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CLIMATE CHANGE 2023

Synthesis Report

A Report of the Intergovernmental Panel on Climate Change



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CLIMATE CHANGE 2023

Synthesis Report

Edited by

The Core Writing Team

Synthesis Report
IPCC

Hoesung Lee

Chairman
IPCC

José Romero

Head, Technical Support Unit
IPCC

Core Writing Team

Hoesung Lee (Chair), Katherine Calvin (USA), Dipak Dasgupta (India/USA), Gerhard Krinner (France/Germany), Aditi Mukherji (India), Peter Thorne (Ireland/United Kingdom), Christopher Trisos (South Africa), José Romero (Switzerland), Paulina Aldunce (Chile), Ko Barrett (USA), Gabriel Blanco (Argentina), William W. L. Cheung (Canada), Sarah L. Connors (France/United Kingdom), Fatima Denton (The Gambia), Aïda Diongue-Niang (Senegal), David Dodman (Jamaica/United Kingdom/Netherlands), Matthias Garschagen (Germany), Oliver Geden (Germany), Bronwyn Hayward (New Zealand), Christopher Jones (United Kingdom), Frank Jotzo (Australia), Thelma Krug (Brazil), Rodel Lasco (Philippines), June-Yi Lee (Republic of Korea), Valérie Masson-Delmotte (France), Malte Meinshausen (Australia/Germany), Katja Mintenbeck (Germany), Abdalah Mokssit (Morocco), Friederike E. L. Otto (United Kingdom/Germany), Minal Pathak (India), Anna Pirani (Italy), Elvira Poloczanska (United Kingdom/Australia), Hans-Otto Pörtner (Germany), Aromar Revi (India), Debra C. Roberts (South Africa), Joyashree Roy (India/Thailand), Alex C. Ruane (USA), Jim Skea (United Kingdom), Priyadarshi R. Shukla (India), Raphael Slade (United Kingdom), Aimée Slangen (The Netherlands), Youba Sokona (Mali), Anna A. Sörensson (Argentina), Melinda Tignor (USA/Germany), Detlef van Vuuren (The Netherlands), Yi-Ming Wei (China), Harald Winkler (South Africa), Panmao Zhai (China), Zinta Zommers (Latvia)

Technical Support Unit for the Synthesis Report

José Romero (Switzerland), Jinmi Kim (Republic of Korea), Erik F. Haites (Canada), Yonghun Jung (Republic of Korea), Robert Stavins (USA), Arlene Birt (USA), Meeyoung Ha (Republic of Korea), Dan Jezreel A. Orendain (Philippines), Lance Ignon (USA), Semin Park (Republic of Korea), Youngin Park (Republic of Korea)

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Extended Writing Team

Jean-Charles Hourcade (France), Francis X. Johnson (Thailand/Sweden), Shonali Pachauri (Austria/India), Nicholas P. Simpson (South Africa/Zimbabwe), Chandni Singh (India), Adelle Thomas (Bahamas), Edmond Totin (Benin)

Review Editors

Paola Arias (Colombia), Mercedes Bustamante (Brazil), Ismail Elgizouli (Sudan), Gregory Flato (Canada), Mark Howden (Australia), Carlos Méndez (Venezuela), Joy Jacqueline Pereira (Malaysia), Ramón Pichs-Madruga (Cuba), Steven K Rose (USA), Yamina Saheb (Algeria/France), Roberto Sánchez Rodríguez (Mexico), Diana Ürge-Vorsatz (Hungary), Cunde Xiao (China), Noureddine Yassaa (Algeria)

Contributing Authors

Andrés Alegria (Germany/Honduras), Kyle Armour (USA), Birgit Bednar-Friedl (Austria), Kornelis Blok (The Netherlands), Guéladio Cissé (Switzerland/Mauritania/France), Frank Dentener (EU/Netherlands), Siri Eriksen (Norway), Erich Fischer (Switzerland), Gregory Garner (USA), Céline Guivarch (France), Marjolijn Haasnoot (The Netherlands), Gerrit Hansen (Germany), Mathias Hauser (Switzerland), Ed Hawkins (UK), Tim Hermans (The Netherlands), Robert Kopp (USA), Noémie Leprince-Ringuet (France), Jared Lewis (Australia/New Zealand), Debora Ley (Mexico/Guatemala), Chloé Ludden (Germany/France), Leila Niamir (Iran/The Netherlands/Austria), Zebedee Nicholls (Australia), Shreya Some (India/Thailand), Sophie Szopa (France), Blair Trewin (Australia), Kaj-Ivar van der Wijst (The Netherlands), Gundula Winter (The Netherlands/Germany), Maximilian Witting (Germany)

Scientific Steering Committee

Hoelsing Lee (Chair, IPCC), Amjad Abdulla (Maldives), Edvin Aldrian (Indonesia), Ko Barrett (United States of America), Eduardo Calvo (Peru), Carlo Carraro (Italy), Diriba Korecha Dadi (Ethiopia), Fatima Driouech (Morocco), Andreas Fischlin (Switzerland), Jan Fuglestvedt (Norway), Thelma Krug (Brazil), Nagmeldin G.E. Mahmoud (Sudan), Valérie Masson-Delmotte (France), Carlos Méndez (Venezuela), Joy Jacqueline Pereira (Malaysia), Ramón Pichs-Madruga (Cuba), Hans-Otto Pörtner (Germany), Andy Reisinger (New Zealand), Debra C. Roberts (South Africa), Sergey Semenov (Russian Federation), Priyadarshi Shukla (India), Jim Skea (United Kingdom), Youba Sokona (Mali), Kiyoto Tanabe (Japan), Muhammad Irfan Tariq (Pakistan), Diana Ürge-Vorsatz (Hungary), Carolina Vera (Argentina), Pius Yanda (United Republic of Tanzania), Noureddine Yassaa (Algeria), Taha M. Zatari (Saudi Arabia), Panmao Zhai (China)

Visual Conception and Information Design

Arlene Birt (USA), Meeyoung Ha (Republic of Korea)

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Foreword and Preface

Foreword

This Synthesis Report (SYR) concludes the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC). The SYR synthesizes and integrates materials contained within the three Working Groups Assessment Reports and the Special Reports contributing to the AR6. It addresses a broad range of policy-relevant but policy-neutral questions approved by the Panel.

The SYR is the synthesis of the most comprehensive assessment of climate change undertaken thus far by the IPCC: Climate Change 2021: The Physical Science Basis; Climate Change 2022: Impacts, Adaptation and Vulnerability; and Climate Change 2022: Mitigation of Climate Change. The SYR also draws on the findings of three Special Reports completed as part of the Sixth Assessment – Global Warming of 1.5°C (2018): an IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (SR1.5); Climate Change and Land (2019): an IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL); and The Ocean and Cryosphere in a Changing Climate (2019) (SROCC).

The AR6 SYR confirms that unsustainable and unequal energy and land use as well as more than a century of burning fossil fuels have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020. This has led to widespread adverse impacts and related losses and damages to nature and people. The nationally determined contributions (NDCs) committed by 2030 show the temperature will increase by 1.5°C in the first half of the 2030s, and will make it very difficult to control temperature increase by 2.0°C towards the end of 21st century. Every increment of global warming will intensify multiple and concurrent hazards in all regions of the world.

