E.P. Petkova, 2019: Who is responsible for climate change adaptation? *Environ. Res. Lett.*, **14**(014010).

Reckien, D., et al., 2018a: How are cities planning to respond to climate change? Assessment of local climate plans from 885 cities in the EU-28. *J. Clean. Prod.*, **191**, 207–219, doi:10.1016/j.jclepro.2018.03.220.

Reckien, D., et al., 2019: Dedicated versus mainstreaming approaches in local climate plans in Europe. *Renew. Sustain. Energy Rev.*, **112**, 948–959, doi:10.1016/j.rser.2019.05.014.

Reckien, D., M. Wildenberg and M. Bachhofer, 2013: Subjective realities of climate change: how mental maps of impacts deliver socially sensible adaptation options. *Sustain. Sci.*, **8**(2), 159–172, doi:10.1007/s11625-012-0179-z.

Reguero, B.G., et al., 2020: Financing coastal resilience by combining nature-based risk reduction with insurance. *Ecol. Econ.*, **169**, 106487, doi:10.1016/j.ecolecon.2019.106487.

Reid, H., 2016: Ecosystem-and community-based adaptation: learning from community-based natural resource management. *Clim. Dev.*, **8**(1), 4–9.

Reilly, T. and R.T. Clemen, 2013: *Making hard decisions with decision tools*. South-Western Cengage Learning, Boston, USA, ISBN 978-1285708348.

Reis, J. and J. Shortridge, 2020: Impact of uncertainty parameter distribution on robust decision making outcomes for climate change adaptation under deep uncertainty. *Risk Anal.*, **40**(3), 494–511, doi:10.1111/risa.13405.

Renner, T. and S. Meijerink, 2018: Policy entrepreneurs in international river basins—getting climate adaptation on the cross-border water policy agenda. *Reg. Environ. Change*, **18**(5), 1287–1298, doi:10.1007/s10113-017-1178-5.

Resch, E., S. Allan, L.G. Álvarez and H. Bisht, 2017: *Mainstreaming, Accessing and Institutionalising Finance for Climate Change Adaptation*. Learning Paper, Action on Climate Today.

Resurrección, B.P., et al., 2019: *Gender-Transformative Climate Change Adaptation: Advancing Social Equity*. Background paper to the 2019 report of the Global Commission on Adaptation, Stockholm Environment Institute, accessed 4 April 2022, https://www.sei.org/publications/gender-transformative-climate-change-adaptation-advancing-social-equity/.

Revi, A., et al., 2020: Transformative adaptation in cities. *One Earth*, **3**(4), 384–387.

Reynolds, C.J., G.W. Horgan, S. Whybrow and J.I. Macdiarmid, 2019: Healthy and sustainable diets that meet greenhouse gas emission reduction targets and are affordable for different income groups in the UK. *Public Health Nutr.*, **22**(8), 1503–1517, doi:10.1017/s1368980018003774.

Richards, G.W., 2018: The Science–Policy Relationship Hierarchy (SPRHi) model of co-production: how climate science organizations have influenced the policy process in Canadian case studies. *Policy Sci.*, **52**(1), 67–95, doi:10.1007/s11077-018-9328-2.

Richards, R., et al., 2013: Bayesian belief modeling of climate change impacts for informing regional adaptation options. *Environ. Model. Softw. With Environ. Data N.*, **44**, 113–121, doi:10.1016/j.envsoft.2012.07.008.

Richards, R.G., M. Sanò and O. Sahin, 2016: Exploring climate change adaptive capacity of surf life saving in Australia using Bayesian belief networks. *Ocean. Coast. Manag.*, **120**, 148–159, doi:10.1016/j.ocecoaman.2015.11.007.

Richmond, M. and K. Hallmeyer, 2019: *Tracking Adaptation Finance: Advancing Methods to Capture Finance Flows in the Landscape. A CPI Climate Finance Tracking Brief*. Initiative, C. P., accessed 4 April 2022, https://climatepolicyinitiative.org/wp-content/uploads/2019/12/Tracking-Adaptation-Finance-Brief.pdf.

Richmond, M., et al., 2020: *A Snapshot of Global Adaptation Investment and Tracking Methods*. Climate Policy Initiative, accessed 4 April 2022, https://www.climatepolicyinitiative.org/publication/a-snapshot-of-global-adaptation-investment-and-tracking-methods/.

Richmond, M., N. Upadhyaya and A.O. Pastor, 2021: *An Analysis of Urban Climate Adaptation Finance*. Alliance, C. C. F. L., accessed 4 April 2022, https://www.climatepolicyinitiative.org/wp-content/uploads/2021/02/An-Analysis-of-Urban-Climate-Adaptation-Finance.pdf.

Ricke, K., L. Drouet, K. Caldeira and M. Tavoni, 2018: Country-level social cost of carbon. *Nat. Clim. Change*, **8**(10), 895–900, doi:10.1038/s41558-018-0282-y.

Río, P. and M.P. Howlett, 2013: *Beyond the 'Tinbergen Rule' in Policy Design: Matching Tools and Goals in Policy Portfolios*. Lee Kuan Yew School of Public Policy Research Paper Series.

Rios Insua, D., 1990: *Sensitivity Analysis in Multi-objective Decision Making*, 1st edn., Lecture Notes in Economics and Mathematical Systems. Springer, Berlin Heidelberg. 193 pp.

Rios Insua, D., 1999: Sensitivity Analysis in MCDA. *J. Multi Crit. Decis. Anal.*, **8**(3), 117–187, doi:10.1002/(SICI)1099-1360(199905)8:3<117::AID-MCDA251>3.0.CO;2-5.

Rios Insua, D. and F. Ruggeri, 2000: *Robust Bayesian Analysis*. Lecture Notes in Statistics.Springer, New York, https://www.springer.com/gp/book/9780387988665#aboutBook . (422 pp).

Rizzo, A., et al., 2020: The Agadir platform: a transatlantic cooperation to achieve sustainable drylands. In: *Stewardship of Future Drylands and Climate Change in the Global South*. Springer, Berlin Heidelberg, pp. 227–251.

Roberts, D., J. Douwes, C. Sutherland and V. Sim, 2020: Durban's 100 Resilient Cities journey: governing resilience from within. *Environ. Urban.*, **32**(2), 547–568, doi:10.1177/0956247820946555.

Roberts, J.T., et al., 2017: How will we pay for loss and damage? *Ethics Policy Environ.*, **20**(2), 208–226.

Roberts, J.T. and R. Weikmans, 2017: Postface: fragmentation, failing trust and enduring tensions over what counts as climate finance. *Int. Environ. Agreements Polit. Law Econ.*, **17**(1), 129–137, doi:10.1007/s10784-016-9347-4.

Roberts, J.T., et al., 2021: Rebooting a failed promise of climate finance. *Nat. Clim. Chang.*, **11**(3), 180–182, doi:10.1038/s41558-021-00990-2.

Robertson, J. and J. Barling, 2015: *The Psychology of Green Organizations*. ISBN 13:9780199997480.

Robins, S., 2019: 'Day zero', hydraulic citizenship and the defence of the commons in cape town: a case study of the politics of water and its infrastructures (2017–2018). *J. South. Afr. Stud.*, doi:10.1080/03057070.2019.1552424.

Robinson, J.P., et al., 2020: Diversification insulates fisher catch and revenue in heavily exploited tropical fisheries. *Sci. Adv.*, **6**(8), eaaz587.

Robinson, S-a., 2018: Adapting to climate change at the national level in Caribbean small island developing state. *Isl. Stud. J.*, **13**(1).

Robinson, S-a., et al., 2021: Financing loss and damage from slow onset events in developing countries. *Curr. Opin. Environ. Sustain.*, **50**, 138–148.

Robinson, S. and C. Wren, 2020: Geographies of vulnerability: A research note on human system adaptations to climate change in the Caribbean. *Geogr. Tidsskr. Danish J. Geogr.*, **120**(1), 79–86.

Roehrer, C. and K.E. Kouadio, 2015: Monitoring, reporting, and evidence-based learning in the climate investment funds' pilot program for climate resilience. *N. Dir. Evaluation*, **147**, 129–145.

Roelich, K. and J. Giesekam, 2019: Decision making under uncertainty in climate change mitigation: introducing multiple actor motivations, agency and influence. *Clim. Policy*, **19**(2), 175–188, doi:10.1080/14693062.2018.1479238.

Rolnick, D., et al., 2019: *Tackling Climate Change with Machine Learning*.

Romero-Lankao, P., et al., 2018: Urban transformative potential in a changing climate. *Nat. Clim. Change*, **8**(9), 754–756.

Roncoli, C., T. Crane and B. Orlove, 2016: Fielding climate change in cultural anthropology. In: *Anthropology and climate change*. Routledge, Oxford, UK, pp. 87–115. ISBN 978-1315434773.

Rosenhead, J., 2001: Robust Analysis: Keeping Your Options Open. In: *Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty, and Conflict* [Rosenhead, J. and J. Mingers (eds.)]. John Wiley & Sons, Chichester, United Kingdom, pp. 181–207.

Rosenhead, J. and J. Mingers, 2001: *Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty and Conflict*, 2nd edn., John Wiley and Sons, New Jersey, USA, ISBN 978-0471495239. 386 pp.

