Chapter 1: Point of Departure and Key Concepts

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Executive Summary

The IPCC Working Group II contribution to the Sixth Assessment Report addresses the challenges of climate action in the context of sustainable development with a particular focus on climate change impacts, adaptation and vulnerability. This chapter frames the point of departure and key concepts building on the IPCC's Fifth Assessment Report (WGII AR5), the Special Report on Global Warming of 1.5°C, the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) and the Special Report on Climate Change and Land (SRCCL); as well as the WGI contributions to the Sixth Assessment Report and compliments the contribution of the WGIII Sixth Assessment Report which will be published after this report.

Since IPCC AR5, human influence on the Earth's climate has become unequivocal, increasingly apparent, and widespread, reflected in both the growing scientific literature and in the perception and experiences of people worldwide (*high confidence*). Current changes in the climate system and those expected in the future will increasingly have significant and deleterious impacts on human and natural systems. The impacts of climate change and extreme weather events have adversely affected, or caused the loss of ecosystems including terrestrial, freshwater, ocean and coastal ecosystems, including tropical coral reefs; reduced food security; contributed to migration and displacement; damaged livelihoods, health and security of people; and increased inequality. Climate change impacts are concurrent and interact with other significant societal changes that have become more salient since AR5, including a growing and urbanising global population; significant inequality and demands for social justice; rapid technological change; continuing poverty, land and water degradation, biodiversity loss; food insecurity; and a global pandemic. {1.1.1, 1.3, Cross-Working Group Box ATTRIB in Chapter 1}

Since AR5, climate action has grown in salience worldwide across all levels of government as well as among non-governmental organisations, small and large enterprises and citizens (*high confidence*). At the international level the Paris Agreement and the Sustainable Development Goals (SDGs), along with other targets and frameworks such as the Sendai Framework for Disaster Risk Reduction, the Convention on Biological Diversity (CBD) Aichi targets, the Addis Ababa Action Agenda for finance and the New Urban Agenda, provide overarching goals and policy context. These agreements also provide policy goals used by this IPCC Report to assess climate action across all levels of society. {1.1.2, 1.4.1, 1.4.3}

IPCC's assessments have grown and changed substantially over the last three decades. Compared to earlier IPCC assessments, this report emphasizes a common risk-solution framing across all three working groups. This report focuses on solutions for risk reduction and adaptation, provides more integration across the natural and social sciences, applies a more comprehensive risk framework; assesses adaptation directly in the context of sectoral or regional risks; engages with different forms of knowledge, including Indigenous knowledge and local knowledge; and includes an increasing focus on social justice. {1.1.4, 1.4.2, Cross-Chapter Box ADAPT in Chapter 1}

Adaptation plays a key role in reducing risks and vulnerability from climate change. Implementing adaptation and mitigation actions together with SDGs helps to exploit synergies, reduce trade-offs and makes all three more effective. From a risk perspective, limiting atmospheric greenhouse gas concentrations reduces climate-related hazards while adaptation and sustainable development reduce exposure and vulnerability to those hazards. Adaptation facilitates development, which is increasingly hindered by impacts and risks from climate change. Development facilitates adaptation by expanding the resources and capacity to reduce climate risks and vulnerability. {1.1.3, 1.5.1, 1.5.3}

The concepts of risk and risk management have become increasingly central to climate change literature, research, practice and decision making (*medium confidence*). Risk, defined as the potential for adverse consequences for human and ecological systems, recognising the diversity of values and objectives associated with such systems, provides a framework for understanding the increasingly severe, interconnected and often irreversible impacts of climate change; how these impacts differentially affect different regions, sectors and populations; how to allocate resources best to manage the resulting risks and how to evaluate the responses that reduce residual risks for current and future generations, economies and ecosystems. {1.2.1, 1.3.1, 1.4.2}

The concepts of adaptation, vulnerability, resilience and risk provide overlapping, alternative entry points for the climate change challenge (*high confidence*). Vulnerability is a component of risk, but also an important focus independently, improving understanding of the differential impacts of climate change on people of different gender, race, wealth, social status and other attributes. Vulnerability also provides an important link between climate adaptation and disaster risk reduction. Resilience, which can refer to either a process or outcome, encompasses not just the concept of maintaining essential function, identity and structure, but also maintaining a capacity for transformation. Such transformations bring forth questions of justice, power and politics. {1.2.1, 1.4.1}

Risks from climate change differ through space and time and cascade across and within regions and systems. The total risk in any location may thus differ from the sum of individual risks if these interactions, as well as risks from responses themselves, are not considered (*high confidence*). The risks of climate change responses include the possibility of mitigation or adaptation responses not achieving their intended objectives or having trade-offs or adverse side effects for other societal objectives. Another core area of complexity in climate risk is the behaviour of systems, which includes multiple stressors unfolding together, cascading or compounding interactions within and across sectors and regions and non-linear responses and the potential for surprises, all of which is crucial for effective decision-making and decision-support methods. The key risks assessed in this report become important in interaction with the cultures, values, ethics, identities, experiences and knowledge systems of affected communities and societies. {1.3.1}

Increasingly, impacts are detected and attributed to the changing climate. Improved understanding of deep history (palaeoclimate and biotic responses) suggests that past climate changes have already caused substantial ecological, evolutionary and socio-economic impacts (*high confidence*). Many recent impacts are not detected, due to a shortage of monitoring and robust attribution analysis (*high confidence*). Detection and attribution assessments inform the risk assessment by demonstrating the sensitivity of a system to climate change, and they can inform the loss and damage estimates including those involved in potential climate litigation cases. Robust detection and attribution methods now exist, they play a significant role in increasing awareness and willingness to act among decision makers and the general population. {1.3.2.1, Cross-Working Group Box ATTRIB in Chapter 1, Cross-Chapter Box PALEO in Chapter 1}

Narratives play an important role in communicating climate risks and motivating solutions. A narrative describes a chronological chain of events, often with a premise and conclusions. In the AR6, as in previous IPCC assessments, climate change scenarios and related narratives (also called storylines) are central in the analysis, synthesis and communication of climate change impacts and of adaptation and mitigation responses. AR6 employs narratives to describe the assumptions, evolution and driving forces for the Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs) and links these to Global Warming Levels (GWLs) as a complement to RCPs and SSPs for framing impacts (Ch1 Cross-Chapter Box CLIMATE). Narratives can also be enablers of transformation by communicating societal goals and the actions needed to achieve them {1.2.2, 1.3.3, 1.5.2}

AR6 highlights adaptation solutions and the extent to which they are successful and adequate at reducing climate risk, increasing resilience and pursuing other climate-related societal goals. For adaptation, a solution is defined as an option which is effective, feasible and conforms to principles of justice. Effectiveness refers to the extent to which an action is anticipated or is observed to reduce climate-related risk. Feasibility refers to the extent to which a measure is considered possible and desirable in a particular context. A successful action is one observed to be effective, feasible and just. Adequacy refers to a set of solutions that together are sufficient to avoid dangerous, intolerable, or severe climate risks. {1.4}

Indigenous knowledge and local knowledge (IK and LK) can provide important understanding for acting effectively on climate risk and can help diversify knowledge that may enrich adaptation policy and practice (*high confidence*). Indigenous Peoples have been faced with adaptation challenges for centuries and have developed strategies for resilience in changing environments that can enrich and strengthen current and future adaptation efforts. Valuing IK and LK is also important for recognition, a key component of climate justice. {1.3.2.3}

AR6 highlights three principles of climate justice: distributive justice, procedural justice and recognition. Distributive justice refers to the allocation of burdens and benefits among individuals, nations and generations; procedural justice refers to who decides and participates in decision-making; and recognition entails basic respect and robust engagement with and fair consideration of diverse cultures and perspectives. This report considers all three principles in the assessment of adaptation options and evaluates the extent to which better outcomes are obtained by choosing just ones. Since potential trade-offs exist among the principles, adaptation assessments will in general involve normative judgements as well as science-based evidence. {1.4.1.1}

Concepts of justice and measures of well-being are increasingly used to evaluate the extent to which climate change adaptation is equitable and effective (*medium confidence*). AR6 employs evaluation frameworks based on both single and multi-criteria to assess adaptation effectiveness and consistency with principles of justice. Single criteria frameworks aggregate many attributes into a one number or ranking, often quantified using benefit-cost analysis or measures of social welfare. Existing decision processes often favour such single criteria, which also correlate well with many measures of social progress and sustainable development. Multi-criteria frameworks simultaneously report several different biophysical and socio-economic attributes, which provides more information on potential trade-offs and synergies and can engage with emerging concepts of well-being. {1.4.1.1, 1.4.1.2}

The concepts of enablers, catalysts and the solution space help AR6 assess ways to speed the implementation of and expand the range of adaptation solutions. Many potential solutions exist, which have not yet been implemented despite the gap between current and adequate levels of adaption. Enablers enhance the feasibility of adaptation options and include governance, finance and knowledge**.** Catalysts accelerate and motivate the adaptation decision-making process. The concept of solution space -- defined as the space within which opportunities and constraints determine why, how, when and who adapts to climate risks – helps this report assess how human choices and exogenous changes can expand and contract the set of effective, feasible and just solutions. {1.4.2}

Effective governance, adaptation finance and nature-based solutions are important enablers for expanding the solutions space and reducing adaptation gaps (*high confidence*). Actors at many scales and in many sectors are adapting already and can take additional and more significant adaptation action. These include individuals and households, communities, governments at all levels, private sector businesses, non-governmental organisations and religious groups and social movements. Many forms of adaptation (depending on the type of climatic risk and societal context) are likely to be more effective, cost-efficient, and potentially also more equitable when organized collectively. Stronger governance and adaptation finance capabilities are usually associated with more ambitious adaptation plans and more effective implementation of such plans. {1.4.2, 1.4.2}

Monitoring and Evaluation (M&E) of adaptation refers to a broad range of activities necessary for tracking adaptation progress over time, improving adaptation effectiveness and successful iterative risk management. Monitoring usually refers to continuous information gathering whereas evaluation denotes more comprehensive assessments of effectiveness and equity, often resulting in recommendations for decision makers. In some literatures M&E refers solely to efforts undertaken after implementation. In other literatures, M&E refers both to efforts conducted before and after implementation. Since AR5, a growing literature provides initial inventories of adaptation plans and implementation worldwide, but information on effectiveness remains scare (*high confidence*). {1.4.3, Cross-Chapter Box ADAPT in Chapter 1}

The concept of limits to adaptation is dynamic in terms of the temporal, spatial and contextual dimensions of climate change risks, impacts and response. Socioeconomic, technological, governance and institutional systems or policies can be changed or transformed in responses to the different dimensions of adaptation limits to climate change and extreme events. Adaptation limits can be soft or hard. Soft adaptation limits occur when options may exist but are currently not available to avoid intolerable risks through adaptive actions and hard adaptation limits occur when no adaptive actions are possible to avoid intolerable risks. The level of greenhouse gas reduction, adaptation and risk management measures are the key factors determining if and when adaptation limits are reached. When a limit (soft) is reached, then intolerable risks and impacts may occur and additional adaptations (incremental or transformational) would be required. Transformational adaptation can allow a system to extend beyond its soft limits and prevent soft limits to become hard limits. The loss and damage associated with the future climate change impacts, beyond the limits to adaptation, is an area of increasing focus, although yet to be fully developed in terms of methods of assessing including non-economic values and identifying means to avoid and reduce both economic (loss of asset, infrastructure, land etc.) and non-economic (loss of societal beliefs and values, cultural heritage, biodiversity and ecosystem services) losses and damages. {1.4.4.1, 1.4.4.2}

Key concepts in this report provide a framework for assessing the urgency of climate change adaptation. Adaptation is urgent to the extent that soft adaptation limits are currently being approached or exceeded and that achieving levels of adaptation adequate to address these soft limits requires action at a speed and scale faster than that represented by current trends (*high confidence*). In addition, adaptation is urgent to the extent that any needed expansion of the future solution space requires near-term strengthening and expansion of enablers such as governance, finance and information. Finally, adaptation is urgent to the extent that current maladaptation and socio-economic trends, such as rapid urbanisation and continued inequalities, lock in patterns of vulnerability and exposure that increase future risk (*high confidence*). {1.1.3, 1.4.4, 1.5.1}

AR6 highlights the role of transformation in meeting the Paris Agreement, the SDG and other policy goals. Transformation, and the related term transition, are pluralistic concepts, embracing the idea of major, fundamental changes in society or natural systems as opposed to changes that are minor, marginal, or incremental. AR6 has a particular focus on transformational adaptation, which changes the fundamental attributes of a socio-economic system in anticipation of climate change and its impacts. AR6 describes transitions in five systems: energy, land and ecosystem, urban and infrastructure, industrial and societal. In the past, transformations of such scale have been associated not only with technological and economic changes, but with shifts in most aspects of society. {1.2.1.3, 1.4.4, 1.5.1}

Future transformation could be deliberate, envisioned and intended by at least some societal actors, who seek to expand the solution space, overcome soft limits to adaptation, reduce residual risk to tolerable levels and achieve societal goals. If such a transformation is not pursued or is not successful and risk remains above intolerable levels a forced transformation may occur less consistent with societal goals. The literature describes incremental and transformational change as linked processes. The transformational adaptation literature suggests shifts from incremental to transformational processes are made possible by knowledge and skills, as well adjustments to vision, agendas and coalitions achieved through monitoring and learning. The socio-ecological and sustainability transitions literature suggests that actors seeking deliberate transformation may take incremental steps that aim to induce societal tipping point behaviour in the near or longer-term. Alternative pathways for pursuing deliberate transformations range from a focus on modernisation of sectors such as energy, agriculture and use of natural resources to proposals for degrowth that aim for intentional decreases in both GDP and coupled GHG emissions. {1.2.1.3, 1.4.4, 1.5.1}

Transformation is understood as a collective action challenge among actors with both common and differing values interacting with a mix of competition and cooperation. Significant innovations often begin in niches or protected spaces, sometimes introduced by new entrants or outsiders. The drivers of transformation are multi-dimensional, involving social, cultural, economic, environmental, technical and political processes the combination of which create the potential for abrupt and systemic change, the stability of entrenched and interlocked power structures and the importance of individual beliefs and behaviours. Decision frameworks that consider multiple objectives and multiple scenarios can avoid privileging some views over others and help multiple actors to identify resilient and equitable solutions to complex, deeply uncertain challenges. Nonetheless, common goals and narratives are both enablers of transformation and help align the activities of multiple, loosely co-ordinated actors. {1.5.2}.

This report employs the climate resilient development concept to inform co-ordinated implementation of adaptation and mitigation solutions to support sustainable development for all. As a transformation that emerges from the choices of many different actors, climate resilient development follows no single or preferred pathway and no single best combination of adaptation, mitigation and sustainable development strategies. All pathways involve complex trade-offs and synergies among different actions. The climate resilient development concept helps assess the extent to which solutions currently exist to meet societal goals or the extent to which an expanded solution space is required. The concept also helps assess the role of various actors, including governments, citizens, civil society, knowledge institutions, media, investors and businesses as well as assessing the need for arenas of engagement in which they can interact. {1.2.3, 1.5.2, 1.5.3}

1.1 The Current Urgent Moment

1.1.1 A Changing Climate in a Changing World

Numerous additional significant climate-related changes have unfolded worldwide since publication of the IPCC Fifth Assessment Report (AR5) in 2014 (IPCC, 2014a). Consistent with projections, multiple, concurrent, changes in the physical climate system have grown more salient, including increasing global temperatures, loss of ice volume, rising sea levels and changes in global precipitation patterns (WGI AR6 Chapter 1). The changes in the physical climate system, most notably more intensive extreme events, have adversely affected natural and human systems around the world, contributing to a loss and degradation of ecosystems including tropical coral reefs; reduced water and food security; increased damage to infrastructure; additional mortality and morbidity; human migration and displacement; damaged livelihoods; increased mental health issues; and increased inequality. Since AR5, a growing literature attributes change in particular climate variables to observed damages to specific, localized human and natural systems in many regions of the world, as shown in Figure 1.1 (Chapter 1 BOX ATTRIBUTE).

Concurrently, since AR5, a growing share of people around the world perceive a changing climate, regard these changes as significant, and consider climate action as a matter of high urgency (Wilson and Orlove, 2019; Section 17.4.5). A survey, representing over half the world's population, found that almost two-thirds of people across 50 countries view climate change as an emergency (Flynn et al., 2021), compared to just over half across 23 countries in 2013 (Fagan, 2019). The highest level of support for climate action is among small-island developing states (74%), followed by high income countries (72%), middle income countries (62%), and, then, least developed countries (58%) (Flynn et al., 2021). Notably after mid-2018, global media showed a large increase number of mentions of "global warming", "climate change" and similar terms (Thackeray et al., 2020). The business communities' now consistently includes climate change, including "climate action failure" as a major risk (World Economic Forum, 2021). In late 2019, protests calling for strengthened climate action reached an unprecedented level of over 6000 events in 185 countries, with a reported estimate of 7.6 million participants, largely led by the "Fridays for Future" youth movement (Chase-Dunn and Almeida, 2020).

Since AR5, governments, businesses and civil society have increasingly responded with planning and actions aimed at reducing current and future risks from climate change (Section 1.1.2; Chapter 16 and 17). Concern with climate change has increasingly motivated actions by governments, the private sector, and civil society (Hale et al., 2021; Section 18.4.3). As described in this report, however, current climate policies and actions alone are not sufficient to meet stated policy goals (Section 1.1.3) *(high confidence)*.

This report addresses the challenges of climate action in the context of sustainable development. Climate action takes place in a world already undergoing some of the most rapid and significant societal and environmental change in decades (IPCC, 2018c, Box 1.1), including: species and ecosystems lost due to land- and sea-use change and pollution (IPBES, 2019a); a growing and urbanising world population (Gerten et al., 2019; van Vliet et al., 2017); technology reshaping the workplace through automation (Schwab, 2017) and information dissemination through social media (Mavrodieva et al., 2019; Pearce et al., 2019), and increasing inequalities due to gender, poverty, age, race and ethnicity (Cross-Chapter Box GENDER in Chapter 18). Economic inequality grows within nations even as it has narrowed among them (UN Department of Economic and Social Affairs, 2020). International polycentric governance and nonstate actors play an important role (Beck and Mahony, 2018; Sections 1.4.2 and 17.1.2.1). In 2020 and 2021, a global pandemic dramatically affected the lives of most of the world's population, likely accelerating many of the changes already underway (Cross-Chapter Box COVID in Chapter 7).

The point of departure for this AR6 Working Group II report thus lies in rapid and significant changes in our climate and our world, growing attentiveness to those changes, a gap between current climate action and that needed to address policy goals, and a growing literature that improves understanding and informs potential responses. This chapter defines key concepts and the connections among them useful for comprehending and evaluating these changes, the risks they generate, and options for incremental and transformative solutions that could reduce climate-related risks, impacts and vulnerability.

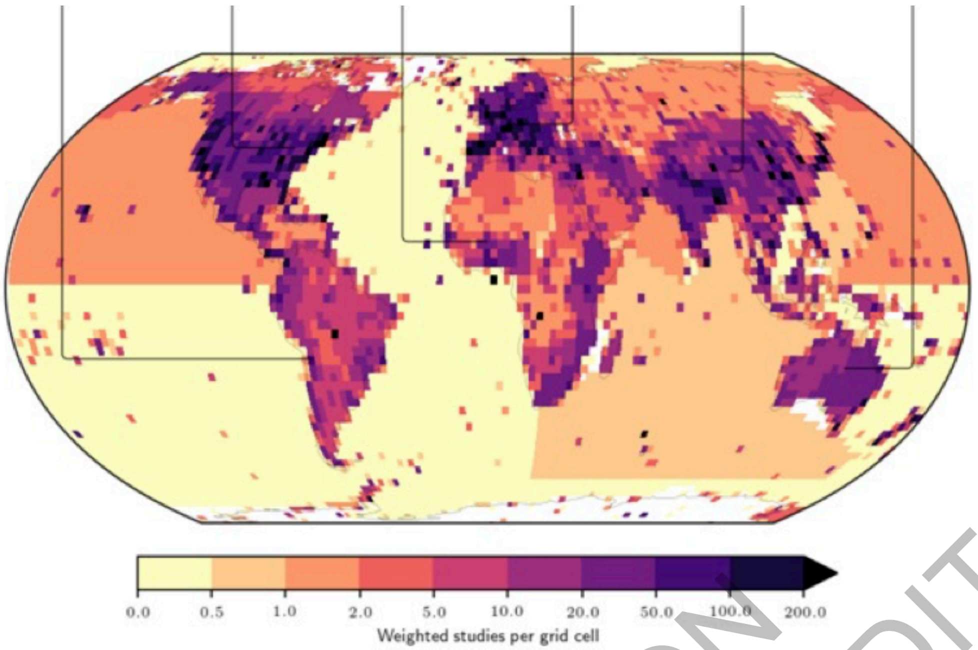

Figure 1.1: Evidence of climate change impacts in many regions of the world. Global density map shows climate impact evidence, derived by machine-learning from 77,785 studies. Bar charts show the number of studies per continent and impact category. Bars are coloured by the climate variable predicted to drive impacts. Colour intensity indicates the percentage of cells a study refers to where a trend in the climate variable can be attributed (partially attributable: >0% of grid cells, mostly attributable: >50% of grid cells) From Callaghan et al. (2021)

1.1.2 Policy Context

Since AR5, climate action has grown at all levels of governance as well as among non-governmental organisations, small and large enterprises, and citizens. Two international agreements – the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement and the 2030 Agenda for Sustainable Development – jointly provide overarching goals for climate action. The 2015 Paris Agreement frames direct local, national, and private sector actions aligned with long-term goals addressing mitigation, adaptation, and finance. For mitigation, the agreement calls for "holding the increase in global average temperature to well below 2°C above pre-industrial levels", "pursuing efforts to limit the temperature increase to 1.5°C," and "reaching net-zero greenhouse gas emissions in the second half of this century" (UNFCCC, 2016). For adaptation, the agreement calls for "increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience" (UNFCCC, 2016, Article 2) as well as a dedicated "global goal on adaptation" (Lesnikowski et al., 2017; Persson, 2019b). For finance, the agreement seeks to make "financial flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development."

The 2030 Agenda for Sustainable Development, adopted in 2015 by UN member states, sets out 17 Sustainable Development Goals (SDGs), frames policies for achieving a more sustainable future and aligns efforts globally to prioritizing ending extreme poverty, protecting the planet, and promoting more peaceful, prosperous, and inclusive societies. SDG 13 ("Climate Action") provides benchmarks to align the Paris Agreement's call to "strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty." Since AR5, several new international conventions have identified climate change adaptation and risk reduction as important global priorities for sustainable development, including the Sendai Framework for Disaster Risk Reduction (SFDRR) (Tozier de la Poterie and Baudoin, 2015; UNISDR, 2015), the finance-oriented Addis Ababa Action Agenda (UN, 2015), and the New Urban Agenda (UN, 2017). For example, the SFDRR recognizes some disasters as "exacerbated by climate change and increasing in frequency and intensity, significantly [impeding] progress towards sustainable development" (UNISDR, 2015). The Convention on Biological Diversity (CBD) is one of the key international legal instruments for sustainable development for "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" (CBD, 2011). The CBD and its Aichi targets recognizes that biodiversity is affected by climate change, with negative consequences for human well-being, but biodiversity, through the ecosystem services, contributes to both climate-change mitigation and adaptation (CBD, 2010). There is concern that many of the proposed post-2020 Biodiversity-targets of the Convention on Biological Diversity (CBD) may not be met due to climate change impacts (Arneth et al., 2020; post-2020 biodiversity targets from Chapter 2).

At the national level, over 2,315 laws and policies that address climate change now exist in 196 countries and a number of territories as of May 2021 (Grantham Research Institute on Climate Change and the Environment and Sabin Center for Climate Change Law, 2021). Sub-national and non-state actors, including city and state governments and firms and investors, have also increasingly launched climate actions (Hale et al., 2021). Climate change litigation is gaining salience for both governments and corporations as the number of cases filed around the world grew from 834 between 1986 and 2014 to 1,006 since 2015 and growing (Setzer and Higham, 2021).

[START BOX 1.1 HERE]

Box 1.1: Summary of IPCC AR5 and Special Report findings

The IPCC WGII AR6 builds upon key findings of the IPCC AR5, three subsequent special reports, and the simultaneous assessment of the IPCC WGI and WGIII AR6. The findings and assessment approaches adopted across these reports have implications for the point of departure in the WGII AR6, including the strong recognition of the urgency for climate action, the enhanced focus on risk, and the aim to connect the search for near-term climate solutions with longer-term transitions. Headline conclusions of the IPCC AR5 include the following, directly quoted (IPCC, 2014a):

- Human influence on the climate system is clear.
- Recent climate changes have had widespread impacts on human and natural systems.
- Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems.
- Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change.
- Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate-resilient pathways for sustainable development.
- Effective implementation depends on policies and cooperation at all scales and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives.

Compared to previous IPCC assessments of impacts, adaptation and vulnerability, the IPCC WGII AR5 assessment highlighted new data and more formal approaches for attributing observed climate changes and impacts (Cramer et al., 2014; IPCC, 2014c), a more formal approach to risk in WGII (IPCC, 2014c; Jones et al., 2014), and an expanded assessment of adaptation (Chambwera et al., 2014; IPCC, 2014c; Klein et al., 2014a; Mimura et al., 2014; Noble et al., 2014).

At the time of the IPCC AR5, very few scientific studies relevant to the impacts of global warming of 1.5°C above pre-industrial levels were available. In 2018, the IPCC concluded a Special Report on the impacts of global warming of 1.5°C levels and related global greenhouse gas emission pathways, following an invitation expressed in the Decision text of the Paris Agreement (UNFCCC, 2015a). The report assessed available literature on global warming of 1.5°C and on comparison between global warming of 1.5°C and 2°C above preindustrial levels. It also addressed possible pathways for achieving the ambitious goals of the Paris Agreement. Key findings from this report include the following, directly quoted (IPCC, 2018d):

- Global warming is *likely* to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate.
- Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C. Most adaptation needs will be lower for global warming of 1.5°C compared to 2°C.

- In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO_2 emissions decline by about 45% from 2010 levels by 2030 (40–60% interquartile range), reaching net zero around 2050 (2045-2055 interquartile range).
- Pathways reflecting current nationally stated mitigation ambitions as submitted under the Paris Agreement would not limit global warming to 1.5°C, even if supplemented by very challenging increases in the scale and ambition of emissions reductions after 2030.

In 2019, a Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) was published, motivated by the observation that many of the world's most exposed people to risks caused by climate change live in the mountains or near the coast. Key findings include the following, directly quoted (IPCC, 2019c):

- Over the last decades, global warming has led to widespread shrinking of the cryosphere and unabated ocean warming with an uptake of more than 90% of the excess heat in the climate system. Marine heatwaves have doubled in frequency since 1982 and the oceans acidify (*virtually certain*). Global mean sea level is rising, with acceleration in recent decades. Increases in tropical cyclone winds and rainfall exacerbate extreme sea level events and coastal hazards.
- All these trends have impacted ecosystems, food security, water resources, water quality, livelihoods, health and well-being, infrastructure, transportation, tourism and recreation, as well as the culture of human societies, particularly for Indigenous peoples.
- The Greenland and Antarctic Ice Sheets are projected to lose mass at an increasing rate throughout the 21st century and beyond. Projected ecosystem responses include losses of species habitat and diversity, and degradation of ecosystem functions. Warm-water corals are at high risk already and are projected to transition to very high risk even if global warming is limited to 1.5°C.
- Increased mean and extreme sea level, alongside ocean warming and acidification, are projected to exacerbate risks for human communities in low-lying coastal areas. People with the highest exposure and vulnerability are often those with lowest capacity to respond.
- Services provided by ocean and cryosphere-related ecosystems can be supported by protection, restoration, precautionary ecosystem-based management of renewable resource use, and the reduction of pollution and other stressors.
- Coastal communities face challenging choices in crafting context-specific and integrated responses to sea level rise that balance costs, benefits and trade-offs of available options and that can be adjusted over time.

Also in 2019, IPCC published a Special Report on Climate Change and Land, addressing greenhouse gas (GHG) fluxes in land-based ecosystems, land use and sustainable land management in relation to climate change adaptation and mitigation, desertification, land degradation and food security. Key findings include the following, directly quoted (IPCC, 2019c):

- Human use directly affects more than 70% of the global, ice-free land surface. Land also plays an important role in the climate system. Climate change has adversely impacted food security and terrestrial ecosystems as well as contributed to desertification and land degradation in many regions. Changes in land conditions, either from land-use or climate change, affect global and regional climate.
- Pathways with higher demand for food, feed, and water, more resource-intensive consumption and production, and more limited technological improvements in agriculture yields result in higher risks from water scarcity in drylands, land degradation, and food insecurity. Most of the response options assessed contribute positively to sustainable development and other societal goals. Sustainable land management, including sustainable forest management, can prevent and reduce land degradation, maintain land productivity, and sometimes reverse the adverse impacts of climate change on land degradation. It can also contribute to mitigation and adaptation.
- Response options throughout the food system, from production to consumption, including food loss and waste, can be deployed and scaled up to advance adaptation and mitigation. All assessed modelled pathways that limit warming to 1.5°C or well below 2°C require land-based mitigation and land-use change.

- The effectiveness of decision-making and governance is enhanced by the involvement of local stakeholders (particularly those most vulnerable to climate change including Indigenous peoples and local communities, women, and the poor and marginalised) in policies for land-based climate change adaptation and mitigation.
- Near-term action to address climate change adaptation and mitigation, desertification, land degradation and food security can bring social, ecological, economic and development co-benefits.

In 2021, IPCC Working Group 1 published its Sixth Assessment Report on The Physical Science Basis. Key findings from the report include the following, directly quoted from its SPM quoted (IPCC, 2019c):
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- The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years.
- Global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered. Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in carbon dioxide and other greenhouse gas emissions occur in the coming decades.
- Many changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets and global sea level.
- With further global warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. Changes in several climatic impact-drivers would be more widespread at 2°C compared to 1.5°C global warming and even more widespread and/or pronounced for higher warming levels. Low-likelihood outcomes, such as ice sheet collapse, abrupt ocean circulation changes, some compound extreme events and warming substantially larger than the assessed very likely range of future warming cannot be ruled out and are part of risk assessment.
- From a physical science perspective, limiting human-induced global warming to a specific level requires limiting cumulative CO2 emissions, reaching at least net zero CO2 emissions, along with strong reductions in other greenhouse gas emissions. Strong, rapid and sustained reductions in Chapter 4 emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality.

Other assessment processes also inform the IPCC AR6. For example, a recent joint workshop between IPBES and IPCC, the first of its kind, made key observations relevant to the work of IPCC AR6 WG2 (Pörtner et al., 2021). In this broad context, the workshop explored diverse facets of the interaction between climate and biodiversity, from current trends to the role and implementation of nature-based solutions and the sustainable development of human society. Key highlighting synopsis of the workshop include the following, directly quoted from the workshop report:

- Limiting global warming to ensure a habitable climate and protecting biodiversity are mutually supporting goals, and their achievement is essential for sustainably and equitably providing benefits to people.
- Several land- and ocean-based actions to protect, sustainably manage and restore ecosystems have co-benefits for climate mitigation, climate adaptation and biodiversity objectives.
- Measures narrowly focused on climate mitigation and adaptation can have direct and indirect negative impacts on nature and nature's contributions to people.
- Measures narrowly focusing on protection and restoration of biodiversity have generally important knock-on benefits for climate change mitigation, but those benefits may be sub-optimal compared to measures that account for both biodiversity and climate.
- Treating climate, biodiversity and human society as coupled systems is key to successful outcomes from policy interventions.
- Transformative change in governance of socio-ecological systems can help create climate and biodiversity resilient development pathways.

[END BOX 1.1 HERE]

1.1.3 Adaptation Efforts and Gaps

Adaptation to climate change plays a key role in reducing climate-related risks along with mitigation and sustainable development. From a risk perspective (Section 1.2), emission reductions and carbon removal can both reduce the greenhouse gas forcing and thus climate-related hazards while adaptation and sustainable development reduce exposure and vulnerability to those hazards.

Important synergies and trade-offs exist among adaptation and mitigation actions (Section 1.5, Chapter 18). Limiting atmospheric concentrations of greenhouse gases reduces the extent of adaptation needed to keep risk within tolerable levels (Section 1.3; Chapter 16). From a global perspective, understanding of adaptation and its limits can inform judgements about the best balance among levels of mitigation and adaptation .Such judgements underlie the mitigation goals of the Paris Agreement. From a more local perspective, there exist a wide range of mitigation scenarios (Cross-Chapter Box CLIMATE in Chapter 1), including those which meet or miss the Paris Agreement goals, and overshoot scenarios in which global mean temperature exceed targets for several decades before dropping to desired levels. Such scenarios inform assessments of the level of adaptation that may be required (Section 1.4, Chapter 17).

Adaptation and sustainable development are also interlinked (Section 18.1). Adaptation facilitates development, which is hindered by impacts and risks from climate change. Development facilitates adaptation by expanding the resources and capacity available to manage climate risks. Viewed from a climate justice perspective, some argue that a more just society is more capable of successful adaptation while others argue that only adaptation that results in a more just society can be judged successful (Section 1.4.1, Chapter 18).

Two concepts – adaptation gaps and limits to adaptation – help frame this report's assessment of the extent to which current adaptation efforts are adequate to meet societal goals. **Adaptation gaps** are defined as "the difference between actually implemented adaptation and a societally set goal, determined largely by preferences related to tolerated climate change impacts and reflecting resource limitations and competing priorities" (UNEP et al., 2021). Limits to adaptation describe the extent to which no plausible level of adaptation can meet societal goals (Section 1.4.4). Within the limits, adaptation gaps can be closed by increased and more successful adaptation actions. Beyond the limits, only mitigation can close adaptation gaps.

Numerous climate-related impacts already cause severe damages in many places and are projected to increase in the future (Chapter 16). Adaptation can reduce these risks, often significantly, but limits to adaptation have already been reached or are being approached in some sectors and regions (Sections 16.3.1, 16.4). While natural systems worldwide are changing in response to climate change, many are not adapting sufficiently quickly to retain their resilience in the face of current and projected future climate change (Section 16.4). For human systems, numerous lines of evidence suggest that in many regions and sectors current infrastructure, settlement patterns, policies, practices, and institutions remain inadequate for current changes in climate conditions (Section 16.2). Inadequate or insufficient adaptation to current conditions is called an adaptation deficit.

In response, adaptation efforts have increased significantly since AR5 (Sections 16.3, 17.2, 17.5.2, Chapter 1 Cross-Chapter Box ADAPT in Chapter 1). Assessing the adequacy and effectiveness of these efforts as called for in Article 7 of the Paris Agreement remains challenging (Section 1.3.2.2), because much adaptation is not recorded in the literature and because assessment depends on judgements of effectiveness (Section 1.4.1.2), judgements about societal goals including climate justice (Section 1.4.1.1), and expectations about future greenhouse gas concentration pathways and other socio-economic conditions (16.5, Cross-Chapter Box DEEP in Chapter 17).