The report points out that limiting human-caused global warming requires net zero CO₂ emissions. Deep, rapid, and sustained mitigation and accelerated implementation of adaptation actions in this decade would reduce projected losses and damages for humans and ecosystems and deliver many co-benefits, especially for air quality and health. Delayed mitigation and adaptation action would lock-in high-emissions infrastructure, raise risks of stranded assets and cost-escalation, reduce feasibility, and increase losses and damages. Near-term actions involve high up-front investments and potentially disruptive changes that can be lessened by a range of enabling policies.

As an intergovernmental body jointly established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), the IPCC has provided policymakers with the most authoritative and objective scientific and technical assessments in this field. Beginning in 1990, this series of IPCC Assessment Reports, Special Reports, Technical Papers, Methodology Reports, and other products have become standard works of reference.

The SYR was made possible thanks to the voluntary work, dedication and commitment of thousands of experts and scientists from around the globe, representing a range of views and disciplines. We would like to express our deep gratitude to all the members of the Core Writing Team of the SYR, members of the Extended Writing Team, Contributing Authors, and the Review Editors, all of whom enthusiastically took on the huge challenge of producing an outstanding SYR on top of the other tasks they had already committed to during the AR6 cycle. We would also like to thank the staff of the Technical Support Unit of the SYR and the IPCC Secretariat for their dedication in organizing the production of this IPCC report.

We also wish to acknowledge and thank the governments of the IPCC member countries for their support of scientists in developing this report, and for their contributions to the IPCC Trust Fund to provide the essentials for participation of experts from developing countries and countries with economies in transition. We would like to express our appreciation to the government of Singapore for hosting the Scoping Meeting of the SYR, to the government of Ireland for hosting the third Core Writing Team meeting of the SYR, and to the government of Switzerland for hosting the 58th Session of the IPCC where the SYR was approved. The generous financial support from the government of the Republic of Korea enabled the smooth operation of the Technical Support Unit of the SYR. This is gratefully acknowledged.

We would particularly like to express our thanks to the IPCC Chair, the IPCC Vice-Chairs and the Co-Chairs for their dedicated work throughout the production of this report.

Petteri Taalas

Secretary-General of the World Meteorological Organization

Inger Andersen

Under-Secretary-General of the United Nations and Executive Director of the UN Environment Programme

Preface

This Synthesis Report (SYR) constitutes the final product of the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC). It summarizes the state of knowledge of climate change, its widespread impacts and risks, and climate change mitigation and adaptation, based on the peer-reviewed scientific, technical, and socio-economic literature since the publication of the IPCC's Fifth Assessment Report (AR5) in 2014.

This SYR distills, synthesizes, and integrates the key findings of the three Working Group contributions – Climate Change 2021: The Physical Science Basis; Climate Change 2022: Impacts, Adaptation and Vulnerability; and Climate Change 2022: Mitigation of Climate Change. The SYR also draws on the findings of three Special Reports completed as part of the Sixth Assessment – Global Warming of 1.5°C (2018): an IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (SR1.5); Climate Change and Land (2019): an IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL); and The Ocean and Cryosphere in a Changing Climate (2019) (SROCC). The SYR, therefore, is a comprehensive, timely compilation of assessments of the most recent scientific, technical, and socio-economic literature dealing with climate change.

Scope of the report

The SYR is a self-contained synthesis of the most policy-relevant material drawn from the scientific, technical, and socio-economic literature assessed during the Sixth Assessment. This report integrates the main findings of the AR6 Working Group reports and the three AR6 Special Reports. It recognizes the interdependence of climate, ecosystems and biodiversity, and human societies; the value of diverse forms of knowledge; and the close linkages between climate adaptation, mitigation, ecosystem health, human well-being, and sustainable development. Building on multiple analytical frameworks, including those from the physical and social sciences, this report identifies opportunities for transformative action which are effective, feasible, just and equitable systems transitions, and climate resilient development pathways. Different regional classification schemes are used for physical, social and economic aspects, reflecting the underlying literature.

The Synthesis Report emphasizes near-term risks and options for addressing them to give policymakers a sense of the urgency required to address global climate change. The report also provides important insights about how climate risks interact with not only one another but non-climate-related risks. It describes the interaction between mitigation and adaptation and how this combination can better

confront the climate challenge as well as produce valuable co-benefits. It highlights the strong connection between equity and climate action and why more equitable solutions are vital to addressing climate change. It also emphasizes how growing urbanization provides an opportunity for ambitious climate action to advance climate resilient development and sustainable development for all. And it underscores how restoring and protecting land and ocean ecosystems can bring multiple benefits to biodiversity and other societal goals, just as a failure to do so presents a major risk to ensuring a healthy planet.

Structure

The SYR comprises a Summary for Policymakers (SPM) and a longer report from which the SPM is derived, as well as annexes.

To facilitate access to the findings of the SYR for a wide readership, each part of the SPM carries highlighted headline statements. Taken together, these 18 headline statements provide an overarching summary in simple, non-technical language for easy assimilation by readers from different walks of life.

The SPM follows a structure and sequence like that in the longer report, but some issues covered in more than one section of the longer report are summarized in a single location in the SPM. Each paragraph of the SPM contains references to the supporting text in the longer report. In turn, the longer report contains extensive references to relevant portions of the Working Group Reports or Special Reports mentioned above.

The longer report is structured around three topic headings as mandated by the Panel. A brief Introduction (Section 1) is followed by three sections.

Section 2, 'Current Status and Trends', opens with the assessment of observational evidence for our changing climate, historical and current drivers of human-induced climate change, and its impacts. It assesses the current implementation of adaptation and mitigation response options. Section 3, 'Long-Term Climate and Development Futures', provides an assessment of climate change to 2100 and beyond in a broad range of socio-economic futures. It considers long-term impacts, risks and costs in adaptation and mitigation pathways in the context of sustainable development. Section 4, 'Near-Term Responses in a Changing Climate', assesses opportunities for scaling up effective action in the period to 2040, in the context of climate pledges, and commitments, and the pursuit of sustainable development.

Annexes containing a glossary of terms used, list of acronyms, authors, Review Editors, the SYR Scientific Steering Committee, and Expert Reviewers complete the report.

Process

The SYR was prepared in accordance with the procedures of the IPCC. A scoping meeting to develop a detailed outline of the AR6 Synthesis Report was held in Singapore from 21 to 23 October 2019 and the outline produced in that meeting was approved by the Panel at the 52nd IPCC Session from 24 to 28 February 2020 in Paris, France.

In accordance with IPCC procedures, the IPCC Chair, in consultation with the Co-Chairs of the Working Groups, nominated authors for the Core Writing Team (CWT) of the SYR. A total of 30 CWT members and 9 Review Editors were selected and accepted by the IPCC Bureau at its 58th Session on 19 May 2020. In the process of developing the SYR, 7 Extended Writing Team (EWT) authors were selected by the CWT and approved by the Chair and the IPCC Bureau, and 28 Contributing Authors were selected by the CWT with the approval of the Chair. These additional authors were to enhance and deepen the expertise required for the preparation of the Report. The Chair established at the 58th Session of the Bureau an SYR Scientific Steering Committee (SSC) with a mandate to advise the development of the SYR. The SYR SSC comprised the members of the IPCC Bureau, excluding those members who served as Review Editors for the SYR.