Rosenow, J., F. Kern and K. Rogge, 2017: The need for comprehensive and well targeted instrument mixes to stimulate energy transitions: the case of energy efficiency policy. *Energy Res. Soc. Sci.*, **33**, 95–104, doi:10.1016/j.erss.2017.09.013.

Rosenzweig, C., et al., 2017: Assessing inter-sectoral climate change risks: the role of ISIMIP. *Environ. Res. Lett.*, **12**(1), doi:10.1088/1748-9326/12/1/010301.

Rosenzweig, C. and W. Solecki, 2014: Hurricane Sandy and adaptation pathways in New York: Lessons from a first-responder city. *Glob. Environ. Chang.*, **28**, 395–408.

Rosenzweig, C. and W. Solecki, 2018: Action pathways for transforming cities. *Nat. Clim. Change*, **8**(9), 756–759.

Roser, D., C. Huggel, M. Ohndorf and I. Wallimann-Helmer, 2015: Advancing the interdisciplinary dialogue on climate justice. *Clim. Change*, **133**(3), 349–359.

Rouillard, J.J. and C.J. Spray, 2016: Working across scales in integrated catchment management: lessons learned for adaptive water governance from regional experiences. *Reg. Environ. Change*, **17**(7), 1869–1880, doi:10.1007/s10113-016-0988-1.

Rousseau, S. and N. Deschacht, 2020: Public awareness of nature and the environment during the COVID-19 crisis. *Environ. Resour. Econ.*, **76**(4), 1149–1159, doi:10.1007/s10640-020-00445-w.

Roy, B., 1996: *Multicriteria Methodology for Decision Aiding*. Kluwer Academic Publishers, Dordrecht, Netherlands.

Roy, J., P. Tschakert, H. Waisman, S. Abdul Halim, P. Antwi-Agyei, P. Dasgupta, B. Hayward, M. Kanninen, D. Liverman, C. Okereke, P.F. Pinho, K. Riahi, and A.G. Suarez Rodriguez, 2018: Sustainable Development, Poverty Eradication and Reducing Inequalities. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.

Rozenberg, J. and S. Hallegatte, 2015: *The Impacts of Climate Change on Poverty in 2030 and the Potential from Rapid, Inclusive, and Climate-Informed Development*. World Bank Policy Research Working Paper, **7483**. 52 pp.

Ruano, S. and A. Milan, 2014: *Climate change, rainfall patterns, livelihoods and migration in Cabricán, Guatemala*. United Nations University, I. f. E. a. H. S. U.-E, Bonn.

Rudel, T.K., 2019: Shocks, states, and societal corporatism: a shorter path to sustainability? *J. Environ. Stud. Sci.*, **9**(4), 429–436, doi:10.1007/s13412-019-00560-1.

Ruhl, J., 2010: Climate change adaptation and the structural transformation of environmental law. *Envtl. L.*, **40**, 363.

Ruiz-Mallén, I., 2020: Co-production and Resilient Cities to Climate Change. In: *Participatory Research and Planning in Practice* [Nared, J. and D. Bole (eds.)]. Springer International Publishing, Cham, pp. 1–11. ISBN 978-3030280147.

Rulleau, B. and H. Rey-Valette, 2017: Forward planning to maintain the attractiveness of coastal areas: choosing between seawalls and managed retreat. *Environ. Sci. Policy*, **72**, 12–19.

Rumble, O. (ed.), 2019a: *Climate change legislative development on the African continent*. Law| Environment| Africa, Nomos Verlagsgesellschaft mbH & Co. KG, Baden-Baden, Germany, 31–60. ISBN 978-3848752874.

Rumble, O., 2019b: Facilitating African climate change adaptation through framework laws. *Carbon Clim. Law Rev.*, **13**, doi:10.21552/cclr/2019/4/4.

Runhaar, H., et al., 2018: Mainstreaming climate adaptation: taking stock about "what works" from empirical research worldwide. *Reg. Environ. Change*, **18**(4), 1201–1210, doi:10.1007/s10113-017-1259-5.

Rusca, M., et al., 2017: An interdisciplinary political ecology of drinking water quality. Exploring socio-ecological inequalities in Lilongwe's water supply network. *Geoforum*, **84**, 138–146, doi:10.1016/j.geoforum.2017.06.013.

Rusca, M., K. Schwartza, L. Hadzovica and R. Ahlers, 2015: Adapting generic models through bricolage: elite capture of water users associations in Peri-urban Lilongwe. *Eur. J. Dev. Res.*, **27**(5), 777–792.

Ryan, D. and E. Bustos, 2019: Knowledge gaps and climate adaptation policy: a comparative analysis of six Latin American countries. *Clim. Policy*, **19**(10), 1–13, doi:10.1080/14693062.2019.1661819.

Saarikoski, H., et al., 2016: Multi-criteria decision analysis and cost-benefit analysis: comparing alternative frameworks for integrated valuation of ecosystem services. *Ecosyst. Serv.*, **22**, 238–249, doi:10.1016/j.ecoser.2016.10.014.

Saaty, T.L., 1980: *The Analytical Hierarchy Process*. McGraw-Hill, New York.

Saltelli, A., G. Bammer, I. Bruno, et al., 2020: Five ways to ensure that models serve society: a manifesto. *Nature*, **582**, 482–484, https://doi.org/10.1038/d41586-020-01812-9.

Samuwai, J. and J. Hills, 2018: Assessing climate finance readiness in the asia-pacific region. *Sustainability*, **10**(4), 1192, doi:10.3390/su10041192.

Sanchez Rodriguez, R., D. Ürge-Vorsatz and A.S. Barau, 2018: Sustainable development goals and climate change adaptation in cities. *Nat. Clim. Change*, **8**(3), 181–183, doi:10.1038/s41558-018-0098-9.

Sandholz, S., W. Lange and U. Nehren, 2018: Governing green change: ecosystem-based measures for reducing landslide risk in Rio de Janeiro. *Int. J. Disaster Risk Reduct.*, **32**, 75–86.

Sanson, A.V., J. Van Hoorn and S.E.L. Burke, 2019: Responding to the Impacts of the Climate Crisis on Children and Youth. *Child. Dev. Perspect.*, **13**(4), 201–207, doi:10.1111/cdep.12342.

Sarewitz, D.R. and R.J. Byerly, 2000: *Prediction: science, decision making, and the future of nature*. Island Press, Washington, D.C.