Knowledge about adaptation has significantly expanded since AR5 (Cross-Chapter Box ADAPT in Chapter 1). While understanding regarding the extent of adaptation gaps remains limited, the available evidence suggests significant adaptation gaps exist (*high confidence*). Many current adaptation efforts constitute adaptation planning, rather than implementation (Section 16.3). Most current implementation efforts represent incremental as opposed to transformational adaptation despite the proximity to adaptation limits (Sections 17.2 and 17.5.2). Some current adaptation efforts are considered maladaptive because they increase some climate-related risks even if they reduce others (Sections 1.4.2.4 and 17.5; Chapter 16). Gaps exist in key enablers of adaptation, such as finance (Cross-Chapter Box FINANCE in Chapter 17). Given the long-time scales involved with many adaptation actions and the potential to significantly reduce longer-term costs with near-term actions, closing many adaptation gaps requires actions over the next few years by governments, business, civil society and individuals at a scale and speed significantly faster than that represented by current trends.

1.1.4 What is New in the History of Interdisciplinary Climate Change Assessment

Interdisciplinary climate change assessment, which has played a prominent role in science–society interactions on the climate issue since 1988, has advanced in important ways since AR5 (Mach and Field, 2017; Mitchell et al., 2006; Oppenheimer et al., 2019). Building on a substantially expanded scientific and technical literature (Burkett et al., 2014; Minx et al., 2017), this AR6 report emphasizes at least three broad themes.

First, this AR6 assessment has an increased focus on risk- and solutions-frameworks. The risk framing can move beyond the limits of single best estimates or most-likely outcomes and include high-consequence outcomes for which probabilities are low or in some cases unknown (Jones et al., 2014; Mach and Field, 2017). In this report, the risk framing for the first time spans all three working groups, includes risks from the responses to climate change, considers dynamic and cascading consequences (Section 1.3.1.1), describes with more geographic detail risks to people and ecosystems, and assesses such risks over a range of scenarios (Chapter 16). The focus on solutions encompasses the interconnections among climate responses, sustainable development, and transformation—and the implications for governance across scales within the public and private sectors (Section 17.5.2, Chapter 18). The assessment therefore includes climate-related decision-making and risk management, climate-resilient development pathways, implementation and evaluation of adaptation, and also limits to adaptation and loss and damage (Cross-Chapter Box LOSS in Chapter 17, Section 1.4.4). Specific focal areas reflect contexts increasingly important for the implementation of responses, such as cities (Chapter 6).

Second, emphases on social justice and different forms of expertise have emerged (Section 1.4.1.1, 17.5.2). As climate change impacts and implemented responses increasingly occur, there is heightened awareness of the ways that climate responses interact with issues of justice and social progress. In this report, there is expanded attention to inequity in climate vulnerability and responses, the role of power and participation in processes of implementation, unequal and differential impacts, and climate justice. The historic focus on scientific literature has also been increasingly accompanied by attention to and incorporation of Indigenous knowledge, local knowledge, and associated scholars (Section 1.3.2.3, Chapter 12).

Third, AR6 has a more extensive focus on the role of transformation in meeting societal goals (Section 1.5).

To support these three themes, this report assesses a literature with an increasing diversity of topics and geographical areas covered. The diversity is encompassed through sectoral and regional chapters (Chapters 2-15) as well as cross-chapter papers and boxes. The literature also increasingly evaluates the lived experiences of climate change—the physical changes underway, the impacts for people and ecosystems, the perceptions of the risks, and adaptation and mitigation responses planned and implemented. In particular, scientific capabilities to attribute individual extreme weather and climate events to greenhouse gas emissions have gone from hypothetical to standard and routine over the last three decades, and societal perceptions of these events and their impacts for people and ecosystems are now being studied as well (Figure 1.1; Cross-Working Group Box: ATTRIBUTION in Chapter 1; see synthesis in Chapter 16).

Finally, climate change assessment has become increasingly integrative across multiple disciplines within the natural and social sciences. This report's chapters combine experts across working groups and disciplines, such as natural and social sciences, engineering, humanities, law, and business administration. In this assessment cycle, the special reports (Allen et al., 2018; IPCC, 2019a; IPCC, 2019b) all emphasize such integration, and the chapter teams in the present report integrate disciplinary perspectives and also science-policy interactions inherent in climate change impacts, adaptation and vulnerability. There has been increasing real-time assessment of the assessment process itself, including interpersonal dynamics and how they shape key findings (Oppenheimer et al., 2019). Additionally, best practices are being adopted from applied decision and policy analysis, decision support, and co-production, in order to increase assessment relevance and usability for decision-making (Hall et al., 2019; Mach et al., 2019). Methods of integration in this report include systematic review, meta-analysis, multi-criteria integration, and expert elicitation (see synthesis in Chapter 16). The emphasis on knowledge for action has also included the role of public communication, stories, and narratives within assessment and associated outreach (Section 1.2.2).

1.2 Different Entry Points for Understanding Climate Change Impacts, Adaptation, and Vulnerability

This section introduces key concepts used in this report and the connections between them that present different entry points for understanding climate change impacts, adaptation, and vulnerability.

1.2.1 Overlapping, Complementary Entry Points

Many actors from different research and practice communities engage with understanding and responding to climate risk. Not surprisingly, there thus exist alternative, overlapping, and complementary entry points to the discussion widely used throughout the literature and this report.

The concepts of risk and risk management have in recent years been central to climate change research and practice related to impacts, adaptation, and vulnerability. The concepts provide a framework for understanding climate change and its increasingly severe, interconnected, and irreversible impacts. They support the implementation of solutions that reduce adverse consequences, pursue opportunities, and enable beneficial outcomes for people, economies, and nature (IPCC, 2014c; IPCC, 2018d). All three AR6 Working Groups now apply a common risk framework (IPCC, 2020).

Additional concepts—adaptation, vulnerability, exposure, resilience, and transformation —also provide important framings for the climate change challenge.

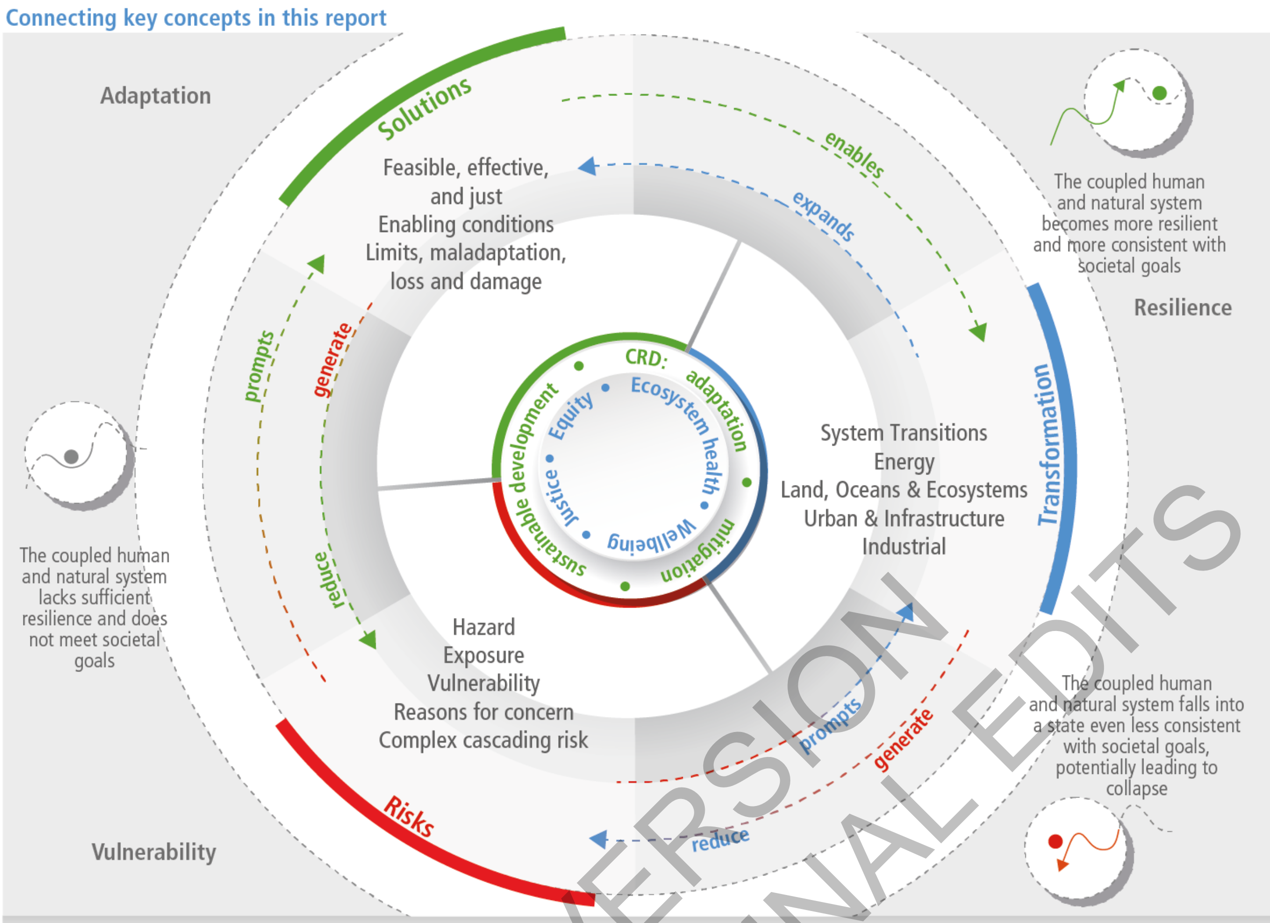

Figure 1.2: Connecting Key Concepts in this Report The current coupled human and natural system is insufficiently resilient and does not meet societal goals of equity, well-being, and ecosystem health. Meeting the objectives of the Paris Agreement, Sustainable Development Goals, and other policy statements requires the system to move to a new and more resilient state. Key concepts used in this report help illuminate our current situation and potential solutions. These key concepts are usefully organized around the concepts of risk, solutions, and transformation. Risk can prompt solutions and transformation. Both solutions and transformation seek to reduce some risks but may also generate others. Solutions can enable transformation, and transformation can expand the set of feasible solutions.

Figure 1.2 displays the connections among many of the key concepts used in this report. This chapter, the Summary for Policymakers, Technical Summary, and sectoral and regional chapters are organized around the concepts of risks (Section 1.3), solutions (Section 1.4), and transformation (Section 1.5).

Key concepts that contribute to an understanding of risk include its components hazards, exposure, and vulnerability (Section 1.2.1.1); the recognition that risks may be complex and cascading (Section 1.3.1.2); and the reasons for concern framework used to summarize the most policy-relevant risks (Section 1.3.1.1). Key concepts that contribute to an understanding of solutions include the enablers of governance, finance, and knowledge (Section 1.4.2); learning processes supported by monitoring and evaluation (Section 1.4.3); and nature-based solutions (Section 1.4.2). Transformation is supported by systems transitions in energy, land, infrastructure, industry, and society (Section 1.5.1), which if successful can contribute to climate resilient development (Section 1.5).

The centre of Figure 1.2 shows societal goals of equity, effectiveness, well-being, and climate justice as articulated by the Paris Agreement, Sustainable Development Goals, and other policies and plans (Section 1.4.1). The ring around these goals shows the limits to adaptation (Section 1.4.4), potential for maladaptation (Sections 1.4.2. 17.5.2), and loss and damage (Section 1.4.4.2) that present barriers to reaching these goals.

The concept of vulnerability can provide a unique window into the effects of climate change on different communities, individuals, and ecosystems, in particular as human systems are affected by race, gender, wealth inequalities, and other attributes (Section 1.2.1.2). The concept of adaptation can provide a unique window into the process of adjustment to climate change by human and natural systems (Section 1.2.1.3). Resilience (Section 1.3.1.4) is a broad concept, encompassing both outcomes and processes, an ability to main essential function, and an ability to transform.

The ball and cup diagrams (Holling, 1973) in Figure 1.2 indicate that the current coupled human and natural system is not resilient, nor does it meet societal goals of equity, well-being, and ecosystem health. Some types of transformation may prove inevitable (Section 1.5.1), either a deliberate transformation that results in a more resilient state consistent with societal goals or a forced transformation to a system state inconsistent with the goals.

1.2.1.1 Risk Framing

Risk in this report is defined as the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system. In the context of climate change responses, risks result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs or negative side-effects (see Annex II: Glossary). **Risk management** is defined as plans, actions, strategies or policies to reduce the likelihood and/or magnitude of adverse potential consequences, based on assessed or perceived risks (see Annex II: Glossary).

A risk framing is increasingly used to assess climate change impacts on human and natural systems (Connelly et al., 2018; IPCC, 2012; Mach and Field, 2017; O'Neill et al., 2017; see also WGII AR6 Sections 1.2.4.1, 16.1, and 17.3 and Cross-Chapter Box CLIMATE; Oppenheimer et al., 2014). A risk framing reflects key dimensions of the climate challenge. These features include the changing likelihoods of many different outcomes (including adverse consequences and beneficial opportunities), uncertainties that will persist, and different and contested values, priorities, and goals (Jones and Preston, 2011; Mach et al., 2016). The IPCC AR6 and associated Special Reports apply a broad definition of risk (WGI AR6 Cross-Chapter Box 1.3. WGI AR6 uses the Climatic Impact Driver (CID) terminology, rather than hazard, to neutrally assess changing climatic conditions that are relevant to human and natural systems, leaving the determination of positive/negative consequences and resulting impacts and risks for WGII assessment (WGI AR6 Section 12.3). In most cases throughout this WGII report, the term "risk" refers to the risks of climate change impacts. The full assessment, however, incorporates all relevant risks from climate change impacts and responses.

The broad definition of risk involves quantitative and integrative understandings of risk (Mach and Field, 2017; Oppenheimer et al., 2014; see also Section 17.3). Risk is sometimes defined as the probability of a consequence, multiplied by the magnitude of that consequence, acknowledging both the diversity of possible consequences and the relevance of values. Yet it also applies in circumstances where probabilities cannot be fully quantified (e.g., Adger et al., 2013). For example, in some cases the probability and magnitude of consequences may be more uncertain, dependent on complex dimensions of the climate (e.g., a cyclone, high tide, and heatwave co-occurring) or the vulnerability of different communities (e.g., the ways in which social networks and community cohesion support most-vulnerable individuals during disasters) (Ford et al., 2018). The determinants of risk vary dynamically through space and time (Jurgilevich et al., 2017; Viner et al., 2020). They interact, compound, and cascade (Adger et al., 2018; Dawson, 2015; see also Section 16.1.2).

A risk framing supports connections with solutions (Adger et al., 2018; Jones and Preston, 2011; Mach et al., 2016). First, a risk framing connects the present with the future. (Papathoma-Kohle et al., 2016). For instance, whether wildfire or drought, recent experiences have demonstrated limits to current response capacities, relevant to future preparedness (e.g., evacuation of large communities on tight time frames or water management simultaneously responsive to intensifying drought and flooding). Second, a risk framing emphasizes that uncertainties and complex interactions are integral to decision-making (Dawson, 2015; Jones et al., 2014). The uncertainties include high-impact, low-probability outcomes and deep uncertainties for which core processes are not understood and meaningful probabilities cannot be applied (Adler et al., 2016see also Section 17.2.1 and Cross-Chapter Box DEEP in Chapter 17; Chapter 7 in SRCCL, IPCC, 2019a; Cross-Chapter Box 5 in SROCC, IPCC, 2019b). In these circumstances, risk assessment can occur through tools used for risk management across contexts, such as insurance, business, social protection, security, and policy planning, and decision-making can be iterative and support dynamic adaptive pathways through time (Aven, 2016; Jones and Preston, 2011; Watkiss et al., 2015; see also Section 17.3.2)

Iterative risk management (Vervoort and Gupta, 2018) emphasizes that anticipating and responding to climate change does not consist of a single set of judgments at a single point in time, but rather an "ongoing cycle of assessment, action, reassessment, learning, and response" (USGCRP, 2018). It is consistent with most approaches applied for implementing adaptation (Jones et al., 2014; Jones and Preston, 2011). For instance, the Paris Agreement is organized as a polycentric process (see Section 1.4) of iterative risk management in which national governments pledge to take specific actions, those actions are monitored and assessed, and nations asked to update their pledges in light of that assessment.

1.2.1.2 Vulnerability

Vulnerability is a component of risk, but also an important focus independently. Vulnerability in this report is defined as the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (see Annex II: Glossary). Over the past several decades, approaches to analysing and assessing vulnerability have evolved. An early emphasis on top-down, biophysical evaluation of vulnerability included -and often started with - exposure to climate hazards in assessing vulnerability. From this starting point, attention to bottom-up, social and contextual determinants of vulnerability, which often differ, has emerged, although this approach is incompletely applied or integrated across contexts (Bergstrand et al., 2015; Rufat et al., 2015; Spielman et al., 2020; Taberna et al., 2020). Vulnerability is now widely understood to differ within communities and across societies, also changing through time (Jurgilevich et al., 2017; Kienberger et al., 2013; see also Chapter 16). In the WGII AR6, assessment of the vulnerability of people and ecosystems encompasses the differing approaches that exist within the literature, both critiquing and harmonizing them based on available evidence. In this context, **exposure** is defined as the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected (Annex II: Glossary). Potentially affected places and settings can be defined geographically, as well as more dynamically, for example through transmission or interconnections through markets or flows of people.

Vulnerability is also a link between the climate risk and disaster risk communities, recognizing complementarities and differences between these communities. **Disaster risk management** is the set of processes that improve understanding of disaster risk, foster disaster risk reduction and transfer, and promote continuous improvement in disaster preparedness, response, and recovery practices, increasing human security, well-being, and sustainable development (see Annex II: Glossary). Climate risk and disaster risk are increasingly addressed together, bridging the climate change adaptation and disaster risk reduction communities (e.g., IPCC, 2012; UNDRR, 2019, especially Chapter 13 in that report). Building from the scientific literature and adaptation and risk reduction practice, the IPCC Special Report on Extremes resulted in several major IPCC advances that continue to the present report, including emphasis on risk and climate-related extremes (e.g., Burton et al., 2012; Lavell et al., 2012) and re-conceptualisation of vulnerability to encompass both social and biophysical orientations (i.e., bridging contextual/bottom-up and climate-driven/top-down approaches) (Cardona et al., 2012; Polsky et al., 2007). Linking disaster risk reduction and climate change adaptation can also be an important basis for discussion in climate negotiations regarding the allocation of funds needed for tackling climate change, especially in developing countries and small island developing states (Begum et al., 2014). The integration of disaster risk management and climate change adaptation in the IPCC AR6 is seen for example in the assessment of key risks within and across sectors and regions, along with global-scale reasons for concern, which is attuned to extreme events and disasters (Oppenheimer et al., 2014; see also Chapter 16). Additionally, the assessment of adaptation has prioritized these interconnections (e.g., Mimura et al., 2014), as have literature and practice especially in the context of sustainable development (e.g., Schipper et al., 2016).

1.2.1.3 Adaptation

Adaptation in this report is defined, in human systems, 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 Annex II: Glossary). Adaptation planning in human systems generally entails a process of iterative risk management. Different types of adaptation have been distinguished, including anticipatory versus reactive, autonomous versus planned, and incremental versus transformational adaptation (IPCC WGII glossaries for the TAR, AR4, AR5, and AR6; Chapters 16–18). Adaptation is often seen as having five general stages: 1) awareness, 2) assessment, 3) planning, 4) implementation, and 5) monitoring and evaluation (Jones et al., 2014; Mimura et al., 2014; Moser and Boykoff, 2013; Noble et al., 2014; see also Section 17.4). Government, non-government, and private-sector actors have adopted a wide variety of specific approaches to adaptation that, to varying degrees, address these five general stages. Adaptation in natural systems includes "autonomous" adjustments through ecological and evolutionary processes. It also involves the use of nature through ecosystem-based adaptation. The role of species, biodiversity, and ecosystems in such adaptation options can range from the rehabilitation or restoration of ecosystems (e.g., wetlands or mangroves) to hybrid combinations of "green and grey" infrastructure (e.g., horizontal levees) (Chapters 2-3; IPBES, 2018).

The IPCC assessment of adaptation has evolved through time. The WGII AR4 included one chapter dedicated to adaptation, the WGII AR5 expanded to four, and the WGII AR6 mainstreams adaptation comprehensively throughout the report. Adaptation science is rapidly evolving, including evaluation of adaptation effectiveness, feasibility, implementation, and maladaptation, although major knowledge gaps persist in modeling and analysis (CCB ADAPT; Chapter 16; Section 1.4; Holman et al., 2019). The WGII AR6 emphasizes assessment of observed adaptation-related responses to climate change, governance and decision-making in adaptation, and the role of adaptation in reducing key risks and global-scale reasons for concern, as well as limits to such adaptation (e.g., Chapters 16 and 17). The assessment approach includes adaptation needs, options, planning, and implementation across sectors and regions, as well as adaptation opportunities, constraints, and also limits (Capela Lourenço et al., 2019; Eisenack et al., 2014; Herrmann and Guenther, 2017; Klein et al., 2014b; Lehmann et al., 2015; Moser et al., 2019b; Oberlack, 2017; Oberlack and Eisenack, 2014; Roggero, 2015; Russel et al., 2020; Sieber et al., 2018; Thaler et al., 2019; see also Chapters 16 and 17).

Since AR5, more adaptation has progressed (IPCC, 2014a; Lesnikowski et al., 2016; see also Sections 16.2.5 and 17.2) and the focus of activity has expanded to include social, institutional, and governance dimensions beyond engineered and technical options and to decision processes beyond technocratic, linear framings (IPCC, 2014a; see also Chapter 17). Adaptation includes increasing attention to implementation, monitoring and evaluation, and learning through time, not just planning processes (Section 17.3 and 17.5.1). On the one hand, an important advance has been recognition of generalized capacities, such as resources and knowledge, necessary for the feasibility of effective adaptation. Adaptation thereby strongly overlaps with risk management and with the building of resilience and sustainable development (Chapters 17–18).

1.2.1.4 Resilience, Including Connections with Development Pathways and Transformation

Resilience in this report is defined as the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation (see Annex II: Glossary). Resilience is an entry point commonly used, although under a wide spectrum of meanings (Aldunce et al., 2015; Fisichelli et al., 2016; Flood and Schechtman, 2014; Meerow et al., 2016; Moser et al., 2019a; Reghezza-Zitt et al., 2012; Tanner et al., 2015). Resilience as a system trait overlaps with concepts of vulnerability, adaptive capacity, and thereby risk, and resilience as a strategy overlaps with risk management, adaptation, and also transformation (Moser et al., 2019a; Woodruff et al., 2018). Implemented adaptation is often organized around resilience as bouncing back and returning to a previous state after a disturbance (Fisichelli et al., 2016).

In much of the literature, resilience encompasses not just maintaining essential function, identity, and structure, but also maintaining a capacity for adaptation, learning, and transformation. Since the earliest framings of resilience around stability and persistence, ecology and allied fields have come to recognize that while systems are often persistent in the face of disturbance, disturbance also creates opportunity for transformation and the emergence of new pathways (Section 1.5.2) (Allen and Holling, 2010; Doppelt, 2017; Folke, 2006; Folke et al., 2010; Gelcich et al., 2010; Stockholm Resilience Center, 2015). Across this literature, disturbance is framed as outside the system in question, for which the timeframes and spatial scales of disturbances, impacts, and responses are central to outcomes (Béné et al., 2011; Brown, 2014; Hamborg et al., 2020). Endogenous processes of transformation are presented as emergent, characterized by thresholds, and as a result very difficult to anticipate (Hughes et al., 2013; Scheffer et al., 2001; Scheffer et al., 2015; Scheffer et al., 2012; Suding and Hobbs, 2009; Walker and Meyers, 2004). In the last 5 years (2016-2020), the concept of resilience has gained prominence as a core theme in the climate change adaptation literature (Nalau and Verrall, 2021).

Often, development and adaptation communities of practice default to persistence and stability in their use of resilience (Cote and Nightingale, 2012; MacKinnon and Derickson, 2013). Such a framing aligns resilience with a long-standing but increasingly questioned belief that sustainable development can be achieved through incremental adjustments in behaviour and advances in technology that allow for the persistence of existing socio-economic and socio-ecological arrangements (Banerjee, 2003; Klauer, 1999; Redclift, 2005; UN Inter-agency Task Force on Financing for Development 2019; Chap 18; Section 1.5). However, the literature increasingly suggests that the achievement of sustainable development will require transformative change in socio-ecological systems at scales ranging from the community to the globe. The concept of climate resilient development, initially introduced in AR5 and now a key focus in this report (see Chapter 18), engages with such transformations and the associated questions of justice, power, and politics as shaped by internal, endogenous social factors and their interactions with other drivers of change (Carr, 2019; Eriksen et al., 2015; Nightingale, 2015b; Nightingale et al., 2019; see also Chapter 18).

1.2.2 Narratives, Storylines, Scenarios and Pathways

The concepts of narratives, storylines, scenarios, and pathways play an important role in this report. While distinct concepts, they are inter-related and sometimes confused.
A **narrative** is a story with a chronological order or, when cast in the form of an argument, with premises and conclusions (Adger et al., 2001; Roe, 1991). Narratives enable people to envision what various potential futures may mean for environments and livelihoods and in this way facilitate the development of scenarios for the future (Miller et al., 2015). Narratives can also play a key role in enabling collective action (Section 1.5) by helping disparate groups co-create a common vision of a desirable future and achieve a common understanding of actions needed to move towards that future (Linnér and Wibeck, 2019; Muiderman et al., 2020).

A narrative contains a storyline in addition to a set of actors (Elliott, 2005). A **storyline** is a series of events including their causal connections within a narrative. The IPCC and climate change literature more broadly often use the terms storylines and narratives interchangeably (O'Neill et al., 2017; see also WGI AR6 Cross-Chapter Box 6 in Chapter 1 and Sections 1.4.4 and 10.5.3). A **scenario storyline** refers to a narrative description of a scenario including its main characteristics, relationships between driving forces and how these factors evolve (AR6 WG1 Section 1.4.4.2). Storylines are used to assess risks related to low-likelihood, but high-impact events (Sutton, 2018). In this use of the terms, narratives and storylines do not include specific actors. There is also a critical literature on the use of narratives and storylines based on projected scenarios, which points out the conservative character of these concepts whose performative effect tends to preserve the status quo and the current socio-economic relationships. (Chollet and Felli, 2015; Demortain, 2019; Lövbrand et al., 2015; Malm and Hornborg, 2014; Theys J. and Cornu, 2019).

Standard research communication may fail to engage policymakers, media and the public at large (WGI AR6 Section 1.2.4). Rather, policies and decision-making tend to be based on narratives and storylines (Roe, 1994; Roe, 2017). Although mathematical models and narratives are often presumed to be antithetical, in practice they may be complementary and work together (Morgan and Wise, 2017). Communicating research insights through storylines and narratives may have a better chance of transmitting key messages. AR6 employs these communication tools in many places, for instance storylines for constructing and communicating regional climate information or climate services (WGI AR6 Chapter 10, Chapter 12) or "Low-Likelihood High Warming Storylines" (Chapter 4). To better communicate deep uncertainty in sea level rise projections, WGI uses storylines to describe the physical events that would have to unfold to generate its high-end estimates (Cross-Chapter Box DEEP in Chapter 17).

Scenarios are defined in IPCC reports as plausible descriptions 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 (Annex II: Glossary). Scenarios are neither predictions nor forecasts but rather ‘foresights’, which imply envisioning challenging futures (Vervoort and Gupta, 2018). Scenarios are used to provide a view of the potential consequences and implications of developments and actions in a ‘what-if’ mode of exploring the future (AR6 WGIII Section 1.5.1; AR6 WGI Section 1.6.1). They may be presented as numerical or mental models. Climate change scenarios are generated by climate modellers to highlight possible alternative greenhouse gas emission pathways and are used to develop and integrate projections of emissions and their climate change impacts and for analysing and contrasting climate policy choices. Cross-Chapter Box CLIMATE in Chapter 1 describes scenarios used in this report.

Pathways are one element of a larger scenario (O’Neill et al., 2017), focusing on just one element of a larger system of drivers, emissions or concentrations. Scenarios provide one means to represent deep uncertainty when there is disagreement or uncertainty about conceptual models (IPCC, 2019b; Cross-Chapter Box DEEP in Chapter 17). In addition, scenarios provide several important functions in decision support. A lack of strong association with probabilities enables scenarios to promote buy-in from parties to a decision who hold different expectations about the future, helping them to expand the range of futures and options they consider. The process of generating scenarios can serve as the focus of participatory stakeholder exercises and processes, and scenarios can also be used to support risk management by stress testing alternative policies and identifying robust and adaptive policies under conditions of deep uncertainty (Cross-Chapter Box DEEP in Chapter 17).

[START CROSS-CHAPTER BOX CLIMATE HERE]

Cross-Chapter Box CLIMATE: Climate Reference Periods, Global Warming Levels, and Common Climate Dimensions

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This Cross-Chapter Box sets out common climate dimensions to contextualize and facilitate AR6 WGII analyses, presentation, synthesis, and communication of assessed, observed and projected climate change impacts across WGII Chapters and Cross-Chapter Papers. “Common climate dimensions” are defined as common Global Warming Levels (GWLs), time periods, and levels of other variables as needed by WGII authors for consistent communications. The set of climate variable ranges given below were derived from the AR6 WGI report and supporting resources and help contextualize and inform the projection of potential future climate impacts and key risks. The information enables the mapping of climate variable levels to climate projections and vice versa, with ranges of results provided to characterize the physical uncertainties relevant to assessing climate impacts risk.

AR6 WGI Reference Periods, Climate Projections and Global Warming Levels

AR6 WGI adopts a common set of reference years and time periods to assess observed and projected climate change, namely the pre-industrial (PI) period, the current ‘modern’ period and future reference time periods. The IPCC Glossary defines the pre-industrial period as “the multi-century period prior to the onset of large-scale industrial activity around 1750. The reference period 1850-1900 is used to approximate pre-industrial global mean surface temperature (GMST)”. The ‘modern’ period is defined as 1995 to 2014 in AR6, while three future reference periods are used for presenting climate change projections, namely near-term (2021-2040), mid-term (2041-2060) and long-term (2081-2100), in both the AR6 WGI and WGII reports. Importantly, the historical rate of warming assessed by WGI in AR6 is different to that assessed in AR5 and SR1.5, due to methodological updates (see WGI Cross-Chapter Box 2.3 in Chapter 2 for details). This means that the ‘modern’ period is assessed as slightly warmer compared to 1850-1900 than it would have been with AR5-era methods. This also has implications for the projected timing of reaching policy-relevant levels of global warming, which need to be understood.

To explore and investigate climate futures, climate change projections are developed using sets of different input projections. These inputs consist of sets of projections of greenhouse gas emissions, aerosols or aerosol precursor emissions, land use change, and concentrations designed to facilitate evaluation of a large climate space and enable climate modelling experiments. For AR5 (and the CMIP5 climate model experiments), the input projections were referred to as Representative Concentration Pathways (RCPs). For AR6 (and the CMIP6 climate model experiments), new sets of inputs are used and referred to as SSP scenarios, where SSP refers to socioeconomic assumptions called the Shared Socio-Economic Pathways (SSPs).

The RCPs are a set of four trajectories that span a large radiative forcing range, defined as increased energy input at surface level in Watts per square meter, ranging from 2.6 W m^{-2} (RCP2.6) to 8.5 W m^{-2} (RCP8.5) by the end of the 21st century, with RCP4.5 and RCP6.0 as intermediate scenarios, and RCP2.6 a peak and decline scenario reaching 3 W m^{-2} before 2100. A range of emissions scenarios compatible with each specific RCP was also assessed in AR5 (Ciais et al., 2013).

A core set of five SSP scenarios, namely SSP1–1.9, SSP1–2.6, SSP2–4.5, SSP3–7.0, and SSP5–8.5, was selected in the AR6 WGI report with the objective to fill certain gaps identified in the RCPs (see AR6 WG1 Cross-Chapter Box 1.4 in Chapter 1). The first number in the label is the particular set of socioeconomic assumptions driving the emissions and other climate forcing inputs taken up by climate models and the second number is the radiative forcing level reached in 2100. WG1 Cross-Chapter Box 1.4 in Chapter 1 provides a comparison of this core set of SSP scenarios with scenarios used in previous reports, with SSP1–1.9 a low overshoot scenario consistent with limiting global average warming to 1.5°C, and SSP1-2.6 a scenario consistent with limiting warming to 2°C.

Also of importance to the impact literature and the WGII report are SSP-RCP combinations, that is, studies that employ climate outcomes based on RCPs and socio-economic assumptions based on SSPs. SSPs can be paired with a range of different RCPs because SSPs can be combined with mitigation policy assumptions to produce a range of emissions pathways. In addition to the SSPs, there are many other emissions pathways and societies consistent with any global mean temperature outcome. These represent uncertainty and broad ranges of possibilities that affect climate change exposure and vulnerability (Rose and and M. Scott, 2020; Rose and Scott, 2018). Furthermore, there are large uncertainties in translating emissions scenarios into concentration pathways due to uncertainties in climate-carbon cycle feedbacks (Booth et al., 2017; Jones et al., 2013).

The plausibility of emissions levels as high as the emissions scenario conventionally associated with the RCP8.5 and SSP5–8.5 concentration pathways has been called into question since AR5, as has the emissions pathway feasibility of the low scenarios (Hausfather and Peters, 2020; Rose and and M. Scott, 2020). However, these views are contested (Schwalm et al., 2020, for RCP8.5), and it is important to realise that emissions scenarios and concentration pathways are not the same thing, and higher concentration pathways such as RCP8.5 could arise from lower emissions scenarios if carbon cycle feedbacks are stronger than assumed in the integrated assessment models (IAMs) used to create the standard scenarios (Booth et al., 2017). In the majority of full-complexity Earth System Models, these feedbacks are stronger than in the IAMs (Jones et al., 2013), so the RCP8.5 concentration pathway cannot be ruled out purely through consideration of the economic aspects of emissions scenarios. Nonetheless, the likelihood of a climate outcome, and the overall distribution of climate outcomes, are a function of the emissions scenario's likelihood. Note that the original RCPs were created explicitly to facilitate a broad range of climate modelling experiments, with the expectation that other issues, such as socioeconomic uncertainty, could be subsequently explored (Moss et al., 2010).