Due to the covid pandemic, the first two meetings of the CWT were held virtually from 25 to 29 January 2021 and from 16 to 20 August 2021. The First Order Draft (FOD) was released to experts and governments for review on 10 January 2022 with comments due on 20 March 2022. The CWT met in Dublin from 25 to 28 March 2022 to discuss how best to revise the FOD to address the more than 10,000 comments received. The Review Editors monitored the review process to ensure that all comments received appropriate consideration. The IPCC circulated a final draft of the Summary for Policymakers and a longer report of the SYR to governments for review from 21 November 2022 to 15 January 2023 which resulted in over 6,000 comments. A final SYR draft for approval incorporating the comments from the final government distribution was submitted to the IPCC member governments on 8 March 2023.

The Panel at its 58th Session, held from 13 to 17 March 2023 in Interlaken, Switzerland, approved the SPM line by line and adopted the longer report section by section.

Acknowledgements

The SYR was made possible thanks to the hard work and commitment to excellence shown by the Section Facilitators, members of CWT and EWT, and Contributing Authors. Specific thanks are due to Section Facilitators Kate Calvin, Dipak Dasgupta, Gerhard Krinner, Aditi Mukherji, Peter Thorne, and Christopher Trisos whose work was essential in ensuring a high standard of the longer report sections and the SPM.

We would like to express our appreciation to the IPCC member governments, observer organizations, and expert reviewers for providing constructive comments on the draft reports. We would like to thank the Review Editors Paola Arias, Mercedes Bustamante, Ismail Elgizouli, Gregory Flato, Mark Howden, Steven Rose, Yamina Saheb, Roberto Sánchez, and Cunde Xiao for their work on the treatment of FOD comments, and Gregory Flato, Carlos Méndez, Joy Jacqueline Pereira, Ramón Pichs-Madruga, Diana Ürge-Vorsatz, and Nouredine Yassaa for their work during the approval session, collaborating with author teams to ensure consistency between the SPM and the underlying reports.

We are grateful to the members of the SSC for their thoughtful advice and support for the SYR throughout the process: IPCC Vice-Chairs Ko Barret, Thelma Krug, and Youba Sokona; Co-Chairs of Working Groups (WG) and Task Force on National Greenhouse Gas Inventories (TFI) Valérie Masson-Delmotte, Panmao Zhai, Hans-Otto Pörtner, Debra Roberts, Priyadarshi R. Shukla, Jim Skea, Eduardo Calvo Buendía, and Kiyoto Tanabe; WG Vice-Chairs Edvin Aldrian, Fatima Driouech, Jan Fuglestedt, Muhammad Tariq, Carolina Vera, Nouredine Yassaa, Andreas Fischlin, Joy Jacqueline Pereira, Sergey Semenov, Pius Yanda, Taha M, Zatar, Amjad Abdulla, Carlo Carraro, Diriba Korecha Dadi, Nagmeldin G.E. Mahmoud, Ramón Pichs-Madruga, Andy Reisinger, and Diana Ürge-Vorsatz. The IPCC Vice-Chairs and WG Co-Chairs served also as members of the CWT and we are grateful for their contributions.

We wish to thank the IPCC Secretariat for their guidance and support for the SYR in preparation, release and publication of the Report: Deputy Secretary Emira Fida, Mudathir Abdallah, Jesbin Baidya, Laura Biagioni, Oksana Ekzarkho, Judith Ewa, Joëlle Fernandez, Emelie Larrode, Jennifer Lew Schneider, Andrej Mahecic, Nina Peeva, Mxolisi Shongwe, Melissa Walsh, and Werani Zabula. Their support for the successful SYR was truly outstanding throughout the entire process.

Our thanks go to José Romero, Head of the SYR Technical Support Unit (SYR TSU) and Jinmi Kim, Director of Administration, and the members of the SYR TSU, Arlene Birt, Meeyoung Ha, Erik Haites, Lance Ignon, Yonghun Jung, Dan Jezreel Orendain, Robert Stavins, Semin Park, and Youngin Park for their hard work to facilitate the development and production of the SYR with deep commitment and dedication to ensure an outstanding SYR. Our thanks also go to Woonchong Um and his team at the Asian Development Bank for facilitation of the SYR TSU operation.

We extend our appreciation of the enthusiasm, dedication, and professional contributions of WG TSU members Sarah Connors, Clotilde Péan, and Anna Pirani from WG I, Marlies Craig, Katja Mintenbeck, Elvira Poloczanska, Melinda Tignor from WG II and Roger Fradera, Minal Pathak, Raphael Slade, Shreya Some, and Geninha Gabao Lisboa from WG III, working as a team with the SYR TSU, which contributed to the successful outcome of the Session.

We are appreciative of the member governments of the IPCC who graciously hosted the SYR scoping meeting, a CWT Meeting and the 58th Session of the IPCC: Singapore, Ireland, and Switzerland, respectively. We express our thanks to the IPCC member governments, WMO, UNEP and the UNFCCC for their contributions to the Trust Fund which supported various elements of expenditure. We wish to particularly

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Hoesung Lee
Chairman of the IPCC



Abdalah Mokssit
Secretary of the IPCC

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In the Summary for Policymakers, the references refer to the numbers of the sections, figures, tables and boxes in the underlying Introduction and Topics of this Synthesis Report.

In the Introduction and Sections of the longer report, the references refer to the contributions of the Working Groups I, II and III (WGI, WGII, WGIII) to the Sixth Assessment Report and other IPCC Reports (in italicized curly brackets), or to other sections of the Synthesis Report itself (in round brackets).

The following abbreviations have been used:

SPM: Summary for Policymakers

TS: Technical Summary

ES: Executive Summary of a chapter

Numbers denote specific chapters and sections of a report.

Other IPCC reports cited in this Synthesis Report:

SR1.5: Global Warming of 1.5°C

SRCCCL: Climate Change and Land

SROCC: The Ocean and Cryosphere in a Changing Climate

Climate Change 2023 Synthesis Report Summary for Policymakers

This Summary for Policymakers should be cited as:

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Introduction

This Synthesis Report (SYR) of the IPCC Sixth Assessment Report (AR6) summarises the state of knowledge of climate change, its widespread impacts and risks, and climate change mitigation and adaptation. It integrates the main findings of the Sixth Assessment Report (AR6) based on contributions from the three Working Groups¹, and the three Special Reports². The summary for Policymakers (SPM) is structured in three parts: SPM.A Current Status and Trends, SPM.B Future Climate Change, Risks, and Long-Term Responses, and SPM.C Responses in the Near Term³.

This report recognizes the interdependence of climate, ecosystems and biodiversity, and human societies; the value of diverse forms of knowledge; and the close linkages between climate change adaptation, mitigation, ecosystem health, human well-being and sustainable development, and reflects the increasing diversity of actors involved in climate action.

Based on scientific understanding, key findings can be formulated as statements of fact or associated with an assessed level of confidence using the IPCC calibrated language⁴.

¹ The three Working Group contributions to AR6 are: AR6 Climate Change 2021: The Physical Science Basis; AR6 Climate Change 2022: Impacts, Adaptation and Vulnerability; and AR6 Climate Change 2022: Mitigation of Climate Change. Their assessments cover scientific literature accepted for publication respectively by 31 January 2021, 1 September 2021 and 11 October 2021.