Sarra, J., 2018: The anthropocene in the time of trump, financial markets, climate change risk, and vulnerability. *UBS Law Rev.*, **51**(2), 489–547.
Sartzetakis, E.S., 2020: Green bonds as an instrument to finance low carbon transition. *Econ. Chang. Restruct.*, doi:10.1007/s10644-020-09266-9.
Sarzynski, A., 2015: Public participation, civic capacity, and climate change adaptation in cities. *Urban Clim.*, **14**, 52–67, doi:10.1016/j.uclim.2015.08.002.
Sauter, V.L., 2014: *Decision Support Systems for Business Intelligence*, 2nd edn., John Wiley & Sons, Massachusetts, USA.
Schäfer, L. and V. Künzel, 2019: *Steps towards closing the Loss & Damage finance gap*. German Watch, accessed 4 April 2022, https://www.germanwatch.org/sites/default/files/Policy%20Briefing_Steps%20towards%20closing%20the%20Loss%26Damage%20finance%20gap_0.pdf.
Schäfer, L., K. Warner and S. Kreft, 2019: Exploring and managing adaptation frontiers with climate risk insurance. In: *Loss and Damage from Climate Change*. Springer, Berlin Heidelberg, pp. 317–341.
Schäfer, L., et al., 2016: *Making Climate Risk Insurance Work for the Most Vulnerable: Seven Guiding Principles* (UNU-EHS), I. f. E. a. H. S. United Nations University Policy Report 2016 No. 1. United Nations University (UNU), Tokyo.
Schalatek, L., 2020: *Gender and Climate Finance*. Climate Finance Fundamentals, **10**. Heinrich Böll Stiftung, Washington, DC, accessed 6 April 2022, https://us.boell.org/en/2019/11/30/climate-finance-fundamentals-10-gender-and-climate-finance.
Scheidel, A., et al., 2020: Environmental conflicts and defenders: A global overview. *Glob. Environ. Chang.*, **63**, doi:10.1016/j.gloenvcha.2020.102104.
Schipper, E.L.F., 2020: Maladaptation: when adaptation to climate change goes very wrong. *One Earth*, **3**(4), 409–414.
Schipper, E.L.F., J. Ayers, H. Reid and S. Huq, 2014: *Community-Based Adaptation to Climate Change. Scaling it Up*. Routledge, London, UK.
Schipper, L. and L. Langston, 2015: *A Comparative Overview of Resilience Measurement Frameworks. Analysing Indicators and Approaches*.
Schipper, L. and M. Pelling, 2006: Disaster risk, climate change and international development: scope for, and challenges to, integration. *Disasters*, **30**(1), 19–38, doi:10.1111/j.1467-9523.2006.00304.x.
Schlosberg, D., L.B. Collins and S. Niemeyer, 2017: Adaptation policy and community discourse: risk, vulnerability, and just transformation. *Environ. Polit.*, **26**(3), 413–437, doi:10.1080/09644016.2017.1287628.
Schneider, T., G. Michelon and M. Maier, 2017: Environmental liabilities and diversity in practice under international financial reporting standards. *Account. Auditing Account. J.*, **30**(2), 378–403, doi:10.1108/AAAJ-01-2014-1585.
Schwan, S. and X. Yu, 2018: Social protection as a strategy to address climate-induced migration. *Management*, **10**(1), 43–64.
Scotford, E., S. Minas and A. Macintosh, 2017: Climate change and national laws across Commonwealth countries. *Commonw. Law Bull.*, **43**(3-4), 318–361.
Scott, D., et al., 2018: The story of water in Windhoek: a narrative approach to interpreting a transdisciplinary process. *Water*, **10**(10), 1366, doi:10.3390/w10101366.
Scussolini, P., et al., 2016: FLOPROS: an evolving global database of flood protection standards. *Nat. Hazards Earth Syst. Sci.*, **16**(5), 1049–1061.
Sen, S. (ed.), 2000: *Involving Stakeholders in Aquaculture Policy-Making, Planning and Management. Aquaculture in the Third Millennium*. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20–25.
Seneviratne, S.I., X. Zhang, M. Adnan, W. Badi, C. Dereczynski, A. Di Luca, S. Ghosh, I. Iskandar, J. Kossin, S. Lewis, F. Otto, I. Pinto, M. Satoh, S.M. Vicente-Serrano, M. Wehner, and B. Zhou, 2021: Weather and Climate Extreme Events in a Changing Climate. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.
Serdeczny, O., 2019: Non-economic Loss and Damage and the Warsaw International Mechanism. In: *Loss and Damage from Climate Change: Concepts, Methods and Policy Options* [Mechler, R., L.M. Bouwer, T. Schinko, S. Surminski and J. Linnerooth-Bayer)](eds.)]. Springer International Publishing, Cham, pp. 205–220. ISBN 978-3319720265.
Serrao-Neumann, S., G. Di Giulio and D. Low Choy, 2020: When salient science is not enough to advance climate change adaptation: lessons from Brazil and Australia. *Environ. Sci. Policy*, **109**, 73–82, doi:10.1016/j.envsci.2020.04.004.
Setzer, J. and L.C. Vanhala, 2019: Climate change litigation: A review of research on courts and litigants in climate governance. *WIREs Clim. Chang.*, **10**(3), e580, doi:10.1002/wcc.580.
Shackleton, S., et al., 2015: Why is socially-just climate change adaptation in sub-Saharan Africa so challenging? A review of barriers identified from empirical cases. *Wiley Interdiscip. Rev. Clim. Chang.*, **6**(3), 321–344, doi:10.1002/wcc.335.
Shafer, G., 1976: *A Mathematical Theory of Evidence*. Princeton University Press, Princeton, USA.
Shakya, C. and R. Byrnes, 2017: *Turning up the Volume: Financial Aggregation for off-grid Energy*. Issue Paper. IIED, London, ISBN 978-1784315429.
Shannak, S., D. Mabrey and M. Vittorio, 2018: Moving from theory to practice in the water–energy–food nexus: an evaluation of existing models and frameworks. *Water Energy Nexus*, **1**(1), 17–25, doi:10.1016/j.wen.2018.04.001.
Sharifi, A., 2020: Trade-offs and conflicts between urban climate change mitigation and adaptation measures: A literature review. *J. Clean. Prod*, **276**, doi:10.1016/j.jclepro.2020.122813.
Sharifi, A., 2021: Co-benefits and synergies between urban climate change mitigation and adaptation measures: a literature review. *Sci. Total Environ.*, **750**, 141642, doi:10.1016/j.scitotenv.2020.141642.
Shaw, D., A. Franco and M. Westcombe, 2006: *Special Issue: Problem Structuring Methods I*, 757–878.
Shaw, D., A. Franco and M. Westcombe, 2007: *Special Issue: Problem Structuring Methods II*, 545–682.
Shawoo, Z. and C.L. McDermott, 2020: Justice through polycentricity? A critical examination of climate justice framings in Pakistani climate policymaking. *Clim. Policy*, **20**(2), 199–216, doi:10.1080/14693062.2019.1707640.
Sherman, M.H. and J. Ford, 2013: Stakeholder engagement in adaptation interventions: an evaluation of projects in developing nations. *Clim. Policy*, **14**(3), 417–441, doi:10.1080/14693062.2014.859501.
Shi, R., B.F. Hobbs and H. Jiang, 2019: When can decision analysis improve climate adaptation planning? Two procedures to match analysis approaches with adaptation problems. *Clim. Change*, **157**(3-4), 611–630, doi:10.1007/s10584-019-02579-3.
Shockley, K. and M. Hourdequin, 2017: Addressing the harms of climate change: making sense of loss and damage. *Ethics Policy Environ.*, **20**(2), 125–128, doi:10.1080/21550085.2017.1342965.
Shortridge, J., S. Guikema and B. Zaitchik, 2016: Robust decision making in data scarce contexts: addressing data and model limitations for infrastructure planning under transient climate change. *Clim. Change*, **140**(2), 323–337, doi:10.1007/s10584-016-1845-4.
Shortridge, J.E. and S.D. Guikema, 2016: Scenario discovery with multiple criteria: an evaluation of the robust decision-making framework for climate change adaptation. *Risk Anal.*, **36**(12), 2298–2312, doi:10.1111/risa.12582.
Shukla, A. and C. Peyraud, 2017: *Klabin Green Bond: Framework Overview and Second Part Opinion by Sustainalytics. Sustainalytics*, accessed 6 April 2022, https://www.sustainalytics.com/wp-content/uploads/2017/09/Klabin-Green-Bond-Framework-and-Opinion-08302017_FINAL.pdf.
Siciliano, G. and F. Urban, 2017: Equity-based natural resource allocation for infrastructure development: evidence from large hydropower dams in Africa and Asia. *Ecol. Econ.*, **134**, 130–139.

Siddiqi, A., 2018: Disasters in conflict areas: finding the politics. *Disasters*, **42**(Suppl 2), S161–S172, doi:10.1111/disa.12302.

Siddiqi, A., K. Peters and J. Zulver, 2019: *'Doble Afectación': Living with Disasters and Conflict in Colombia*.

Siders, A., M. Hino and K.J. Mach, 2019: The case for strategic and managed climate retreat. *Science*, **365**(6455), 761–763.

Siders, A.R., 2017: A role for strategies in urban climate change adaptation planning: lessons from London. *Reg. Environ. Change*, **17**(6), 1801–1810.

Siegner, A.B., 2018: Experiential climate change education: Challenges of conducting mixed-methods, interdisciplinary research in San Juan Islands, WA and Oakland, CA. *Energy Res. Soc. Sci.*, **45**, 374–384, doi:10.1016/j.erss.2018.06.023.

Sietsma, A.J., J.D. Ford, M.W. Callaghan and J.C. Minx, 2021: Progress in climate change adaptation research. *Environ. Res. Lett.*, **16**(5), 54038.

Silvestrini, S., I. Bellino and S. Väth, 2015: *Impact Evaluation Guidebook for Climate Change Adaptation Projects*, accessed 6 April 2022, https://www.adaptationcommunity.net/?wpfb_dl=260.

Simlinger, F. and B. Mayer, 2019: Legal responses to climate change induced loss and damage. In: *Loss and Damage from Climate Change*. Springer, Berlin Heidelberg, pp. 179–203.

Simmons, B.A., R. Ray, H. Yang and K.P. Gallagher, 2021: China can help solve the debt and environmental crises. *Science*, **371**(6528), 468–470, doi:10.1126/science.abf4049.

Simpson, N.P., et al., 2021: A framework for complex climate change risk assessment. *One Earth*, **4**(25903322), 489–501.

Singh, C., et al., 2017: The utility of weather and climate information for adaptation decision-making: current uses and future prospects in Africa and India. *Clim. Dev.*, **10**(5), 389–405, doi:10.1080/17565529.2017.1318744.

Singh, C., P. Dorward and H. Osbahr, 2016: Developing a holistic approach to the analysis of farmer decision-making: Implications for adaptation policy and practice in developing countries. *Land Use Policy*, **59**, 329–343, doi:10.1016/j.landusepol.2016.06.041.

Singh, C., et al., 2021: Interrogating 'effectiveness' in climate change adaptation: 11 guiding principles for adaptation research and practice. *Clim. Dev.*, 1–15, doi:10.1080/17565529.2021.1964937.

Singh, C., et al., 2019: Opening up the methodological toolkit on climate change vulnerability and adaptation research: reflections from using life history approaches. *Reg Environ Change*. **19**, 2667–2682, https://doi.org/10.1007/s10113-019-01562-z.

Singh, R., P.M. Reed and K. Keller, 2015: Many-objective robust decision making for managing an ecosystem with a deeply uncertain threshold response. *Ecol. Soc.*, **20**(3), http://www.jstor.org/stable/26270230.

Sitati, A., et al., Climate change adaptation in conflict-affected countries: A systematic assessment of evidence. *Discover Sustainability,* **2**(1), 1–15.