An important feature of the AR6 cycle is a stronger emphasis on the use of future Global Warming Levels (GWLs) to support consistency and comparability across the three IPCC Working Groups' contributions to the AR6 and improve communication. The common range of GWLs relative to the 1850 to 1900 period, termed the "Tier 1" range by WGI, are 1.5, 2.0, 3.0, and 4.0°C. The use of GWLs assists in the comparison of climate states across climate change scenarios (projections) and in assessing the broader literature as well as for cross-chapter and cross-working group comparisons. They facilitate the integration of climate projections, impacts, adaptation challenges and mitigation challenges within and across the three WGs as there is a close connection between the level of global warming and climate change impacts. Of particular interest is the timing of when the "Tier 1" global warming levels are reached, relative to the period 1850–1900, under the five SSP x–y scenarios, as well as RCP scenarios . For climate change impacts and adaptation responses, linking GWLs to RCP and SSP climate projections using a climate information translation resource is of great relevance for the WGII contribution to AR6.

AR6 WGII Common Climate Dimensions

WGII's common climate dimensions include (1) a common range of GWLs from WGI, (2) common ranges for other climate variables, (3) information for translating climate variable levels to climate projections and vice versa. See Table Cross-Chapter Box CLIMATE.1 for global warming level ranges by time periods for RCP and SSP climate projections, and Table Cross-Chapter Box CLIMATE.2 for information regarding the timing for when GWLs are reached in climate projections. The common GWL range is based on WGI's "Tier 1" dimensions of integration range: 1.5, 2, 3, and 4°C. The first table illustrates the greater levels of projected global warming with higher emissions pathways, as well as the increasing uncertainty in the climate response over time for a given pathway. The second table illustrates significant uncertainty in the timing for passing GWL thresholds which can narrow for a given GWL the higher the emissions pathway. Finally, given the importance of geographic heterogeneity in projected changes in future climate, Table Cross-Chapter Box CLIMATE.3a and 3b are provided with ranges for select climate variables (temperature, precipitation, ocean) by global warming level and continent (or ocean biome). The ranges illustrate spatial heterogeneity in potential physical changes in levels and uncertainty that are relevant to assessing climate impacts risk. There is significantly more spatial heterogeneity than represented in the table that is relevant to local decision makers (see, for instance, WGI AR6 Interactive Atlas).

The common climate dimensions can be used as a dimension of integration for impacts studies in WGII, for example by providing a common framework for comparison of projected impacts for different studies (Figure Cross-Chapter Box CLIMATE.1). Moreover, GWL bands are needed in WGII to map the diverse temperature levels found across WGII's literature. The GWL's also facilitate integration with WGIII's global emissions projections categorisation by global mean temperature (WGIII Chapter 3).

Table Cross-Chapter Box CLIMATE.1: GWL ranges by time periods for CMIP5 (RCP) and CMIP6 (SSP) climate projections (20-yr averages). Temperature anomalies relative to 1850-1900. Full ranges for CMIP raw results (across all models and ensemble runs) and WGI AR6 assessed very likely (5-95%) ranges. *Sources: Hauser et al. (2019); WGI AR6 SPM,* Table *SPM.1*

	Full ranges			WG1 AR6 assessed *very likely* (5-95%) ranges		
Projection	**2021-2040**	**2041-2060**	**2081-2100**	**2021-2040**	**2041-2060**	**2081-2100**
RCP2.6	1.0 to 2.2	1.0 to 2.3	0.9 to 2.3	n/a	n/a	n/a
RCP4.5	1.1 to 2.2	1.4 to 2.7	1.8 to 3.3	n/a	n/a	n/a
RCP6.0	1.0 to 2.0	1.3 to 2.5	2.3 to 3.6	n/a	n/a	n/a
RCP8.5	1.1 to 2.6	1.7 to 3.7	3.0 to 6.2	n/a	n/a	n/a
SSP1-1.9	1.0 to 2.4	1.1 to 2.7	1.0 to 2.5	1.2 to 1.7	1.2 to 2.0	1.0 to 1.8
SSP1-2.6	1.0 to 2.4	1.2 to 2.9	1.3 to 3.1	1.2 to 1.8	1.3 to 2.2	1.3 to 2.4
SSP2-4.5	0.9 to 2.5	1.3 to 3.3	1.9 to 4.4	1.2 to 1.8	1.6 to 2.5	2.1 to 3.5
SSP3-7.0	1.0 to 2.6	1.5 to 3.7	2.7 to 6.2	1.2 to 1.8	1.7 to 2.6	2.8 to 4.6
SSP5-8.5	1.0 to 2.7	1.6 to 4.0	3.1 to 7.2	1.3 to 1.9	1.9 to 3.0	3.3 to 5.7

Table Cross-Chapter Box CLIMATE.2: Timing for when 20-year average GWLs are reached in CMIP5 (RCP) and CMIP6 (SSP) climate projections. GWL anomalies relative to 1850-1900. Ranges based on CMIP raw results (all models and ensemble runs), and WGI AR6 assessed results. For each GWL and RCP/SSP, the earliest and latest 20-year window when a 20-year average GWL is reached across the CMIP models and ensemble members is reported, or the very likely (5-95%) assessed range is reported. n entry "n.c." means the GWL is not reached during the period 2021-2100. *Sources: Hauser et al. (2019); WGI AR6 TS Cross-Section Box TS.1, Table 1*

CMIP5 full ranges

GWL	RCP2.6	RCP4.5	RCP6.0	RCP8.5
4°C	n.c.	n.c.	n.c.	2047 - 2066 to 2080 - 2099
3°C	n.c.	2054 - 2073 to 2070 - 2089	2062 - 2081 to 2080 - 2099	2030 - 2049 to 2077 - 2096
2°C	2015 - 2034 to 2079 - 2098	2014 - 2033 to 2075 - 2094	2023 - 2042 to 2068 - 2087	2004 - 2023 to 2048 - 2067
1.5°C	1998 - 2017 to 2075 - 2094	1998 - 2017 to 2051 - 2070	2001 - 2020 to 2050 - 2069	1990 - 2009 to 2035 - 2054

CMIP6 full ranges

GWL	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
4°C	n.c.	n.c.	2061 - 2080 to 2081 - 2100	2046 - 2065 to 2081 - 2100	2042 - 2061 to 2081 - 2100
3°C	n.c.	2050 - 2069 to 2068 - 2087	2034 - 2053 to 2081 - 2100	2030 - 2049 to 2081 - 2100	2027 - 2046 to 2079 - 2098
2°C	2009 - 2028 to 2063 - 2082	2008 - 2027 to 2075 - 2094	2009 - 2028 to 2080 - 2099	2008 - 2027 to 2060 - 2079	2008 - 2027 to 2055 - 2074
1.5°C	1997 - 2016 to 2058 - 2077	1997 - 2016 to 2073 - 2092	1997 - 2016 to 2051 - 2070	1997 - 2016 to 2042 - 2061	1997 - 2016 to 2038 - 2057

WGI AR6 assessed *very likely* (5-95%) ranges

GWL	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
4°C	n.c.	n.c	n.c	2070 - 2089 to n.c.	2058 - 2077 to n.c.
3°C	n.c.	n.c	2061 - 2080 to n.c.	2050 - 2069 to n.c.	2042 - 2061 to 2074 - 2093
2°C	n.c.	2031 - 2050 to n.c.	2028 - 2047 to 2075 - 2094	2026 - 2045 to 2053 - 2072	2023 - 2042 to 2044 - 2063
1.5°C	2013 - 2032 to n.c	2012 - 2031 to n.c.	2012 - 2031 to 2037 - 2056	2013 - 2032 to 2033 - 2052	2011 - 2030 to 2029 - 2048

Table Cross-Chapter Box CLIMATE.3a: Projected continental level result ranges for select temperature and precipitation climate change variables by global warming level. Ranges are 5th and 95th percentiles from SSP5-8.5 WGI CMIP6 ensemble results. There is little variation in the 5th and 95th percentile values by GWL across the SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 projections. *Source: WGI AR6 Interactive Atlas (https://interactive-atlas.ipcc.Chapter/).*

Climate variable	Global warming level	All Regions	North America	Europe	Asia	Centra-South America	Africa	Australia	Antarctica
Mean temperature (degrees C)	4°C	12 to 15	8 to 11	5 to 9	12 to 14	24 to 27	26 to 29	24 to 27	-33 to -27
	3°C	11 to 14	6 to 11	4 to 7	10 to 14	23 to 26	25 to 28	23 to 26	-35 to -26
	2°C	10 to 13	5 to 9	3 to 6	8 to 12	22 to 25	24 to 27	22 to 25	-36 to -27
	1.5°C	9 to 12	4 to 8	2 to 5	8 to 12	22 to 24	24 to 26	22 to 24	-36 to -27
Mean daily minimum temperature (degrees C)	4°C	8 to 11	4 to 8	1 to 6	6 to 11	19 to 24	21 to 25	18 to 23	-38 to -29
	3°C	6 to 11	2 to 8	0 to 5	4 to 10	19 to 22	19 to 23	17 to 21	-39 to -30
	2°C	5 to 10	0 to 6	-2 to 4	3 to 9	17 to 21	18 to 22	16 to 20	-40 to -31
	1.5°C	4 to 9	-1 to 5	-2 to 3	2 to 8	17 to 21	17 to 22	16 to 19	-41 to -32
Minimum of daily minimum temperatures (degrees C)	4°C	-12 to -5	-25 to -15	-22 to -14	-18 to -9	11 to 15	10 to 14	5 to 10	-64 to -48
	3°C	-13 to -6	-27 to -15	-24 to -15	-20 to -11	10 to 15	8 to 14	4 to 10	-64 to -50
	2°C	-15 to -8	-30 to -18	-27 to -17	-22 to -13	9 to 14	7 to 13	3 to 9	-65 to -51
	1.5°C	-16 to -9	-32 to -20	-28 to -19	-23 to -14	8 to 14	6 to 12	3 to 9	-66 to -51
Mean maximum daily temperature (degrees C)	4°C	16 to 19	12 to 15	8 to 11	15 to 18	27 to 32	30 to 35	28 to 33	-31 to -25
	3°C	15 to 19	11 to 15	7 to 11	14 to 18	27 to 32	30 to 37	27 to 34	-32 to -25
	2°C	14 to 18	9 to 13	6 to 9	13 to 17	26 to 31	29 to 36	27 to 33	-33 to -25
	1.5°C	13 to 17	8 to 12	5 to 9	12 to 16	25 to 30	28 to 35	26 to 33	-33 to -26
Maximum of daily maximum temperatures (degrees C)	4°C	32 to 37	32 to 38	28 to 33	35 to 40	36 to 43	40 to 47	41 to 49	-12 to -5
	3°C	31 to 39	31 to 38	28 to 34	35 to 41	35 to 44	39 to 51	41 to 54	-12 to -3
	2°C	30 to 37	30 to 36	26 to 33	33 to 39	34 to 43	38 to 50	39 to 53	-13 to -4
	1.5°C	29 to 36	29 to 35	25 to 31	32 to 39	33 to 42	38 to 49	39 to 52	-14 to -5

Number of days with maximum temperature above 35˚C – bias adjusted	**4˚C**	81 to 106	36 to 50	11 to 22	57 to 77	138 to 194	153 to 210	140 to 168	0 to 0
	3˚C	66 to 87	27 to 40	6 to 15	44 to 59	100 to 153	131 to 183	124 to 147	0 to 0
	2˚C	52 to 68	19 to 29	4 to 8	33 to 45	61 to 106	116 to 151	102 to 124	0 to 0
	1.5˚C	45 to 58	16 to 24	2 to 5	30 to 39	43 to 85	107 to 133	94 to 115	0 to 0
Number of days with maximum temperature above 40˚C – bias adjusted	**4˚C**	28 to 40	9 to 16	1 to 5	19 to 26	21 to 68	69 to 92	53 to 83	0 to 0
	3˚C	20 to 30	5 to 11	1 to 2	14 to 21	9 to 32	56 to 77	41 to 64	0 to 0
	2˚C	14 to 21	2 to 6	0 to 1	9 to 15	3 to 13	41 to 57	27 to 45	0 to 0
	1.5˚C	11 to 17	2 to 4	0 to 0	8 to 12	1 to 8	35 to 47	22 to 38	0 to 0
Near-surface total precipitation (mm/day)	**4˚C**	2 to 3	2 to 3	2 to 2	2 to 3	4 to 5	2 to 3	1 to 2	1 to 1
	3˚C	2 to 3	2 to 3	2 to 2	2 to 3	3 to 5	2 to 3	1 to 2	1 to 1
	2˚C	2 to 3	2 to 3	2 to 2	2 to 3	3 to 5	2 to 3	1 to 2	1 to 1
	1.5˚C	2 to 3	2 to 3	2 to 2	2 to 3	3 to 5	2 to 3	1 to 2	1 to 1
Maximum 1-day precipitation amount (mm)	**4˚C**	35 to 55	40 to 53	27 to 35	36 to 52	47 to 90	29 to 67	43 to 68	9 to 13
	3˚C	31 to 52	34 to 50	23 to 33	30 to 50	37 to 88	25 to 66	38 to 69	8 to 12
	2˚C	29 to 50	32 to 48	22 to 32	28 to 47	37 to 85	22 to 59	36 to 66	8 to 11
	1.5˚C	28 to 48	31 to 47	21 to 31	27 to 45	35 to 84	21 to 58	36 to 64	8 to 11
Maximum 5-day precipitation amount (mm)	**4˚C**	79 to 99	75 to 93	53 to 71	81 to 105	118 to 168	68 to 113	81 to 124	20 to 29
	3˚C	66 to 99	68 to 87	48 to 68	70 to 101	97 to 165	60 to 118	76 to 129	19 to 27
	2˚C	64 to 93	65 to 84	47 to 65	66 to 95	93 to 162	55 to 107	73 to 122	18 to 26
	1.5˚C	63 to 91	63 to 83	46 to 64	64 to 93	92 to 160	52 to 105	74 to 119	18 to 25
Consecutive dry days (precipitation < 1 mm)	**4˚C**	36 to 80	23 to 31	26 to 38	35 to 68	31 to 88	48 to 146	45 to 109	44 to 99
	3˚C	36 to 88	21 to 33	25 to 43	35 to 76	29 to 82	49 to 160	40 to 127	45 to 120
	2˚C	37 to 88	21 to 32	24 to 40	36 to 74	29 to 77	49 to 161	38 to 128	45 to 127
	1.5˚C	36 to 87	22 to 31	25 to 37	36 to 74	28 to 77	49 to 159	40 to 125	46 to 131

Table Cross-Chapter Box CLIMATE.3b: Projected sea surface temperature change ranges by global warming level and ocean biome (degrees Celsius). Ranges are 5th and 95th percentiles from SSP5-8.5 WGI CMIP6 ensemble results. There is little variation in the 5th and 95th percentile values by GWL across the SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 projections. *Source: WGI AR6 Interactive Atlas* (*https://interactive-atlas.ipcc.Chapter/*).

Global warming level	All ocean biomes	Northern Hemisphere - High Latitudes	Northern Hemisphere - Subtropics	Equatorial	Southern Hemisphere - Subtropics	Southern Hemisphere - High Latitudes	Gulf of Mexico	Eastern Boundaries	Amazon River	Arabian Sea	Indonesian Flowthrough
4˚C	1.9 to 2.4	2.0 to 3.3	2.2 to 2.8	2.1 to 3.0	1.8 to 2.4	1.3 to 2.0	2.1 to 2.8	2.1 to 2.7	1.7 to 2.5	2.3 to 2.9	1.9 to 2.7

3˚C	1.3	to	1.7	1.2	to	2.2	1.4	to	2.4	1.4	to	2.2	1.2	to	1.7	0.7	to	1.4	1.5	to	2.3	1.4	to	2.1	1.2	to	2.0	1.6	to	2.2	1.3	to	1.9
2˚C	0.6	to	1.0	0.5	to	1.4	0.7	to	1.4	0.7	to	1.3	0.5	to	1	0.3	to	0.8	0.6	to	1.4	0.6	to	1.3	0.6	to	1.3	0.6	to	1.3	0.5	to	1.2
1.5˚C	0.2	to	0.7	0.1	to	0.9	0.2	to	1.0	0.2	to	0.8	0.2	to	0.6	0.1	to	0.5	0.2	to	1.0	0.2	to	0.9	0.2	to	0.9	0.2	to	0.9	0.1	to	0.8

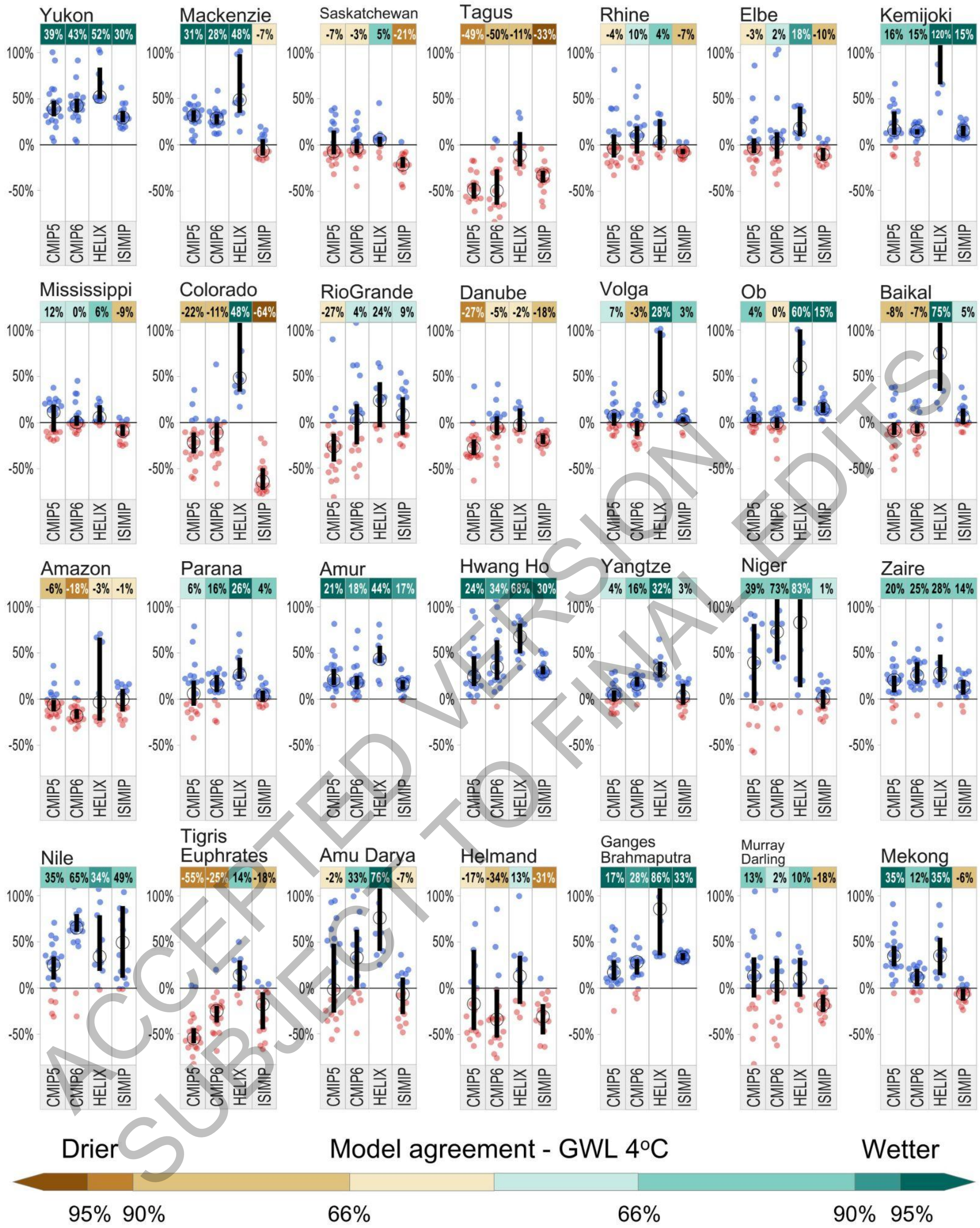

Figure Cross-Chapter Box CLIMATE.1: Illustration of the use of Global Warming Levels (GWLs) as a dimension of integration for impact studies: projected changes in river flows in major basins at 4°C global warming from four different multi-model ensembles. Results are shown for projected flow changes direct from Earth System Models (ESMs) in CMIP5 and CMIP6, for the JULES (Joint UK Land Environment Simulator) land surface model driven by meteorological outputs of the HadGEM3 and EC-Earth model in the HELIX (High-End cLimate Impacts and eXtremes) ensemble (Betts et al., 2018; Koutroulis et al., 2019), and 9 hydrological models driven by a subset of 5 CMIP5 ESMs in the Inter-Sectoral Impacts Model Intercomparison Project (ISIMIP; Warszawski et al., 2014). Dots show results from individual models, blue for increased flows and red for decreased flows, black circles show the median for each ensemble, and black bars show the 95% confidence range in the median. See Chapter 4 Figure 4.11 for further details.

To contextualize reported impacts by warming level for the influence of other determinants of risk where appropriate and feasible (e.g., level of exposure/vulnerability, level of adaptation, time period), common time periods for the past and future are available to align with WGI's historical and projected time windows. Given differences in available literature, WGII chapters and CCPs contextualize impacts with respect to exposure, vulnerability and adaptation as they see fit and appropriate for their literature.

Common ranges for other "climate" variables, such as min/max temperature and regional climates, are available based on WGI projections, with feasible combinations with GWLs taken into consideration using the WGI Interactive Atlas. Climate information translation may have been necessary within chapters for mapping the WGII literature and assessments to the common climate dimensions. WGII's climate impacts literature is based primarily on climate projections circa AR5 and earlier or assumed temperature levels, though some recent impacts literature uses newer climate projections based on the CMIP6 exercise. Thus, it was important to be able to map climate variable levels to climate projections of different vintages and vice versa and adjust variables, when possible, to a common reference year. Note that WGII Chapters and CCPs only provide climate impact information for the common climate dimensions that their literature supports and only provide information for dimensions where there is sufficient evidence.

Interpretation of the update in projected time of reaching 1.5°C global warming from SR1.5 to AR6

In an assessment using multiple lines of evidence including models, observational constraints and improved understanding of climate sensitivity, WG1 project a central estimate of the 20-year average warming crossing the 1.5°C GWL in the early 2030s in all scenarios assessed except SSP5-8.5 (Lee et al., 2021). This is about ten years earlier than the midpoint of the likely range (2030–2052) assessed in the SR1.5, which assumed continuation of the observed warming rate reported at that time. However, this does not imply that the projected impacts of 1.5°C will be reached ten years earlier, because roughly half of the ten-year difference is a result of updating the diagnosed historical rate of warming due to methodological advances, new datasets and other improvements (Gulev et al., 2021). The other half of the ten-year difference arises because, for central estimates of climate sensitivity, most scenarios show stronger warming over the near term than was assessed as 'current' in SR1.5 (*medium confidence*).

The revised historical warming rate does not necessarily contribute to a change in timing of estimated impacts. It depends on how impacts are calculated relative to climate. Because the revised historical warming results in a redefinition of the 1.5°C GWL relative to the modern time period (1995-2014) rather than a different level of overall change (Figure Cross-Chapter Box CLIMATE.2), impacts assessed relative to the modern time period are unaffected. There are, in effect 'old' and 'new' definitions of the 1.5°C GWL with different levels of impacts, and the impacts assessed for the 'old' 1.5°C GWL now apply to a different level of global warming. However, the timing of impacts assessed relative to pre-industrial (e.g., aggregate economic impact estimates), are affected and we are closer to impact levels associated with 1.5°C and 2°C.

To illustrate with a worked example: in SR1.5, the historical warming between 1850-1900 and the modern period of 2006-2015 was assessed as 0.87°C, implying that the 1.5°C GWL would be accompanied by impacts associated with 0.63°C warming from the modern period. However, AR6 WG1 (Gulev et al., 2021) revised the assessment of warming between 1850-1900 and 2006-2015 to 0.94°C, implying that the 1.5°C GWL would be accompanied by a slightly lower level of impacts associated with only 0.56°C warming from the modern period. So, while the redefined 1.5°C GWL would be reached earlier, it would also be accompanied by a lower level of impacts (Figure Cross-Chapter Box CLIMATE.2). The impacts associated with the 'old' 1.5°C GWL would now be seen at 1.57°C global warming relative to 1850-1900, reached at the time of the 'old' 1.5°C GWL, if the same future level of warming were to be used as in SR1.5.

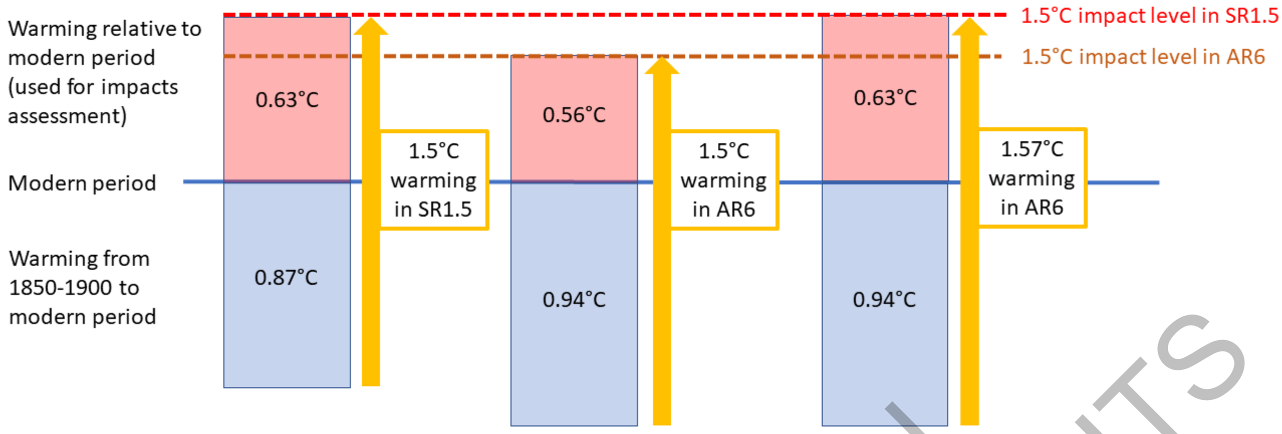

Figure Cross-Chapter Box CLIMATE.2: Definitions of the 1.5°C Global Warming Level (GWL) in SR1.5 and AR6 WG1. GWLs are defined relative to 1850-1900 but impacts at the GWL are typically assessed in association with warming relative to a modern period 1995-2014, which in SR1.5 was 2006-2015. Revised assessment of the historical warming between 1850-1900 and the modern period (0.87°C in SR1.5 to 0.94°C in AR6) has the effect of slightly reducing the warming between the modern period and the 1.5°C GWL (0.63°C in SR1.5 to 0.56°C in AR6), and the impacts at the GWL previously defined as 1.5°C in SR1.5 now occur at 1.57°C global warming with the AR6 definition. Warming values are central estimates. Heights of the bars are not to scale.

However, in addition to this redefinition of the historical warming rate, the assessed future warming in AR6 is also slightly faster than the continuation of reported recent warming used in SR1.5. This means that both the 'old' and 'new' 1.5°C GWLs are projected to be reached earlier than they would have been using the SR1.5 method. This and the revised historical warming diagnosis contribute approximately equally to the assessment of 1.5°C global warming being reached about ten years earlier than projected in SR1.5.

Central estimates of impacts associated with a specifically defined 1.5°C GWL could therefore be considered to be projected to be reached approximately 5 years earlier than implied by SR1.5. However, uncertainties in regional climate responses at a given GWL are large (Table Cross-Chapter Box CLIMATE.3a) and natural climate variability occurs in parallel with ongoing warming, so the potential for impacts higher than central estimates could be a more urgent consideration for risk assessments and adaptation planning than the earlier projected timing of reaching 1.5°C (*high confidence*). It should also be noted that individual years may exceed 1.5°C above 1850-1900 sooner, but this is not the same as exceedance of the 1.5°C GWL which refers to the 20-year mean.

[END CROSS-CHAPTER BOX CLIMATE HERE]

1.3 Understanding and Evaluating Climate Risks

Understanding of climate change has advanced in important ways that shape the AR6 assessment. This section describes advances in the understanding of the complex nature of climate change risks, the deep integration of social sciences, and increased utilization of Indigenous knowledge and local knowledge. These multifaceted dimensions of understanding climate change and evaluating risks are introduced here.

1.3.1 Nature of Climate Risk

Since AR5, understanding of the nature of climate risk has advanced substantially. The AR6 assesses the serious, complex, and cascading climate risks unfolding across sectors and regions. These risks are shaped by many societal factors including cultural norms and social practice, socioeconomic development, underlying physical and social vulnerability, and societal responses themselves (Section 1.2.1.1). Throughout, there is increased attention to the important role of different forms of knowledge, especially Indigenous knowledge and local knowledge, in the understanding and the management of the changing climate.

1.3.1.1 The Nature of Climate Risk as Assessed in this Report

Greater understanding of climate-related risks is emerging; however, there are important shortcomings for the information in some regions and sectors and for developing versus developed countries. These risks assume significance in interaction with the cultures, values, ethics, identities, experiences, and knowledge systems of affected communities and societies, as well as their governance, finances, capabilities, and resources. The key risk assessment in the IPCC AR5 informed the long-term temperature goal in the 2015 Paris Agreement—limiting the increase in global mean temperature to well below 2°C and pursuing efforts towards limiting warming to 1.5°C (Oppenheimer et al., 2014; Pachauri et al., 2014). The IPCC Special Report on Global Warming of 1.5°C, responding to an invitation by UNFCCC, used new scientific information to provide a specific risk assessment associated with the ambitious warming levels targeted by the Paris Agreement (Hoegh-Guldberg et al., 2019), and the Special Reports on Oceans and Land further advanced the methods of transparent risk assessment (Zommers et al., 2020). The current assessment expands significantly from the previous reports, aiming to inform and advance understanding of the following core themes: (1) the ways changes in vulnerability and exposure modulate risks of climate change impacts and risk complexity in addition to warming; (2) the knowledge basis relevant to continued refinement of temperature goals; (3) the effectiveness of adaptation solutions; (4) the management of risks at higher levels of warming, should ambitious climate change mitigation be unsuccessful, including limits to adaptation; and (5) the benefits of climate change mitigation and emissions reductions (Section 16.1).

This report evaluates key risks—potentially severe risks—meriting society's full attention globally and regionally across sectors, in order to inform judgments about dangerous anthropogenic interference with the climate system (Mach et al., 2016; Oppenheimer et al., 2014; see also Sections 16.1.2 and 16.4; WGI AR6 Section 1.2.4.1). As described detail in Chapter 16, evaluation of key risks is based on expert judgment applied to all relevant lines of evidence, with attention to the role of societal values in determining the importance of a risk. Specific criteria considered relate to the magnitude of adverse consequences, including the potential for irreversibility, thresholds, or cascading effects; the likelihood of adverse consequences; the timing of the risk; and the ability to respond to the risk (Section 16.5.1).

The key risk assessment conveys increasing urgency given the growing visibility of climate change impacts in the current world (Sections 1.1 and 16.1). Representative key risks emerging across sectors and regions include risks to coastal socio-ecological systems and terrestrial and ocean ecosystems, risks associated with critical infrastructure, networks, and services; risks to living standards and human health; risks to food and water security; and risks to peace and migration (Section 16.5). Compared to the AR5, the emphasis on human dimensions of key climate-related risks has continued and increased, for instance the potentially severe impacts for cultural heritage (IPCC, 2014c; Pachauri et al., 2014; see also Section 16.4). These human dimensions are essential for understanding vulnerability, impacts, and risks central to ensuring human well-being, human security, sustainable development, and poverty reduction in a changing climate.

To encompass the nature of climate risk, IPCC assessment since the Third Assessment Report has used five overarching domains, named "reasons for concern", to assess increasing risk for societies and ecosystems under climate change (IPCC, 2014b; O'Neill et al., 2017; see also Section 16.5; WGI AR6 Section 1.2.4.1). The reasons-for-concern approach has enabled evidence to combine with expert judgment, in order to provide a holistic assessment across multiple lines of evidence (O'Neill et al., 2017). The approach also respects the uncertainties inherent to climate risk and highlights the ways in which values are relevant in connecting scientific knowledge to societal decision-making and risk management. The different reasons for concern underscore that there is no single metric that can reflect all dimensions of climate-related risk and the diversity of consequences for lives and livelihoods, health and well-being, economic and sociocultural assets, infrastructure, and ecosystems (Mach and Field, 2017; see also Section 1.4.1.2).

The AR6 Reasons for Concern framework enables integration across key risks and representative key risks, including how risks vary with the magnitude of global warming, socioeconomic development pathways, and levels of adaptation (Section 16.6). Risk levels are determined through a formal elicitation approach for both representative key risks and reasons for concern, following the authors' assessment of the literature. The reasons for concern consider *unique and threatened systems* (RFC1), such as coral reefs or Arctic Sea ice systems that have especially high vulnerability and low capacity to adapt. They also include the role of *extreme weather events* (RFC2), such as heat waves, heavy rain, drought, coastal flooding, or wildfires. The reasons for concern address both the *distributional* and the *aggregate impacts* of climate change (RFC3, RFC4), including the unfairness factor for populations that have contributed little in terms of historic emissions but that are disproportionately vulnerable to the impacts of a changing climate. The final reason for concern relates to *large-scale singular events*, nonlinearities, and tipping points (RFC5), including ice sheet collapse and ecosystem regime shifts.

1.3.1.2 The Complexities of Climate Risk

The AR6 assessment incorporates the inherently complex nature of climate risk, vulnerability, exposure, and impacts, which includes feedbacks, cascades, non-linear behaviour, and the potential for surprise (Figure 1.3, 1.4). Many different overlapping and complementary terms and methods are used to evaluate and understand complex climate risk relevant to this report, such as aggregated, compounding, or cascading risks, all of which are considered here as relevant to complex climate risk (Pescaroli and Alexander, 2018; Simpson, In review).