² The three Special Reports are: Global Warming of 1.5°C (2018): an IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (SR1.5); Climate Change and Land (2019): an IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCLL); and The Ocean and Cryosphere in a Changing Climate (2019) (SROCC). The Special Reports cover scientific literature accepted for publication respectively by 15 May 2018, 7 April 2019 and 15 May 2019.

³ In this report, the near term is defined as the period until 2040. The long term is defined as the period beyond 2040.

⁴ Each finding is grounded in an evaluation of underlying evidence and agreement. The IPCC calibrated language uses five qualifiers to express a level of confidence: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms are used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, more likely than not >50–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%; and extremely unlikely 0–5%) are also used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*. This is consistent with AR5 and the other AR6 Reports.

A. Current Status and Trends

Observed Warming and its Causes

A.1 Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020. Global greenhouse gas emissions have continued to increase, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals (*high confidence*). {2.1, Figure 2.1, Figure 2.2}

- A.1.1 Global surface temperature was 1.09 [0.95 to 1.20]°C⁵ higher in 2011–2020 than 1850–1900⁶, with larger increases over land (1.59 [1.34 to 1.83]°C) than over the ocean (0.88 [0.68 to 1.01]°C). Global surface temperature in the first two decades of the 21st century (2001–2020) was 0.99 [0.84 to 1.10]°C higher than 1850–1900. Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years (*high confidence*). {2.1.1, Figure 2.1}
- A.1.2 The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019⁷ is 0.8°C to 1.3°C, with a best estimate of 1.07°C. Over this period, it is *likely* that well-mixed greenhouse gases (GHGs) contributed a warming of 1.0°C to 2.0°C⁸, and other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural (solar and volcanic) drivers changed global surface temperature by –0.1°C to +0.1°C, and internal variability changed it by –0.2°C to +0.2°C. {2.1.1, Figure 2.1}
- A.1.3 Observed increases in well-mixed GHG concentrations since around 1750 are unequivocally caused by GHG emissions from human activities over this period. Historical cumulative net CO₂ emissions from 1850 to 2019 were 2400 ± 240 GtCO₂ of which more than half (58%) occurred between 1850 and 1989, and about 42% occurred between 1990 and 2019 (*high confidence*). In 2019, atmospheric CO₂ concentrations (410 parts per million) were higher than at any time in at least 2 million years (*high confidence*), and concentrations of methane (1866 parts per billion) and nitrous oxide (332 parts per billion) were higher than at any time in at least 800,000 years (*very high confidence*). {2.1.1, Figure 2.1}
- A.1.4 Global net anthropogenic GHG emissions have been estimated to be 59 ± 6.6 GtCO₂-eq⁹ in 2019, about 12% (6.5 GtCO₂-eq) higher than in 2010 and 54% (21 GtCO₂-eq) higher than in 1990, with the largest share and growth in gross GHG emissions occurring in CO₂ from fossil fuels combustion and industrial processes (CO₂-FFI) followed by methane, whereas the highest relative growth occurred in fluorinated gases (F-gases), starting from low levels in 1990. Average annual GHG emissions during 2010–2019 were higher than in any previous decade on record, while the rate of growth between 2010 and 2019 (1.3% yr⁻¹) was lower than that between 2000 and 2009 (2.1% yr⁻¹). In 2019, approximately 79% of global GHG

⁵ Ranges given throughout the SPM represent *very likely* ranges (5–95% range) unless otherwise stated.

⁶ The estimated increase in global surface temperature since AR5 is principally due to further warming since 2003–2012 (0.19 [0.16 to 0.22]°C). Additionally, methodological advances and new datasets have provided a more complete spatial representation of changes in surface temperature, including in the Arctic. These and other improvements have also increased the estimate of global surface temperature change by approximately 0.1°C, but this increase does not represent additional physical warming since AR5.

⁷ The period distinction with A.1.1 arises because the attribution studies consider this slightly earlier period. The observed warming to 2010–2019 is 1.06 [0.88 to 1.21]°C.

⁸ Contributions from emissions to the 2010–2019 warming relative to 1850–1900 assessed from radiative forcing studies are: CO₂ 0.8 [0.5 to 1.2] °C; methane 0.5 [0.3 to 0.8]°C; nitrous oxide 0.1 [0.0 to 0.2]°C and fluorinated gases 0.1 [0.0 to 0.2]°C. {2.1.1}

⁹ GHG emission metrics are used to express emissions of different greenhouse gases in a common unit. Aggregated GHG emissions in this report are stated in CO₂-equivalents (CO₂-eq) using the Global Warming Potential with a time horizon of 100 years (GWP100) with values based on the contribution of Working Group I to the AR6. The AR6 WGI and WGIII reports contain updated emission metric values, evaluations of different metrics with regard to mitigation objectives, and assess new approaches to aggregating gases. The choice of metric depends on the purpose of the analysis and all GHG emission metrics have limitations and uncertainties, given that they simplify the complexity of the physical climate system and its response to past and future GHG emissions. {2.1.1}

emissions came from the sectors of energy, industry, transport, and buildings together and 22%¹⁰ from agriculture, forestry and other land use (AFOLU). Emissions reductions in CO₂-FFI due to improvements in energy intensity of GDP and carbon intensity of energy, have been less than emissions increases from rising global activity levels in industry, energy supply, transport, agriculture and buildings. (*high confidence*) {2.1.1}

- A.1.5 Historical contributions of CO₂ emissions vary substantially across regions in terms of total magnitude, but also in terms of contributions to CO₂-FFI and net CO₂ emissions from land use, land-use change and forestry (CO₂-LULUCF). In 2019, around 35% of the global population live in countries emitting more than 9 tCO₂-eq per capita¹¹ (excluding CO₂-LULUCF) while 41% live in countries emitting less than 3 tCO₂-eq per capita; of the latter a substantial share lacks access to modern energy services. Least Developed Countries (LDCs) and Small Island Developing States (SIDS) have much lower per capita emissions (1.7 tCO₂-eq and 4.6 tCO₂-eq, respectively) than the global average (6.9 tCO₂-eq), excluding CO₂-LULUCF. The 10% of households with the highest per capita emissions contribute 34–45% of global consumption-based household GHG emissions, while the bottom 50% contribute 13–15%. (*high confidence*) {2.1.1, Figure 2.2}

Observed Changes and Impacts

A.2 Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred. Human-caused climate change is already affecting many weather and climate extremes in every region across the globe. This has led to widespread adverse impacts and related losses and damages to nature and people (*high confidence*). Vulnerable communities who have historically contributed the least to current climate change are disproportionately affected (*high confidence*). {2.1, Table 2.1, Figure 2.2, Figure 2.3} (Figure SPM.1)