Skelton, M., et al., 2017: The social and scientific values that shape national climate scenarios: a comparison of the Netherlands, Switzerland and the UK. *Reg. Environ. Change*, **17**(8), 2325–2338, doi:10.1007/s10113-017-1155-z.

Slavíková, L., T. Hartmann and T. Thaler, 2021: Paradoxes of financial schemes for resilient flood recovery of households. *Wiley Interdiscip. Rev. Water*, **8**(2), e1497.

Sletto, B., S. Tabory and K. Strickler, 2019: Sustainable urban water management and integrated development in informal settlements: the contested politics of co-production in Santo Domingo, Dominican Republic. *Glob. Environ. Chang.*, **54**, 195–202, doi:10.1016/j.gloenvcha.2018.12.004.

Slotte, S. and R.P. Hämäläinen, 2014: *Decision Structuring Dialogue*, 141–159.

Smet, K.S.M., 2017: *Engineering options: A proactive planning approach for aging water resource infrastructure under uncertainty*. Harvard University, Harvard.

Smith, J.B., et al., 2011: Development and climate change adaptation funding: coordination and integration. *Clim. Policy*, **11**(3), 987–1000, doi:10.1080/14693062.2011.582385.

Smith, J.Q., 2010: *Bayesian Decision Analysis : Principles and Practice*.

Smith, P., et al., 2020: Which practices co-deliver food security, climate change mitigation and adaptation, and combat land degradation and desertification? *Glob. Change Biol.*, **26**(3), 1532–1575.

Snowden, D., 2002: Complex acts of knowing: paradox and descriptive self awareness. *J. Knowl. Manag.*, **62**(2), 100–111.

Soanes, M., et al., 2017: *Delivering real change: getting international climate finance to the local level*. Working Paper. IIED, London.

Soares, B. and C. Buontempo, 2019: *Challenges to the Sustainability of Climate Services in Europe*.

Soares, B. and S. Dessai, 2016: Barriers and enablers to the use of seasonal climate forecasts amongst organisations in Europe. *Clim. Change*, **137**(1), 89–103, doi:10.1007/s10584-016-1671-8.

Solecki, W., et al., 2021: Accelerating climate research and action in cities through advanced science-policy-practice partnerships. *Nat. Urban Sustain.* **1**(1), 1–8.

Solecki, W., et al., 2019: Extreme events and climate adaptation-mitigation linkages: Understanding low-carbon transitions in the era of global urbanization. *WIREs Clim. Chang.*, **10**(6), e616, doi:10.1002/wcc.616.

Solecki, W., M. Pelling and M. Garschagen, 2017: Transitions between risk management regimes in cities. *Ecol. Soc.*, **22**(2), doi:10.5751/ES-09102-220238.

Son, H.N., D.T.L. Chi and A. Kingsbury, 2019: Indigenous knowledge and climate change adaptation of ethnic minorities in the mountainous regions of Vietnam: A case study of the Yao people in Bac Kan Province. *Agric. Syst.*, **176**, 102683, doi:10.1016/j.agsy.2019.102683.

Spearman, M. and H. McGray, 2011: *Making adaptation count: concepts and options for monitoring and evaluation of climate change adaptation*, accessed 6 April 2022, http://star-www.giz.de/dokumente/bib-2011/giz2011-0219en-monitoring-evaluation-climate-change.pdf.

Spencer, B., et al., 2016: Case studies in co-benefits approaches to climate change mitigation and adaptation. *J. Environ. Plan. Manag.*, **60**(4), 647–667, doi:10.1080/09640568.2016.1168287.

Sperotto, A., et al., 2017: Reviewing Bayesian networks potentials for climate change impacts assessment and management: a multi-risk perspective. *J. Environ. Manag.*, **202**(Pt 1), 320–331, doi:10.1016/j.jenvman.2017.07.044.

Sperotto, A., et al., 2019: A Bayesian Networks approach for the assessment of climate change impacts on nutrients loading. *Environ. Sci. Policy*, **100**, 21–36, doi:10.1016/j.envsci.2019.06.004.

Spetzler, C.S., H. Winter and J. Meyer, 2016: *Decision Quality: Value Creation from Better Business Decisions*. John Wiley & Sons, Hoboken.

Sriver, R.L., R.J. Lempert, P. Wikman-Svahn and K. Keller, 2018: Characterizing uncertain sea-level rise projections to support investment decisions. *PLoS ONE*, **13**(2), e190641, doi:10.1371/journal.pone.0190641.

Steed, C.A., et al., 2013: Big data visual analytics for exploratory earth system simulation analysis. *Comput. Geosci.*, **61**, 71–82, doi:10.1016/j.cageo.2013.07.025.

Steele, P., 2015: *Development Finance and Climate Finance: Achieving Zero Poverty and Zero Emissions*. Vol. 16587. IIED, London, ISBN 978-1784311698. 32 pp.

Steele, P. and S. Patel, 2020: *Tackling the triple crisis: Using debt swaps to address debt, climate and nature loss post-COVID-19*. Issue Paper. International Institute for, E. and Development, London, accessed 6 April 2022, https://pubs.iied.org/16674iied.

Stegmaier, P., R. Hamaker-Taylor and A. Jiménez, 2020: Reflexive climate service infrastructure relations. *Clim. Serv.*, **17**, 100151, doi:10.1016/j.cliser.2020.100151.

Stelzenmuller, V., et al., 2018: A risk-based approach to cumulative effect assessments for marine management. *Sci. Total Environ.*, **612**, 1132–1140, doi:10.1016/j.scitotenv.2017.08.289.

Stephens, S.A., R.G. Bell and J. Lawrence, 2017: Applying principles of uncertainty within coastal hazard assessments to better support coastal adaptation. *J. Mar. Sci. Eng.*, **5**(3), 40.

Stephens, S.A., R.G. Bell and J. Lawrence, 2018: Developing signals to trigger adaptation to sea-level rise. *Environ. Res. Lett.*, **13**(10), 104004, doi:10.1088/1748-9326/aadf96.

Stern, P.C., et al., 2016: Opportunities and insights for reducing fossil fuel consumption by households and organizations. *Nat. Energy*, **1**(5), 16043, doi:10.1038/nenergy.2016.43.

Stewart, T.J., S. French and J. Rios, 2013: Integrating multicriteria decision analysis and scenario planning—review and extension. *Omega*, **41**(4), 679–688, doi:10.1016/j.omega.2012.09.003.

Stezer, J. and R. Byrnes, 2019: *Global trends in climate change litigation: 2019 snapshot*. Policy Publication.Grantham Research Institute on Climate Change and the Environment and Centre for Climate change Economics and Policy, London, accessed 6 April 2022, https://www.lse.ac.uk/granthaminstitute/publication/global-trends-in-climate-change-litigation-2019-snapshot/.

Stone, D., 2019: Transnational policy entrepreneurs and the cultivation of influence: individuals, organizations and their networks. *Globalizations*, **16**(7), 1128–1144, doi:10.1080/14747731.2019.1567976.

Street, R.B., et al., 2019: How could climate services support disaster risk reduction in the 21st century. *Int. J. Dis. Risk Reduct.*, **34**, 28–33, doi:10.1016/j.ijdrr.2018.12.001.

Street, R.B. and S. Jude, 2019: Enhancing the value of adaptation reporting as a driver for action: lessons from the UK. *Clim. Policy*, **19**(10), 1340–1350, doi: 10.1080/14693062.2019.1652141.

Streimikiene, D. and T. Balezentis, 2013: Multi-objective ranking of climate change mitigation policies and measures in Lithuania. *Renew. Sustain. Energy Rev.*, **18**, 144–153, doi:10.1016/j.rser.2012.09.040.

Stults, M. and S.C. Woodruff, 2017: Looking under the hood of local adaptation plans: shedding light on the actions prioritized to build local resilience to climate change. *Mitig. Adapt. Strateg. Glob. Change*, **22**(8), 1249–1279.

Surminski, S., 2013: Private-sector adaptation to climate risk. *Nat. Clim. Change*, **3**(11), 943–945, doi:10.1038/nclimate2040.

Surminski, S., L.M. Bouwer and J. Linnerooth-Bayer, 2016: How insurance can support climate resilience. *Nat. Clim. Change*, **6**(4), 333–334, doi:10.1038/nclimate2979.

Sutter, D., 2013: Broadcast meteorology and the supply of weather forecasts: an exploration. *J. Econ. Finance*, **37**(3), 463–477, doi:10.1007/s12197-011-9186-7.

Swanson, D. and S. Bhadwal (eds.), 2009: *Creating Adaptive Policies: A Guide for Policy-Making in an Uncertain World*.

Sylvester, Z.T. and C.M. Brooks, 2020: Protecting Antarctica through co-production of actionable science: lessons from the CCAMLR marine protected area process. *Mar. Policy.*, **111**, 103720, doi:10.1016/j.marpol.2019.103720.

Symstad, A.J., et al., 2017: Multiple methods for multiple futures: Integrating qualitative scenario planning and quantitative simulation modeling for natural resource decision making. *Clim. Risk Manag.*, **17**(C), 78–91, doi:10.1016/j.crm.2017.07.002.