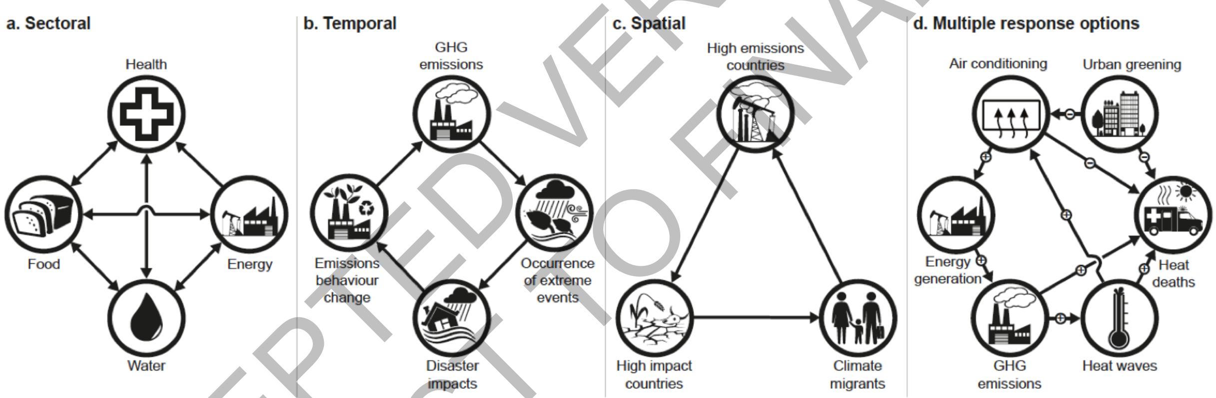

Figure 1.3: Different interactions can decrease or increase climate-related risks. Key examples include interactions (a) among sectors, (b) through time, (c) across regions, or (d) between impacts and responses. The specific interactions indicated within each panel of this figure are illustrative, not comprehensive or indicative of relative importance. Source: (Simpson, In review)

The dynamic nature of risk and its determinants is one important dimension of complexity. The risk of climate change impacts can be usefully understood as resulting from dynamic interactions among climate-related hazards, the exposure and vulnerability of affected human and ecological systems, and also responses (see AR6 Glossary; Section 1.2.1; WGI AR6 Cross-Chapter Box 2 in Chapter 1; Oppenheimer et al., 2014). The determinants of risk all can vary and change through space and time in response to socioeconomic development and decision-making (Figures 1.4 and 1.5, Section 16.1). Hazards are affected by current and future changes in climate, including altered climate variability and shifts in frequency and intensity of extreme events (WGI AR6 Chapter 12). Such hazards can be sudden, e.g., a heat wave or heavy rain event, or slower onset, e.g., land loss, degradation, and erosion linked to multiple climate hazards compounding. The severity of climate change impacts will depend strongly on vulnerability, which is also dynamic and includes the sensitivity and adaptive capacity of affected human and ecological systems (Ford et al., 2018; Jurgilevich et al., 2017; McDowell et al., 2016; Viner et al., 2020). As a result, risks vary at fine scale across communities and societies and also among people within societies, for example dependent on intersecting inequalities and context-specific factors such as culture, gender, religion, ability and disability, or ethnicity (Carr and Thompson, 2014; Jones and Boyd, 2011; Kuruppu, 2009; also Section 16.1.4). The dynamic social distribution of impacts is the subject of increasing attention within climate assessment and responses), including the role of adaptation, iterative risk management, and climate-resilient sustainable development (Section 16.1).

Another core area of complexity in climate risk is the behaviour of complex systems, which includes multiple stressors unfolding together, cascading or compounding interactions, and non-linear responses and the potential for surprises (Clarke et al., 2018; Kopp et al., 2017; Yokohata et al., 2019). Risks and responses, including their determinants, can all interact dynamically in shaping the complexity of climate risk (Figure 1.4). The combined effects of multiple stressors or compound hazards and risks are unlikely to be assessed through simple addition of the independent effects and instead require system approaches to understanding risk. While some components may cancel out each other, others may non-linearly increase risk. Non-linearities can result from abrupt climate changes, tipping points or thresholds in responses, alternative stable states, low-probability/high-consequence outcomes, or events that cannot be predicted based on current understanding (WGI AR6 Section 1.4.4.3).

The nature of climate risk also involves risks from responses themselves (Figure 1.4). The risks of climate change responses include the possibility of responses not achieving their intended objectives or having trade-offs or adverse side effects for other societal objectives (Annex II: Glossary; Section 16.1). In particular, human responses may create novel hazards and unexpected side effects and entail opportunity costs and path dependencies (Boonstra, 2016). Such feedback loops can unfold at local and global scales, including large-scale interactions among climate, ecological, and human systems with human behaviour and decision-making affecting such interactions. Response risks can originate from uncertainty in implementation, maladaptation, action effectiveness, technology development or adoption, or transitions in systems (see Sections 1.4 and 1.5). Typical risks may be related to regulation, litigation, competition, socio-politics, or reputation. Interactions across responses can importantly involve co-benefits for other objectives, such as for human health and well-being which may be improved from both reduced air pollution (e.g., WGI Chapter 6, WGIII) and enhanced adaptation to climate change. The nature of risk also entails residual impacts that will occur even with ambitious societal responses, given limits to adaptation at sectoral and regional levels (Section 1.4, Sections 16.1 and 16.4). In some cases, the losses will be irreversible.

Due to these complexities, the challenge of assessing risks of climate change is not well bounded, will be framed differently by individuals and groups, involves large and deep uncertainties, and will have unclear solutions and pathways to solutions (Renn, 2008; Rittel and Webber, 1973; see also Sections 1.5.2 and 17.2.1). Challenges also include the degree to which time is running out, there is no central authority, those seeking the solutions are also causing the problem, and the present is favoured over the future (Sun and Yang, 2016; see also Section 17.2.1). Both the needs for and the limits to adaptation responses fundamentally depend on progress achieved in reducing greenhouse gas emissions and limiting the magnitude of climate change that occurs, interlinked with socioeconomic development trajectories and the many social and political factors shaping climate risks and responses.

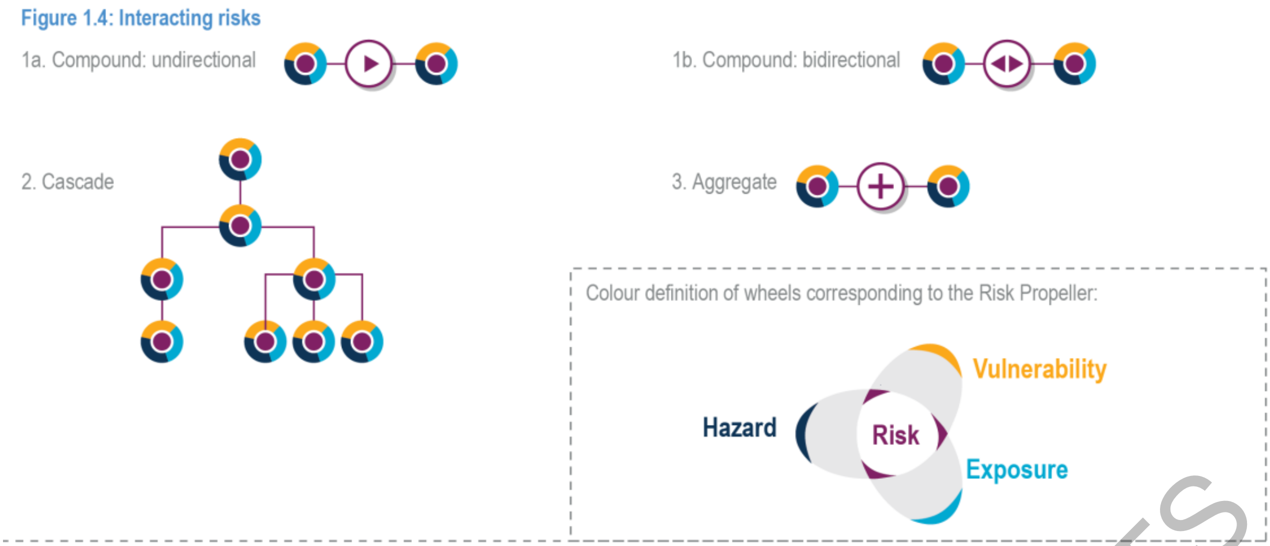

Figure 1.4: Increasingly complex climate-related risks. Risk results from interactions among the determinants of risk—hazard, vulnerability, and exposure, shaped by responses—which can interact in complex ways. Different risks and responses can compound (e.g., often linked to compounding hazards; 1a and 1b), cascade (e.g., with one event triggering another; 2), and aggregate (e.g., with independent determinants of risks co-occurring; 3). This complex nature of risk is central in the AR6 assessment. Figure adapted from Simpson et al., 2021.

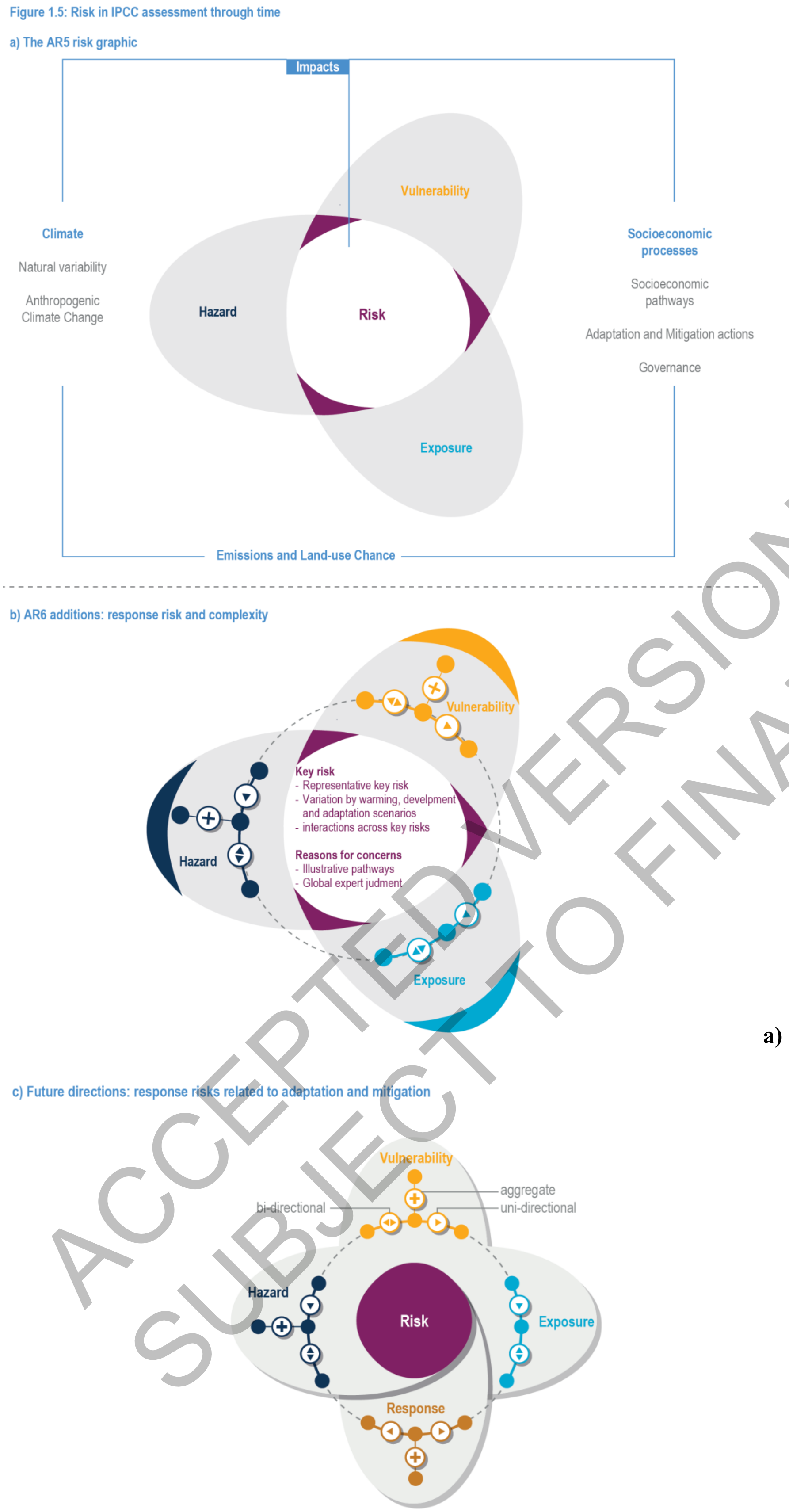

Figure 1.5: Risk in IPCC assessment through time. (a) An explicit risk framing emerged in the IPCC SREX and WGII AR5. (b) In the current assessment, the role of responses in modulating the determinants of risk is a new emphasis (the "wings" of the hazard, vulnerability, and exposure "propellers" represents the ways in which responses modulate each of these risk determinants). (c) As the risk assessment spans working groups, the differential role of risk determinants for risk related to impacts, adaptation, and vulnerability versus risk related to mitigation becomes an increasingly important feature of climate risk assessment as well as management.

1.3.2 Assessing, Evaluating, and Understanding Climate Impacts and Risks

Multiple, diverse sources of information underlie our understanding of climate risks and response, including climate change science, diverse social sciences, and Indigenous knowledge and local knowledge.

1.3.2.1 Detection and Attribution of Climate Change and Its Impacts

Anthropogenic climate change is unequivocal and ongoing. The detection of specific changes in the climate and their diverse impacts on people and nature is advancing, with robust attribution of climate change to greenhouse gas emissions as well as to other contributing factors (e.g., socio-economic development, land-use change). In the AR6, advances include increasing ability to link individual extreme weather and climate events to emissions of greenhouse gases, increasing identification of impacts for societies and economies, and strong linkages in the attribution methods across working groups (Cross-Working Group Box: ATTRIBUTION in Chapter 1).

[START CROSS-WORKING GROUP BOX: ATTRIBUTION HERE]

Cross-Working Group Box: ATTRIBUTION: Attribution in the IPCC Sixth Assessment Report

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Introduction

Changes in the climate system are becoming increasingly apparent, as are the climate-related impacts on natural and human systems. Attribution is the process of evaluating the contribution of one or more causal factors to such observed changes or events. Typical questions addressed by the IPCC are for example: 'To what degree is an observed change in global temperature induced by anthropogenic greenhouse gas and aerosol concentration changes or influenced by natural variability?' or 'What is the contribution of climate change to observed changes in crop yields that are also influenced by changes in agricultural management?' Changes in the occurrence and intensity of extreme events can also be attributed, addressing questions such as: 'Have human greenhouse gas emissions increased the likelihood or intensity of an observed heat wave?'

This Cross-Working Group Box briefly describes why attribution studies are important. It also describes some new developments in the methods used and provides recommendations for interpretation.

Attribution studies serve to evaluate and communicate linkages associated with climate change, for example: between the human-induced increase in greenhouse gas concentrations and the observed increase in air temperature or extreme weather events (WGI Chapters 3, 10 and 11); or between observed changes in climate and changing species distributions and food production (e.g., Verschuur et al., 2021; WGII Chapter 2 and others; summarised in Chapter 16) or between climate change mitigation policies and atmospheric greenhouse gas concentrations (WGI Chapter 5; WGIII Chapter 14). As such, they support numerous statements made by the IPCC (IPCC, 2013; IPCC, 2014c; WGI Section 1.3; Appendix 1A) (IPCC, 2013b, 2014b; WGI Chapter 1, Section 1.3, Appendix 1A).

Attribution assessments can also serve to monitor mitigation and assess the efficacy of applied climate protection policies (e.g., Banerjee et al., 2020; Nauels et al., 2019; WGI Section 4.6.3)), inform and constrain projections (Gillett et al., 2021; Ribes et al., 2021; WGI Section 4.2.3) or inform the loss and damages estimates and potential climate litigation cases by estimating the costs of climate change (Frame et al., 2020; Huggel et al., 2015; Marjanac et al., 2017). These findings can thus inform mitigation decisions as well as risk management and adaptation planning (e.g., Climate & Development Knowledge Network, 2017).

Steps towards an attribution assessment

The unambiguous framing of what is being attributed to what is a crucial first step for an assessment (Easterling et al., 2016; Hansen et al., 2016; Stone et al., 2021), followed by the identification of the possible and plausible drivers of change and the development of a hypothesis or theory for the linkage (see Figure ATTRIBUTION.1). The next step is to clearly define the indicators of the observed change or event and note the quality of the observations. There has been significant progress in the compilation of fragmented and distributed observational data, broadening and deepening the data basis for attribution research (Cohen et al., 2018; Poloczanska et al., 2013; Ray et al., 2015; WGI Section 1.5). The quality of the observational record of drivers should also be considered (e.g., volcanic eruptions: WGI Chapter 2, Section 2.2.2). Impacted systems also change in the absence of climate change; this baseline and its associated modifiers such as agricultural developments or population growth need to be considered, alongside the exposure and vulnerability of people depending on these systems.

There are many attribution approaches, and several methods are detailed below. In physical and biological systems, attribution often builds on the understanding of the mechanisms behind the observed changes and numerical models are used, while in human systems other methods of evidence-building are employed. Confidence in the attribution can be increased if more than one approach is used and the model is evaluated as fit-for-purpose (Hegerl et al., 2010; Otto et al., 2020a; Philip et al., 2020; Vautard et al., 2019; WGI Section 1.5). Finally, appropriate communication of the attribution assessment and the accompanying confidence in the result (e.g., Lewis et al., 2019).

Attribution methods

Attribution of changes in atmospheric greenhouse gas concentrations to anthropogenic activity

AR6 WGI Chapter 5 presents multiple lines of evidence that unequivocally establish the dominant role of human activities in the growth of atmospheric CO_2, including through analysing changes in atmospheric carbon isotope ratios and the atmospheric O_2-N_2 ratio (WGI Section 5.2.1.1). Decomposition approaches can be used to attribute emissions underlying those changes to various drivers such as population, energy efficiency, consumption or carbon intensity (Hoekstra and van den Bergh, 2003; Raupach et al., 2007; Rosa and Dietz, 2012). Combined with attribution of their climate outcomes, the attribution of the sources of greenhouse gas emissions can inform the attribution of anthropogenic climate change to specific countries or actors (Matthews, 2016; Nauels et al., 2019; Otto et al., 2017; Skeie et al., 2017), and in turn inform discussions on fairness and burden sharing (WGIII Chapter 14).

Attribution of observed climate change to anthropogenic forcing

Changes in large-scale climate variables (e.g., global mean temperature) have been reliably attributed to anthropogenic and natural forcings (e.g., Bindoff and et al., 2014; Hegerl et al., 2010; WGI Section 1.3.4). The most established method is to identify the 'fingerprint' of the expected space-time response to a particular climate forcing agent such as the concentration of anthropogenically induced greenhouse gases or aerosols, or natural variation of solar radiation. This technique disentangles the contribution of individual forcing agents to an observed change (e.g., Gillett et al., 2021). New statistical approaches have been applied to better account for internal climate variability and the uncertainties in models and observations (e.g., Naveau et al., 2018; Santer et al., 2019; WGI Section 3.2). There are many other approaches, for example, global mean sea-level change has been attributed to anthropogenic climate forcing by attributing the individual contributions from, for example, glacier melt or thermal expansion, while also examining which aspects of the observed change are inconsistent with internal variability (WGI Section 3.5.2 and WGI Section 9.6.1.4).

Specific regional conditions and responses may simplify or complicate attribution on those scales. For example, some human forcings, such as regional land use change or aerosols, may enhance or reduce regional signals of change (Boé et al., 2020; Lejeune et al., 2018; Thiery et al., 2020; Undorf et al., 2018; see also WGI Sections 10.4.2, 11.1.6, and 11.2.2). In general, regional climate variations are larger than the global mean climate, adding additional uncertainty to attribution (e.g., in regional sea-level change, WGI Section 9.6.1). These statistical limitations may be reduced by 'process-based attribution', focusing on the physical processes known to influence the response to external forcing and internal variability (WGI Section 10.4.2).

Attribution of weather and climate events to anthropogenic forcing

New methods have emerged since AR5 to attribute the change in likelihood or characteristics of weather or climate events or classes of events to underlying drivers (Jézéquel et al., 2018; National Academies of Sciences, 2016; Stott et al., 2016; Wang et al., 2020; Wehner et al., 2019; WGI Sections 10.4.1 and 11.2.2). Typically, historical changes, simulated under observed forcings, are compared to a counterfactual climate simulated in the absence of anthropogenic forcing. Another approach examines facets of the weather and thermodynamic status of an event through process-based attribution (Grose et al., 2020; Hauser et al., 2016; Shepherd et al., 2018; WGI Section 10.4.1 and Chapter 11). Events where attributable human influences have been found include hot and cold temperature extremes (including some with wide-spread impacts), heavy precipitation, and certain types of droughts and tropical cyclones (e.g., Herring et al., 2021; Vogel et al., 2019; WGI Section 11.9). Event attribution techniques have sometimes been extended to 'end-to-end' assessments from climate forcing to the impacts of events on natural or human systems (Otto et al., 2017; examples in WGII Table 16.1, SI of WGII Chapter 16, Section 16.2).

Attribution of observed changes in natural or human systems to climate-related drivers

The attribution of observed changes to climate-related drivers across a diverse set of sectors, regions and systems is part of each chapter in the WGII contribution to the AR6 and is synthesised in WGII Chapter 16 (Section 16.2). The number of attribution studies on climate change impacts has grown substantially since AR5, generally leading to higher confidence levels in attributing the causes of specific impacts. New studies include the attribution of changes in socio-economic indicators such as economic damages due to river floods (e.g., Sauer et al., 2021; Schaller et al., 2016), the occurrence of heat related human mortality (e.g., Sera et al., 2020; Vicedo-Cabrera et al., 2018), or economic inequality (e.g., Diffenbaugh and Burke, 2019).

Impact attribution covers a diverse set of qualitative and quantitative approaches, building on experimental approaches, observations from remote sensing, long-term in situ observations, and monitoring efforts, teamed with local knowledge, process understanding and empirical or dynamical modelling (WGII Section 16.2; Cramer et al., 2014; Stone et al., 2013). The attribution of a change in a natural or human system (e.g., wild species, natural ecosystems, crop yields, economic development, infrastructure or human health) to changes in climate-related systems (i.e., climate, and ocean acidification, permafrost thawing or sea-level rise) requires accounting for other potential drivers of change, such as technological and economic changes in agriculture affecting crop production (Butler et al., 2018; Hochman et al., 2017), changes in human population patterns and vulnerability affecting flood or wildfire induced damages (Huggel et al., 2015; Sauer et al., 2021), or habitat loss driving declines in wild species (IPBES, 2019b). These drivers are accounted for by estimating a baseline condition that would exist in the absence of climate change. The baseline might be stationary and be approximated by observations from the past, or it may change over time and be simulated by statistical or process-based impact models (Cramer et al., 2014; WGII Section 16.2). Assessment of multiple independent lines of evidence, taken together, can provide rigorous attribution when more quantitative approaches are not available (Parmesan et al., 2013). These include palaeodata, physiological and ecological experiments, natural 'experiments' from very long-term datasets indicating consistent responses to the same climate trend/event, and 'fingerprints' in species' responses that are uniquely expected from climate change (e.g. poleward range boundaries expanding and equatorial range boundaries contracting in a coherent pattern world-wide, Parmesan and Yohe, 2003). Meta-analyses of species/ecosystem responses, when conducted with wide geographic coverage, also provide a globally coherent signal of climate change at an appropriate scale for attribution to anthropogenic climate change (Parmesan et al., 2013; Parmesan and Yohe, 2003).

Impact attribution does not always involve attribution to anthropogenic climate forcing. However, a growing number of studies include this aspect (e.g., Diffenbaugh and Burke, 2019 for the attribution of economic inequality between countries; Frame et al., 2020 for the attribution of damages induced by Hurricane Harvey; or Schaller et al., 2016for flood damages).

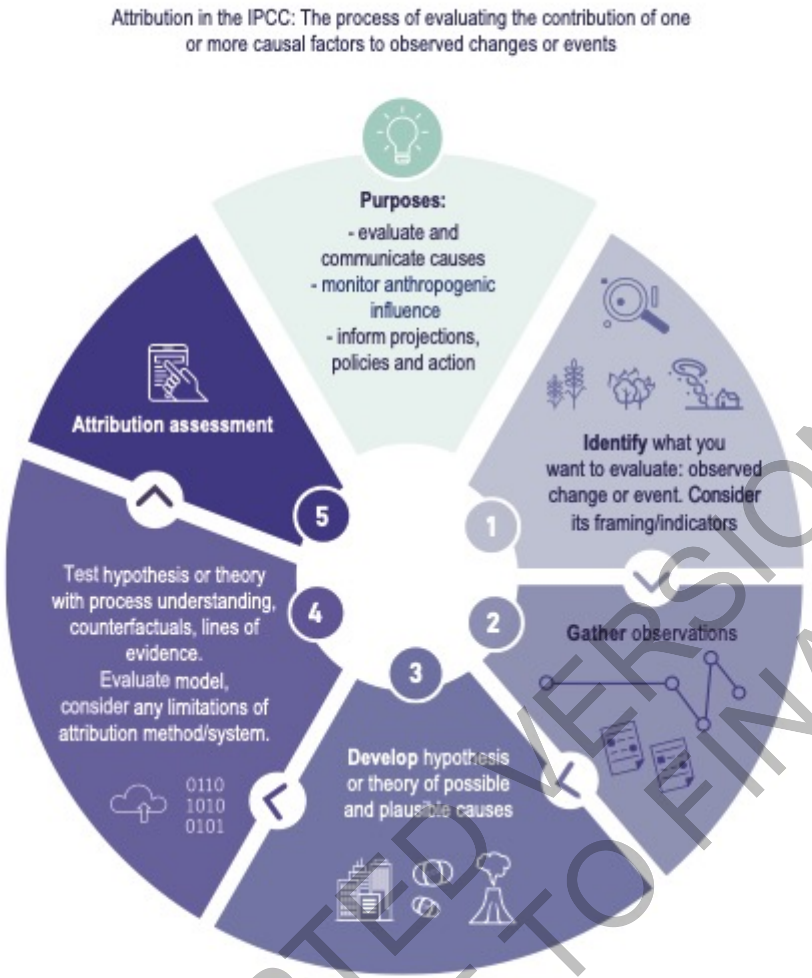

Figure Cross-Working Group Box: ATTRIBUTION.1: Schematic of the steps to develop an attribution assessment, and the purposes of such assessments. Methods and systems used to test the attribution hypothesis or theory include model-based fingerprinting, other model-based methods, evidence-based fingerprinting, process-based approaches, empirical or decomposition methods and the use of multiple lines of evidence. Many of the methods are based on the comparison of the observed state of a system to a hypothetical counterfactual world that does not include the driver of interest to help estimate the causes of the observed response.

[END CROSS-WORKING GROUP BOX: ATTRIBUTION HERE]

Impacts occurring today can be put into context through understanding of long-term changes on Earth, introduced in the Cross-Chapter Box PALEO (see below). Climate has always varied and changed in the past, and this change often caused substantial ecological, evolutionary and socio-economic impacts. Adaptation of ecosystems and societies occurred through responses as diverse as migration to mass extinction. Humankind is at the verge of leaving the Holocene climatic envelope, in which all human achievement since the advent of agriculture has occurred. In some systems, the changes and losses will be irreversible.

[START CROSS-CHAPTER BOX PALEO HERE]

Cross-Chapter Box PALEO: Vulnerability and Adaptation to Past Climate Changes

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Understanding how Earth's biota have responded to past climate dynamics is essential to understanding current and future climate-related risks, as well as the adaptive capacity and vulnerabilities of ecosystems and the human livelihoods depending on them. Here we assess climate impacts on long geological time scales (Figure PALEO.1), as well as for the last 70 kyr of *Homo sapiens*' existence (Figure PALEO.2). Climate responses of natural and human systems are intertwined through the physiological limits of wild animals, livestock, plants and humans, subject to a slow evolutionary dynamic (Pörtner, 2021; Sections 2.6.1 and 3.3).

Climate has always changed, often with severe effects on nature, including species loss

Observations provided by the historical, archaeological, and paleontological records, together with paleoclimatic data, demonstrate that climatic variability has high potential to affect biodiversity and human society (*high confidence*). The evolution of the Earth's biota has been punctuated by global biodiversity crises often triggered by rapid warming (*high confidence*) (Benton, 2018; Figure PALEO.1; Bond and Grasby, 2017; Foster et al., 2018). These so-called hyperthermal events were marked by rapid warming of >1°C, which coincided with global disturbances of the carbon and water cycles, and by reduced oxygen and pH in seawater (Clapham and Renne, 2019; Foster et al., 2018). Magnitudes of global temperature shifts in hyperthermal events were sometimes greater than those predicted for the current century but extended over longer periods of time. Rates inferred from paleo records that are coarsely resolved are inevitably lower than those from direct observations during recent decades, and caution must be exercised when describing the rate of recent temperature changes as unprecedented (Kemp et al., 2015). Mass extinctions, each with greater than 70% marine species extinctions, occurred when the magnitude of temperature change exceeded 5.2°C (Song et al., 2021), albeit species extinctions occurred at lower magnitudes of warming (*medium confidence*).

Adaptation options to rapid climate change are limited

Responses of biota to rapid climate change have included range shifts (*very high confidence*), phenotypic plasticity (*high confidence*), evolutionary adaptation (*medium confidence*), and species extinctions, including mass extinctions (*very high confidence*). While knowledge about the relative roles of these processes in promoting survival during times of climate change is still limited (Nogués-Bravo et al., 2018), they have influenced the evolutionary trajectories of species and entire ecosystems (*high confidence*), and also the course of human history (*medium confidence*). The combined ecological and evolutionary responses to ancient rapid warming events ranged from extinction of 81% of marine animal species and 70% of terrestrial tetrapod species on land at the end of the Permian period (~ 252 million years ago, Ma) (Smith and Botha, 2005; Stanley, 2016) to low rates of species extinctions but biome- and range-shifts on land and in the ocean at the Palaeocene-Eocene Thermal Maximum (PETM, ~ 56 Ma) (Figure PALEO.1; Fraser and Lyons, 2020; Huurdeman et al., 2021; Ivany et al., 2018). Temperature and deoxygenation were key drivers of past biotic responses in the oceans (Gibbs et al., 2016; Section 3.3; Penn et al., 2018) (*high confidence*), whereas on land the interplay between temperature and precipitation is less well established in ancient hyperthermals (Frank et al., 2021) (*medium confidence*). Climate-driven extinction risk increased by up to 40% when a short-term climate change added to a long-term trend in the same direction, for example when a long-term warming trend was followed by rapid warming (Mathes et al., 2021).

Organismic traits associated with extinctions during ancient climate changes help identify present-day vulnerabilities and conservation priorities (Barnosky et al., 2017; Calosi et al., 2019; Reddin et al., 2020; Chapters 2 and 3; Cross-Chapter Paper 1). Marine invertebrates and fishes are at greater extinction risk in response to warming than terrestrial ones because of reduced availability of thermal refugia in the sea (Pinsky et al., 2019) (*high confidence*). Terrestrial plants showed reduced extinction during past rapid warming compared to animals (*high confidence*), although they readily adjusted their ranges and reorganized vegetation types (Heimhofer et al., 2018; Huurdeman et al., 2021; Lindström, 2016; Slater et al., 2019; Yu et al., 2015).

Population range shifts including migrations are common adaptations to climate changes across multiple time scales and ecological systems in the past and in response to current warming (*high confidence*). Poleward expansions and retractions (Fordham et al., 2020; Reddin et al., 2018; Williams et al., 2018) as well as migration upslope and downslope in response to warming and cooling were common adaptations (Iglesias et al., 2018; Ortega-Rosas et al., 2008). During warming periods, diversity loss was common near the equator (*medium confidence*)(Kiessling et al., 2012; Kröger, 2017; Yasuhara et al., 2020) while diversity gains and forest expansion occurred in high latitudes (Brovkin et al., 2021). Comparison of contemporary shells and skeletons with historical collections in museums (Barnes et al., 2011) and the analysis of skeletons of long-lived organisms (Cantin et al., 2010) indicate significant climate-induced change in organismic growth rates today (*high agreement, medium confidence*).

Humankind has responded to regional climate variability within a narrow Holocene climatic envelope

Early human evolution (beginning ~2.1 Ma) occurred in a highly variable climate characterized by glacial-interglacial cycles. This variability may have favoured key hominin adaptations such as bipedality, increased brain size, complex sociality, and more diverse tools (Potts, 1998; Potts et al., 2020) (*medium confidence*), but extinctions of five species of *Homo* have also been attributed partly to climate change (Raia et al., 2020) (*low confidence*). The "out-of-Africa" dispersal of anatomically modern humans may have been driven by climate variability (Tierney et al., 2017; Timmermann and Friedrich, 2016) (*medium confidence, low agreement*). Most late Pleistocene megafaunal extinctions are attributed to direct and indirect human impacts (Sandom et al., 2014), although some were likely accelerated by climate change (Carotenuto et al., 2018; Saltré et al., 2019; Wan and Zhang, 2017; Westaway et al., 2017) (*low confidence*).

The emergence of agriculture (~10.2 ka) in SW Asia was associated with stable (within ± 1°C global mean annual on multi-century time scale; *WGI Chapter 2*) warm and moist conditions (Palmisano et al., 2021; Richerson et al., 2001; Rohling et al., 2019). Variability in resource availability and agricultural production, entrained by climatic variability, is implicated in the disruption and decline of numerous past human societies (*medium confidence*) (Cookson et al., 2019; d'Alpoim Guedes and Bocinsky, 2018; Jones, 2019; Park et al., 2019). These crises are partially caused by regional climate anomalies including Holocene "Rapid Climate Change Events" (Rohling et al., 2019) not visible in the globally averaged conditions shown in Fig. Palaeo.2. Such anomalies affected human population size (Clark et al., 2019; Kuil et al., 2019; Riris and Arroyo-Kalin, 2019), health (Campbell and Ludlow, 2020), social stability/conflict (Büntgen et al., 2011; Kohler et al., 2014), and triggered migrations (Chiotis, 2018; D'Andrea et al., 2011; Pei et al., 2018; Schwindt et al., 2016) or retarded them (Betti et al., 2020; FAQ 14.2). Populations have also been impacted by sea-level change in coastal areas (Turney and Brown, 2007; Cross-Chapter Box SLR in Chapter 3).

Evidence for widespread droughts ~4.2 ka lasting for several centuries in some regions has been tentatively linked to declines of the Akkadian Empire (Carolin et al., 2019; Weiss, 2017), the Indus Valley (Giosan et al., 2018; Sengupta et al., 2020) and the Egyptian Old Kingdom and Yangtze River Valley (Ran and Chen, 2019). Deteriorating climates often exacerbate accumulating weaknesses in social systems to which population growth and urban expansion contribute (Knapp and Manning, 2016; Lawrence et al., 2021; Scheffer et al., 2021). The rather narrow climatic niche favoured by human societies over the last six thousand years is poised to move on the Earth's surface at speeds unprecedented in this time span (IPCC, 2021), with consequences for human well-being and migration that could be profound under high-emission scenarios (Xu et al., 2020). This will overturn the long-lasting stability of interactions between humans and domesticated plants and animals as well as challenge the habitability for humans in several world regions (Horton et al., 2021) (*medium confidence*).

Climate change destroys unique natural archives and important cultural heritage sites

Climate change not only impacts past ecosystems and societies but also the remains they have left. The progressive loss of archaeological and historical sites and natural archives of paleo environmental data WGI Chapter 2 constitutes often-overlooked impacts of climate change (Anderson et al., 2017; Climate Change

Cultural Heritage Working Group International, 2019; Cross-Chapter Box SLR in Chapter 3; Hollesen et al., 2018). These archives include peat bogs and coastal archives lost to sea-level rise, droughts and fires, degradation through permafrost thaw, and dissolution. The ancient cultural diversity documented by such sites is an important resource for future adaptation (Burke et al., 2021; Rockman and Hritz, 2020). Since many of these sites constitute anchors for indigenous knowledge, their loss is not just data lost to science; it also interrupts intergenerational transmission of knowledge (Green et al., 2009).