- A.2.1 It is unequivocal that human influence has warmed the atmosphere, ocean and land. Global mean sea level increased by 0.20 [0.15 to 0.25] m between 1901 and 2018. The average rate of sea level rise was 1.3 [0.6 to 2.1] mm yr⁻¹ between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm yr⁻¹ between 1971 and 2006, and further increasing to 3.7 [3.2 to 4.2] mm yr⁻¹ between 2006 and 2018 (*high confidence*). Human influence was *very likely* the main driver of these increases since at least 1971. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has further strengthened since AR5. Human influence has *likely* increased the chance of compound extreme events since the 1950s, including increases in the frequency of concurrent heatwaves and droughts (*high confidence*). {2.1.2, Table 2.1, Figure 2.3, Figure 3.4} (Figure SPM.1)
- A.2.2 Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change. Human and ecosystem vulnerability are interdependent. Regions and people with considerable development constraints have high vulnerability to climatic hazards. Increasing weather and climate extreme events have exposed millions of people to acute food insecurity¹² and reduced water security, with the largest adverse impacts observed in many locations and/or communities in Africa, Asia, Central and South America, LDCs, Small Islands and the Arctic, and globally for Indigenous Peoples, small-scale food producers and low-income households. Between 2010 and 2020, human mortality from floods, droughts and storms was 15 times higher in highly vulnerable regions, compared to regions with very low vulnerability. (*high confidence*) {2.1.2, 4.4} (Figure SPM.1)
- A.2.3 Climate change has caused substantial damages, and increasingly irreversible losses, in terrestrial, freshwater, cryospheric, and coastal and open ocean ecosystems (*high confidence*). Hundreds of local losses of species have been driven by increases in the magnitude of heat extremes (*high confidence*) with mass mortality events recorded on land and in the ocean (*very high confidence*). Impacts on some ecosystems are approaching irreversibility such as the impacts of hydrological changes resulting from the retreat of glaciers, or the changes in some mountain (*medium confidence*) and Arctic ecosystems driven by permafrost thaw (*high confidence*). {2.1.2, Figure 2.3} (Figure SPM.1)

¹⁰ GHG emission levels are rounded to two significant digits; as a consequence, small differences in sums due to rounding may occur. {2.1.1}

¹¹ Territorial emissions.

¹² Acute food insecurity can occur at any time with a severity that threatens lives, livelihoods or both, regardless of the causes, context or duration, as a result of shocks risking determinants of food security and nutrition, and is used to assess the need for humanitarian action. {2.1}

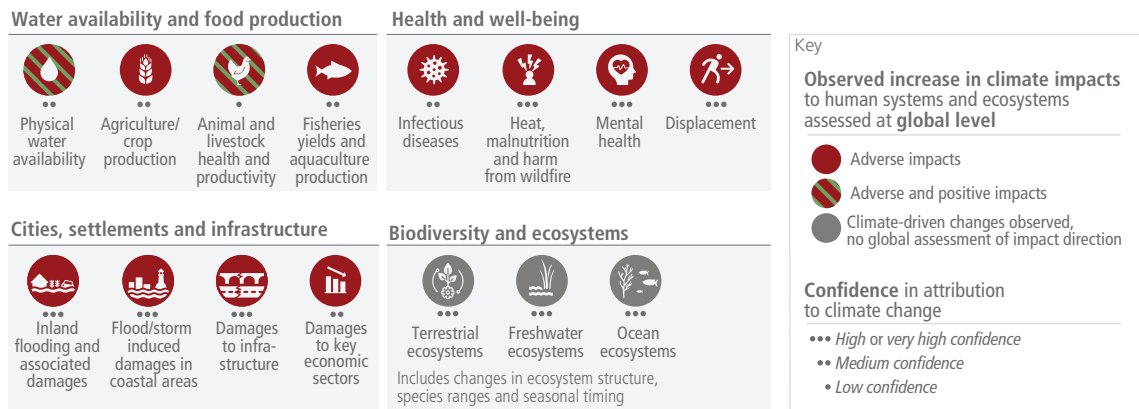
- A.2.4 Climate change has reduced food security and affected water security, hindering efforts to meet Sustainable Development Goals (*high confidence*). Although overall agricultural productivity has increased, climate change has slowed this growth over the past 50 years globally (*medium confidence*), with related negative impacts mainly in mid- and low latitude regions but positive impacts in some high latitude regions (*high confidence*). Ocean warming and ocean acidification have adversely affected food production from fisheries and shellfish aquaculture in some oceanic regions (*high confidence*). Roughly half of the world's population currently experience severe water scarcity for at least part of the year due to a combination of climatic and non-climatic drivers (*medium confidence*). {2.1.2, Figure 2.3} (Figure SPM.1)
- A.2.5 In all regions increases in extreme heat events have resulted in human mortality and morbidity (*very high confidence*). The occurrence of climate-related food-borne and water-borne diseases (*very high confidence*) and the incidence of vector-borne diseases (*high confidence*) have increased. In assessed regions, some mental health challenges are associated with increasing temperatures (*high confidence*), trauma from extreme events (*very high confidence*), and loss of livelihoods and culture (*high confidence*). Climate and weather extremes are increasingly driving displacement in Africa, Asia, North America (*high confidence*), and Central and South America (*medium confidence*), with small island states in the Caribbean and South Pacific being disproportionately affected relative to their small population size (*high confidence*). {2.1.2, Figure 2.3} (Figure SPM.1)
- A.2.6 Climate change has caused widespread adverse impacts and related losses and damages¹³ to nature and people that are unequally distributed across systems, regions and sectors. Economic damages from climate change have been detected in climate-exposed sectors, such as agriculture, forestry, fishery, energy, and tourism. Individual livelihoods have been affected through, for example, destruction of homes and infrastructure, and loss of property and income, human health and food security, with adverse effects on gender and social equity. (*high confidence*) {2.1.2} (Figure SPM.1)
- A.2.7 In urban areas, observed climate change has caused adverse impacts on human health, livelihoods and key infrastructure. Hot extremes have intensified in cities. Urban infrastructure, including transportation, water, sanitation and energy systems have been compromised by extreme and slow-onset events¹⁴, with resulting economic losses, disruptions of services and negative impacts to well-being. Observed adverse impacts are concentrated amongst economically and socially marginalised urban residents. (*high confidence*) {2.1.2}

¹³ In this report, the term 'losses and damages' refers to adverse observed impacts and/or projected risks and can be economic and/or non-economic (see Annex I: Glossary).

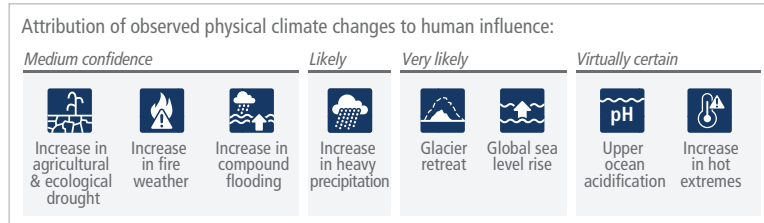
¹⁴ Slow-onset events are described among the climatic-impact drivers of the AR6 WGI and refer to the risks and impacts associated with e.g., increasing temperature means, desertification, decreasing precipitation, loss of biodiversity, land and forest degradation, glacial retreat and related impacts, ocean acidification, sea level rise and salinization. {2.1.2}

Adverse impacts from human-caused climate change will continue to intensify

a) Observed widespread and substantial impacts and related losses and damages attributed to climate change



b) Impacts are driven by changes in multiple physical climate conditions, which are increasingly attributed to human influence



c) The extent to which current and future generations will experience a hotter and different world depends on choices now and in the near term