Szabo, S., et al., 2016: Making SDGs work for climate change hotspots. *Environ. Sci. Policy Sustain. Dev.*, **58**(6), 24–33, doi:10.1080/00139157.2016.1209016.

Tàbara, J.D., J. Jäger, D. Mangalagiu and M. Grasso, 2019: Defining transformative climate science to address high-end climate change. *Reg. Environ. Change*, **19**(3), 807–818.

Taberna, A., T. Filatova, D. Roy and B. Noll, 2020: Tracing resilience, social dynamics and behavioral change: a review of agent-based flood risk models. *Soc. Environ. Syst. Model.*, **2**, 17938–17938.

Takahashi, B., et al., 2016: Climate change perceptions of NY state farmers: the role of risk perceptions and adaptive capacity. *Environ. Manage*, **58**(6), 946–957.

Taner, M.Ü., P. Ray and C. Brown, 2017: Robustness-based evaluation of hydropower infrastructure design under climate change. *Clim. Risk Manag.*, **18**(C), 34–50, doi:10.1016/j.crm.2017.08.002.

Tanner, T., et al., 2019: Influencing resilience: the role of policy entrepreneurs in mainstreaming climate adaptation. *Disasters*, **43**(S3), S388–S411, doi:10.1111/disa.12338.

Tardy, F. and B. Lee, 2019: Building related energy poverty in developed countries – past, present, and future from a Canadian perspective. *Energy Build.*, **194**, 46–61, doi:10.1016/j.enbuild.2019.04.013.

Taylor, A., 2016a: Urban Adaptation. In: *Climate change law and governance in South Africa* [Gilder, A., T.L. Humby, L. Kotzé and O. Rumble(eds.)]. Juta, Cape Town, ISBN 978-1485118824.

Taylor, M., 2015: *The Political Ecology of Climate Change Adaptation: Livelihoods, Agrarian Change and the Conflicts of Development*. Routledge, London, UK.

Taylor, M., 2016b: Risky Ventures: Financial Inclusion, Risk Management and the Uncertain Rise of Index-Based Insurance. In: *Risking Capitalism*. Emerald Group Publishing Limited, Bingley, pp. 237–266, https://doi.org/10.1108/S0161-723020160000031013.

Taylor, M. and S. Bhasme, 2018: Model farmers, extension networks and the politics of agricultural knowledge transfer. *J Rural Stud*, **64**, 1–10.

Taylor, M. and S. Bhasme, 2020: Between deficit rains and surplus populations: the political ecology of a climate-resilient village in South India. *Geoforum,* **126**, 431–440.

TCFD, 2017: *Implementing the Recommendations of the Task Force on Climate-related Financial Disclosures*. Task Force on Climate-related Financial Disclosures, London, UK.

TCFD, 2020: *Task Force on Climate-related Financial Disclosures: Status Report*. Disclosures, T. F. o. C.-r. F., London, UK.

Tempels, B. and T. Hartmann, 2014: A co-evolving frontier between land and water: dilemmas of flexibility versus robustness in flood risk management. *Water Int.*, **39**(6), 872–883, doi:10.1080/02508060.2014.958797.

Tengö, M., et al., 2014: Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. *AMBIO*, **43**(5), 579–591, doi:10.1007/s13280-014-0501-3.

Teo, H.C., et al., 2019: Environmental impacts of infrastructure development under the belt and road initiative. *Environments*, **6**(6), 72.

Thackeray, S.J., et al., 2020: Civil disobedience movements such as School Strike for the Climate are raising public awareness of the climate change emergency. *Glob. Change Biol.*, **26**(3), 1042–1044, doi:10.1111/gcb.14978.

Thirawat, N., S. Udompol and P. Ponjan, 2017: Disaster risk reduction and international catastrophe risk insurance facility. *Mitig. Adapt. Strateg. Glob. Chang.*, **22**(7), 1021–1039.

Thomas, A., et al., 2020: Climate change and small island developing states. *Annu. Rev. Environ. Resour.*, **45**, 1–27.

Thomas, A. and L. Benjamin, 2017: Management of loss and damage in small island developing states: implications for a 1.5°C or warmer world. *Reg. Environ. Change*, **18**(8), 2369–2378, doi:10.1007/s10113-017-1184-7.

Thomas, K., et al., 2019: Explaining differential vulnerability to climate change: A social science review. *Wiley. Interdiscip. Rev. Clim. Change.*, **10**(2), e565, doi:10.1002/wcc.565.

Thomas, K.A. and B.P. Warner, 2019: Weaponizing vulnerability to climate change. *Glob. Environ. Chang.*, **57**, 101928–101928, doi:10.1016/j.gloenvcha.2019.101928.

Thorn, J., T.F. Thornton and A. Helfgott, 2015: Autonomous adaptation to global environmental change in peri-urban settlements: Evidence of a growing culture of innovation and revitalisation in Mathare Valley Slums, Nairobi. *Glob. Environ. Chang.*, **31**, 121.

Tittensor, D.P., et al., 2018: A protocol for the intercomparison of marine fishery and ecosystem models: Fish-MIP v1.0. *Geosci. Model Dev.*, **11**(4), 1421–1442, doi:10.5194/gmd-11-1421-2018.

Tompkins, E.L., K. Vincent, R.J. Nicholls and N. Suckall, 2018: Documenting the state of adaptation for the global stocktake of the Paris Agreement. *Wiley Interdiscip. Rev. Clim. Chang.*, **9**(5), doi:10.1002/wcc.545.

Tonmoy, F.N., D. Wainwright, D.C. Verdon-Kidd and D. Rissik, 2018: An investigation of coastal climate change risk assessment practice in Australia. *Environ. Sci. Policy*, **80**, 9–20, doi:10.1016/j.envsci.2017.11.003.

Torabi, E., A. Dedekorkut-Howes and M. Howes, 2018: Adapting or maladapting: Building resilience to climate-related disasters in coastal cities. *Cities*, **72**, 295–309.

Tormos-Aponte, F. and G.A. García-López, 2018: Polycentric struggles: the experience of the global climate justice movement. *Environ. Policy Gov.*, **28**(4), 284–294, doi:10.1002/eet.1815.

Torresan, S., et al., 2016: DESYCO: A decision support system for the regional risk assessment of climate change impacts in coastal zones. *Ocean. Coast. Manag.*, **120**, 49–63, doi:10.1016/j.ocecoaman.2015.11.003.

Toussaint, P. and A. Martinez Blanco, 2020: A human rights-based approach to loss and damage under the climate change regime. *Clim. Policy*, **20**(6), 743–757.

Townshend, T., et al., 2011: Legislating climate change on a national level. *Environ. Sci. Policy Sustain. Dev.*, **53**(5), 5–17.

Townshend, T. and A. Matthews, 2013: *National climate change legislation: the key to more ambitious international agreements*. CDKN/Globe International, London, https://cdkn.org/resource/national-climate-change-legislation-the-key-to-more-ambitious-international-agreements. Accessed 2019.

Treichel, P., 2020: Why focus on children: a literature review of child-centred climate change adaptation approaches. *Aust. J. Emerg. Manag.*, **35**(2), 26–33.

Tschakert, P., et al., 2017: Climate change and loss, as if people mattered: values, places, and experiences. *Wiley Interdiscip. Rev. Clim. Chang.*, **8**(5), e476.

Tschakert, P., et al., 2019: One thousand ways to experience loss: a systematic analysis of climate-related intangible harm from around the world. *Glob. Environ. Chang.*, **55**, 58–72.

Tschakert, P. and M. Machado, 2012: Gender justice and rights in climate change adaptation: opportunities and pitfalls. *Ethics Soc. Welf.*, **6**(3), 275–289, doi:10.1080/17496535.2012.704929.

Tschakert, P., B. van Oort, A.L.St. Clair and A. LaMadrid, 2013: Inequality and transformation analyses: a complementary lens for addressing vulnerability to climate change. *Clim. Dev.*, **5**(4), 340–350, doi:10.1080/17565529.2013.828583.

Tubi, A. and J. Williams, 2021: Beyond binary outcomes in climate adaptation: the illustrative case of desalination. *Wiley Interdiscip. Rev. Clim. Chang.*, **12**(2), e695.

Tuhkanen, H., 2020: *Green bonds: a mechanism for bridging the adaptation gap?* SEI Working Paper, **February 2020**.Stockholm Environment Institute, Stockholm, accessed 6 April 2022, https://www.sei.org/publications/green-bonds-a-mechanism-for-bridging-the-adaptation-gap/.

Tuncok, I.K., 2015: Transboundary river basin flood forecasting and early warning system experience in Maritza River basin between Bulgaria and Turkey. *Nat. Hazards*, **75**(1), 191–214.

Turnhout, E., et al., 2020: The politics of co-production: participation, power, and transformation. *Curr. Opin. Environ. Sustain.*, **42**, 15–21, doi:10.1016/j.cosust.2019.11.009.

Tzeng, G.-H. and J.-J. Huang, 2011: *Multiple attribute decision making: methods and applications*. CRC Press, Taylor & Francis Group, Florida, United States of America, ISBN 978-0429110702.

Ulrichs, M., R. Slater and C. Costella, 2019: Building resilience to climate risks through social protection: from individualised models to systemic transformation. *Disasters*, **43**(Suppl 3), S368–S387, doi:10.1111/disa.12339.