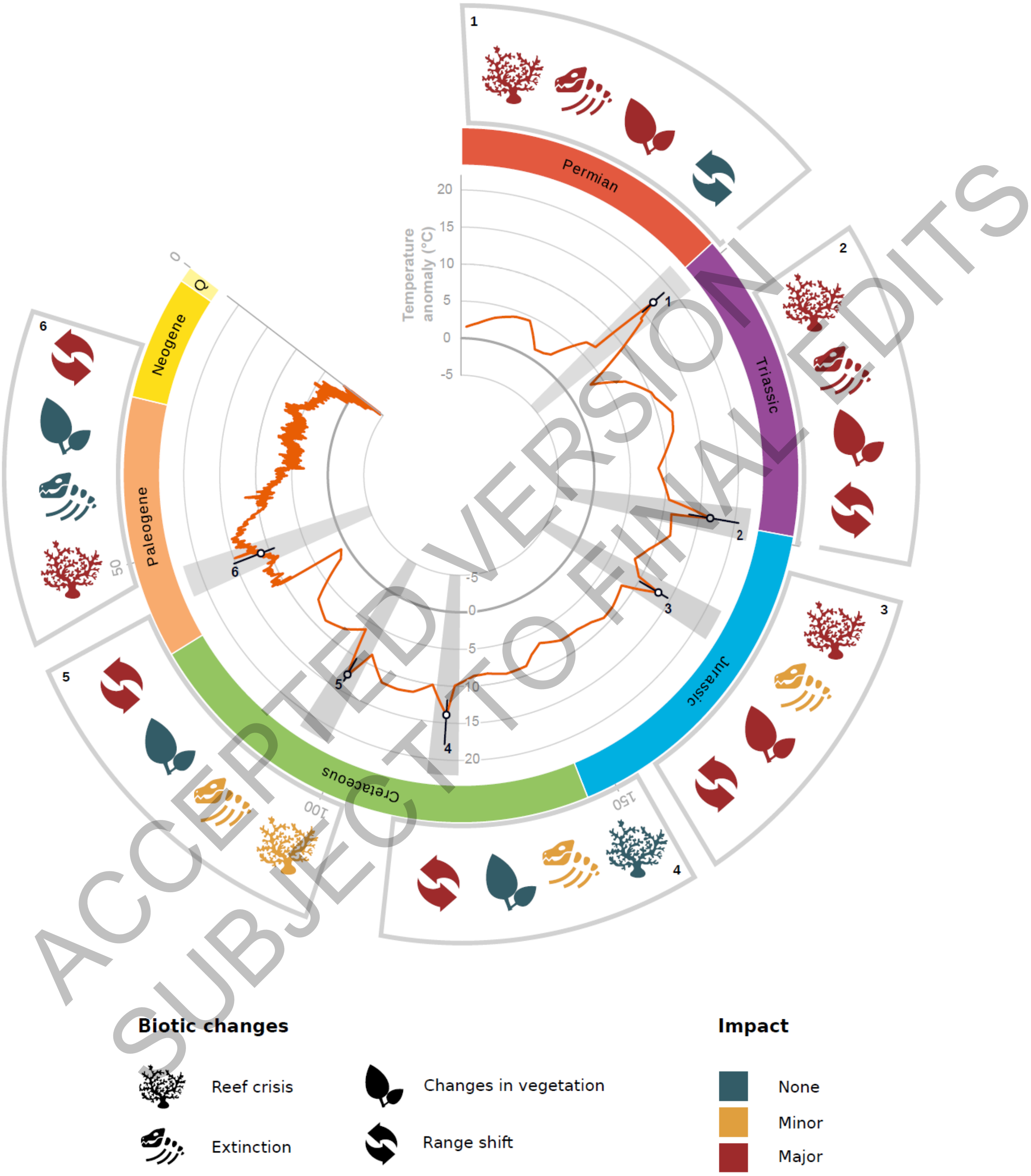

Figure Cross-Chapter Box PALEO.1: Biological responses to six well-known ancient rapid warming events (hyperthermals) over the last 300 million years. Temperature anomalies (mean temperature difference to pre-industrial (1850–1900), solid orange curve) derived from climate modelling (300–66 Ma) (Haywood et al., 2019) and deep-sea proxy data (66–0.1 Ma) (Hansen et al., 2013). Temperature peaks underneath the grey bars indicate well-known hyperthermals with temperature anomalies derived from temperature-sensitive proxy data (Foster et al., 2018). Error bars indicate uncertainties in peak warming events (ranges in the literature). Insets show observed impacts to the biosphere. Q = Quaternary.

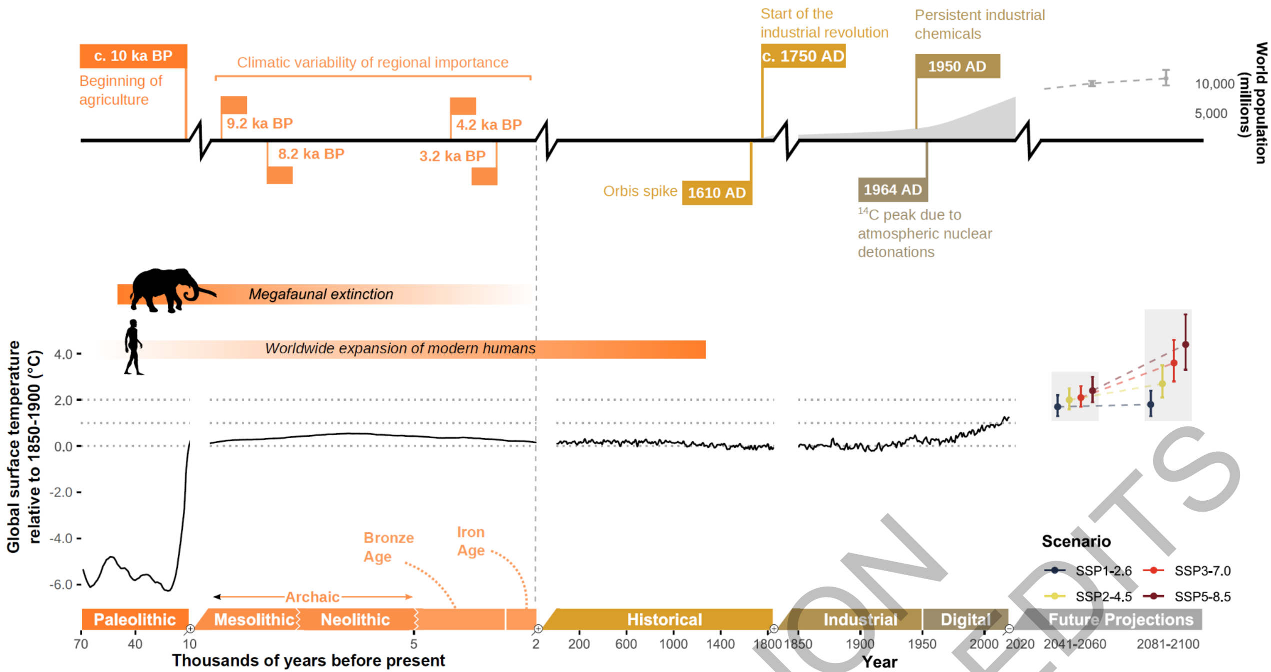

Figure Cross-Chapter Box PALEO 2: Humankind is embarking on a trajectory beyond the global temperatures experienced since at least the advent of agriculture. Global surface temperature change for the last 70,000 years [relative to 1850-1900; data from AR6-WGI-Ch2] alongside projections (with 5-95% range; AR6-WGI-Ch4) and major events in human societies. Global climatic parameters do not always capture regional variability of importance to specific societies. The "Orbis Spike" represents a pronounced dip in atmospheric CO_2 from the Law Dome ice core (Antarctica) (MacFarling Meure et al., 2006) marking the globalization in biota and trade of the Columbian Exchange and population declines and afforestation in the Americas. This, and the 1964 ^{14}C peak, have been suggested as possible markers for the onset of the Anthropocene (Lewis and Maslin, 2015). Population trends from United Nations (2019).

[END CROSS-CHAPTER BOX PALEO HERE]

1.3.2.2 Perceiving Climate Risk and Human Response

Since AR5, social science literature on how individuals and societies perceive and respond to climate risk has dramatically advanced (Jones et al., 2014; Neaves and Royer, 2017; Renn, 2008; Taylor et al., 2014; Van Valkengoed and Steg, 2019). The literature is increasingly integrating and advancing long-standing scholarship on environmental and social governance, human dimensions of environmental change, risk perception and communication, and enabling conditions for effective policy making. These emergent literatures on climate risk, human action, and solution reflect into three broad areas of analysis: 1) root drivers (i.e., role of cultural norms and social practice, social structures and economic development status that shape physical and social vulnerability; 2) context specific barriers and enablers (i.e., governance structures, institutional structure and function, risk perceptions, access to financing and knowledge availability and needs) and 3) the solution-proximate decision space (i.e., climate urgency and catalysing conditions, risk communication strategies, monitoring and evaluation strategies) (see Jorgenson et al., 2019; Solecki et al., 2017).

These three areas are deeply embedded in the social sciences and reflect fundamental questions of how and why humans and their institutions act and respond (Chapter 17). In the past two decades, these basic issues have been applied to research of climate change, dynamic risk, and adaptation. Underlying this analysis, particularly of root drivers and barriers and enablers are assertions regarding the foundational properties of individual and collective behaviour (i.e., self-interest, optimisation, rationality, bounded rationality), how they are structured, and how these properties can be revealed. This literature draws on several academic disciplines including anthropology, economics, geography, political science, psychology, sociology, and urban studies. Climate change social science research is often interdisciplinary or transdisciplinary and hence utilizes a variety of methods to derive new knowledge (Orlove et al., 2020).

In contrast to previous assessments, AR6 is increasingly focused on the needs for and challenges of assessing the societal response to climate change. The accurate tabulation of adaptation, a key question for examining the solution space is difficult (Chapter 16, Cross-Chapter Box ADAPT in Chapter 1), since many forms of adaptation activity are under-represented in the peer-reviewed and grey literature. Moreover, the related question of assessing the effectiveness of adaptation, that is, the extent to which it reduces risk, is also difficult. Estimating risk reduction often involves counterfactuals, for instance, quantifying the damage a flood would have caused had a community not adapted prior to a storm or projecting the damage averted by today's adaptation in some future storm (see Cross-Chapter Box PROGRESS in Chapter 17). Many socio-economic drivers affect risk, so attribution for any observed or projected changes must be allocated among those due to adaptation and those due to economic development, cultural changes, and other types of policies and trends. For instance, many measures of sustainable development overlap with those for adaptive capacity and both can reduce climate risk while also yielding benefits irrespective of future climate regimes (UNEP, 2018). There also exist many different goals for adaptation both among and within different jurisdictions, so that adaptation efforts deemed effective by some individuals may not be deemed effective by others (Dilling et al., 2019).

1.3.2.3 Indigenous Knowledge and Local Knowledge

While scientific knowledge is vital, Indigenous knowledge (IK) and local knowledge (LK) are also necessary for understanding and acting effectively on climate risk (IPCC, 2014a; SROCC Chapter 1,IPCC, 2019b; see also Section 2.4). **Indigenous knowledge** refers to the understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings (IPCC, 2019a). **Local knowledge** is defined as the understandings and skills developed by individuals and populations, specific to the places where they live (IPCC, 2019a). These definitions relate to the debates on the world's cultural diversity (UNESCO, 2018a), which are increasingly connected to climate change debates (UNESCO, 2018b). However, there is agreement that, in the same way that there is not a unique definition of Indigenous Peoples because it depends on self-determination, there is not a single definition of neither Indigenous knowledge nor local knowledge. Therefore, contextualisation is highly needed. IK and LK will shape perceptions of climate risk which are vital to managing climate risk in day-to-day activities to longer term actions.

Such experience-based and practical knowledge is obtained over generations through observing and working directly within various environments. Knowledge may be place-based and rooted in local cultures, especially when it reflects the beliefs of long-settled communities who have strong ties to their natural environments (Orlove et al., 2010). Other times, knowledge may be embedded in institutions or oral traditions that mobilise them across contexts, for example, as migrant populations bring their knowledge across different regions, and have global relevance. Scientific insights often confirm findings from both IK and LK (Ignatowski and Rosales, 2013), but IK and LK also provide specific, alternative ways to understand environmental change including tacit and embodied aspects of knowledge (Mellegård and Boonstra, 2020), that may be crucial to foster local action and which are not easily captured in scientific knowledge (including cultural indicators, scales and interconnectedness between ecosystems). Multiple knowledge systems (i.e. IK, LK, disciplinary knowledge, technical expertise) may coevolve in iterative and interactive processes whereby they influence each other, but at the same time, they may have specific characteristics so that they cannot be reduced to each other, or subsumed under it and they all have relevance to understand the interactions between society and climate (Bremer et al., 2019).

Moreover, IK and LK may be particularly relevant to ensure that climate action not only does not cause further harm, but also addresses historical injustices committed against Indigenous Peoples and other marginalised social groups, recognising them as active agents of their own change (Nursey-Bray et al., 2019). There are between 370 and 500 in at least 90 countries belonging to about 5,000 different ethnic groups that are classified as 'Indigenous' (Sangha et al., 2019). While there is no single, universal definition of Indigenous Peoples, self-determination is a core criteria within both the ILO Convention on Indigenous and Tribal Peoples (1989) and the UN Declaration on the Rights of Indigenous Peoples distinct social and cultural groups that retain collective ancestral ties to the lands they inhabited or to the lands from which they have been displaced. Indigenous peoples attribute cultural and spiritual values to land, environmental features and landscapes (ILO, 2013; ILO, 2019). Indigenous Peoples suffer disproportionally. For example they are three times more likely to live in extreme poverty than non-Indigenous Peoples; they are also more likely to suffer discrimination and violence (UN, 2020). At the same time, Indigenous Peoples have long led climate change and environmental protection agendas.

Indigenous Peoples have been faced with adaptation challenges for centuries and have developed coping strategies in changing environments (Coates, 2004). Along with other local groups, they hold relevant knowledge about the environment and environmental change, the impact of those changes on ecosystems and livelihoods, and possible effective adaptive responses (see Cross-Chapter Box INDIG in Chapter 18). Therefore, the participation of Indigenous Peoples in climate change decisions and the inclusion of Indigenous knowledge in the IPCC assessment process should be of high priority (following recommendations in UN, 2020 and UNESCO, 2018b). Furthermore, the participation of scientifically trained climate specialists with indigenous backgrounds is valuable to the work of IPCC because the assessment must reflect a diverse range of views and expertise (for examples of IK please see Cross-Chapter Box INDIG in Chapter 18). Including IK & LK in the IPCC assessment process is supported by Article 31 in the UN Declaration on the Rights of Indigenous Peoples (2007) which calls for the use of IK and LK to be protected and validated by Indigenous Peoples themselves and include them as active participants in the assessment (Klenk et al., 2017). Paying special attention to the mechanism whereby some forms of knowledge have been excluded in previous reports- such as the use of technical knowledge or acronyms, or the deployment of discipline-specific validation mechanism- is a first step towards developing an inclusive assessment that reflects a wide range of voices.

The AR4 was the first IPCC report to explicitly discuss the value of IK and LK in adaptation and mitigation processes. AR5 recognized the importance of creating synergies across disciplines in the production of knowledge, acknowledging the importance of 'non-scientific sources such as Indigenous knowledge, which may not follow discipline conventions but nevertheless reflects the outcomes of learning across generations (Burkett et al., 2014) and explains the importance of including local and Indigenous knowledge and diverse stakeholder interests, values, and in local decision-making processes (Jones et al., 2014). Such processes should not only be done in partnership with IK and LK knowledge holders but, when possible, led by them (Inuit Tapiriit Kanatami, 2018). Recent IPCC reports have included distinct sections dedicated to IK and LK (e.g., SROCC, IPCC, 2019b). The IPCC Special Report on Climate Change and Land (SRCCL) includes a section on "Local and Indigenous knowledge for addressing land degradation" (2019a) and the IPCC Special Report on Ocean and Cryosphere (SROCC) describes local knowledge as 'what non-Indigenous communities, both rural and urban, use on a daily and lifelong basis,' a type of knowledge which is recognized as 'multi-generational, embedded in community practices and cultures, and adaptive to changing conditions' (2019b). The IPCC Special Report on Global Warming of 1.5°C emphasized the high vulnerability of Indigenous Peoples to climate change, and stated that disadvantaged and vulnerable populations including Indigenous Peoples and certain local communities are at disproportionately higher risk of suffering adverse consequences with global warming of 1.5°C and beyond (IPCC, 2018b). The report also assessed evidence in relation to the importance of including IK and LK in adaptation options, explaining their role in early warning systems and arguing that they are part of a range of approaches to catalyse wide-scale values and consistent with adapting to and limiting global warming to 1.5°C (IPCC, 2018b).

Since AR5, several academic publications have directly addressed the challenges of including IK and LK in climate research (David-Chavez and Gavin, 2018; Ford et al., 2016; Yeh, 2016) and demonstrated its value in building resilience to extreme events related to climate change (Janif et al., 2016; Olazabal et al., 2021). For instance, IK and LK has proved useful in land management methods that reduce wildfire risk (Cook et al., 2012)(Mistry et al., 2016; Nepstad et al., 2006; Welch et al., 2013). Since Indigenous knowledge is traditionally communicated through storytelling and oral history, there is a practical challenge integrating it in a assessment that prioritises scientific knowledge, and a need for increased critical engagement towards a co-production of knowledge (Ford et al., 2016). Scholars now recognize the ontological and epistemological differences in approaches, understandings and effects of climate change (Yeh, 2016). One common strategy has been assessing Indigenous observations of climate change alongside scientific data (Klein et al., 2014a) as a means to bridge the gap between scientific inquiry and Indigenous knowledge systems (Fernández-Llamazares et al., 2017). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Convention on Biological Diversity (CBD) have helped illustrate how to bridge multiple knowledge systems, particularly those conceived from different ontologies. Rather than viewing Indigenous knowledge as a single source of knowledge to be compared with scientific data, recent scholarship suggests assessments such as the IPCC directly involve Indigenous researchers (Yumagulova et al., 2019) to ensure ethical and equitable engagement with Indigenous knowledge. Such partnership with and leadership of Indigenous Peoples on climate research is also consistent with the UN Declaration on the Rights of Indigenous Peoples (e.g., Bawaka Country et al., 2015; Inuit Tapiriit Kanatami, 2018; Cross-Chapter Box INDIG in Chapter 18).

1.3.3 Regional Assessment

As climate change is a multiscale phenomenon from the local to the global, the assessment of climate risks and climate change impacts is strongly spatial, with a focus on regional climate change. The term "regions" is used in different ways throughout the AR6 assessment as the use of the term varies across disciplines and context.

First, there are chapters dedicated to regional assessment in AR6 WGII (Chapters 9-14 and Cross-Chapter Papers 4 and 6), and within the content of these and other chapters of AR6, the term region is often used to describe continental and sub-continental regions, oceanic regions, hemispheres, or more specific localities within these geographic areas. Building on the continental domains defined in AR5 WGII and to ensure consistency with WGI Chapter 12 and the WGI Atlas, AR6 WGII uses a Continental Set of Regions, namely Africa, Asia, Australasia, Europe, North America, Central & South America, Small Islands, Polar Regions, and the Ocean.

Second, the term regions is used to categorize areas around the globe with common topographical characteristics or biological characteristics. For example, Chapter 2 introduces regions in its discussion of biomes, as in arid, grassland, savanna, tundra, tropical, temperate, and boreal forested regions. Chapter 3 adds reference to an area's orientation with bodies of water, using terms such as deltaic, coastal, intercoastal, freshwater, and salty. In addition, Cross-Chapter Paper 2 uses a coastal region typology based on physical geomorphology considering elevation, coastal type, and topography (see Cross-Chapter Paper 2, pg. 5; Barragán and de Andrés, 2015; Haasnoot et al., 2019a; Kay and and Adler, 2017).

Third, Cross-Chapter Papers are dedicated to *typological regions*, defined in the Annex II: Glossary as regions that share one or more specific features (known as 'typologies'), such as geographic location (e.g., *coastal*), physical processes (e.g., *monsoons*), and biological (e.g., coral reefs, tropical forests, deserts), geological (e.g., mountains) or *anthropogenic* (e.g., megacities) formation, and for which it is useful to consider the common climate features. Typological regions are generally discontinuous (such as monsoon areas, mountains, deserts, and megacities) and are specifically used to integrate across similar climatological, geological and human domains.

Understanding climate risks across regions also requires attention to the capabilities of developing countries and scientists across country contexts in conducting climate assessments. Substantial unevenness of available climate observations, risks assessments, and scientific literature across regions and country capacities substantially challenges a globally comprehensive assessment (Connelly et al., 2018).

1.3.4 Evaluating and Characterising the Degree of Certainty in Assessment Findings

Since 1990, IPCC assessments have included designated terms and other approaches for communicating the expert judgments made by authors (Mastrandrea and Mach, 2011). The goal of such methods has been consistent treatment of uncertainties in assessing and communicating the current state of knowledge. Because terms such as "probable" or "likely" hold very different meanings to different people, a standardized approach is essential for enabling consistent interpretation (WGI AR6 Section 1.2.3.1). Since its 2001 assessment, IPCC authors have applied common guidance on expert judgment across the working groups (IPCC, 2005; Moss and Schneider, 2000). The AR5, iteratively building from past IPCC guidance, was the first report to apply a single framework consistently across the working groups and their diverse topics and associated disciplines (Figure 1.3; Mastrandrea et al., 2010; Mastrandrea and Mach, 2011). The outcome was increased comparability of assessment conclusions across the full spectrum of the physical science basis of climate change and resulting impacts, risks, and responses (Mach et al., 2017).

This framework for expert judgment is again being applied in the AR6 and associated special reports in the assessment cycle (Mastrandrea et al., 2010; see also WGI AR6 Box 1.1). Under the framework, the assessment of scientific understanding and uncertainties begins with evaluation of **evidence** and **agreement**—especially the type, amount, quality, and consistency of evidence and the degree of agreement (steps 1–3 in Figure 1.6). Evidence assessed can reflect observations, experimental results, process-based understanding, statistical analyses, or model outputs. Evidence is most robust when it consists multiple lines of consistent, independent, and high-quality evidence. The degree of agreement considers the extent of established, competing, or speculative explanations for a given topic or phenomenon across the scientific community. Together, this evaluation of evidence and agreement forms a traceable account for each key finding in the assessment. Subsequently, the framework proceeds to evaluation of levels of **confidence**, which integrate evidence and agreement (steps 3–5 in Figure 1.6). Confidence reflects qualitative judgments of the validity of findings. It thereby facilitates, more readily, comparisons across assessment conclusions. Increasing evidence and agreement corresponds to increasing confidence (step 4 in Figure 1.6).

If uncertainties can be quantified, the framework involves a further option of characterising assessment findings with **likelihood** terms or more precise presentations of probability (steps 5–6 in Figure 1.6). The relevant probabilities can pertain to single events or broader outcomes. Probabilistic judgments can be based on statistical or modeling analyses, elicitation of expert views, or other quantitative analyses. Where appropriate, authors can present probability more precisely with complete probability distributions or percentile ranges, also considering tails of distributions important for risk management. Usually, likelihood assignments are underpinned by high or very high confidence in the findings.

Confidence is often most applicable in characterising key findings in WGII assessment (Mach et al., 2017). This tendency results from the diverse lines of evidence across disciplines relevant to climate change impacts, adaptation, and vulnerability. By contrast, likelihood is more common in WGI assessment.

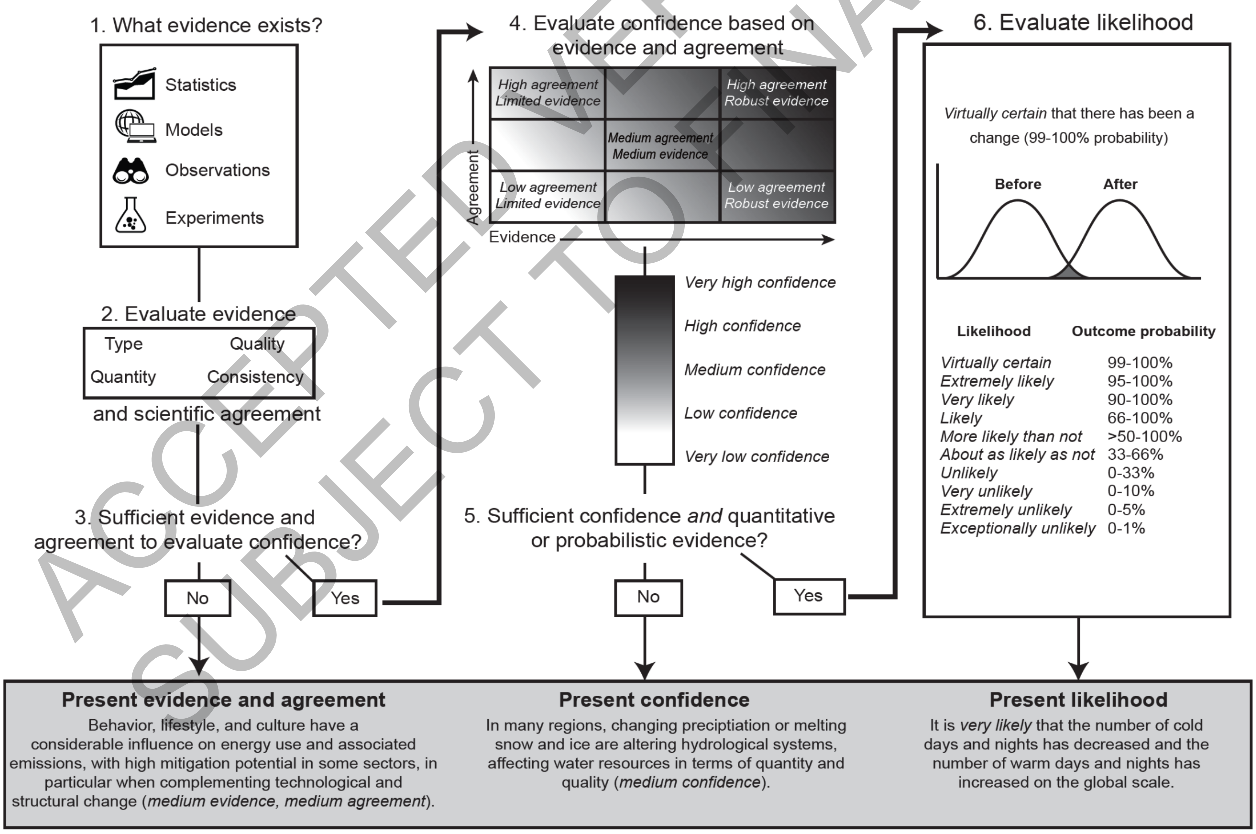

Figure 1.6: The IPCC AR5 and AR6 framework for applying expert judgment in the evaluation and characterisation of assessment findings. This illustration depicts the process assessment authors apply in evaluating and communicating the current state of knowledge. Guidance for the application of this framework is described in full detail in Mastrandrea et al., 2010. In addition to scientific knowledge, Indigenous knowledge and local knowledge are central to understanding and acting effectively on climate risk (Section 1.3.2.3). The diagram in this figure is reproduced from Mach et al. (2017)

The guidance to authors additionally identifies other practices and approaches relevant in applying expert judgment and developing assessment findings (Mach and Field, 2017; Mastrandrea et al., 2010; Mastrandrea and Mach, 2011). First, authors are encouraged to carefully consider appropriate generalisation within assessment findings, emphasising insights that are integrative, nuance, and rigorous (IAC, 2010; Mastrandrea et al., 2010; NEAA, 2010). Second, authors are instructed to attend to potential biases, including in group dynamics, such as tendencies towards overconfidence and anchoring or Type I (false positive) error aversion (Anderegg et al., 2014; Brysse et al., 2013; Mastrandrea et al., 2010; Morgan, 2014). Third, particular attention is drawn to the importance of evaluating and communicating ranges of potential outcomes to inform decision-making and risk management (Mastrandrea et al., 2010). In some cases, deep uncertainties related to parameters or processes that are unknown or disagreed upon strongly benefit from dedicated methods of assessment and decision support (see Cross-Chapter Box DEEP in Chapter 17). Fourth, the guidance explores the different ways that framings of conclusions can shape their interpretation by readers. Finally, the guidance underscores the importance of reflecting upon all sources of uncertainty, which can include deep, difficult-to-quantify, and easy-to-underestimate uncertainties arising from incomplete understanding of relevant processes or competing conceptualisations across the literature (Mastrandrea et al., 2010). A detailed review of literature assessing IPCC uncertainty characterization methods is provided in WGI AR6 1.2.3.1.

1.4 Societal Responses to Climate Change Risks

AR6 highlights the concept of **solutions**, defined as *effective*, *feasible,* and *just* means of reducing climate risk, increasing resilience, and pursuing other climate-related societal goals. This section introduces key concepts used in this report to assess the goals associated with adaptation, its process and governance, its implementation, monitoring and evaluation, and its limits.

The term solutions has various synonyms used across this and previous IPCC reports, including options, measures, actions, and responses. All denote policies, technologies, processes, investments, or other activities undertaken in reaction to or with the intent to address some aspect of climate change (Chapter 17). The term solutions has drawbacks, suggesting a finality, that is, the problem is solved. Solving climate change in this sense is not likely for the foreseeable future. In addition, the word solutions sometimes denotes a narrow set of responses, such as “technical solution,” as opposed to more wide-ranging actions as might be involved in a transition to resilience. Nonetheless, AR6 highlights the term solutions because, compared to these other terms, when acted upon or incorporated in policy, it denotes effectiveness and some degree of progress at achieving desired goals.

Assessing successful adaptation is, however, difficult (Cross-Chapter Box ADAPT in Chapter 1). WGIII Section 1.6 summarizes four broad analytic frameworks -- aggregate efficiency; ethics and equity; transition dynamics; and psychology and politics -- relevant to mitigation and concludes that failure to integrate understanding across them has been a fundamental reason for inadequate progress to date in reducing greenhouse gas emissions. While the four analytic frameworks used in WGIII also all contribute to the understanding of adaptation, an integrated view remains elusive because adaptation differs strongly from mitigation. In particular, the goals of adaptation are harder to define and measure than those for mitigation. The feasibility, effectiveness, and success of many adaptation actions depend more strongly on context. A different, often more diffuse set of actors are involved, and it is often hard to distinguish what activities count as adaptation.

Given these challenges, this report provides an assessment of adaptation solutions based on the attributes **justice**, **feasibility**, and **effectiveness**, as shown in Figure 1.7.

A solution is just when its outcomes, the process of implementing the action, and the process of choosing the action respects principles of distributive, procedural, and recognitional **justice** (Section 1.4.1.1). Any assessment of justice depends on an understanding of potential outcomes of alternative options (Chapter 16) as well as processes of decision-making (Chapter 17). Consideration of justice necessarily introduces normative elements into any assessment of what constitutes a solution.

A solution is **effective** to the extent it reduces climate risk. Effectiveness can refer to whether an adaptation-related action reduces risk (Section 1.4.1.2, Chapter 16) or the extent to which an action achieves its intended outcomes within a stated time frame (Chapter 17). Effectiveness can also include measures of economic efficiency, assessment of net benefits over costs, and the extent to which an action enhances broader and multi-dimensional measures of societal well-being (Section 1.4.1.2). Assessments of effectiveness will often involve uncertainty, which may affect judgements about the comparative effectiveness and justice of alternative options (Chapters 16 and 17, Cross-Chapter Box DEEP in Chapter 17). Assessment of effectiveness also involves consideration of maladaptation (Section 1.4.2.4) in which an action, often inadvertently, increases risk or vulnerability for some or all affected individuals or communities.

A solution is **feasible** to the extent it is consider possible and desirable, taking into consideration barriers, enablers, synergies, and trade-offs (Section 1.4.2). AR6 assesses the feasibility of a wide range of adaptation options (Cross-Chapter Box FEASIB in Chapter 18), building on the approach of the SR1.5 report, which uses five dimensions of feasibility: geophysical, environmental-ecological, technological, economic, socio-cultural, institutional. In addition, feasibility can also refer to a specific set of actions, so that feasibility in any particular situation may depend on specific conditions of governance capacity, financial capacity, public opinion, interest group pressure, and the distribution of political and economic power (Chapter 17). For instance, a particular jurisdiction may find either of two options feasible when implemented alone but might lack the capacity to implement them both at the same time. Feasibility can be a context-dependent and time-varying attribute. Many solutions, for instance those that seek to unlock financing or build public support for certain actions, aim at increasing the feasibility of future adaptation responses (Sections 1.4.2 and 1.5).