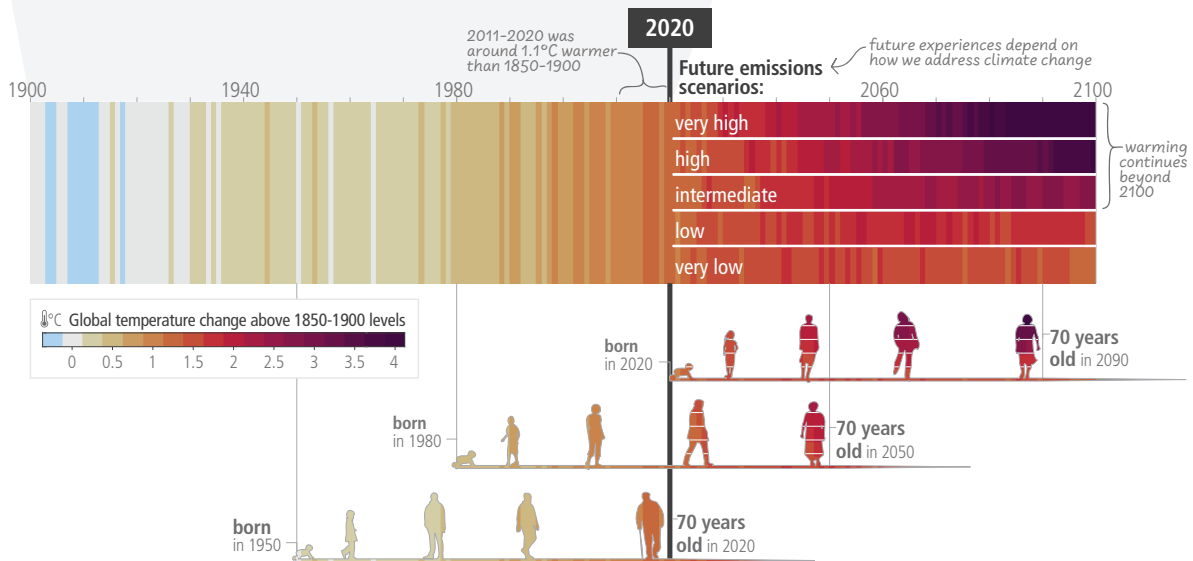


Figure SPM.1: (a) Climate change has already caused widespread impacts and related losses and damages on human systems and altered terrestrial, freshwater and ocean ecosystems worldwide. Physical water availability includes balance of water available from various sources including ground water, water quality and demand for water. Global mental health and displacement assessments reflect only assessed regions. Confidence levels reflect the assessment of attribution of the observed impact to climate change. (b) Observed impacts are connected to physical climate changes including many that have been attributed to human influence such as the selected climatic impact-drivers shown. Confidence and likelihood levels reflect the assessment of attribution of the observed climatic impact-driver to human influence. (c) Observed (1900–2020) and projected (2021–2100) changes in global surface temperature (relative to 1850-1900), which are linked to changes in climate conditions and impacts, illustrate how the climate has already changed and will change along the lifespan of three

representative generations (born in 1950, 1980 and 2020). Future projections (2021–2100) of changes in global surface temperature are shown for very low (SSP1-1.9), low (SSP1-2.6), intermediate (SSP2-4.5), high (SSP3-7.0) and very high (SSP5-8.5) GHG emissions scenarios. Changes in annual global surface temperatures are presented as ‘climate stripes’, with future projections showing the human-caused long-term trends and continuing modulation by natural variability (represented here using observed levels of past natural variability). Colours on the generational icons correspond to the global surface temperature stripes for each year, with segments on future icons differentiating possible future experiences. {2.1, 2.1.2, Figure 2.1, Table 2.1, Figure 2.3, Cross-Section Box.2, 3.1, Figure 3.3, 4.1, 4.3} (Box SPM.1)

Current Progress in Adaptation and Gaps and Challenges

A.3 Adaptation planning and implementation has progressed across all sectors and regions, with documented benefits and varying effectiveness. Despite progress, adaptation gaps exist, and will continue to grow at current rates of implementation. Hard and soft limits to adaptation have been reached in some ecosystems and regions. Maladaptation is happening in some sectors and regions. Current global financial flows for adaptation are insufficient for, and constrain implementation of, adaptation options, especially in developing countries (*high confidence*). {2.2, 2.3}

- A.3.1 Progress in adaptation planning and implementation has been observed across all sectors and regions, generating multiple benefits (*very high confidence*). Growing public and political awareness of climate impacts and risks has resulted in at least 170 countries and many cities including adaptation in their climate policies and planning processes (*high confidence*). {2.2.3}
- A.3.2 Effectiveness¹⁵ of adaptation in reducing climate risks¹⁶ is documented for specific contexts, sectors and regions (*high confidence*). Examples of effective adaptation options include: cultivar improvements, on-farm water management and storage, soil moisture conservation, irrigation, agroforestry, community-based adaptation, farm and landscape level diversification in agriculture, sustainable land management approaches, use of agroecological principles and practices and other approaches that work with natural processes (*high confidence*). Ecosystem-based adaptation¹⁷ approaches such as urban greening, restoration of wetlands and upstream forest ecosystems have been effective in reducing flood risks and urban heat (*high confidence*). Combinations of non-structural measures like early warning systems and structural measures like levees have reduced loss of lives in case of inland flooding (*medium confidence*). Adaptation options such as disaster risk management, early warning systems, climate services and social safety nets have broad applicability across multiple sectors (*high confidence*). {2.2.3}
- A.3.3 Most observed adaptation responses are fragmented, incremental¹⁸, sector-specific and unequally distributed across regions. Despite progress, adaptation gaps exist across sectors and regions, and will continue to grow under current levels of implementation, with the largest adaptation gaps among lower income groups. (*high confidence*) {2.3.2}
- A.3.4 There is increased evidence of maladaptation in various sectors and regions. Maladaptation especially affects marginalised and vulnerable groups adversely. (*high confidence*) {2.3.2}
- A.3.5 Soft limits to adaptation are currently being experienced by small-scale farmers and households along some low-lying coastal areas (*medium confidence*) resulting from financial, governance, institutional and policy constraints (*high confidence*). Some tropical, coastal, polar and mountain ecosystems have reached hard adaptation limits (*high confidence*). Adaptation does not prevent all losses and damages, even with effective adaptation and before reaching soft and hard limits (*high confidence*). {2.3.2}

¹⁵ Effectiveness refers here to the extent to which an adaptation option is anticipated or observed to reduce climate-related risk. {2.2.3}

¹⁶ See Annex I: Glossary. {2.2.3}

¹⁷ Ecosystem-based Adaptation (EbA) is recognized internationally under the Convention on Biological Diversity (CBD14/5). A related concept is Nature-based Solutions (NbS), see Annex I: Glossary.