UN, 2015: *Adoption of the Paris Agreement* Change, U. N. F. C. o. C. 21st Conference of the Parties, Paris.

UN, 2016a: *Final list of proposed Sustainable Development Goal indicators*. Report of the Inter-Agency and Expert Group on Sustainable Development Goal Indicators.

UN, 2016b: *Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction*. Note by the Secretary-General.

UN, 2019: *Special edition: progress towards the Sustainable Development Goals*. Report of the Secretary-General, accessed 6 April 2022, https://unstats.un.org/sdgs/files/report/2019/secretary-general-sdg-report-2019--EN.pdf.

Cambodia, U.N.D.P., 2014: *Practitioner's Handbook: Implementing the Vulnerability Reduction Assessment*, 2nd edn., UNDP Cambodia, Phnom Penh, Cambodia.

UNDRR, 2019: *Global assessment report on disaster risk reduction*, accessed 6 April 2022, https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2019.

UNEP, 2014: *The Adaptation Gap Report*. UNEP, accessed 6 April 2022, https://wedocs.unep.org/bitstream/handle/20.500.11822/9331/-Adaptation_gap_report_a_prel.pdf?sequence=2&isAllowed=y.

UNEP, 2016: *The Adaptation Finance Gap Report 2016*. United Nations Environment Programme, Nairobi, Kenya, accessed 6 April 2022, https://climateanalytics.org/media/agr2016.pdf.

UNEP, 2017: *The Adaptation Gap Report 2017*. Programme, U. N. E., Nairobi.

UNEP, 2018: *The Adaptation Gap Report 2018*. UNEP, Nairobi.

UNEP, 2020: *Annex 1. Challenges in estimating adaptation costs. Adaptation Gap Report 2020*. https://www.unep.org/resources/adaptation-gap-report-2020. Accessed 2021.

UNEP, 2021a: *The Adaptation Gap Report 2020*. UNEP, Nairobi, Kenya.

UNDP and UNFCCC, 2019: *The Heat is on: Taking Stock of Global Climate Ambition*. United Nations Development Programme and UNFCCC Secretariat, https://unfccc.int/news/the-heat-is-on-taking-stock-of-global-climate-ambition#:~:text=This%20is%20according%20to%20a,date%20of%20intentions%20for%202020.

UNFCCC, 2009: *Decision 2/CP. 15 Copenhagen Accord. FCCC/CP/2009/11/Add. 1*. United Nations Framework Convention on Climate Change. Copenhagen.

UNFCCC, 2010a: *Report of the Conference of the Parties on its fifteenth session*. Copenhagen, accessed 6 April 2022, accessed 6 April 2022, https://unfccc.int/documents/6103.

UNFCCC, 2010b: *Synthesis Report on Efforts Undertaken to Monitor and Evaluate the Implementation of Adaptation Projects, Policies and Programmes and the Costs and Effectiveness of Completed Projects, Policies and Programmes, and Views on Lessons Learned, Good Practices, Gaps and Needs*.

UNFCCC, 2013: *Decision 2/CP.19: Warsaw International Mechanism for Loss and Damage Associated With Climate Change Impacts*.

UNFCCC, 2014: UNFCCC Standing Committee on Finance 2014 Biennial Assessment and Overview of Climate Finance Flows Report. United Nations Framework Convention on Climate Change (Standing Committee on Finance), Berlin, 94 pp. Accessed 15 August 2021, http://unfccc.int/6877.

UNFCCC, 2015: *The Paris Agreement, United Nations Framework Convention on Climate Change*.

UNFCCC, 2019a: *Opportunities and Options for Adaptation Finance, Including in Relation to the Private Sector*, accessed 6 April 2022, https://unfccc.int/documents/200703.

UNFCCC, 2019b: *CMA.2 Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts and its 2019 review*. UNFCCC, Bonn.

UNFCCC, 2020: *Compilation and synthesis of fourth biennial reports of Parties included in Annex I to the Convention*. United Nations Framework Convention on Climate, C, Berlin, https://unfccc.int/sites/default/files/resource/sbi2020_inf10a01.pdf. Accessed 2021 . (101 pp).

UNFCCC, 2021: *Private Sector Initiative (PSI) database*, accessed 6 April 2022, https://unfccc.int/topics/resilience/resources/psi-database.

UNFCCC SCF, 2018: *2018 Biennial Assessment and Overview of Climate Finance Flows*, accessed 6 April 2022, https://unfccc.int/sites/default/files/resource/2018.

Vähämäki, J. and C. Verger, 2019: *Learning From Results-Based Management Evaluations and Reviews*.
Valente, S. and F. Veloso-Gomes, 2020: Coastal climate adaptation in port-cities: adaptation deficits, barriers, and challenges ahead. *J. Environ. Plan. Manag.*, **63**(3), 389–414.
Van Alphen, J., 2016: The Delta Programme and updated flood risk management policies in the Netherlands. *J. Flood Risk Manag.*, **9**(4), 310–319, doi:10.1111/jfr3.12183.
van den Homberg, M. and C. McQuistan, 2019: Technology for Climate Justice: A Reporting Framework for Loss and Damage as Part of Key Global Agreements. In: *Loss and Damage from Climate Change*. Springer, Berlin Heidelberg, pp. 513–545.
van der Geest, K. and R. van den Berg, 2021: Slow-onset events: a review of the evidence from the IPCC Special Reports on Land, Oceans and Cryosphere. *Curr. Opin. Environ. Sustain.*, **50**, 109–120.
van der Geest, K. and K. Warner, 2015: Loss and damage from climate change: emerging perspectives. *Int. J. Glob. Warming*, **8**(2), 133–140.
van Niekerk, D., C. Coetzee and L. Nemakonde, 2020: Implementing the Sendai Framework in Africa: Progress Against the Targets (2015–2018). *Int. J. Disaster Risk Sci.*, **11**(2), 179–189.
van Rüth, P. and K. Schönthaler, 2018: *Setting up a national monitoring system for climate change impacts and adaptation* L. Christiansen, G. M. and P. Naswa. UNEP DTU Partnership, Copenhagen, 97–111.
van Valkengoed, A.M. and L. Steg, 2019: Meta-analyses of factors motivating climate change adaptation behaviour. *Nat. Clim. Change*, **9**(2), 158–163, doi:10.1038/s41558-018-0371-y.
van Vliet, M.T.H., et al., 2015: European scale climate information services for water use sectors. *J. Hydrol.*, **528**, 503–513, doi:10.1016/j.jhydrol.2015.06.060.
van Wilgen, B.W. and A. Wannenburgh, 2016: Co-facilitating invasive species control, water conservation and poverty relief: achievements and challenges in South Africa's Working for Water programme. *Curr. Opin. Environ. Sustain.*, **19**, 7–17.
Vandenbergh, M.P. and J.M. Gilligan, 2017: *Beyond Politics: The Private Governance Response to Climate Change* Business and Public Policy. Cambridge University Press, Cambridge, ISBN 978-1107181229.
Vanhala, L. and C. Hestbaek, 2016: Framing climate change loss and damage in UNFCCC negotiations. *Glob. Environ. Polit.*, **16**(4), 111–129.
Vaughan, C., L. Buja, A. Kruczkiewicz and L. Goddard, 2016: Identifying research priorities to advance climate services. *Clim. Serv.*, **4**, 65–74, doi:10.1016/j.cliser.2016.11.004.
Vaughan, C., et al., 2019a: Evaluating agricultural weather and climate services in Africa: Evidence, methods, and a learning agenda. *Wiley. Interdiscip. Rev. Clim. Change.*, **10**(4), e586.
Vaughan, C., M.F. Muth and D.P. Brown, 2019b: Evaluation of regional climate services: learning from seasonal-scale examples across the americas. *Clim. Serv.*, **15**, 100104, doi:10.1016/j.cliser.2019.100104.
Velasquez, M. and P.T. Hester, 2013: An analysis of multi-criteria decision making methods. *Int. J. Oper. Res.*, **10**, 56–66.
Vella, K., et al., 2016: Voluntary collaboration for adaptive governance: the southeast florida regional climate change compact. *J. Plan. Educ. Res.*, **36**(3), 363–376, doi:10.1177/0739456x16659700.
Vellinga, P., et al., 2001: *Insurance and other financial services*. Cambridge University Press, Cambridge, 417–450.
Venn, A., 2019: Social justice and climate change. In: *Managing Global Warming* [Letcher and T.M. (eds.)]. Academic Press, Massachusetts, USA, pp. 711–728. ISBN 978-0128141045.
Vermeulen, S.J., et al., 2018: Transformation in practice: a review of empirical cases of transformational adaptation in agriculture under climate change. *Front. Sustain. Food Syst.*, **2**, 65.
Villanueva, P.S., 2012: *Learning to ADAPT: Monitoring and Evaluation Approaches in Climate Change Adaptation and Disaster Risk Reduction—Challenges, Gaps and Ways Forward*, accessed 6 April 2022, https://www.ids.ac.uk/files/dmfile/SilvaVillanueva_2012_Learning-to-ADAPTDP92.pdf.
Vincent, K., M. Daly, C. Scannell and B. Leathes, 2018: What can climate services learn from theory and practice of co-production? *Clim. Serv.*, **12**, 48–58, doi:10.1016/j.cliser.2018.11.001.
Vincent, K., et al., 2015: Identifying climate services needs for national planning: insights from Malawi. *Clim. Policy*, **17**(2), 189–202, doi:10.1080/14693062.2015.1075374.
Visser, H., S. de Bruin, J. Knoop and W. Ligtvoet, 2020: What users of global risk indicators should know. *Glob. Environ. Chang.*, **62**(102068).
Economics, V.I.V.I.D., 2021: *Greenness of Stimulus Index*, 6th edn., Initiative, V. E. F. f. B., London.
Vogel, J., E. McNie and D. Behar, 2016: Co-producing actionable science for water utilities. *Clim. Serv.*, **2-3**(C), 30–40, doi:10.1016/j.cliser.2016.06.003.
Volz, U., et al., 2021: *Debt Relief for a Green and Inclusive Recovery: Securing Private-Sector Participation and Creating Policy Space for Sustainable Development*. Heinrich Böll, S., U. o. L. Soas and U. Boston, Berlin, London and Boston, accessed 28 April 2022, https://www.boell.de/sites/default/files/2021-06/DRGR%20Report%202021%20Endf.pdf.
Walch, C., 2018: Disaster risk reduction amidst armed conflict: informal institutions, rebel groups, and wartime political orders. *Disasters*, **42**(Suppl 2), S239–S264, doi:10.1111/disa.12309.
Wallimann-Helmer, I., 2015: Justice for climate loss and damage. *Clim. Chang.*, **133**(3), 469–480.
Wallimann-Helmer, I., et al., 2019: The ethical challenges in the context of climate loss and damage. In: *Loss and Damage from Climate Change*. Springer, Berlin Heidelberg, pp. 39–62.
Walshe, R. and A. Argumedo, 2016: Ayni, Ayllu, Yanantin and Chanincha: the cultural values enabling adaptation to climate change in communities of the potato park, in the Peruvian andes. *Gaia*, **25**(3), 166–173, doi:10.14512/gaia.25.3.7.
Wamsler, C., 2017: Stakeholder involvement in strategic adaptation planning: transdisciplinarity and co-production at stake? *Environ. Sci. Policy*, **75**, 148–157.
Wamsler, C., et al., 2019: Beyond participation: when citizen engagement leads to undesirable outcomes for nature-based solutions and climate change adaptation. *Clim. Change*, **158**(2), 235–254, doi:10.1007/s10584-019-02557-9.
Wang, L., A. Yang and K. Thorson, 2019b: Serial participants of social media climate discussion as a community of practice: a longitudinal network analysis. *Inf. Commun. Soc.*, 1–19, doi:10.1080/1369118x.2019.1668457.
Wang, T. and X. Gao, 2018: Reflection and operationalization of the common but differentiated responsibilities and respective capabilities principle in the transparency framework under the international climate change regime. *Adv. Clim. Chang. Res.*, **9**(4), 253–263, doi:10.1016/j.accre.2018.12.004.
Wang, Y., M. van Roon and S. Knight-Lenihan, 2021: Opportunities and challenges in water sensitive industrial development: an Auckland case study, New Zealand. *Int. J. Sustain. Dev. World Ecol.*, **28**(2), 143–156.
Warner, K., et al., 2019: Characteristics of transformational adaptation in climate-land-society interactions. *Sustainability*, **11**(2), doi:10.3390/su11020356.
Warnken, J. and R. Mosadeghi, 2018: Challenges of implementing integrated coastal zone management into local planning policies, a case study of Queensland, Australia. *Mar. Policy*, **91**, 75–84, doi:10.1016/j.marpol.2018.01.031.
Wasim, R., 2019: Corporate (non)disclosure of climate change information. *Columbia Law Rev*, **119**(5), 1311–1356.
Watkins, S.L., S.K. Mincey, J. Vogt and S.P. Sweeney, 2016: Is planting equitable? An examination of the spatial distribution of nonprofit urban tree-planting programs by canopy cover, income, race, and ethnicity. *Environ. Behav.*, **49**(4), 452–482, doi:10.1177/0013916516636423.