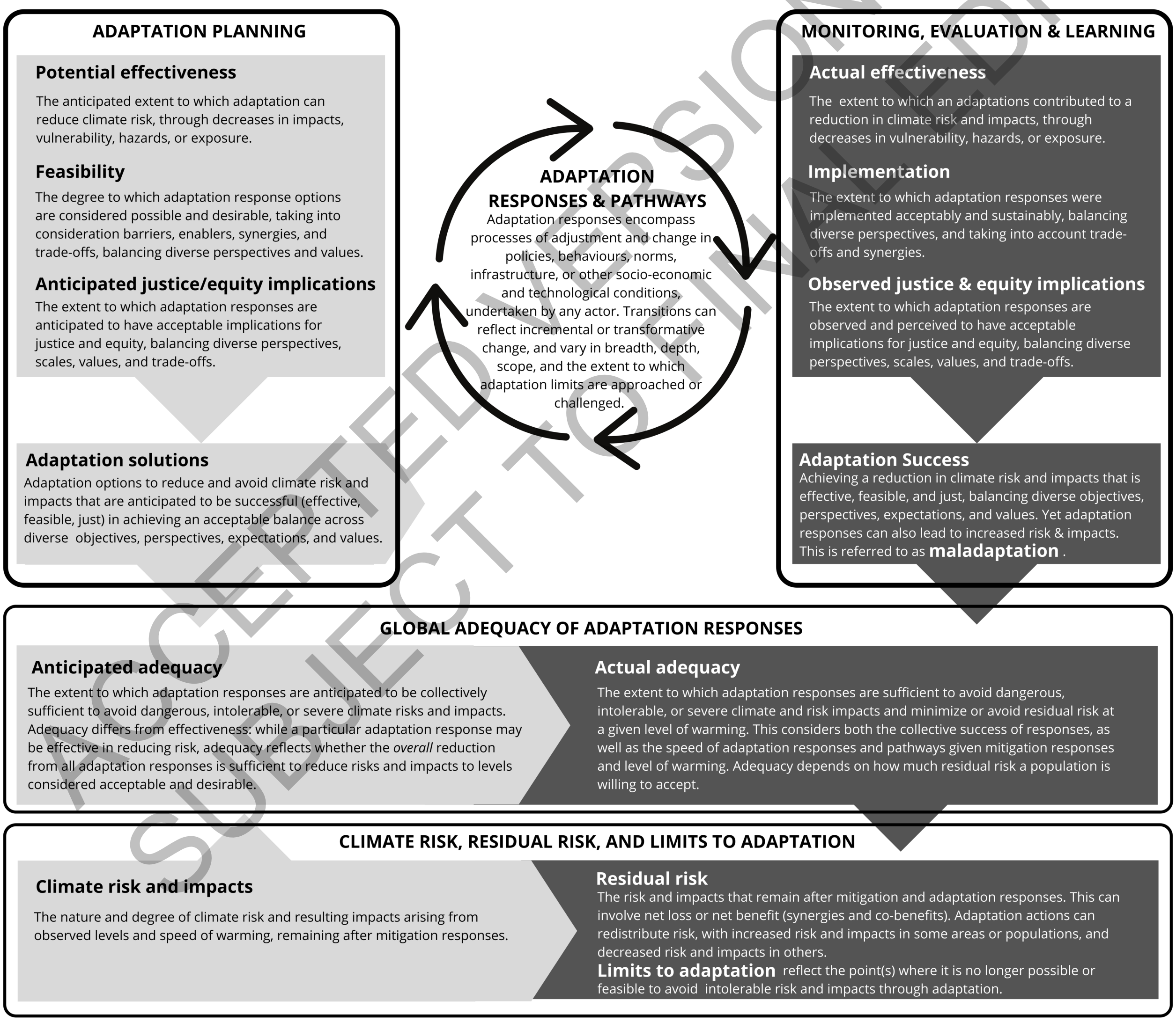

Figure 1.7: **Assessing adaptation solutions and success**. A solution is defined as an adaptation option which is effective, feasible, and conforms to principles of justice. These attributes can be assessed ex ante during adaptation planning. During implementation, the overall success of a response can be judged via monitoring and evaluation of these attributes. Adaptation unfolds as an iterative learning process of assessment, implementation, monitoring, adjustment, and learning. A set of responses is adequate to the extent that they sufficiently reduce climate risk to levels considered tolerable. Adaptation may not fully avoid residual risks, but the more adequate the response, the less

residual risk. Remains. Adaptation also has limits beyond which it is no longer possible to avoid intolerable risks and impacts.

1.4.1 What is Equitable, Just and Effective Adaptation?

Articulating the goals of adaptation is an important initial step in the decision-making process (Jones et al 2014). Adaptation often involves trade-offs among various options of adaptation, mitigation and sustainable development as well as judgements based on science, engineering, and economics and questions of distribution and democratic participation (Jafry et al., 2018). Articulating the goals of adaptation at the international, national, and local levels thus requires engaging with the concepts of equity, justice, and effectiveness (*high confidence*).

1.4.1.1 Equitable Adaptation Informed by Concepts of Justice

Assessing climate action involves ethical considerations that the literature often describes as climate justice. The term 'climate justice,' however, has been used in different ways in different contexts and by different communities. Grassroot organisations and activists often focus on unequal global power relations, wealth, and interests within communities, within nations, and along the North-South divide, as well as the historical responsibility for climate change (Chatterton et al., 2013). Some national governments also view climate justice as the right of developing countries to industrialize. Balancing these issues, international climate change negotiations have primarily focused on current capacities and responsibilities for addressing climate change as reflected in the UNFCCC principle of 'common but differentiated responsibilities' (Fisher, 2015).

Since principles of justice are substantive normative commitments that have been debated for centuries, it would be unrealistic to expect a universal consensus. Nevertheless, there is broad agreement about the core issues. Just normative principles are ones that result in fair and equitable allocation of goods, vulnerabilities and risks (Caney, 2014; Jafry et al., 2018; Schlosberg, 2009; Schlosberg, 2013)

It is common to distinguish between distributive justice, procedural justice and recognition (Forsyth, 2018; Fraser, 1999; Olazabal et al., 2021; Reckien et al., 2017; Schlosberg, 2003; Schlosberg, 2009). The first refers to the distribution of burdens and benefits; the second to who decides and participates in decision-making; while recognition entails basic respect and robust engagement with and fair consideration of diverse values, cultures, perspectives, and worldviews. Recognition is closely to distributive and procedural justice (Hourdequin, 2016). Without recognition, actors may not benefit from the two other aspects of justice (*medium confidence*). Recognition thus represents both a normative principle as well as an underlying cause of unjust distribution and lack of democratic participation (Svarstad and Benjaminsen, 2020). However, recognition is still under-represented in climate justice compared to general scholarship and debate on justice principles (Benjaminsen et al., 2021; Chu and Michael, 2018).

Three principles of distributive justice are especially relevant to adaptation: *fairness between individuals*, *fairness between states*, and *fairness between generations* (Fleurbaey et al., 2014*)*. Fairness between individuals means that the distribution of goods, vulnerabilities, and risks of climate change should not fall on individuals for arbitrary reasons. It would be arbitrary if, say, a family were disproportionately affected by climate-induced drought by chance alone. Similarly, an adaptation action that protects some and creates risks for others is unfair if the final distribution of burdens and benefits is arbitrary.

The second consideration of distributive justice is *international justice*, or fairness between states. An important idea in international climate negotiations has been *common but differentiated responsibilities* and respective capabilities (CBDR**) (**stated in Principle 7 in the Rio Declaration (1992)as well as by the Kyoto Protocol (1997). The principle reflects the underlying idea that *all* countries must address climate change, but the form of climate action depends on the situation the country finds itself in. Developed countries may find themselves in a position where they can decarbonize more rapidly and ensure financial flows, while the responsibilities of LDCs and SIDS may primarily come in the form of adaptation actions. This means that uneven distribution of wealth and power between (and within) countries is a key driver of climate injustice.

The third consideration of distributive justice relevant to climate adaptation is fairness between generations and the obligation to ensure that future generations are guaranteed at least a minimally decent life (Jonas, 1985; Llavador et al., 2010). For example, youth climate activists and political philosophers have argued that today's children, as well as generations yet unborn, will be exposed to far greater risks than most living adults so that policymakers should work to avoid shifting all burdens of adaptation to future generations.

Procedural justice addresses the fairness of the processes by which decisions are made and the legitimacy of those making the decisions (Gutmann and Thompson, 2009; Kitcher, 2011). Criteria include transparency, the application of neutral principles among parties, respect for participants' rights, and inclusive participation in decision-making, which often takes the form of participatory processes. Article 6 of the Framework Convention creates a binding commitment on parties to promote public participation in addressing climate change. Increased participation by civil society in climate policy discussion, including new forums such as the Local Communities and Indigenous People's Platform of the UNFCCC work toward this goal (UNFCCC, 2021). Genuine, not merely formal, participation requires communities be well-acquainted with the climate change risks they face and are given a full voice in the process of adaptation planning. Many local communities, especially those most vulnerable to climate change, remain excluded, which is inconsistent with principles of procedural justice. In addition to a normative principle, models of decision making also suggest that diverse, representative decision makers can be expected to make better decisions than more limited groups (Hong and Page, 2004; Landemore, 2013; Singer, 2019).

In AR5 WGIII discussions of justice and ethical concepts were combined with discussions of economic principles while the adaptation chapters did not explicitly discuss climate justice. This report moves beyond AR5 by connecting the assessment of policy choices to normative principles and showing how better outcomes are obtained by choosing just ones.

1.4.1.2 Equitable and Effective Adaptation Informed by Concepts and Measures of Well-Being

Planning and assessment of effective and just adaptation require appropriate measures of both criteria. This report uses both single and multi-criteria measures.

Local and regional decision makers employ benefit-cost analysis to efficiently allocate scarce resources among alternative adaptation efforts and among adaptation and other societal needs. Decision makers at national and global levels can employ measures of social welfare to consider trade-offs and synergies among adaptation, mitigation, and development. Such measures can avoid wasteful allocation of resources and help avoid maladaptation. Such measures also prove useful because well-established approaches exist to evaluate such quantities, and because income is highly correlated with a wide range of indicators of social progress and climate change adaptation capacity (Dasgupta et al., 2018).

Aggregate, monetized economic measures are, however, insufficient to address fully issues of climate justice or to reflect that wide range of worldviews and values that different people bring to questions of climate action and development (Chambwera et al., 2014). While recent work has enriched the consideration of distributive justice in aggregate social welfare functions (Adler, 2012), multi-objective approaches that separately report several biophysical and socio-economic attributes can prove valuable (17.3.3). Many adaptation measures, in particular those that encompass transformational social changes (Section 1.5), involve complicated trade-offs among multi-dimensional benefits and costs (Adger, 2016). Different people commonly value such trade-offs differently, particularly in heterogeneous societies. Multi-objective measures can thus enhance transparency, fairness, legitimacy, and participation by highlighting the different outcomes that different people and communities might find important, making the specific trade-offs more transparent and explicit, and avoiding privileging any particular view on the appropriate trade-offs (Lempert et al., 2018; Siders, 2019b; Siders and Keenan, 2020).

The SDGs and Key Representative Risks (Chapter 16) exemplify such multi-criteria measures. In addition, many communities increasingly measure policy outcomes using multi-objective measures, often organized around the concept of well-being and designed to allocate resources and implement policies to advance social progress (City of Santa Monica, 2018; Lee et al., 2015). Similarly, the Human Development Index (HDI), which derives from the capabilities approach, combines income (as Gross National Income-GNI and Parity Purchasing Power-PPP) with an education and a health indicator and integrates human and socio-economic factors (Herrero et al., 2012; Leal Filho et al., 2018; Nagy et al., 2018; UNDP, 2018; USEPA, 2016). The inequality-adjusted HDI value, or IHDI, can be interpreted as the level of human development when inequality is accounted for (UNDP, 2018).

The multi-criteria concept of well-being has been increasingly employed as a structured framework for measuring social progress in many areas of public policy (Lamb and Steinberger, 2017) including climate and health (Chapter 7) and, to a lesser extent in other areas of the climate change adaptation literature (Singh et al., 2021). Wellbeing reflects the ability of a person to pursue and realize the goals that they value (Sen, 1985). The disaster risk management community employs well-being to evaluate mental health impacts in terms of peoples' abilities to cope with trauma and loss because of natural disasters (Berry et al., 2010; MacDonald et al., 2015; Willox et al., 2015). The term appears in the literature with concepts such as human security (Adger, 2010; Koren and Butler, 2006; Pasgaard et al., 2017), subjective wellbeing or happiness (Fanning and O'Neill, 2019; Rehdanz et al., 2015; Sekulova and van den Bergh, 2013), welfare (Gough, 2015), and living standards or quality of life (Degorska and Degorski, 2018; Rao and Min, 2018).

Recent work has used quantified measures of well-being and multi-objective decision support tools) to balance among equity and efficiency objectives in disaster risk management (Markhvida et al., 2020; Section 1.5.2; Chapter 17). Rather than focus on the economic value of lost assets, the well-being measure evaluates disaster impacts and recovery policies by considering the fraction of consumption lost at the household level for different income cohorts. Not surprisingly, poor households account for twice as much of the disaster losses when evaluated by effects on well-being rather than by asset losses. The most effective policy responses also differ when using well-being and asset loss-based measures. Ciullo et. al. (2020) compare flood control strategies using multi-objective decision criteria that include both benefit-cost and distributional components, show how the favoured strategy can depend on whether one seeks equitable risk or equitable risk reduction, and propose tools that can help embed both ethical and efficiency considerations in adaptation decisions. Widespread use of such approaches could strengthen consideration of climate justice along with efficiency in the evaluation of climate risks and adaptation. (Dryzek et al., 2013; Section 1.5.2).

1.4.2 Enabling and Governing Adaptation

Adaptation actions taken by individuals, social groups, and organisations in response to climate and environmental stimuli depend, in part, on the options they have (see Chapters 16 and 17). Actions previously taken can reduce the scale of responses needed subsequently, increase the options available, reduce barriers to additional action, and increase capacity to respond. Successful adaptation sufficient to meet Paris and SDG Goals needs to involve actors at many scales and in many sectors, including individuals and households, communities, governments at all levels, private sector businesses, non-governmental organisations, religious groups and social movements. This report highlights the increased range of societal actors engaged in adaptation and the need for multi-level and polycentric governance. The section describes key concepts related to the process of adaptation and assessment of how human choices and exogenous changes can expand and contract the set of available solutions.

1.4.2.1 Adaptation Process and Expanding the Solution Space

Adaptation actions include those taken with the explicit intention of reducing climate risk, as well as actions taken without reference to climate change, e.g., building community resilience irrespective of any particular hazard. Adaptation actions can include those aimed at reducing a specific risk, or actions aimed at systemic changes and also include adjustments to current practices, or transformational changes. In addition, the success of adaptation in one place or jurisdiction can depend on activities in other places or jurisdictions.

Adaptation actions span a vast range of activities. Successful adaptation generally requires a portfolio of actions, often implemented by multiple actors in different sectors, often in different places and over time (Section 17.2.2). Useful taxonomies include categorizing such actions around Representative Key Risks (RKRs) (Figure 17.3), and by human systems and scenarios of adaptation extent for four components of adaptation (depth, scope, speed, and limits) (Table 16.2). As shown in Chapter 17, for instance, ecosystem-based adaptation, hardening buildings and physical barriers, and changes to zoning and planned retreat can reduce risks to coastal socio-ecological systems. Restoration and protection of forests, enhancing ecosystem connectivity through corridors, and ecosystem-based adaptation can reduce risks to terrestrial and ocean ecosystems. Increased use of grey, green, and blue infrastructure, and upgrading design standards, city plans, and more redundancy in power systems and other networks can reduce risks associated with critical infrastructure. Insurance and diversified or changed livelihoods can reduce risks to living standards and equity. Improved health care systems, disaster management and early warning can reduce risks to human health. Better management of land, soil and fisheries; and changing diets and reducing food waste can reduce risks to food security. Improved water efficiency, and policies to reduce demand can reduce risks to water security.

Previous IPCC reports have described in detail adaptation for individual actors as an iterative risk management process of scoping (identifying risks, vulnerabilities, objectives, and decision-making criteria), analysis (identifying options, assessing risks, evaluating trade-offs), and implementation (implementing chosen options, monitoring, and reviewing and learning) (Jones et. al. 2014). This AR6 report expands the focus to consider adaptation processes with multiple actors and a richer temporal dimension in which actions taken at one time can expand or contract the set of feasible, effective, and just options available at another time, thereby increasing or decreasing the ability of adaptation to reduce risks (Section 17.1). This AR6 report also expands the focus to include decision processes the implement both adaptation and mitigation (Chapter 18) as well as a heightened attention to Monitoring and Evaluation (M&E), which is a key prerequisite for successful iterative risk management and achieving effective and just adaptation outcomes at local to global levels (Section 1.4.3, 17.5.2). The challenges of implications for adaptation, mitigation and sustainable development outcomes result from decision-making process at different levels (Bertram et al., 2016, Von Stechow et al., 2015). To overcome these challenges often require significant learning and innovative ways of linking science, practice and policy at all scales (Shaw and Kristjanson, 2014).

Two concepts – enabling conditions and catalysing conditions – help frame this report's assessment of factors that over time can help expand the set of available solutions (Section 17.4). Enabling conditions enhance the feasibility of adaptation and mitigation options (cross-AR6 glossary). Enablers include finance, technological innovation, strengthening policy instruments, institutional capacity, multi-level governance, and changes in human behaviour and lifestyles. Chapter 17 (see also WGIII Figure 1.4) identifies three broad categories of enabling conditions: (Section 17.4): governance; finance and knowledge. Catalysing conditions motivate and accelerate the adaptation decision-making process, leading to more frequent and more substantial adaptation (Chapter 17). While enablers make adaptation more feasible and effective, catalysing conditions provide an impetus for action. These later conditions include a sense of urgency (Section 17.4.5.1); system shocks, such as those from natural disasters; policy entrepreneurs; and social movements.

The concept of the **solution space** provides a framework for assessing how the options available for adaptation for any particular community are not constant over time and can depend on the past, current and future choices of many actors. The solution space is defined as the space within which opportunities and constraints determine why, how, when and who adapts to climate risks (Haasnoot et al., 2020). The concept aims to capture the dynamic inter-temporal, spatial and jurisdictional interconnections among adaptation actions. A larger solution space indicates people and organisations with more options for adapting to and reducing their risk from climate change. Both human choices and exogenous changes in human and natural systems affect the future solution space. For instance, changes such as the magnitude and rate of climate change may shrink the space. Economic growth can generate more resources that expand the solution space as can implemented adaptation actions such as pilot projects, awareness raising, and changes in laws and regulations.

AR5 used the concept of solution space in its SPM Figure 8. Several AR6 chapters, in particular 13, 14, and 18, use the concept to address challenges salient in AR6. In any assessment of solutions, what is feasible, effective, and just depends not only on the potential solution itself but the particular biophysical and societal context in which it might occur (Section 17.5; Gorddard et al., 2016; Wise et al., 2014). Solutions can also be space and time dependent because the biophysical and societal context can change over space and time (Section 18.1.4). In addition, the large gap that exists between current climate action and that needed to meet policy goals suggests that decision-makers may not only seek to implement available solutions but seek to actively expand the set of solutions (Chapters 17, 18). Finally, as used in this report the concept of solution does not fully engage with questions of "by whom?" and "for whom?" In many cases solutions would necessarily be implemented by multiple, independent actors interacting with varying degrees of cooperation and competition (Sections 1.4.2, 1.5.2).

[START BOX 1.2 HERE]

Box 1.2: Financing as an Example of Enabler

According to the UNFCCC, adaptation finance includes public, private and alternative sources of finance for supporting adaptation actions, whereby adaptation and resilience are often used interchangeably in this context. Adaptation finance constitutes a crucial enabling condition and shaper of the solution space, depending on other enabling conditions such as proper planning, implementation and governance which are also the triggers for investments and finance to flow and to ensure that positive adaptation outcomes. Details of adaptation finance can be found in Chapter 17 (Cross-Chapter Box FINANCE in Chapter 17, Section 17.4). The adaptation and resilience options offer multiple benefits including avoiding risks and losses, economic growth, wellbeing as well as social and environmental benefits (Agrawal and Lemos, 2015; Bayleyegn et al., 2018; Global Commission on Adaptation, 2019). Hence, the rate of return on adaptation is large, for example, there is a huge potential of net benefits i.e. $7.1 trillion while investing $1.8 trillion globally in climate resilience and adaptation options such as early warning systems, climate-resilient infrastructure, improved dryland agriculture crop production, global mangrove protection, and resilience of water resources (Global Commission on Adaptation, 2019). These net benefits resulted primarily from reducing future losses and risk, increasing productivity and innovation, and social and environmental benefits. Despite strong uncertainty associated with benefit-cost estimates, and concerns on focusing efficiency (monetary) ignore important issues of non-economic values, effectiveness of risk reduction and climate justice (procedural/distributional).

The current public and private financial flows to adaptation are much smaller than needed (Cross-Chapter Box FINANCE in Chapter 17). Only a small portion of overall adaptation finance needs is likely to be covered by public sector finance. Private sector investment thus needs to play a crucial role. Hence, tracking adaptation finance flows is important for enabling effective planning and prioritisation of investments, assessing whether needs are being met, and ensuring accountability towards funding commitments, such as the 100 billion USD promised to developing countries per year by 2020 under the Paris Agreement (Donner et al., 2016). Since AR5, significant progress has been made in tracking adaptation finance flows through UNFCCC channels, multilateral development banks and bilateral finance (Cross-Chapter Box FINANCE in Chapter 17), but large information gaps on adaptation finance via national public finance, commercial lenders, investors, asset managers and insurers, company finance, and individuals and households remain. That these financial flows do not occur suggests misaligned incentives and other governance challenges that could be addressed as part of a response to climate change (Chapter 17). Across regions and sectors, financial constraints have identified most significant which leading to limits to adaptation (Chapter 16).

[END BOX 1.2 HERE]

[START BOX 1.3 HERE]

Box 1.3: Nature-Based Solutions

Nature-based solutions (NbS) (Section 2.6 and Cross-Chapter Box NATURAL in Chapter 2) provides an example of how innovative ideas can expand the climate solution space (IPCC, 2018b; Seddon et al., 2019). A commonly-used definition of Nature-based solutions (NbS) is that of IUCN (The World Conservation Union) which defines it as “actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits” (Cohen-Shacham et al., 2016); in the context of IPCC, it focuses on NbS which deliver climate change adaptation and / or mitigation benefits. NbS generally benefits biodiversity and supports its role in both climate mitigation and adaptation. While the carbon sequestering mitigation role of increasing forest and tree cover has dominated much of the earlier discussions, the role of

NbS in promoting adaptation of natural ecosystems and human societies to climate change is being increasingly emphasized. The details of different categories of ecosystem services in the ocean or on land including biodiversity, food provision, other provisioning services e.g., medicinal and commercial products, regulating and cultural services have been described in Chapters 2 and 3.

Forest restoration would certainly contribute substantially towards climate-proofing and achievement of several Sustainable Development Goals as well as the Paris Agreement. There is increasing evidence that diverse, native tree species plantations are more likely to be resilient to climate change in contrast to fast-growing monocultures, (Hulvey et al., 2013) often of exotic species. At the same time, other natural ecosystems such as savannas, grasslands, peatlands, wetlands and mangroves have considerable value in acting as carbon sinks as well as providing other ecosystem services such as hydrological regulation, coastal protection, maintaining biodiversity and contributing to human livelihoods especially pastoralists and fishermen (Conant et al., 2017; Leifeld and Menichetti, 2018; Seddon et al., 2019; Veldman et al., 2015). Coastal and marine ecosystems including wetlands and mangroves have featured prominently in studies of NbS in climate adaptation and mitigation potential for "blue carbon" sequestration (Inoue, 2019; Sections 3.6.2.1; 6.3.3; Cross-Chapter Paper 2.3.2.3). Agroecological practices such as agroforestry, intercropping, rotational grazing, organic manuring, and integrating livestock production with cropping etc can also consider as NbS which contribute to both climate mitigation and adaptation (Altieri and Nicholls, 2017; Bezner Kerr et al., 2019; Leakey, 2020; Webb et al., 2017; Box 5.10).

There are concerns about large-scale conversion of non-forest land into forest plantations for the sole purpose of increasing carbon sinks through bioenergy with carbon capture and storage (BECCS) (Hanssen et al., 2020; Heck et al., 2018; Cross-Chapter Box in Chapter 2), which may actually result in negative carbon sink (Jackson et al., 2002; Mureva et al., 2018) and significant loss of overall biodiversity (Abreu et al., 2017). Such large-scale afforestation may also lead to the dispossession of previous users, such as smallholders and pastoralists. Hence, when NBS includes forest plantations or other large-scale conversion of land-use, there is a risk that it results in maladaptation and malmitigation including climate injustice (Cousins, 2021; Seddon et al., 2019).

Much of the conceptual framework for NbS has come from initiatives to bring environmental, social and economic dimensions to the same level of importance particularly in the context of a highly urbanized society (Faivre et al., 2017; Nesshöver et al., 2017; Section 6.3.3). Emphasis has been given on urban storm water management (Section 2.6.5.2) and heat mitigation using measures such as sustainable drainage systems, urban forests, parks and green roof-tops apart from coastal defences using NbS (Section 13.6.2.3) This has triggered much debate on how distinct the concept of NbS is in relation to other similar concepts such as ecosystem-based adaptation (EbA) approaches (Section 9.11.4.2), and call for an assessment framework for proving the "effectiveness and efficiency" of NbS in providing superior ecosystem and societal benefits (Calliari et al., 2019). Instead, EbA can be treated as a subset of NbS (Chapter 2). However, the time frame of ecosystem-based adaptation is also an important consideration; thus, grassland and forest restoration would operate at different time scales, while mangrove restoration can promote adaptation only at local to national scales, depending on the extent and nature of coastlines (Taillardat et al., 2018). Given the complex nature of plant and animal species adapting to climate change through dispersal and migration to more suitable habitat, this also means that landscape-scale approaches, as opposed to purely protected areas, are needed to promote adaptation, conserve and sustainably use biodiversity, and sustain livelihoods (Sukumar et al., 2016; Vos et al., 2008).

[END BOX 1.3 HERE]

1.4.2.2 Governing Adaptation

Governance and governing refer to the structures, processes, and actions through which private and public actors interact to address societal goals. This includes formal and informal institutions and the associated norms, rules, laws and procedures for deciding, managing, implementing and monitoring policies and measures at any geographic or political scale, from global to local. Governance systems and the specific societal institutions through which they are organized are crucial to the feasibility and success of climate change adaptation, both in terms of its effectiveness in reducing climate risk and vulnerability as well as equity (including climate justice), and with respect to incremental as well as transformational adaptation. This is why AR6 WGII pays even more attention than previous assessments to governance as an important enabling condition, and to the wide range of new actors beyond governments involved in planning, implementing, and monitoring and evaluating adaptation action. The assessments in subsequent chapters of AR6 WGII show that successful and equitable collective adaptation efforts at different levels and scales, and based on key principles of iterative risk management, require strong, usually multi-level governance systems. Multi-level governance refers to the dispersion of governance across multiple levels of jurisdiction and decision-making, including, global, regional, national and local, as well as trans-regional and trans-national levels (see also WG III Chapter 1). The concept emphasises that modern governance generally consists of, and is more flexible, when there are linkages of governance processes across different scales and levels. Multi-level governance is widely regarded as crucial particularly for transformational adaptation, defined as "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 SR1.5, see also Section 1.5). The assessment in subsequent chapters also shows that public governance arrangements and institutions support the majority of adaptation for addressing the most important climate risks, though the importance of the private sector and community organizations in adaptation is increasing. It also shows that polycentric governance tends to benefit adaptation.

The empirical literature on adaptation governance has advanced strongly since AR5. It shows that stronger general governance capabilities are usually associated with more ambitious adaptation plans and more effective implementation of such plans (Chen et al., 2016; Keskitalo and Preston, 2019b: 24; ND-GAIN, 2019; Oberlack, 2017; Oberlack and Eisenack, 2018; UNEP, 2014; UNEP, 2018; UNEP et al., 2021; Woodruff and Regan, 2019). Governance capabilities are, to a significant degree, but not exclusively, a function of available financial resources and technology, but also a function of social capital and societal institutions, including well-functioning local, regional, and national governments and collaboration among these governmental actors and non-governmental stakeholders, including civil society and the private sector. The literature also points to governance conditions that are likely to enable transformational adaptation (Maor et al., 2017; see also Sections 1.4.4 and 1.5, Chapter 17).

Existing comparative data for adaptive capacity worldwide is at a rather coarse level of temporal and spatial resolution. It can, nonetheless, provide a very general picture of rates of change in adaptive capacity at the national scale, and differences between countries. Further empirical research is needed to identify the most important predictors of variation across countries and time, though the available data suggests that differing national income and education levels play a major role in accounting for differences in adaptive capacity (Andrijevic et al., 2020). Spatially more resolved (subnational) data is needed because a large body of case study research suggests that there is strong variation also within countries, particularly the large ones (e.g. India, China, Brazil, United States) (Chapter 16, see also Nalau and Verrall, 2021 and Cross-Chapter Box ADAPT). Moreover, higher degrees of adaptive capacity do not mean that adaptation action will follow automatically, nor that it will succeed in terms of equity and effectiveness in reducing vulnerability to climate change and enhancing well-being. How differences across and within countries in climate risk exposure translate into adaptation action, contingent on differences in adaptive capacity, can to some extent be inferred from case studies, but remains to be studied at a larger, comparable and generalizable scale.

Governance capacity constitutes an important enabling condition not only because it facilitates the (efficient) organization and implementation of adaptation action, but also because it contributes to learning. The latter is central to the process of adaptation as information regarding current and future climate conditions continues to evolve, as does understanding of appropriate response options and the actors involved. In addition, norms, values and practices may change in response to changing conditions (Jones et al., 2014). Much learning by individuals, communities and organisations is unplanned (National Research Council, 2009) as is much current adaptation (Berrang-Ford, 2020), which can reduce near-term costs and administrative complexity, but may prove maladaptive (Section 1.4.2.4). Iterative risk management (Section 1.2.1.1) and related concepts such as risk governance (Renn, 2008) describe a planned learning process of ongoing assessment, action and reassessment. Iterative risk management can be as simple as scheduling future updates of assessments and plans, as with the five-year updates of the global stocktake after 2023 called for in the Paris Agreement or encompass more elaborate learning processes, such as dynamic adaptive pathways (Haasnoot et al., 2019b; Cross-Chapter Box DEEP in Chapter 17) which include specific near-term actions, specific trends to monitor and specific contingency actions to take depending on the future conditions observed. While often more effective at meeting goals, such planned learning processes may pose implementation and governance challenges (Metzger et al., 2021)

Mainstreaming adaptation into existing governance structures and associated organisations and their investments, policies and practices can contribute to expanding the solution space and support efforts at transformative adaptation. For instance, urban planning can support adaptation by mainstreaming adaptation into city plans, such as land-use planning, procuring resilient infrastructure and transportation, supporting health and social services, promoting community-based adaptation, and protecting and integrating biodiversity and ecosystem services into city planning (Section 17.4.3). Mainstreaming adaptation also shows many shortcomings, such as, diminish the visibility of dedicated, stand-alone adaptation approaches (Persson et al., 2016), unequal distribution of adaptation efforts; dilute responsibilities for implementation (Nalau et al., 2016; Reckien et al., 2019); exhibit disconnects between planning, investment and implementation and limited policy coherence (Bizikova et al., 2015; England et al., 2018; Friend et al., 2014; Koch, 2018); and fail to adequately balance overlapping and/or competing policy objectives (Vij et al., 2018).

Finally, governing adaptation in ways that maximize the solution space and facilitate learning can help avoid maladaptation. Maladaptation refers to potentially adverse effects of certain forms of adaptation action, such as increased GHG emissions, or increased vulnerability to climate change and diminished welfare of certain parts of a population now or in the future (Anguelovski et al., 2016; Benzie et al., 2018; IPCC, 2018b; Keskitalo and Pettersson, 2016; Munia et al., 2018; Nadin and Roberts, 2018; Prabhakar et al., 2018; Veldkamp et al., 2017; Zimmermann et al., 2018). Maladaptation is an example of response risk, which is increasingly highlighted in both AR6 WGII and WGIII (Section 1.3.1.2, see also IPCC Risk Guidance). One example is that adaptation action may set paths that limit the choices of future generations to adapt. This last characteristic refers to the lock-in effects of improperly designed and costly infrastructures that affect the ability of future generations to amend.

Maladaptation can result from many potential barriers, including administrative, human, financial and technical resource constraints (Hassanali, 2017; Pardoe et al., 2018; Singh et al., 2018); lack of transparency and/or capacity in governance (Friend et al., 2014); unreliable information on climate impacts and the lack of key policy guidelines (Pilato et al., 2018); entrenched institutional, legal and technical obstacles (Gao, 2018) and low literacy, including environmental and scientific literacy (Wright et al., 2014); and exclusion of vulnerable groups (Forsyth, 2018); governance fragmentation (that is, a fragmentation of laws, regulations, and policy requirements); and limited cross-sectoral collaboration, meaning that there is limited coordination and that top-down planning approaches are not connected to local dynamics (Archer et al., 2014; Pardoe et al., 2018). This report draws attention to maladaptation challenges recognising that not all adaptation-related responses reduce risks (Chapter 16). Besides, maladaptation is the opposite of successful adaptation which is associated with reduction of climate risks and vulnerabilities for humans and ecosystems, increased well-being, and co-benefits with other sustainable development objectives. (Chapter 17)

1.4.3 Monitoring and Evaluation of Adaptation

Monitoring and evaluation (M&E) encompasses a broad range of activities serving multiple purposes, including tracking progress of adaptation efforts over time, understanding equity and effectiveness of adaptation options and outcomes, and informing ongoing adaptation processes (Section 17.5.2.1). While monitoring and evaluation are often referred to jointly as "M&E," monitoring usually refers to continuous information gathering whereas evaluation denotes more comprehensive assessments of effectiveness and equity, often resulting in recommendations for decision makers (Sections 17.5.1.1 and 17.5.1.7). In some literatures M&E refers solely to efforts undertaken after implementation. In other literatures, M&E refers both to efforts conducted before and after implementation. As shown in Figure 1.8, M&E is essential to the process of iterative risk management, both in terms of adaptation assessment prior to implementation and M&E of implemented adaptation measures. AR6 highlights that M&E after implementation is much less common than adaptation assessment prior to implementation (Section 17.5.2.1; Berrang-Ford, 2020).

<u>Tracking adaptation planning and policies</u>: Since AR5, interest in M&E for tracking progress in adaptation has grown substantially at the local, national and global level. I The Paris Agreement calls for a Global Stocktake every five years starting in 2023 (Cross-Chapter Box PROGRESS in Chapter 17). It also

encourages states to monitor and evaluate their adaptation plans, policies, programmes and actions and provides guidance on communicating information about adaptation to the international community (UNFCCC, 2015b, Article 7.9d; UNFCCC, 2018a, Decision 9/CMA.1; UNFCCC, 2018b, Decision 18/CMA.1).

Since AR5, a large number of case studies on individual local to national level adaptation measures have been published (see Chambwera et al., 2014; Keskitalo and Preston, 2019b), as well as comparative studies across countries over multiple years (Biesbroek et al., 2018; Biesbroek and Delaney, 2020; Lesnikowski et al., 2016). The existing literature now allows for at least preliminary conclusions about where and why we observe adaptation efforts, as described in the sectoral, regional and synthesis chapters of this report.

While case studies provide context-specific insights, global inventories are essential for tracking global progress on adaptation (UNEP, 2018; UNEP et al., 2021; Cross-Chapter Box PROGRESS). Until recently, the dominant approach surveyed National Communications to the UNFCCC to measure the amount of adaptation planning activity worldwide (Gagnon-Lebrun and Agrawala, 2007; Lesnikowski et al., 2016). More recent assessments have focused also on the quality of local and national adaptation planning to better characterize its potential merits, shortcomings and effects (UNEP et al., 2021; Woodruff and Regan, 2019) and have compiled inventories of adaptation projects (Leiter, 2021) and local adaptation policies (Lesnikowski et al., 2019b; Olazabal et al., 2019; Reckien et al., 2018; see also Section 6.4.6). Chapters 16 and 17 of this report offer an initial synthesis, but efforts to compile a comprehensive global, empirical inventory of climate change adaptation remain in an early phase (e.g., Berrang-Ford et al., 2011; Fankhauser, 2017; Ford et al., 2015; GEF, 2014; Leiter, 2021; Lesnikowski et al., 2016; Tompkins et al., 2010; Tompkins et al., 2018).