¹⁸ Incremental adaptations to change in climate are understood as extensions of actions and behaviours that already reduce the losses or enhance the benefits of natural variations in extreme weather/climate events. {2.3.2}

- A.3.6 Key barriers to adaptation are limited resources, lack of private sector and citizen engagement, insufficient mobilization of finance (including for research), low climate literacy, lack of political commitment, limited research and/or slow and low uptake of adaptation science, and low sense of urgency. There are widening disparities between the estimated costs of adaptation and the finance allocated to adaptation (*high confidence*). Adaptation finance has come predominantly from public sources, and a small proportion of global tracked climate finance was targeted to adaptation and an overwhelming majority to mitigation (*very high confidence*). Although global tracked climate finance has shown an upward trend since AR5, current global financial flows for adaptation, including from public and private finance sources, are insufficient and constrain implementation of adaptation options, especially in developing countries (*high confidence*). Adverse climate impacts can reduce the availability of financial resources by incurring losses and damages and through impeding national economic growth, thereby further increasing financial constraints for adaptation, particularly for developing and least developed countries (*medium confidence*). {2.3.2, 2.3.3}

Box SPM.1 The use of scenarios and modelled pathways in the AR6 Synthesis Report

Modelled scenarios and pathways¹⁹ are used to explore future emissions, climate change, related impacts and risks, and possible mitigation and adaptation strategies and are based on a range of assumptions, including socio-economic variables and mitigation options. These are quantitative projections and are neither predictions nor forecasts. Global modelled emission pathways, including those based on cost effective approaches contain regionally differentiated assumptions and outcomes, and have to be assessed with the careful recognition of these assumptions. Most do not make explicit assumptions about global equity, environmental justice or intra-regional income distribution. IPCC is neutral with regard to the assumptions underlying the scenarios in the literature assessed in this report, which do not cover all possible futures.²⁰ {Cross-Section Box.2}

WGI assessed the climate response to five illustrative scenarios based on Shared Socio-economic Pathways (SSPs)²¹ that cover the range of possible future development of anthropogenic drivers of climate change found in the literature. High and very high GHG emissions scenarios (SSP3-7.0 and SSP5-8.5²²) have CO₂ emissions that roughly double from current levels by 2100 and 2050, respectively. The intermediate GHG emissions scenario (SSP2-4.5) has CO₂ emissions remaining around current levels until the middle of the century. The very low and low GHG emissions scenarios (SSP1-1.9 and SSP1-2.6) have CO₂ emissions declining to net zero around 2050 and 2070, respectively, followed by varying levels of net negative CO₂ emissions. In addition, Representative Concentration Pathways (RCPs)²³ were used by WGI and WGII to assess regional climate changes, impacts and risks. In WGIII, a large number of global modelled emissions pathways were assessed, of which 1202 pathways were categorised based on their assessed global warming over the 21st century; categories range from pathways that limit warming to 1.5°C with more than 50% likelihood (noted >50% in this report) with no or limited overshoot (C1) to pathways that exceed 4°C (C8). {Cross-Section Box.2} (Box SPM.1, Table 1)

Global warming levels (GWLs) relative to 1850–1900 are used to integrate the assessment of climate change and related impacts and risks since patterns of changes for many variables at a given GWL are common to all scenarios considered and independent of timing when that level is reached. {Cross-Section Box.2}

¹⁹ In the literature, the terms pathways and scenarios are used interchangeably, with the former more frequently used in relation to climate goals. WGI primarily used the term scenarios and WGIII mostly used the term modelled emission and mitigation pathways. The SYR primarily uses scenarios when referring to WGI and modelled emission and mitigation pathways when referring to WGIII.

²⁰ Around half of all modelled global emission pathways assume cost-effective approaches that rely on least-cost mitigation/abatement options globally. The other half looks at existing policies and regionally and sectorally differentiated actions.

²¹ SSP-based scenarios are referred to as SSPx-y, where 'SSPx' refers to the Shared Socioeconomic Pathway describing the socioeconomic trends underlying the scenarios, and 'y' refers to the level of radiative forcing (in watts per square metre, or W m⁻²) resulting from the scenario in the year 2100. {Cross-Section Box.2}

²² Very high emissions scenarios have become *less likely* but cannot be ruled out. Warming levels >4°C may result from very high emissions scenarios, but can also occur from lower emission scenarios if climate sensitivity or carbon cycle feedbacks are higher than the best estimate. {3.1.1}

²³ RCP-based scenarios are referred to as RCPy, where 'y' refers to the level of radiative forcing (in watts per square metre, or W m⁻²) resulting from the scenario in the year 2100. The SSP scenarios cover a broader range of greenhouse gas and air pollutant futures than the RCPs. They are similar but not identical, with differences in concentration trajectories. The overall effective radiative forcing tends to be higher for the SSPs compared to the RCPs with the same label (*medium confidence*). {Cross-Section Box.2}

Box SPM.1, Table 1: Description and relationship of scenarios and modelled pathways considered across AR6 Working Group reports. {Cross-Section Box.2 Figure 1}

Category in WGIII	Category description	GHG emissions scenarios (SSPx-y*) in WGI & WGII	RCPy** in WGI & WGII
C1	limit warming to 1.5°C (>50%) with no or limited overshoot***	Very low (SSP1-1.9)	
C2	return warming to 1.5°C (>50%) after a high overshoot***		
C3	limit warming to 2°C (>67%)	Low (SSP1-2.6)	RCP2.6
C4	limit warming to 2°C (>50%)		
C5	limit warming to 2.5°C (>50%)		
C6	limit warming to 3°C (>50%)	Intermediate (SSP2-4.5)	RCP 4.5
C7	limit warming to 4°C (>50%)	High (SSP3-7.0)	
C8	exceed warming of 4°C (>50%)	Very high (SSP5-8.5)	RCP 8.5

* See footnote 21 for the SSPx-y terminology.

** See footnote 23 for the RCPy terminology.

*** Limited overshoot refers to exceeding 1.5°C global warming by up to about 0.1°C, high overshoot by 0.1°C-0.3°C, in both cases for up to several decades.

Current Mitigation Progress, Gaps and Challenges

A.4 Policies and laws addressing mitigation have consistently expanded since AR5. Global GHG emissions in 2030 implied by nationally determined contributions (NDCs) announced by October 2021 make it *likely* that warming will exceed 1.5°C during the 21st century and make it harder to limit warming below 2°C. There are gaps between projected emissions from implemented policies and those from NDCs and finance flows fall short of the levels needed to meet climate goals across all sectors and regions. (*high confidence*) {2.2, 2.3, Figure 2.5, Table 2.2}

A.4.1 The UNFCCC, Kyoto Protocol, and the Paris Agreement are supporting rising levels of national ambition. The Paris Agreement, adopted under the UNFCCC, with near universal participation, has led to policy development and target-setting at national and sub-national levels, in particular in relation to mitigation, as well as enhanced transparency of climate action and support (*medium confidence*). Many regulatory and economic instruments have already been deployed successfully (*high confidence*). In many countries, policies have enhanced energy efficiency, reduced rates of deforestation and accelerated technology deployment, leading to avoided and in some cases reduced or removed emissions (*high confidence*). Multiple lines of evidence suggest that mitigation policies have led to several²⁴ Gt CO₂-eq yr⁻¹ of avoided global emissions (*medium confidence*). At least 18 countries have sustained absolute production-based GHG and consumption-based CO₂ reductions²⁵ for longer than 10 years. These reductions have only partly offset global emissions growth (*high confidence*). {2.2.1, 2.2.2}

A.4.2 Several mitigation options, notably solar energy, wind energy, electrification of urban systems, urban green infrastructure, energy efficiency, demand-side management, improved forest and crop / grassland management, and reduced food waste and loss, are technically viable, are becoming increasingly cost effective and are generally supported by the

²⁴ At least 1.8 GtCO₂-eq yr⁻¹ can be accounted for by aggregating separate estimates for the effects of economic and regulatory instruments. Growing numbers of laws and executive orders have impacted global emissions and were estimated to result in 5.9 GtCO₂-eq yr⁻¹ less emissions in 2016 than they otherwise would have been. (*medium confidence*) {2.2.2}