Watkiss, P. and A. Hunt, 2013: *Method Overview: Decision Support Methods for Adaptation, Briefing Note 1. Summary of Methods and Case Study Examples from the MEDIATION Project. Funded by the EC's 7FWP. 18*.

Watkiss, P., et al., 2015: The costs and benefits of adaptation: results from the ECONADAPT project. *Policy Rep.* https://doi. org/10.13140/RG.

Watson, C., 2016: *Financing our shared future: navigating the humanitarian, development and climate finance agendas*. Overseas Development Institute (ODI), London, UK.

Watson, C. and L. Schalatek, 2021: *The Global Climate Finance Architecture*. Climate Finance Fundamentals, Overseas Development Institute and Heinrich Böll Stiftung North America, https://climatefundsupdate.org/about-climate-finance/global-climate-finance-architecture. Accessed 2021.

Watts, N., et al., 2015: Health and climate change: policy responses to protect public health. *Lancet*, **386**(10006), 1861–1914, doi:10.1016/s0140-6736(15)60854-6.

Weaver, C.P., et al., 2013: Improving the contribution of climate model information to decision making: the value and demands of robust decision frameworks. *WIREs Clim. Chang.*, **4**(1), 39–60, doi:10.1002/wcc.202.

Webber, S., 2017: Circulating climate services: commercializing science for climate change adaptation in pacific islands. *Geoforum*, **85**, 82–91, doi:10.1016/j.geoforum.2017.07.009.

Webber, S. and S.D. Donner, 2017: Climate service warnings: cautions about commercializing climate science for adaptation in the developing world. *WIREs Clim. Chang.*, **8**(1), e424, doi:10.1002/wcc.424.

Weikmans, R. and J.T. Roberts, 2019: The international climate finance accounting muddle: is there hope on the horizon? *Clim. Dev.*, **11**(2), 97–111, doi:10.1080/17565529.2017.1410087.

Weikmans, R., et al., 2017: Assessing the credibility of how climate adaptation aid projects are categorised. *Dev. Pract.*, **27**(4), 458–471.

Weiler, F., C. Klöck and M. Dornan, 2018: Vulnerability, good governance, or donor interests? The allocation of aid for climate change adaptation. *World Dev.*, **104**, 65.

Weinstein, L., A. Rumbach and S. Sinha, 2019: Resilient growth: fantasy plans and unplanned developments in India's flood-prone coastal cities. *Int. J. Urban Reg. Res.*, **43**(2), 273–291.

Weischer, L., et al., 2016: *Investing in ambition: Analysis of the financial aspects in (Intended) nationally determined contributions* THINK TANK & RESEARCH.

Weitz, N., C. Strambo, E. Kemp-Benedict and M. Nilsson, 2017: Closing the governance gaps in the water-energy-food nexus: Insights from integrative governance. *Glob. Environ. Chang.*, **45**, 165–173, doi:10.1016/j.gloenvcha.2017.06.006.

Weldegebriel, Z. B. and M. Prowse, 2013: Climate-change adaptation in Ethiopia: to what extent does social protection influence livelihood diversification? *Dev. Policy Rev.*, **31**(2), 35–56.

Wenta, J., J. McDonald and J.S. McGee, 2019: Enhancing resilience and justice in climate adaptation laws. *Transnatl. Environ. Law*, **8**(1), 89–118, doi:10.1017/s2047102518000286.

Wesselink, A., 2016: Trends in flood risk management in deltas around the world: are we going 'soft'? *Int. J. Water Gov.*, **4**(4), 25–46, doi:10.7564/15-ijwg90.

Wewerinke-Singh, M. and D.H. Salili, 2019: Between negotiations and litigation: Vanuatu's perspective on loss and damage from climate change. *Clim. Policy*, **20**(6), 681–692, doi:10.1080/14693062.2019.1623166.

Wheeler, H.C., et al., 2020a: The need for transformative changes in the use of Indigenous knowledge along with science for environmental decision-making in the Arctic. *People Nat.*, **2**(3), 544–556, doi:10.1002/pan3.10131.

White, C.J., et al., 2017: Potential applications of subseasonal-to-seasonal (S2S) predictions. *Meteorol. Appl.*, **24**(3), 315–325, doi:10.1002/met.1654.

Wichelns, D., 2017: The water-energy-food nexus: Is the increasing attention warranted, from either a research or policy perspective? *Environ. Sci. Policy*, **69**, 113–123, doi:10.1016/j.envsci.2016.12.018.

Wilkinson, E., et al., 2018: *Forecasting hazards, averting disasters: Implementing forecast-based early action at scale*. Overseas Development Institute (ODI).

Willett, W., et al., 2019: Food in the Anthropocene: the EAT–Lancet; Commission on healthy diets from sustainable food systems. *Lancet*, **393**(10170), 447–492, doi:10.1016/s0140-6736(18)31788-4.

Williamson, D. and M. Goldstein, 2012: *Bayesian Policy Support for Adaptive Strategies Using Computer Models for Complex Physical Systems*, 1021–1033.

Wilson, A.J. and B. Orlove, 2019: *What do we mean when we say climate change is urgent?* Columbia Academic Commons: Columbia University, Center for Research on Environmental Decisions Working Paper 1.