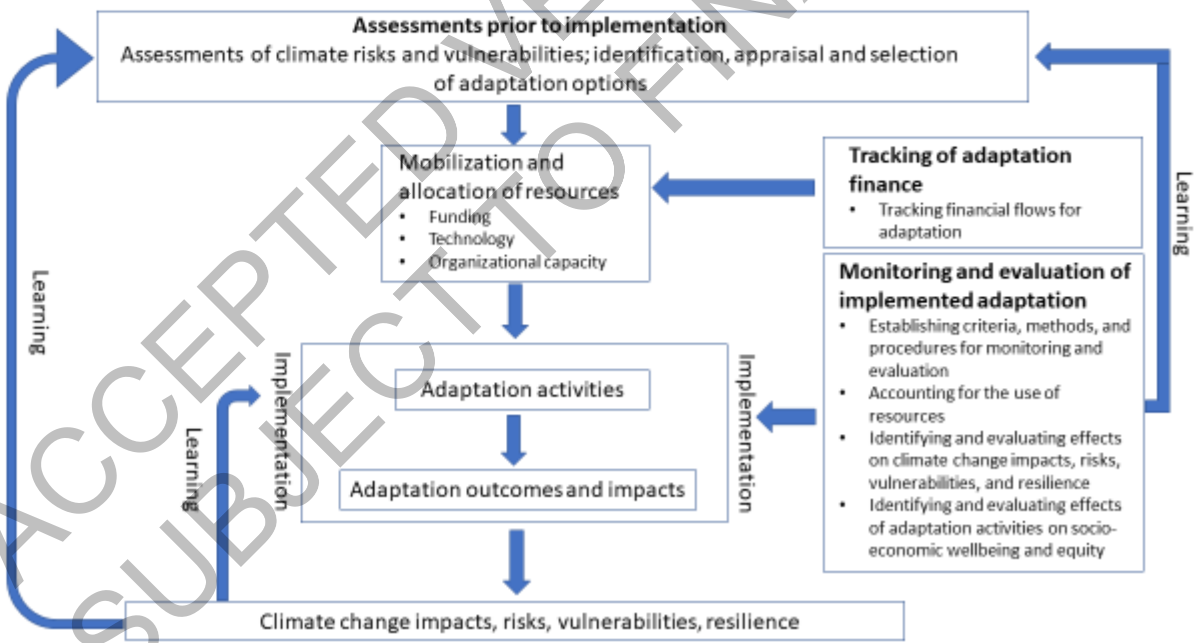

Figure 1.8: Adaptation assessment prior to implementation and M&E during and after implementation. Both systematic assessment of adaptation needs and options and M&E of implemented adaptation are key to iterative climate risk management, and to achieving effective and equitable adaptation. Most assessments to date have referred to aspects prior to implementation. There is much less systematic evidence on adaptation action, and even less evidence on adaptation outcomes and impacts and their implications for climate change impacts, risks, vulnerabilities and resilience. Figure 17.9 in Chapter 17 provides more detail on M&E.

Improving effectiveness: Information regarding the effectiveness of adaptation remains scarce (UNEP et al., 2021), which hinders efforts to improve adaptation practice. A recent comprehensive review found that only 2.3% of the close to 1,700 articles identified by the Global Adaptation Mapping Initiative as documenting implemented adaptation provide evidence of risk reduction (Chapter 16; Berrang-Ford, 2020). However, there exists limited but emerging evidence of the use of M&E by different actors to assess adaptation progress (Section 17.5.1).

Existing case studies use varying criteria for assessing effectiveness, complicating comparisons. Judgements regarding successful adaptation are contingent on the chosen scale and perspective (success for whom?) (Adger et al., 2005; Dilling et al., 2019) and on the level of risk, i.e., increasing climate risks may cause previously successful adaptation to become insufficient. Rather than a binary outcome (successful or unsuccessful), adaptation can be viewed on a continuum from successful adaptation to maladaptation (Section17.5.2). Assessments of adaptation success need to account for distributional effects and differential vulnerability, as well as consider connections across different scales and complex interactions with other change processes (Section 17.5.1). Recent literature has begun to identify how adaptation can better achieve its intended objectives (Eriksen et al., 2021). For instance, inclusive M&E can legitimize and validate M&E and foster commitment and learning.

Informing ongoing adaptation: Iterative risk management involves an ongoing cycle of assessment, action, learning and response in which M&E plays a central, enabling role (Section 1.2.1.1). Assessing the risk reduction provided by adaptation, both planned and implemented, often requires projections of anticipated future climate, socio-economic conditions, and the effectiveness and implications for justice of each option (Section 17.4.4). Understanding the potential for maladaptation may also require such assessments (Section 1.4.2). Processes, such as adaptive pathways, that involve anticipating future responses (Box 11.4; Box 11.6; Sections 11.7; 17.3) entail monitoring to detect early warning of approaching thresholds or changes in the solution space (e.g. more rapid than expected sea level rise or new social acceptance of managed retreat) that suggest the need or opportunity to adjust or expand current adaptation efforts (Haasnoot et al., 2021).

[START CROSS-CHAPTER BOX ADAPT HERE]

Cross-Chapter Box ADAPT: Adaptation Science

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High-level statements:

- Adaptation knowledge consists of a diverse set of sources including academic research, applied analysis and practice and experience with projects and policy on the ground.
- Adaptation science encompasses both research ‘on adaptation’, documenting and analysing experiences of adaptation, and ‘for adaptation’, aiming to advance the planning and implementation of adaptation.
- The nature of adaptation research is diversifying and examines different approaches from local case studies to more global, transboundary, comparative and interactive perspectives, although critical conceptual and empirical gaps remain in defining effectiveness in adaptation and measuring adaptation progress.

This cross-chapter box complements the reviews of specific adaptation knowledge, content and progress described throughout WG2 by providing a higher-level analysis of the shifting characteristics of and trends in **adaptation research** and its evolution over time.

The characteristics and diversity of adaptation knowledge

The knowledge base on adaptation has matured significantly since AR5. Whereas adaptation research was primarily academic during the 1990s and 2000s, it now includes a proliferation of on-the-ground experience of how to adapt to climate change, increasingly documented in reports and papers. Furthermore, academic research on adaptation has diversified significantly. Understanding the characteristics and diversity of this knowledge base is key for it to effectively inform decision making and action on adaptation.

Academic work on adaptation now spans an increasing number of disciplines and countries and is published across diverse academic outlets and disciplines, with 28.5% annual average increase in adaptation specific publications (Nalau and Verrall, 2021). This expands the range of considerations and perspectives within adaptation research and increases the challenge of identifying and synthesising all relevant research on adaptation in reviews or assessments (Berrang-Ford et al., 2015; Sietsma et al., 2021; Singh et al., 2020; Webber, 2016). Also, large bodies of research and knowledge exist that support climate adaptation ideas, theoretical development, and practical implementation, but are not explicitly framed as climate change adaptation (Biesbroek et al., 2018; Dupuis and Biesbroek, 2013; Keskitalo and Preston, 2019a). Therefore, debates still emerge about what actually counts as "adaptation" (Dupuis and Biesbroek, 2013), and what knowledge is being assessed and measured for this purpose.

IPCC assessment reports combine two complementary approaches to adaptation research: that which is 'on' or 'about' adaptation and that which is 'for adaptation'. Both are needed because research 'on adaptation' helpfully investigates the phenomenon and processes of adaptation (e.g., via analyses of others' adaptation practices and efforts) while research 'for adaptation' generates knowledge that can enable the planning and implementation of adaptation (e.g., action research as part of an adaptive capacity building process) (Swart et al., 2014).

One of the contributions of research 'on adaptation' is to track and debate the broader trends, core characteristics and overall assumptions embedded in adaptation knowledge. This reflexive turn about the foundational assumptions is itself one emerging trend in adaptation research (e.g., Atteridge and Remling, 2017; Juhola, 2016; Nalau et al., 2015; Preston et al., 2013). This signals the influence of more social science in adaptation research and increased awareness of the practical value of being transparent and critically reflective about the content, topics, frames and approaches that researchers use (Lacey et al., 2015; Nalau et al., 2021; Singh et al., 2021). For example, different conceptions of adaptation contribute to different definitions of "adaptation success", different ideas about what "effective" adaptation practice looks like and, thus, different conclusions about what is and is not working well (Berrang-Ford et al., 2019; Dilling et al., 2019; Eriksen et al., 2021; Magnan et al., 2020; Owen, 2020; Singh et al., 2021; Section 17.5.1.1). This diversity adds richness and options, but also poses challenges in constructing a conventional evidence base for decision- and policy making. Adaptation researchers are increasingly expected to offer clear and confident advice on adaptation success, yet are also increasingly aware of how context-specific and contested success is (see also Lacey et al., 2015 on ethics).

Grey literature on adaptation is also proliferating, typically authored by organisations funding and implementing adaptation. This literature often documents a range of adaptation strategies (Sections 9.8.3; 10.4.6.4; 14.4.3.3; 17.2.1.) and lived experiences of adaptation efforts, including helping give voice to marginalised groups, and highlighting the importance of Indigenous knowledge and local knowledge (Nunn et al., 2016; Section 4.7.5.4; Box 9.2; 15.6.4; Cross-Chapter Box INDIG in Chapter 18; Petzold et al., 2020). However, most of the lessons learned through implementation of adaptation projects and programmes are still not captured in academic or even grey literature and thus remains less systematically analysed. Crucially, the large gaps in documentation of adaptation knowledge mean that a lack of published evidence about a given issue does not necessarily reflect its absence in real life – a qualification about adaptation research that readers of AR6 need to appreciate.

The evolution of adaptation research trends

In the 1990s, climate change adaptation was constrained as a specific topic of inquiry by the dominant focus on mitigation of greenhouse gas emissions and the related assumption that successful mitigation would render unnecessary the need for adaptation beyond what human and natural systems could inherently manage (Pielke, 1998; Schipper, 2006; Schipper and Burton, 2009). Several key developments in the 1990s included the IPCC 2nd report (1996) and the establishment of several key journals including Climatic Change (1978), Mitigation and Adaptation Strategies to Global Change (1996), and the Global Environmental Change journal that strengthened more dedicated focus on climate change related research.
Many foundational papers on key concepts central to adaptation were published in 1990s and early 2000s onwards (Adger et al., 2005; Burton, 1992; Fankhauser et al., 1999; Klein, 2003; Parry and Carter, 1998; Pittock and Jones, 2000; Smit, 1993; Smit et al., 1999; Smithers and Smit, 1997) while adaptation began to gain more prominence in IPCC's 3rd assessment (2001) and 4th assessment (2007). For example, the Canada

Climate Program report (Smit, 1993) report set out many of the principles of adaptation, and was highly influential charting these concepts also in IPCC's 3rd Assessment Report (Schipper and Burton, 2009). These papers and IPCC reports remain key foundations of climate adaptation science literature (Nalau and Verrall, 2021).

Helping to differentiate adaptation from mitigation during this period was a focus on theoretical principles and a framing of adaptation as local and context-specific, in contrast to mitigation's global character (Nalau et al., 2015; Westoby et al., 2020), leading to locally oriented adaptation research and practice, including the rise of community-based adaptation (Kirkby et al., 2017). Since AR5, however, adaptation has extended beyond the local, recognising the 'borderless' character of many climate change risks and vulnerabilities (Benzie and Persson, 2019) and framing adaptation and global adaptation governance as a global public good (Persson, 2019a). Encompassing this expanded scale is challenging for adaptation research compared to treating adaptation as a local issue, which fits more easily with social research methods. Adaptation now works across scales (Biesbroek et al., 2013; Dzebo and Stripple, 2015; Keskitalo and Preston, 2019a) and attends simultaneously to both the opportunities and risks arising from climate change (Juhola, 2016; Keskitalo and Preston, 2019a). This suggests that empirical adaptation research should incorporate multi-scalar research designs and methods.

A strong focus has been and remains on case studies of adaptation practice, but adaptation science literature reviews have become common. Recent systematic reviews cover topics such as adaptation effectiveness (Owen, 2020), public participation and engagement (Hügel and Davies, 2020), role of local knowledge (Klenk et al., 2017), adaptive capacity (Mortreux and Barnett, 2017; Mortreux et al., 2020; Siders, 2019a), evolution of adaptation science (Nalau and Verrall, 2021), empirical adaptation research in the Global South (Vincent and Cundill, 2021), how cities are adapting (Reckien et al., 2018), how decisions can be made (Siders and Pierce, 2021), Indigenous knowledge (Petzold et al., 2020) and small island developing states (Robinson, 2020). Review papers have developed common methodologies for how to undertake robust reviews in adaptation research (Berrang-Ford et al., 2015; Biesbroek et al., 2018; Lesnikowski et al., 2019a; Singh et al., 2020), and noted an existing imbalance as the majority of the literature still originates from the Global North compared to Global South (Nalau and Verrall, 2021; Robinson, 2020; Sietsma et al., 2021).

At the same time, adaptation research is also challenged by increasing attention to transformational adaptation (TA), which refers to fundamental changes going beyond existing practices, including new approaches to adaptation decision-making (Section 1.5). Whereas AR5 noted TA as an area of future research (Klein et al., 2014b), it has continued to grow in profile since then. Rather than a future or fringe consideration - e.g., an extreme action necessitated by the limits of incremental adaptation - transformational adaptation is increasingly an option that decision-makers are considering today. This increasing attention on TA is driven by a growing recognition of climate risks and impacts as well as the need for urgent, systemic action as laid out in the IPCC's recent special reports (IPCC, 2018d). Yet what incremental and transformational adaptation look like, how they relate in practice, and how to appropriately choose incremental or transformational options, is uncertain and increasingly debated (Few et al., 2017; Magnan et al., 2020; Termeer et al., 2016; Vermeulen et al., 2018; Wilson et al., 2020; Section 17.2.2.3). One of the main challenges is now to generate empirical evidence and policy relevant insights on transformational adaptation (e.g., Jakku et al., 2016). Transformative approaches are especially being discussed in the context of COVID-19 (Schipper et al., 2020; Cross-Chapter Box COVID in Chapter 7).

Increasingly reflective adaptation research

Another characteristic of recent adaptation research is a stronger focus on ethics, justice and power (Byskov et al., 2021; Coggins et al., 2021; Eriksen et al., 2021; Singh et al., 2021). Researchers and practitioners are increasingly impatient to address the root causes of vulnerability and use inclusive climate adaptation processes to generate effective adaptation responses for marginalised and misrecognized groups (Eriksen et al., 2015; Gillard et al., 2016; Scoones et al., 2015; Tschakert et al., 2013; Wisner, 2016). Increasingly ambitious, normative adaptation research often challenges technological solutions that simply reinforce the existing *status quo* (Nightingale et al., 2019, p. 2) and calls for "socially-just pathways for change". Here work on adaptation overlaps with mitigation, transitions and other large-scale social change, encouraging the move towards more systemic, integrated approaches that discern between options according to multiple criteria (Goldman et al., 2018).

Fundamental questions about equity and justice in adaptation include gender and intersectionality (see Cross-Chapter Box GENDER in Chapter 18, Section 1.4.1.1 Chapter 18;) and broader critiques of who participates in processes of adaptation planning and implementation, who receives investments, who and what benefits from them, who makes key decisions regarding adjustments through time (Boeckmann and Zeeb, 2016; Byskov et al., 2021; Eriksen et al., 2021; Nightingale et al., 2019; Pelling and Garschagen, 2019; Taylor et al., 2014), and how climate justice intersects with other justice agendas. Attention is also turning to relations and tensions between different adaptation approaches, scales, constraints, limits, losses, enablers and outcomes (Barnett et al., 2015; Crichton and Esteban, 2017; Deshpande et al., 2018; Gharbaoui and Blocher, 2017; McNamara and Jackson, 2019; Mechler and Schinko, 2016; Pelling et al., 2015). Evident here is an ongoing, serious knowledge gap around the long-term repercussions of adaptation interventions. There is growing awareness of the need to address the potential for maladaptation (Sections 1.4.2.4; 5.13.3; 15.5.1, 17.5.2, Chapter 4 on Water). Concerns about maladaptation have led to renewed calls to open the "black box" of decision making to examine the influence of power relationships, politics and institutional culture(Biesbroek et al., 2013; Eriksen et al., 2015; Goldman et al., 2018), including the power-adaptation linkage itself (Woroniecki et al., 2019), external factors outside the decision-making process (Eisenack et al., 2014) and the influence of leadership on adaptation processes and outcomes (Meijerink et al., 2014; Vignola et al., 2017).

All of these developments indicate that adaptation research is not only more reflexive about some of its central assumptions, methodologies and tools (Biesbroek et al., 2013; Conway and Mustelin, 2014; Eriksen et al., 2015; Lubell and Niles, 2019; Nalau et al., 2015; Nightingale, 2015a; Porter et al., 2015; Singh et al., 2021; Woroniecki et al., 2019), but also cognisant of the need to critically consider its underpinning goals, purpose and impact in the world.

[END CROSS CHAPTER BOX ADAPT HERE]

1.4.4 Limits to Adaptation

The effectiveness of adaptation efforts also depends on the constraints and limits that human and natural systems face when confronted with increasingly higher levels of climate risks. The concept of adaptation limits strongly affects any appropriate balance among adaptation and mitigation actions in the sense that less mitigation makes adaptation harder or even infeasible. **Adaptation limits** refer to the point at which an actor's objectives (or system needs) cannot be secured from intolerable risks through adaptive actions (WGII AR6 Glossary). Adaptation limits can be soft or hard. **Soft adaptation limits** occur when options may exist but are currently not available to avoid intolerable risks through adaptive actions and **hard adaptation limits** occur when no adaptive actions are possible to avoid intolerable risks. Intolerable risks are those which fundamentally threaten a private or social norm — threatening, for instance, public safety, continuity of traditions, a legal standard or a social contract -- despite adaptive action having been taken (Dow et. al. 2013). Intolerable risks threaten core social objectives associated with health, welfare, security, or sustainability (WGII AR5 Chapter 16). Through the lens of resilience, hard limits represent the range of change or disturbance beyond which a system cannot maintain its essential function, identity, and structure. Soft limits represent the range of change or disturbance of a system which can be sustained over time by innovation or policy changes. The level of greenhouse gas reduction, adaptation and risk management measures are the key factors determining if and when adaptation limits are reached.

1.4.4.1 Limits to Adaptation and Relation to Transformation

A species ability to adapt may be significantly impacted by the dynamics of interactions between the ecosystems and species, so that a species may reach its limit to adapt even in a gradually changing environment, leading to sudden changes in range fragmentation (Radchuk et al., 2019). As human interventions affect the ability of species and ecosystems to adapt, a deeper understanding on ecosystems and species interactions and evolution in response to climate change is important in order to reduce future biodiversity losses (Nadeau and Urban, 2019). Hard limits for ecological and natural systems are more proximate than for human systems (Chapter 16) (*medium confidence)*. Many terrestrial, freshwater, ocean and coastal ecosystems are currently near or beyond their hard adaptation limits (Chapters 2, 3 and 16).

Many human and natural systems are currently near or beyond their soft adaptation limits (Dow et al., 2013; Chapters 4, 5, 6, 7, 8, and 16). The concept of limits to adaptation is dynamic in terms of the temporal, spatial and contextual dimensions of climate change risks, impacts and responses (Chapter 17; Storch, 2018). Adaptation limits depend on a complex function of interactions between social, ecological, technological and climatic elements, which appear to have thresholds beyond which adaptation can be infeasible and represent limits to adaptation. Such thresholds are endogenous to society and hence contingent on ethics, knowledge, attitudes, culture, governance, institutions and policies (Abrahamson et al., 2009; Tschakert et al., 2017). Since AR5, the evidence on limits to adaptation has been advanced across regions and sectors. Many adaptation constraints (financial, governance, institutional and policy etc.) lead to soft adaptation limits (see Chapter 16 for detailed evidence on constraints and adaptation limits). The ability of actors to overcome these constraints including social constraints to behavioural changes, depends on additional adaptation implementation. (Abrahamson et al., 2009; Di Virgilio et al., 2019; Juan, 2011). Thus, socioeconomic, technological, governance and institutional systems or policies can be changed or transformed in responses to the different dimension of adaptation limits to climate change and extreme events.

When a soft limit is reached, then intolerable risks and impacts may occur, and additional adaptations (incremental or transformational) are required.to reduce or avoid these risks and impacts (Chapters 2, 3, 4, 5, 6, 7, 16 and 17). IPCC SR1.5 defined incremental adaptation that maintains the essence and integrity of a system or process at a given scale whereas transformational adaptation that changes the fundamental attributes of a socio-ecological system in anticipation of climate change and its impacts. When incremental adaptation is insufficient to avoid intolerable risks, transformational adaptation may be able to extend the potential to sustain human and natural systems (IPCC, 2018a; Cross-Chapter Box LOSS in Chapter 17; Klein et al., 2014b). Transformational adaptation can allow a system to extend beyond its soft limits and prevent soft limits from becoming hard limits. This report provides evidence of assessing transformational adaptation in terms of scope, depth, speed and limits to adaptation (Chapter 16).

This report assesses adaptation limits (soft and hard) and residual risks for some actors and systems (Chapter 16). **Residual risk** is the risk that remains following adaptation and risk reduction efforts (SROCC). Residual risk is also used as other terms such as 'residual impacts', 'residual loss and damage' and 'residual damage'. As noted in AR5 WGII, the residual risk is larger or smaller depending on a society's choices about the appropriate level of adaptation and its ability to achieve an appropriate level. The intersection of inequality and poverty presents significant adaptation limits, resulting in residual impacts for vulnerable groups, including women, youth, elderly, ethnic and religious minorities, Indigenous People and refugees (Section 8.4.5). An appropriate level of adaptation, which ideally reflects a balance between the desired level of risk and the actions needed to achieve that level of risk, depends on the solution space, the society's views on climate justice, the tolerance for climate-related risks, the society's tolerance for the costs and other impacts of the actions needed to reduce risk. IPCC'S special reports stated that residual risks rise with increasing global temperatures from 1.5°C to 2°C (SR 1.5) and emerge from irreversible forms of land degradation (SRCCL). Among other risks, this report is evidenced that at risk to coastal flooding from sea level rise, nature-based adaptation measures (e.g., coral reefs, mangroves, marshes) reach hard limits beginning at 1.5ºC of global warming (Chapter 16). Residual risks may lead to exceeding the limits of adaptation, hence, this report underscores on the role of decision-making on transformational adaptation for dealing with residual risk and soft as well as hard adaptation limits (Cross-Chapter Box LOSS in Chapter 17). Section 1.5 addresses transformational adaptation in the context of climate resilient development pathways, since such adaptation is inseparable from mitigation and sustainable development.

1.4.4.2 Emerging importance of loss and damage

The concept of **Loss and Damage** (with capitalized letters, L&D) refers to discussion point under the UNFCCC, which is to "address loss and damage associated with impacts of climate change, including extreme events and slow onset events, in developing countries that are particularly vulnerable to the adverse effects of climate change." Lowercase letters of **losses and damages** refer broadly to harm from (observed) impacts and (projected) risks (IPCC, 2018a). The IPCC report uses the latter for its assessment on loss and damage which may provide useful information for the former. L&D associated with climate change has gained importance supported by the robust scientific evidence on the anthropogenic climate change amplifying frequency, intensity and duration of climate-related hazards (Mechler et al., 2019). Loss and damage associated with those residual losses and damages that are felt beyond the adaptation actions taken implying a sense of limits to adaptation at a given time and spatial contexts (Tschakert et al., 2017). IPCC's special report on climate change and land also underlined the unavoidable loss and damage due to changes in tropical and extratropical cyclones and marine heatwaves where adaptation and resilience limits are being exceeded for the people and ecosystems (IPCC, 2019a; Cross-Chapter Box LOSS in Chapter 17).

Loss and damage has emerged as an important topic in international climate policy (Boyd et al., 2017; Roberts and Pelling, 2016; Surminski and Lopez, 2015) which originated from Small Island Developing States for compensation, related to sea level rise impacts. It has since become formalized under the UNFCCC, through the establishment of the Warsaw International Mechanism (UNFCCC, 2013) and Article 8 of the Paris Agreement (UNFCCC, 2015b). The WIM promotes the implementation of comprehensive risk management approaches, improves understanding of slow onset events, non-economic losses and human mobility (migration, displacement) and enhances action and support, including finance, technology and capacity-building to avert, minimize and address loss and damage associated with climate change impacts particularly vulnerable and developing countries (UNFCCC, 2021). Different actors have defined loss and damage differently in reference to climate change impacts and responses (Boyd et al., 2017; McNamara and Jackson, 2019; Roberts and Pelling, 2016; Surminski and Lopez, 2015). These understanding includes the following: i) an adaptation and mitigation perspective linking all human-induced climate change impacts to potential loss and damage and the mandate to avoid dangerous anthropogenic interference; ii) a risk management perspective emphasising interconnections among disaster risk reduction, climate change adaptation, and humanitarian efforts; iii) a limits to adaptation perspective focused on residual loss and damage beyond adaptation and mitigation; and iv) an existential perspective highlighting inevitable harm and unavoidable transformation for some people and systems. This report assesses the growing literature on loss and damage across sectors and regions linking with adaptation constraints and limits, global warming level and incremental and or transformational adaptation to climate risks (Section 8.3.4, Cross-Chapter Box LOSS in Chapter 17, Box 10.7).

For assessing the projected losses and damages, residual risks also need to be taken into account. The loss and damage associated with the future climate change impacts, beyond the limits to adaptation, is an area of increasing focus, although yet to be fully developed in terms of methods of assessing including non-economic losses and damages as well as identifying means to avoid and reduce both economic (loss of asset, infrastructure, land etc.) and non-economic (loss of societal beliefs and values, cultural heritage, biodiversity and ecosystem services) losses and damages (Andrei et al., 2015; Fankhauser and Dietz, 2014). There is an increasing evidence in economic and non-economic losses due to climate extremes and slow onset events under observed increases in global temperatures (Coronese et al., 2019; Section 8.3.4; Grinsted et al., 2019; Kahn et al., 2019), however assessing non-economic losses and damages is lacking and needs more attention (Serdeczny et al., 2016; Tschakert et al., 2019). The aggregate losses and damages would be higher if non-economic values are considered in such assessment (Laurila-Pant et al., 2015; McShane, 2017). Solutions to reduce or avoid loss and damage need a robust conceptual framework and analysis, focusing the future losses rather than past losses (Preston, 2017) and emphasis on avoiding versus addressing loss and damage, and the role of justice (Boyd et al., 2017), clarity on the detection and attribution (Section 8.2.1, Section 8.3.3), effectiveness of risk management and adaptation (Cross-Chapter Box FEASIB in Chapter 18, Section 1.4), the concepts of risk transfer, liability and financing (Cross-Chapter Box FINANCE in Chapter 17, Section 17.4.2), and the role of transformation (Section 1.5).

1.5 Facilitating Long-Term Transformation

This report highlights that transformative system change is required to meet sustainable development goals (Chapter 18). **Transformation** is defined as "a change in the fundamental attributes of a system including altered goals or values" (SR 1.5). The related concept of **transition** is defined as "the process of changing from one state or condition to another in a given period of time" (IPCC SR 1.5/SRCCL, also see Section 1.5.2).

Many timescales have been assessed that shape the context for any such transformations: including the present, 2030 and mid-century (Cross-Chapter Box CLIMATE in Chapter 1). In the present, significant changes in the climate system have already occurred in many places (WGI) while commensurate adaptation actions have in general been lacking (Chapter 16). By 2030, the SDGs call for significant societal changes, many of which would be more difficult to achieve without significant reductions in climate risk and impacts. By mid-century, global emissions pathways consistent with the Paris Agreement 1.5°C target drop to zero net greenhouse gas emissions with no overshoot and roughly a decade later with overshoot (Cross-Chapter Box CLIMATE in Chapter 1). Pathways consistent with the Paris 2°C target drop to zero net emissions in the latter half of the 21st century. Even in low emission scenarios temperatures, storm intensities, sea levels and other climate parameters are expected to continuing changing for decades (IPCC, 2021).

The concepts of transition and transformation help organize assessments of near and longer-term adaptation actions that may prove feasible and effective in achieving societal goals related to climate and sustainable development.

1.5.1 Understanding Transformation

Over the last two hundred years, human society has undergone a rapid and profound transformation, with population and income per capita expanding by an order of magnitude or more after many millennia of relative stasis in living standards (Dasgupta et al., 2018). The transformations associated with sustainable development and managing climate risk may be of similar scale as these historic transformations. In the past, changes in technologies and economies of this scale are not separate from, but are necessarily embedded alongside changes in political, religious and social relationships (Polanyi, 1957). Future transformation may similarly involve such interlinked social, cultural, economic, environmental, technical and political factors (Chapter 18; Section 1.5.2). Technology-led, market-led or state-led transitions aimed at meeting Paris Agreement and SDGs may fail without integrating dimensions of social justice and addressing the social and political exclusion that prevent the disadvantaged from accessing such improvements and increasing their incomes (Burkett et al., 2014; Scoones et al., 2015). (*medium confidence*)

As used in the global environmental change literature, transformation is a pluralistic concept embracing many interpretations (Box 18.3), but all focus on the general idea of fundamental change in society as opposed to change that is minor, marginal, or incremental. Uses of the term can differ with respect to: 1) how the system undergoing change is conceptualized, 2) the extent to which change is continuous or discontinuous and the time scales involved, 3) the extent to which transformation is guided towards desired goals or emerges without intent and 4) whether the usage focuses on descriptions of societal processes or includes normative judgements as to which outcomes should or should not occur (Feola, 2015) . The literature generally uses transformation as an analytic-descriptive concept, which aims to describe significant change in couple human-natural systems, or as solutions-oriented concept, which aims to inform or contribute to societal change.

The IPCC Fifth Assessment cycle, starting with its Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX), first highlighted the concept of transformation, drawing primarily on the solutions-oriented approaches of O'Brien (2011) and Pelling (2011). This Sixth Assessment report also generally employs transformation as a solutions-oriented concept, with mention in almost all chapters and significant emphasis in the synthesis chapters.

The IPCC Sixth Assessment cycle also highlights the concept of transition, drawn from the sustainability transitions literature (Köhler et al., 2019). The 1.5 Special Report organizes its assessments of feasibility and potential policy actions around transitions in four socio-technical system: energy, land, urban and infrastructure and industrial system (IPCC, 2018b: Chapter 4). This report adds a fifth system transition -- a societal transition focused on attributes that drive innovation, the evolution of patterns of consumption and development and power relationships among societal actors (Section 18.1.4). The AR6 WGIII report is organized around six systems transitions: energy; agricultural, forestry, other land use; urban; buildings; transportation; and industry, which includes supply chains and the circular economy.

The literature offers multiple views on the relationships between transition and transformation (Box 18.3). The 1.5 Special Report suggests that transformation is needed to generate the four system transitions. In many literatures, transformation is considered a more expansive process than transition, with the former less exclusively focused on socio-technical systems and more engaged with questions of power, politics, capabilities, culture, identity and sense-making (Gillard et al., 2016; Hölscher et al., 2018; Linnér and

Wibeck, 2019). This report generally takes this more expansive view of transformation, often to engage with issues of equity, climate justice and large-scale institutional and societal change (Box 18.3).

This WGII report has a particular focus on **transformational adaptation** (Section 1.4.4.1), which it views as laying on a continuum from incremental and transformational with no sharp division between them (Sections 17.2.2.3, 1.5.2).

The IPCC first highlighted the concept of transformational adaptation in the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX). SREX generally used the phrase transformation to refer to fundamental societal changes that advance climate adaptation, disaster risk management and sustainable development. Transformation was seen as one part of the solution space alongside options such as reducing vulnerability and exposure and increasing resilience for managing risk. WGII of the IPCC Fifth Assessment Report used the phrase transformational adaptation to contrast with incremental adaptation. That report used the former term to refer to: 1) adaptation at large scope or scale, 2) as the type of adaptation that occurs once soft limits have been breached, or 3) change that addresses root causes of vulnerability as well as redressing long-standing inequities. The Fifth Assessment Report's WGIII employed the concepts of transformation and transformation pathways to assess the large-scale societal changes needed to meet greenhouse gas emission reduction goals.

This WGII report focuses on transformational adaptation as one component of climate resilient development in which adaptation, mitigation and development solutions are pursued together to exploit synergies and reduce trade-offs among these actions (Section 1.5.3; Chapter 18). Chapter 16 assesses the extent to which transformational adaptation is currently being implemented, using criteria including the scope, depth and speed of the adaptation actions as well as the extent to which limits to adaptation have been considered (Section 16.3.2.4). Chapter 17 ranks potential adaptation options by where they lie on the incremental to transformational continuum (Section 17.5.1.1.2).

Societal transformation can arise without explicit intent as, arguably, did the industrial revolution and some of the trends re-making today's society (See Section 1.1). In order to help policy-makers achieve societal goals this report seeks to identify the conditions for **deliberate transformations**, that is, those envisioned and intended by at least some societal actors (Linnér and Wibeck, 2019).

Figure 1.9 connects several key concepts that this report employs to help distinguish pathways that lead to deliberative and forced transformations. As shown in the figure, adaptation goals might imply a desired level of adaptation: 1) accessible by actions within the solution space of the existing system or 2) beyond the solution space of the existing system. In the former case, incremental adaptation may stay within soft limits and hold risks to tolerable levels that avoid threatening private or social norms (also see Fig 17.6). In the latter case, deliberate transformational adaptation is necessary to reach the goals. Alternatively, if deliberate transformation does not successfully occur or hard limits are exceeded, the system may nonetheless undergo some type of forced transformation which results in outcomes inconsistent with societal goals. While the figure shows single decision points, multiple actors are involved at each stage. Thus, some people may find themselves coping with what they regard as intolerable risks which are not otherwise avoided. Often such coping situations display significant inequities, with tolerable risks for powerful groups and intolerable ones for marginalized groups.