Wilson, A.J. and B. Orlove, 2021: Climate urgency: evidence of its effects on decision making in the laboratory and the field. *Curr. Opin. Environ. Sustain.*, **51**, 65–76.

Wilson, R.S., A. Herziger, M. Hamilton and J.S. Brooks, 2020: From incremental to transformative adaptation in individual responses to climate-exacerbated hazards. *Nat. Clim. Chang.*, 1–9.

Winters, K.M., J.B. Cushing and D. Lach, 2016: Designing visualization software for super-wicked problems. *Inf. Polity*, **21**(4), 399–409, doi:10.3233/ip-160400.

Wise, R.M., et al., 2016: How climate compatible are livelihood adaptation strategies and development programs in rural Indonesia? *Clim. Risk Manag.*, **12**, 100–114, doi:10.1016/j.crm.2015.11.001.

Wise, R.M., et al., 2014: Reconceptualising adaptation to climate change as part of pathways of change and response. *Glob. Environ. Chang.*, **28**, 325–336, doi:10.1016/j.gloenvcha.2013.12.002.

Woodruff, S.C., 2018: City membership in climate change adaptation networks. *Environ. Sci. Policy*, **84**, 60–68, doi:10.1016/j.envsci.2018.03.002.

Woodruff, S.C. and P. Regan, 2019: Quality of national adaptation plans and opportunities for improvement. *Mitig. Adapt. Strateg. Glob. Change*, **24**(1), 53–71, doi:10.1007/s11027-018-9794-z.

Woodruff, S.C. and M. Stults, 2016: Numerous strategies but limited implementation guidance in US local adaptation plans. *Nat. Clim. Change*, **6**(8), 796–802, doi:10.1038/nclimate3012.

Work, C., V. Rong, D. Song and A. Scheidel, 2019: Maladaptation and development as usual? Investigating climate change mitigation and adaptation projects in Cambodia. *Clim. Policy*, **19**(sup1), S47–S62.

Workman, M., G. Darch, K. Dooley, et al., 2021: *Climate Policy Decision Making in Contexts of Deep Uncertainty - from Optimisation to Robustness*, 127–137.

World Bank, 2010: *Economics of Adaptation to Climate Change: Synthesis report*. World Bank, Washington, DC, accessed 6 April 2022, https://openknowledge.worldbank.org/bitstream/handle/10986/12750/702670ESW0P10800EACCSynthesisReport.pdf?sequence=1&isAllowed=y.

World Bank, 2013: *World Development Report 2014* World Development Report. The World Bank, ISBN 978-0821399033. 360 pp.

World Bank Independent Evaluation Group, 2012: *Adapting to Climate Change: Assessing the World Bank Group Experience*, accessed 6 April 2022, http://ieg.worldbankgroup.org/evaluations/adapting-climate-change-assessing-world-bank-group-experience.

WRI, 2019: *Estimating the Economic Benefits of Climate Adaptation Investments*. Background Paper for Global Comission on Adaptation. Worlds Resources Institute, Washington, D.C.

Wright, C. and D. Nyberg, 2016: An inconvenient truth: how organizations translate climate change into business as usual. *Acad. Manag J.*, **60**(5), 1633–1661, doi:10.5465/amj.2015.0718.

WWF & Practical Action, 2020: *Anchoring Loss & Damage in Enhanced NDCs*. Nature, W. W. F., accessed 6 April 2022, https://wwfint.awsassets.panda.org/downloads/wwf_pa_anchoring_loss_and_damage_in_ndcs_report.pdf.

Xenarios, S. and H. Polatidis, 2015: Alleviating climate change impacts in rural Bangladesh: a PROMETHEE outranking-based approach for prioritizing agricultural interventions. *Environ. Dev. Sustain.*, **17**(5), 963–985, doi:10.1007/s10668-014-9583-0.

Xiang, P., et al., 2019: Individualist-collectivist differences in climate change inaction: the role of perceived Intractability. *Front. Psychol.*, **10**, 187, doi:10.3389/fpsyg.2019.00187.

Xu, D.L., 2012: *An Introduction and Survey of the Evidential Reasoning Approach for Multiple Criteria Decision Analysis*, 163–187.

Xue, X., et al., 2015: Critical insights for a sustainability framework to address integrated community water services: technical metrics and approaches, 2015/04/13. *Water Res*, **77**, 155–169. (Electronic) 0043-1354 (Linking).

Yang, Z., et al., 2018: Risk and cost evaluation of port adaptation measures to climate change impacts. *Transp. Res. Part D Transp. Environ.*, **61**, 444–458, doi:10.1016/j.trd.2017.03.004.

Yohe, G.W., et al., 2008: *Perspectives on climate change and sustainability*. Cambridge University Press, Cambridge, UK, 811–841.

Young, N., et al., 2016: Knowledge users' perspectives and advice on how to improve knowledge exchange and mobilization in the case of a co-managed fishery. *Environ. Sci. Policy*, **66**, 170–178, doi:10.1016/j.envsci.2016.09.002.

Young, S.L., N.W. Goldowsky-Dill, J. Muhammad and M.M. Epstein, 2019a: Connecting experts in the agricultural and meteorological sciences to advance knowledge of pest management in a changing climate. *Sci. Total Environ.*, **673**, 694–698, doi:10.1016/j.scitotenv.2019.04.126.

Yumagulova, L. and I. Vertinsky, 2019: Moving beyond engineering supremacy: knowledge systems for urban resilience in Canada's Metro Vancouver region. *Environ. Sci. Policy*, **100**, 66–73, doi:10.1016/j.envsci.2019.05.022.

Zadek, S., 2018: Financing a Just Transition. *Organ. Environ.*, **32**(1), 18–25, doi:10.1177/1086026618794176.

Zakay, D., 2014: Psychological time as information: the case of boredom. *Front. Psychol.*, **5**, doi:10.3389/fpsyg.2014.00917.

Zanocco, C., et al., 2018a: Great Basin land managers provide detailed feedback about usefulness of two climate information web applications. *Clim. Risk Manag.*, **20**, 78–94, doi:10.1016/j.crm.2018.04.001.

Zarei, Z., E. Karami and M. Keshavarz, 2020: Co-production of knowledge and adaptation to water scarcity in developing countries. *J. Environ. Manag.*, **262**, 110283, doi:10.1016/j.jenvman.2020.110283.

Zebiak, S.E., 2019: International conference on climate services - 5 – an introduction. *Clim. Serv.*, **15**, 100121, doi:10.1016/j.cliser.2019.100121.

Zebiak, S.E., et al., 2015: Investigating El Niño-Southern Oscillation and society relationships. *Wiley Interdiscip. Rev. Clim. Chang.*, **6**(1), 17–34, doi:10.1002/wcc.294.

Zevenbergen, C., et al., 2018: Adaptive delta management: a comparison between the Netherlands and Bangladesh Delta Program. *Int. J. River Basin Manag.*, **16**(3), 299–305, doi:10.1080/15715124.2018.1433185.

Zhang, M.-J., Y.-M. Wang, L.-H. Li and S.-Q. Chen, 2017: *A General Evidential Reasoning Algorithm for Multi-Attribute Decision Analysis under Interval Uncertainty*, 1005–1015.

Zhang, W. and X. Pan, 2016: Study on the demand of climate finance for developing countries based on submitted INDC. *Adv. Clim. Chang. Res.*, **7**(1-2), 99–104, doi:10.1016/j.accre.2016.05.002.

Zhao, Z.-Y., J. Zuo and G. Zillante, 2017: Transformation of water resource management: a case study of the South-to-North Water Diversion project. *J. Clean. Prod.*, **163**, 136–145.

Ziaja, S., 2019: Role of knowledge networks and boundary organizations in coproduction: a short history of a decision-support tool and model for adapting multiuse reservoir and water-energy governance to climate change in California. *Weather. Clim. Soc.*, **11**(4), 823–849, doi:10.1175/wcas-d-19-0007.1.

Ziaja, S. and C. Fullerton, 2015: Judging science: the rewards and perils of courts as boundary organizations. *Hastings Environ. Law J.*, **21**(2), 217–246.

Zickgraf, C., 2021: Climate change, slow onset events and human mobility: reviewing the evidence. *Curr. Opin. Environ. Sustain.*, **50**, 21–30.

Ziervogel, G., 2019: Building transformative capacity for adaptation planning and implementation that works for the urban poor: Insights from South Africa. *Ambio*, **48**(5), 494–506.

Ziervogel, G., et al., 2017: Inserting rights and justice into urban resilience: a focus on everyday risk. *Environ. Urban.*, **29**(1), 123–138.

Ziervogel, G., et al., 2019: Vertical integration for climate change adaptation in the water sector: lessons from decentralisation in Africa and India. *Reg. Environ. Change*, **19**, 2729–2743.

Zommers, Z. and A. Singh, 2014: *Reducing Disaster: Early Warning Systems for Climate Change*. Springer, Berlin Heidelberg, ISBN 978-9401785983.

Zopounidis, C. and P.M. Pardalos, 2010: *Handbook of Multicriteria Analysis. Applied Optimization*. Springer, Berlin Heidelberg, ISBN 978-3540928270.