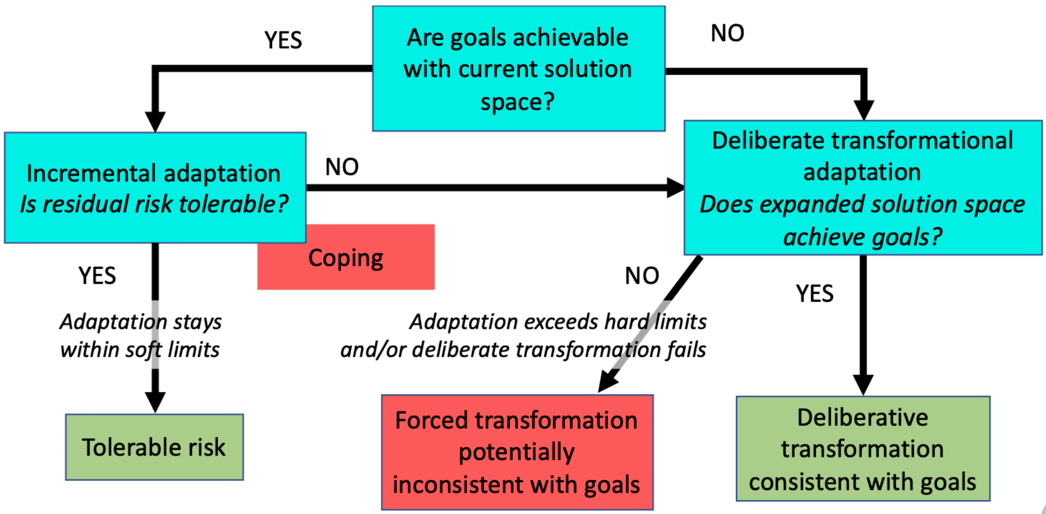

Figure 1.9: **Alternative Pathways to Transformation** Adaptation goals may be accessible by actions within or beyond the existing solution space. In the former case, incremental adaptation may stay within soft limits and hold risks to tolerable levels. In the latter case, deliberate transformational adaptation becomes necessary to achieve goals. If a successful deliberate transformation does not occur, the system may nonetheless undergo a forced transformation. Multiple actors are involved at each stage so that some people may nonetheless find themselves coping with what they regard as intolerable risks.

Multiple narratives describe pathways for pursuing deliberate transformations (Cavanagh and Benjaminsen, 2017). While building on the new "green economy" framing that emerged with the Rio+20 conference in 2012 (De Mello and Dutz, 2012; OECD, 2012; UNEP, 2011), these narratives reflect differing trade-offs among values and differing assumptions about the factors driving system change (see WGIII). The narratives range from "business-as-usual" scenarios focused on modernisation of sectors such as energy, agriculture and use of natural resources to more transformational propositions such as various green new deal proposals (European Commission, 2019), the new climate economy (Global Commission on the Economy and Climate, 2018), and "doughnut economics" (Raworth, 2017). Some literature suggests significant benefits from such new climate economy proposals, claiming tens of trillions in economic benefits, tens of millions of new jobs and close to a million fewer premature deaths from pollution over the coming decade (Global Commission on the Economy and Climate, 2018).

Two contrasting schools of thought, called ecomodernism and degrowth (D'Alisa et al., 2014), offer important bounding narratives for "green economy" approaches that aim achieve the SDGs and Paris Agreement goals.

Ecomodernism aims to decouple GHG emissions and other environmental impacts from GDP growth (Desrochers and Szurmak., 2020)(AR6 WGIII Sect 1.4.1) through three primary strategies: i) 'green' technological innovation, ii) resource efficiency or productivity improvements and iii) the sustainable intensification of land use in both rural and urban areas (Asafu-Adjaye et al., 2015; Isenhour, 2016). Such efforts to mobilize large-scale investment in climate change adaptation and to decouple GDP growth from environmental impacts could generate substantial employment opportunities and open up profitable investment frontiers (Adelman, 2018; Asafu-Adjaye et al., 2015), which could help achieve SDG 8, which calls for accelerated annual growth rates of at least 7 percent in least developed countries and achieve SDG 10, which calls for "income growth of the bottom 40 percent of the population at a rate higher than the national average".

Degrowth proponents question the feasibility of decoupling at a scale and rate sufficient for meeting Paris Agreement goals (Gómez-Baggethun, 2020; Hickel and Kallis, 2020; Kallis, 2017; Parrique et al., 2019). Using precautionary principle-rooted arguments (Latouche, 2001), degrowth aims for the intentional decreases in both GDP and coupled GHG emissions (Kallis, 2011) using policy mechanisms such a "cap and share" framework for distributing emissions permits on an annually declining basis with legislation to prohibit the overshoot of established carbon budgets (Douthwaite, 2012; Kallis et al., 2012). Degrowth thus seeks to minimize reliance on negative emissions technologies, such as the large-scale deployment of

BECCS (e.g., illustrative emissions reduction pathway labelled P4 in IPCC SR1.5, also WGIII Chapter 3) and aims to generate progress toward achieving the SDGs by prioritising redistribution rather than GDP growth. SDGs potentially addressed by degrowth include universal basic income (SDGs 1 and 10), work-sharing to guarantee full employment (SDGs 8 and 10) and shifting taxation burdens from income to resource and energy extraction (SDGs 8 and 12).

The contrasting premises of ecomodernism and degrowth have prompted a series of mutual counterarguments. Degrowth scholars emphasize that global absolute decoupling is currently not proceeding fast enough to meet Paris Agreement targets (Haberl et al., 2020; Moreau et al., 2019; Ward et al., 2016). Ecomodernists point to important progress towards achieving absolute decoupling at the national or regional scale – as shown by Le Quéré et al. (2019) in 18 developed countries – and the future potential of emerging technologies and policy reforms (Asafu-Adjaye et al., 2015)

1.5.2 Enabling Transformation

As one important theme, this Sixth Assessment report assesses who needs to take what actions and when in order that transformations unfold at sufficient speed and scale to meet Paris, SDG and other policy goals. A number of literatures inform these assessments.

Various literatures describe multiple, co-evolving societal elements which organize themselves into stable regimes that, under some circumstance, can undergo significant change. The sustainability transitions literature provides one central focus for understanding such processes and potential intervention points for actors seeking change (Köhler et al., 2019). This literature identifies three, interacting scales: the micro, meso and macro.(Geels, 2004; Köhler et al., 2019) The micro level reflects changing individual choices, attitudes and motivations. The meso reflects socio-technical systems, 'a cluster of elements, including technology, regulations, user practices and markets, cultural meanings, infrastructure, maintenance networks and supply networks' The macro reflects the cultures, institutions, norms, governance and other broad organising features of society. The sustainability transitions literature generally focuses on change that originates and occurs within the meso scale, while the transformation literature focuses on change within and among all scales. This Working Group II report often considers three interacting scales labelled personal, practical and political (O'Brien and Sygna, 2013). Working Group III often employs the multi-level perspectives framework (Geels, 2004) and the more actor-oriented three domains of decision-making framework (Grubb et al., 2014; WGIII Section 1.6.4) to describe related societal scales.

These literatures describe similar processes through which these interacting elements generate significant system change. In the sustainability transitions literature the process begins with a stable system of actors, technologies and institutions (Köhler et al., 2019). Radical innovations begin in niches or protected spaces, sometimes introduced by new entrants or outsiders. Successful innovations expand in scale, scope, and geographically, and ultimately help generate new regimes. Incumbent actors can support or resists innovations through combinations of government policies, economic forces and institutional and behavioural pressures. Such processes can, but need not, follow a common S-curve pattern of initial adoption, take-off, acceleration and stabilisation (Rotmans et al., 2001). The multi-level perspectives literature in WGIII similarly describes innovations as moving from niches to socio-technical regimes, at first mediated by and then potentially altering exogenous socio-technical landscapes (Smith et al., 2010; WGIII Section 1.6.4).

The socio-ecological systems literature, a main source of the resilience concept, focuses on the system elements of society and eco-systems, their interdependence and on how they change in response to shocks (Section 1.2.1.4). Coupled human and natural systems maintain their vital functions through what are called adaptive cycles that begin with growth, reach a period of stasis, experience a disruption, and then reorganize. This repeating cycle can leave the system unchanged or transition it to new states. Human agency can alter system characteristics so that after any disruption the system will reorganize into a different, more desired state; guide the reorganisation in desired directions after a system shock (such as a natural disaster); or provide the shock that catalyses a reorganisation.

These literatures view incremental and transformational change as linked processes. In the transformational adaptation literature, Park et al. (2012) consider incremental and transformational adaptation as two concentric and linked action-learning cycles with similar steps that include monitoring and learning. Systems generally reside in the incremental cycle but can temporarily jump to the transformational cycle before returning to the incremental, albeit in a state with fundamentally changed attributes. Shifts from the incremental to transformational cycle are made possible by knowledge and skills, as well as adjustments to vision, agendas and coalitions achieved through monitoring and learning. The incremental cycle is characterized by reactive responses to external drivers and performance evaluation relative to past performance. Shifts to the transformational cycle are characterized by more pro-active responses and more expansive problem framings.

The socio-ecological and sustainability transitions literature describes transitions as often non-linear, characterized by tipping point behaviour with periods of relative stability interspersed with periods of more rapid change as thresholds are crossed (van Ginkel et al., 2020). Actors seeking transformation may take incremental steps that aim to induce such tipping point behaviour (Otto et al., 2020b). For instance, full accounting of climate risk in insurance and financial lending decisions could similarly act as such social tipping point interventions for adaptation (Hill and Martinez-Diaz, 2019). Transformations need not, however, be equitable or smooth. Historical examples suggest the potential for rigidity traps, in which suppression of innovation and a high degree of connectivity in a system delay an eventual transformation which, when it eventually occurs, unfolds as exceptionally harsh (Hegmon et al., 2008).

Many actors can contribute to launching or blocking significant system change. Pelling et al (2015) highlights power relationships within and among activity spheres that influence the process of transformational adaptation and distribution of risks. In the sustainability transitions literature each set of actors --including those from academia, politics, industry, civil society and households -- brings their own resources, capabilities, beliefs, strategies and interests, which affects their interest, objectives, ability to affect the process and their ability to affect others (Kern and Rogge, 2018).

There is no consensus in the literature on the best means for actors to pursue deliberate transformation (Section 1.5.1) and the extent to which actors can guide the process. The transitions and some transformation literatures derive from a complex systems perspective (Köhler et al., 2019; Section 1.3.1.2; Linnér and Wibeck, 2019) in which behaviours can be understood but not predicted (Mitchell, 2009; Chapter 17). These literatures suggest that interventions in such systems will rarely result in them evolving along some pre-determined pathway. Rather, successful interventions more often resemble iterative processes of action, observation and response, which are described in the literature with terms such as iterative risk management (Section 17.2.1), clumsy solutions (Linnér and Wibeck, 2019; Thompson and Rayner, 1998), probe and response (Chapter 17; French, 2013) and what Young (2017) calls adaptive governance.

These literatures view transformation as a collective action challenge among actors with both common and differing values, interests and capabilities interacting over time with a mix of cooperation and competition (Dasgupta et al., 2018; Young, 2017). Concepts such as radical incremental transformation (Göpel, 2016), direct incrementalism (Grunwald 2007) and progressive incrementalism (Levin et al., 2012) envision strategies in which actors pursue incremental actions in one or more niches that move the current system towards tipping points which, once crossed, will drive the system to a new state (Tàbara et al., 2018). The incremental actions aim to promote learning, remove barriers to change (Baresi et al., 2020; Dasgupta et al., 2018), create a series of wins that generate momentum and generate positive feedbacks (e.g. by creating constituencies) such that the speed and scale of the climate action grows over time (Levin et al., 2012). But incremental strategies can fail to move fast enough; can succumb to path-dependency that locks in initially helpful but long-adverse responses (such as the well-known levee-effect) (Sadoff 2015; Haasnoot 2019); or can result in a transition that meets some goals (e.g., environmental) but not others (e.g., equity). (*high confidence*)

This report describes decision frameworks and tools that can help those involved in such a process – acting independently or collectively - identify, evaluate, seek compromise on, and then implement sequences of solutions that lead to pathways with more desirable outcomes and avoid pathways with less desirable outcomes (Section 17.3.1). For instance, adaptive (also called adaptation) pathways (Cross-Chapter Boxes SLR in Chapter 3 and DEEP in Chapter 17) explicitly chart alternative sequences of actions including near-term steps, indicators to monitor and contingency actions to take if pre-determined monitoring thresholds are breached. Employed in contexts with multiple actors and contested values, adaptive pathways frames deliberate transformation as both a near-term decision problem focused on physical, financial and natural resources as well as a social change process of co-evolving knowledge, policies, institutions, values, rules and norms (Fazey et al., 2016). Transition Management (Loorbach, 2010), rooted in the sustainability transitions literature, supports arenas of actors that co-produce visions of future change, plan pathways and recruit additional actors into the change process.

As a central feature, such frameworks and tools embrace: 1) multiple objectives and measures (Section 1.4.1.2) to help identify and consider trade-offs among parties with a diversity of interests, values and objectives and 2) multiple scenarios enable stress-testing of proposed actions to identify conditions in which they would fail to meet their goals and thus inform consideration of ways to make those actions more robust and resilient over multiple futures in the near- and longer-term (Chapter 17; Cross-Chapter Box DEEP in Chapter 17). A focus on single or overly aggregated measures (Section 1.4.1.2) and single scenarios can privilege some actors' views over others, reduce transparency, and make it more difficult to identify resilient and equitable solutions to complex, deeply uncertain, non-linear and contested problems (Jones et al., 2014; Lempert and Turner, 2020; Renn, 2008; Schoen and and Rein, 1994). (*medium confidence*)

Nonetheless, most concepts of deliberate transformation also emphasize the importance of common goals and principles within a process of goal setting, acting on those goals, monitoring and evaluation and readjustment. Such goals encourage proactive action; help align the activities of multiple, loosely co-ordinated actors (Dasgupta et al., 2018; Göpel, 2016); and provide benchmarks against which to measure progress (Young, 2017). The Paris Agreement and SDGs aim to provide such common goals for the world as a whole and implement what some have described as goal-based as opposed to rule-based governance for galvanising collection action (Kanie and Biermann, 2017; Sachs, 2015). As intended, many public sector, private sector and civil society actors have developed their own goals as that aim to align with the Paris Agreement and the SDGs (see Section 1.1). The existence of goals that helps people envision a future significantly different than present can be one often key difference between decision processes that pursue transformational as opposed to incremental change (Park et al., 2012; Chapter 17). Narratives that help explain where a community is, where it wants to go and how it intends to get there are an important enabler of transformation (Section 1.5.1; Section 1.2.3; Fazey et al., 2020; Linnér and Wibeck, 2019).

1.5.3 Climate-Resilient Development

Adaptation and mitigation can reduce climate-related risks. Implementing these two types of climate action together increases their effectiveness by exploiting synergies and reducing trade-offs among them. In addition, implementing adaptation and mitigation as an integral part of development can similarly make all three more effective (Section 18.2.3). The link between climate change and sustainable development has long been recognized and has been assessed in every Working Group 2 report since AR3. AR5 introduced the concept of climate resilient development to help assess development trajectories that include co-ordinated adaptation and mitigation actions aimed at reducing climate risk.

Building on AR5, this AR6 report expands the focus with increased attention to equity and the processes needed to follow such trajectories. AR6 thus defines **climate resilient development** as "a process of implementing greenhouse gas mitigation and adaptation solutions to support sustainable development for all" (Section 18.1.1). In AR6 WGII, some chapters have a section dedicated to climate resilient development, emphasizing the need for integrative and transformative solutions within a sector or region that address the uneven distribution of climate risks among different groups and geographies, as well as extend the goals of these solutions to more than reducing risk, such as in improving social, economic and ecological outcomes (Sections 2.6.7, 4.1, 5.14.4, 6.4.8, 7.4.3.5, 7.4.5, 10.6, 11.8, 15.7 and 17.6; Boxes 4.7, 13.3 and 8.10). Multiple chapters also employ the concept of climate resilient development to identify and balance trade-offs and make progress on achieving the SDGs (Sections 6.1.3, 7.4.5, 10.6, 13.11, 15.7 and 16.6.4.3; Box 4.7; Chapter 18).

Climate resilient development requires large and equitable changes in human and natural systems. As noted in Section 1.5.1, the SR1.5 finds that four transitions in socio-economic systems - energy, land and ecosystems, urban and infrastructure and industrial – must occur at large scale and rapid rate in order to achieve climate resilient development. This report notes that transitions of such scale, even when beneficial for many people, can also impose significant adverse impacts on others, in particular on marginal and vulnerable populations (Section 18.1.2). This report identifies a fifth socio-economic transition, that in societal systems that "drive innovation, preferences for alternative patterns of consumption and development, and the power relationships among different actors that engage in CRD" (Section 18.1.4). Such societal transitions are necessary to ensure the other four transitions unfold at sufficient speed and scale to meet Paris and Sustainable Development goals as well as to ensure equity in these transitions.

Introduced in the WGII AR5 (Olsson et al., 2014), and further addressed in SR1.5, climate resilient development pathways are trajectories that strengthen sustainable development and efforts to eradicate poverty and reduce inequalities, while promoting fair and equitable reductions of GHG emissions, and serve to steer societies towards low-carbon, prosperous and ecologically safe futures. This report defines a **climate resilient development pathway** as a trajectory in time reflecting a particular sequence of actions and consequences against a background of autonomous developments leading to a specific future situation (Section 18.1.2). Such a pathway emerges from the spatially and temporally distributed choices of many different actors in government, business, civic organizations and households at the individual, community, national and international levels. As such, there exists no single or preferred pathway for climate resilient development and no single best combination of adaptation, mitigation and sustainable development strategies. All pathways involve complex trade-offs and synergies among different actions (Sections 18.1.4, 18.2.2). All pathways are subject to hard-to-predict shocks, both adverse, such as climate disasters, and beneficial, such as new technologies or shifts in public values. The pathway that emerges will represent the results of negotiation, cooperation and competition among actors at many scales whose differing values and objectives would favour differing trajectories (Section 18.1.4). Individual actors at various scales will determine the mix of adaptation, mitigation and development appropriate for their development context and goals, while also influenced by the desire for their collective actions to become consistent with the global policy goals such as those in the Paris Agreement and the SDGs (Section 18.1.2). The norms, institutions and power relationships that mediate such choices determine the extent to which the process unfolds consistent with principles of equity and social justice. (*high confidence*)

Enabling conditions that can accelerate climate resilient development include governance; finance; economy; and science, technology and information (Sections 18.4.2, 18.9.2). The pursuit of equity and justice are both an enabler and an outcome of climate resilient development (Section 18.1.4). Climate resilient development involves a process of action, learning and response (Section 1.5.2), so the capability for such monitoring and iterative risk management also represents an important enabling condition (Section 18.1.4.2). Governments have an important role to play in expanding the solution space, often focusing on technology, policy and finance. Expanding the solution space also requires a broader set of actors. Chapter 18 and other chapters in this report use the climate resilient development concept to highlight the role of citizens, civil society, knowledge institutions, media, investors and businesses and the importance of expanding the arenas of engagement in which they interact.

1.6 Structure of the Report

The IPCC mandate involves the provisioning of available scientific information and evidence to inform climate action by multiple actors, notably governments (including international alliances) in the context of UNFCCC. Increasingly, IPCC assessments also aim to provide valuable information to non-governmental organisations, small and large enterprises and citizens.

Figure 1.10 shows the structure of this report, organized into three sections comprising chapters and cross-chapter papers. This first chapter provides the point of departure for this assessment, defines key concepts, and describes the connections among them.

The next group of chapters assess risks, adaptation and sustainability for systems impacted by climate change from the vantage of seven sectoral chapters, The next group of chapters organizes the assessment from the vantage of seven regional chapters.

In contrast to previous assessments, the current report embeds adaptation in each regional and sectoral chapter rather than in separate adaptation chapters, in order to reflect the increasing prevalence of adaptation and the extent to which many current risk, impacts and vulnerability estimates incorporate adaptation actions already taken. In addition, cross-chapter papers (CCPs) integrate across chapter topics, sectors and regions in particular types of geographies or ecosystems, termed typological regions, such as mountains, cities by the sea, or tropical forests. CCPs are a new element in WGII AR6 included at the request of Governments to highlight and expand relevant material from chapters and beyond into one place to ensure the integrated treatment of particular systems or regions and to improve accessibility of the report to readers.

Finally, section three highlights sustainable development pathways of integrating adaptation and mitigation by three synthesis chapters. The synthesis chapters summarize findings across all the chapters, CCPs and literatures on key risks, decision making options, and climate resilient development pathways that can lead from the current situation to a future more consistent with the stated policy goals. This report also assesses the adaptation options available, the extent to which such options can reduce risk, the effectiveness of current adaptation efforts, and their interactions with mitigation and sustainable development.

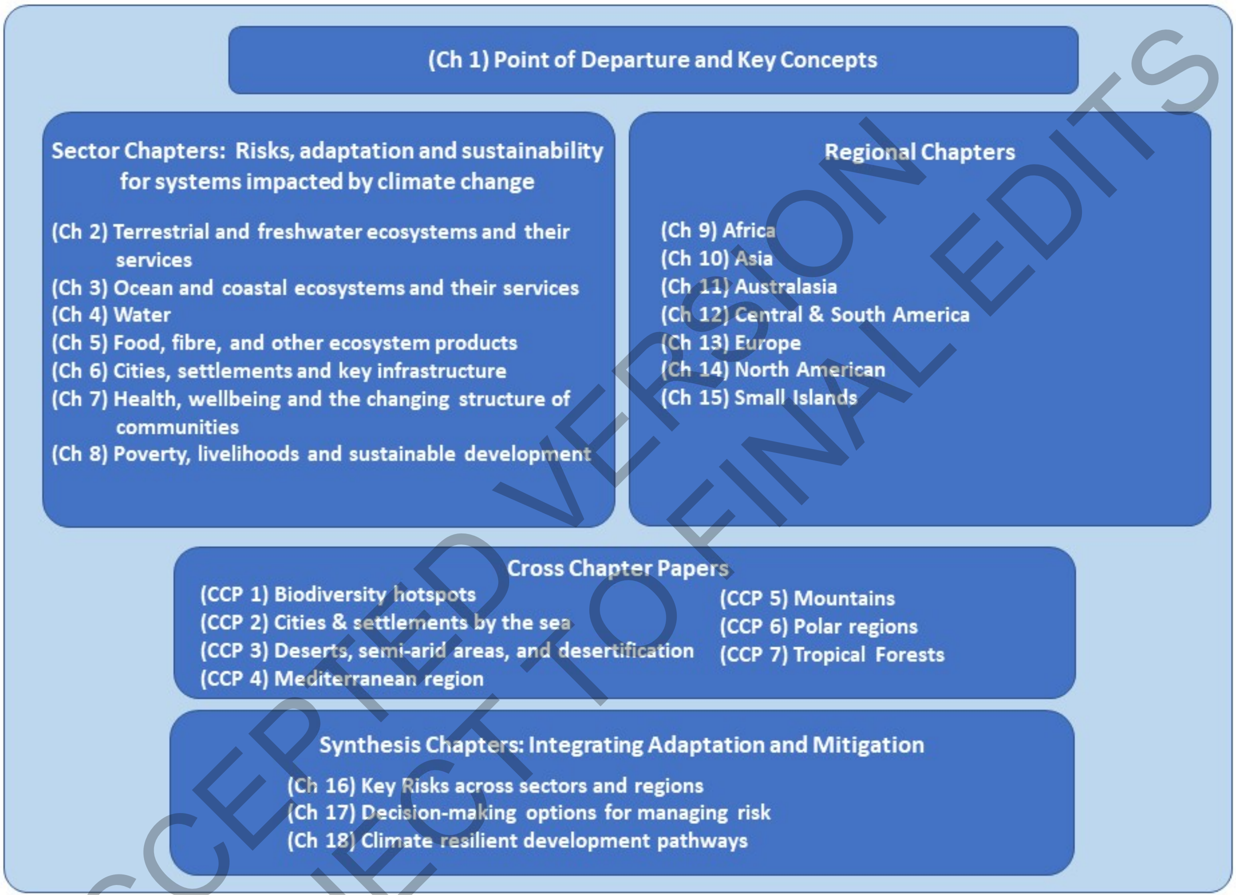

Figure 1.10: Key elements of the IPCC WGII report

[START FAQ1.1 HERE]

FAQ1.1: What are the goals of climate change adaptation?

The goals of climate change adaptation, as a broad concept, are to reduce risk and vulnerability to climate change, strengthen resilience, enhance well-being and the capacity to anticipate, and respond successfully to change. Existing international frameworks provide a high-level direction for coordinating, financing and assessing progress toward these goals. However, specifying the goals for specific adaptation actions is not straightforward because the impacts of climate change affect people and nature in many different ways requiring different adaptation actions. Thereby, goals that accompany these actions are diverse. Goals can relate to health, water or food security, jobs and employment, poverty eradication and social equity, biodiversity and ecosystem services at international, national, and local levels.

Climate change adaptation entails the process of adjustment to actual or expected climate change and its effects in order to moderate harm or exploit beneficial opportunities. At a high level, international frameworks, including the Paris Agreement and the Sustainable Development Goals (SDGs), have come to provide a direction for coordinating, financing and assessing global progress in these terms. The Paris Agreement calls for climate change adaptation actions, referring to these actions as those that reduce risk and vulnerability, strengthen resilience, enhance the capacity to anticipate and respond successfully, and ensure the availability of necessary financial resources, as these processes and outcomes relate to climate change. In addition, the Sustainable Development Goals include 17 targets (with a specific goal SDG 13 on climate action) to fulfil its mission to end extreme poverty by 2030, protect the planet, and build more peaceful, just, and inclusive societies. These goals are difficult to reach without successful adaptation to climate change. Other notable frameworks that identify climate change adaptation as important global priorities include the Sendai Framework for Disaster Risk Reduction, the finance-oriented Addis Ababa Action Agenda and the New Urban Agenda.

While vital for international finance, coordination and assessment, the global goals set forth by these frameworks and conventions do not necessarily provide sufficient guidance to plan, implement or evaluate specific adaptation efforts at the community level. Specifying goals of adaptation is harder than setting goals for reducing emissions of climate-warming greenhouse gas emissions. For instance, emission-reduction effort is ultimately measured by the total amount of greenhouse gases in the Earth's atmosphere. Instead, adaptation aims to reduce risk and vulnerability from climate change and helps to enhance well-being in each individual community worldwide.

Because the impacts of climate change affect people and nature in so many different ways, the specific goals of adaptation depend on the impact being managed and the action being taken . For human systems, adaptation includes actions aimed at reducing a specific risk, such as by hardening a building against flooding, or actions aimed at multiple risks, such as requiring climate risk assessments in financial reporting in anticipation of different kinds of risk. At the local level, communities can take actions that include updating building codes and land use plans, improving soil management, enhancing water use efficiency, supporting migrants and taking measures for poverty reduction. For natural systems, adaptation includes organisms changing behaviours, migrating to new locations and genetic modifications in response to changing climate conditions. The goals for these adaptation actions can relate to health, water or food security, jobs and employment, poverty eradication and social equity, biodiversity and ecosystem services, among others. Articulating the goals of adaptation thus requires engaging with the concepts of equity, justice, and effectiveness at the international, national, and local levels.

[END FAQ1.1 HERE]

[START FAQ1.2 HERE]

FAQ1.2: Is climate change adaptation urgent?

Climate impacts, such as stronger heat waves, longer droughts, more frequent floods, accelerating sea- level rise, and storm surges, are already being observed in some regions, and people around the world are increasingly perceiving changing climates, regarding these changes as significant and considering climate action as a matter of high urgency. Reducing climate risk to levels that avoid threatening private or social norms and ensuring sustainable development will require immediate and long-term adaptation efforts by governments, business, civil society, and individuals at a scale and speed significantly faster than the current trends.

Current observed climate impacts and expected future risks include stronger and longer heat waves, unprecedented droughts and floods, accelerating sea-level rise and storm surges affecting many geographies and communities. People around the world are increasingly perceiving changing climates, regarding these changes as significant and considering climate action as a matter of high urgency. Particularly, marginalised and poor people as well as island and coastal community experience relatively higher risks and vulnerability. The available evidence suggests that current adaptation efforts may be insufficient to help ensure sustainable development and other societal goals in many communities worldwide even under the most optimistic greenhouse gas emissions scenarios.

Climate change adaptation is, therefore, urgent to the extent that meeting important societal goals requires immediate and long-term action by governments, business, civil society, and individuals at a scale and speed significantly faster than that represented by current trends.

[END FAQ1.2 HERE]

[START FAQ1.3 HERE]

FAQ1.3: What constitutes successful adaptation to climate change?

Success of climate change adaptation is dependent on the extent to which relevant actions reduce risk and vulnerability, as well as achieve their respective goals. At a global scale, these goals are set and tracked according to international frameworks and conventions. At smaller scales, such as local and national, goals are dependent on the specific impacts being managed, the actions being taken, and the relevant scale. While success can take shape as uniquely as goals can, the degree to which an adaptation is feasible, effective, and conforms to principles of justice represents important attributes for measuring success across actions. Adaptation responses that lead to increased risk and impacts are considered maladaptation.

Altogether, adaptation success is dependent on the extent to which adaptation actions achieve their respective goals of reducing climate risk, increasing resilience, and pursuing other climate-related societal goals. Viewed globally, successful adaptation consists of actions anticipated to make significant contributions to meeting sustainable development goal such as ending extreme poverty, hunger, and discrimination and reduce risks to ecosystems, water, food systems, human settlements, and health and well-being. Viewed locally, successful adaptation consists of actions that help communities meet their diverse goals including reducing anticipated current and future risks, enhancing capacity to adapt and transform, avoiding maladaptation, yielding benefits greater than costs, serving vulnerable populations, and arising from an inclusive, evidence-based, and equitable decision process.

While success can be unique to an adaptation action, there are important attributes that constitute it as a successful solution. These include the extent to which an action is considered feasible, effective, and conforms to principles of justice.

The degree to which an action is **feasible** is the extent it is appraised as possible and desirable, taking into consideration barriers, enablers, synergies, and trade-offs. These considerations are based on financial or economic, political, physical, historical, and social factors, depending on what is required for an action to be implemented. The degree to which an action is **effective** depends on the extent it reduces climate risk, as well as the extent an action achieves its intended goals or outcomes. An adaptation action can sometimes – usually inadvertently – increase risk or vulnerability for some or all affected individuals or communities. In some cases, such risk increases will be sufficient to call the actions maladaptation. The degree to which an action is **just** is when its outcomes, the process of implementing the action, and the process of choosing the action respects principles of distributive, procedural, and recognitional justice. Distributive justice refers to the different distributions of benefits and burdens of an action across members of society; procedural justice refers to ensuring the opportunity for fairness, transparency, inclusion, and impartiality in the decision-making of an action; and recognitional justice insists on recognizing and including those who are or may be most affected by an action.

These attributes of adaptation success can be assessed throughout the adaptation process of planning, implementation, monitoring and evaluation, adjustment, and learning. However, at the same time, the success of many adaptation actions depend strongly on context and time. For instance, the effectiveness of adaptation will depend on the success of greenhouse gas mitigation efforts, as adaptation has strong synergies and trade-offs with mitigation efforts

[END FAQ1.3 HERE]

[START FAQ1.4 HERE]

FAQ1.4: What is transformational adaptation?

Continuing and expanding current adaptation efforts can reduce some climate risks. But even with emission reductions sufficient to meet the Paris Agreement goals, transformational adaptation will be necessary.

Over six assessment reports, the IPCC has documented transformative changes in the Earth's climate and ecosystems caused by human actions. These changes are now unequivocal and projected to become even more significant in the years and decades ahead. This AR6 report also highlights climate adaptation actions people are taking and can take in response to these significant changes in the climate system.

Some adaptation is incremental, which only modifies existing systems. Other actions are transformational, leading to changes in the fundamental characteristics of a system. For instance, building a seawall to protect a coastal community from flooding might exemplify incremental adaptation. Changing land use regulations in that community and establishing a program of managed retreat might exemplify transformational adaptation. There exists no bright line between incremental and transformational adaptation. Some incremental actions stay incremental. Others may expand the future space of solutions. For instance, including climate risk in mortgages and insurance might at first seem incremental but might lead to more transformational change over time.

Transformation can be deliberate, envisioned and intended by at least some societal actors, or forced, arising without explicit intent.

Deliberate transformational adaptation is not without risks because change can disturb existing power relationships and can unfold in difficult to predict and unintended ways. But transformational adaptation is important to consider because it may be needed to avoid intolerable risks from climate change and may be needed to help meet development goals as articulated in the SDGs. In addition, some type of societal transformation may be inevitable and deliberate rather than forced transformation may bring society closer to its goals.

Some type of transformation may be inevitable because the amount of transformational adaptation needed to avoid intolerable risks depends in part on the level of greenhouse gas mitigation. Low concentration pathways consistent with Paris Agreement goals require deliberate transformations that lead to significant and rapid change in energy, land, urban and infrastructure, and industrial systems. Even with low concentration pathways, some transformational adaptation will be necessary to limit intolerable risks. But with higher concentrations pathways, more extensive transformational adaptation would be required to limit (though not entirely avoid) intolerable risks. In such circumstance, insufficient deliberate transformation could lead to undesirable forced transformations.

[END FAQ1.4 HERE]

[START FAQ1.5 HERE]

FAQ1.5: What is new in this 6th IPCC report on impacts, adaptation and vulnerability?

Since IPCC Fifth Assessment Report, many new sources of knowledge have been employed to provide better understanding of climate change risks, impacts, vulnerability, and also societal responses through adaptation, mitigation and sustainable development. This new, more integrative assessment increasing focuses on risk and solutions, social justice, different forms of knowledge including Indigenous knowledge and local knowledge, role of transformation and the urgency of fast climate actions.

The IPCC Sixth Assessment Report (AR6) plays a prominent role in science-policy–society interactions on the climate issue since 1988, has advanced in important ways of interdisciplinary climate change assessment since AR5. Many new sources of knowledge have been employed to provide better understanding of climate change risks, impacts, vulnerability, and also societal responses through adaptation, mitigation and sustainable development.

This AR6 assessment has increasingly focus on risk and solutions. The risk framing for the first time spans all three working groups, includes risks from the responses to climate change, considers dynamic and cascading consequences, describes with more geographic detail risks to people and ecosystems, and assesses such risks over a range of scenarios. The solutions framing encompasses the interconnections among climate responses, sustainable development, and transformation—and the implications for governance across scales within the public and private sectors. The assessment therefore includes climate-related decision-making and risk management, climate-resilient development pathways, implementation and evaluation of adaptation, and also limits to adaptation and loss and damage.

The AR6 emphases the emergent issue on social justice and different forms of knowledge. As climate change impacts and implemented responses increasingly occur, there is heightened awareness of the ways that climate responses interact with issues of justice and social progress. In this report, there is expanded attention to inequity in climate vulnerability and responses, the role of power and participation in processes of implementation, unequal and differential impacts, and climate justice. The historic focus on scientific literature has also been increasingly accompanied by attention to and incorporation of Indigenous knowledge, local knowledge, and associated scholars.

The AR6 has a more extensive focus on the role of transformation and the urgency of fast climate actions in meeting societal goals. This report assesses extensive literatures with an increasing diversity of topics and geographical areas with more sectoral and regional details. The literature also increasingly evaluates the lived experiences of climate change—the physical changes underway, the impacts for people and ecosystems, the perceptions of the risks, and adaptation and mitigation responses planned and implemented.

The assessment in AR6 has increasingly become integrative across multiple disciplines and combine experts across working groups, chapters, papers and disciplines, such as natural and social sciences, medical and health sciences, engineering, humanities, law, and business administration etc. The emphasis on knowledge for action has also included the role of public communication, stories, and narratives within assessment and associated outreach.

[END FAQ1.5 HERE]

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