²⁵ Reductions were linked to energy supply decarbonisation, energy efficiency gains, and energy demand reduction, which resulted from both policies and changes in economic structure (*high confidence*). {2.2.2}

public. From 2010 to 2019 there have been sustained decreases in the unit costs of solar energy (85%), wind energy (55%), and lithium-ion batteries (85%), and large increases in their deployment, e.g., >10× for solar and >100× for electric vehicles (EVs), varying widely across regions. The mix of policy instruments that reduced costs and stimulated adoption includes public R&D, funding for demonstration and pilot projects, and demand-pull instruments such as deployment subsidies to attain scale. Maintaining emission-intensive systems may, in some regions and sectors, be more expensive than transitioning to low emission systems. (*high confidence*) {2.2.2, Figure 2.4}

- A.4.3 A substantial ‘emissions gap’ exists between global GHG emissions in 2030 associated with the implementation of NDCs announced prior to COP26²⁶ and those associated with modelled mitigation pathways that limit warming to 1.5°C (>50%) with no or limited overshoot or limit warming to 2°C (>67%) assuming immediate action (*high confidence*). This would make it *likely* that warming will exceed 1.5°C during the 21st century (*high confidence*). Global modelled mitigation pathways that limit warming to 1.5°C (>50%) with no or limited overshoot or limit warming to 2°C (>67%) assuming immediate action imply deep global GHG emissions reductions this decade (*high confidence*) (see SPM Box 1, Table 1, B.6)²⁷. Modelled pathways that are consistent with NDCs announced prior to COP26 until 2030 and assume no increase in ambition thereafter have higher emissions, leading to a median global warming of 2.8 [2.1 to 3.4] °C by 2100 (*medium confidence*). Many countries have signalled an intention to achieve net zero GHG or net zero CO₂ by around mid-century but pledges differ across countries in terms of scope and specificity, and limited policies are to date in place to deliver on them. {2.3.1, Table 2.2, Figure 2.5, Table 3.1, 4.1}
- A.4.4 Policy coverage is uneven across sectors (*high confidence*). Policies implemented by the end of 2020 are projected to result in higher global GHG emissions in 2030 than emissions implied by NDCs, indicating an ‘implementation gap’ (*high confidence*). Without a strengthening of policies, global warming of 3.2 [2.2 to 3.5]°C is projected by 2100 (*medium confidence*). {2.2.2, 2.3.1, 3.1.1, Figure 2.5} (Box SPM.1, Figure SPM.5)
- A.4.5 The adoption of low-emission technologies lags in most developing countries, particularly least developed ones, due in part to limited finance, technology development and transfer, and capacity (*medium confidence*). The magnitude of climate finance flows has increased over the last decade and financing channels have broadened but growth has slowed since 2018 (*high confidence*). Financial flows have developed heterogeneously across regions and sectors (*high confidence*). Public and private finance flows for fossil fuels are still greater than those for climate adaptation and mitigation (*high confidence*). The overwhelming majority of tracked climate finance is directed towards mitigation, but nevertheless falls short of the levels needed to limit warming to below 2°C or to 1.5°C across all sectors and regions (see C7.2) (*very high confidence*). In 2018, public and publicly mobilised private climate finance flows from developed to developing countries were below the collective goal under the UNFCCC and Paris Agreement to mobilise USD 100 billion per year by 2020 in the context of meaningful mitigation action and transparency on implementation (*medium confidence*). {2.2.2, 2.3.1, 2.3.3}

²⁶ Due to the literature cutoff date of WGIII, the additional NDCs submitted after 11 October 2021 are not assessed here. {Footnote 32 in the Longer Report}

²⁷ Projected 2030 GHG emissions are 50 (47–55) GtCO₂-eq if all conditional NDC elements are taken into account. Without conditional elements, the global emissions are projected to be approximately similar to modelled 2019 levels at 53 (50–57) GtCO₂-eq. {2.3.1, Table 2.2}

B. Future Climate Change, Risks, and Long-Term Responses

Future Climate Change

B.1 Continued greenhouse gas emissions will lead to increasing global warming, with the best estimate of reaching 1.5°C in the near term in considered scenarios and modelled pathways. Every increment of global warming will intensify multiple and concurrent hazards (*high confidence*). Deep, rapid, and sustained reductions in greenhouse gas emissions would lead to a discernible slowdown in global warming within around two decades, and also to discernible changes in atmospheric composition within a few years (*high confidence*). {Cross-Section Boxes 1 and 2, 3.1, 3.3, Table 3.1, Figure 3.1, 4.3} (Figure SPM.2, Box SPM.1)

- B.1.1 Global warming²⁸ will continue to increase in the near term (2021–2040) mainly due to increased cumulative CO₂ emissions in nearly all considered scenarios and modelled pathways. In the near term, global warming is *more likely than not* to reach 1.5°C even under the very low GHG emission scenario (SSP1-1.9) and *likely* or *very likely* to exceed 1.5°C under higher emissions scenarios. In the considered scenarios and modelled pathways, the best estimates of the time when the level of global warming of 1.5°C is reached lie in the near term²⁹. Global warming declines back to below 1.5°C by the end of the 21st century in some scenarios and modelled pathways (see B.7). The assessed climate response to GHG emissions scenarios results in a best estimate of warming for 2081–2100 that spans a range from 1.4°C for a very low GHG emissions scenario (SSP1-1.9) to 2.7°C for an intermediate GHG emissions scenario (SSP2-4.5) and 4.4°C for a very high GHG emissions scenario (SSP5-8.5)³⁰, with narrower uncertainty ranges³¹ than for corresponding scenarios in AR5. {Cross-Section Boxes 1 and 2, 3.1.1, 3.3.4, Table 3.1, 4.3} (Box SPM.1)
- B.1.2 Discernible differences in trends of global surface temperature between contrasting GHG emissions scenarios (SSP1-1.9 and SSP1-2.6 vs. SSP3-7.0 and SSP5-8.5) would begin to emerge from natural variability³² within around 20 years. Under these contrasting scenarios, discernible effects would emerge within years for GHG concentrations, and sooner for air quality improvements, due to the combined targeted air pollution controls and strong and sustained methane emissions reductions. Targeted reductions of air pollutant emissions lead to more rapid improvements in air quality within years compared to reductions in GHG emissions only, but in the long term, further improvements are projected in scenarios that combine efforts to reduce air pollutants as well as GHG emissions³³. (*high confidence*) {3.1.1} (Box SPM.1)
- B.1.3 Continued emissions will further affect all major climate system components. With every additional increment of global warming, changes in extremes continue to become larger. Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation, and very wet and very dry weather and

²⁸ Global warming (see Annex I: Glossary) is here reported as running 20-year averages, unless stated otherwise, relative to 1850–1900. Global surface temperature in any single year can vary above or below the long-term human-caused trend, due to natural variability. The internal variability of global surface temperature in a single year is estimated to be about $\pm 0.25^\circ\text{C}$ (5–95% range, *high confidence*). The occurrence of individual years with global surface temperature change above a certain level does not imply that this global warming level has been reached. {4.3, Cross-Section Box.2}

²⁹ Median five-year interval at which a 1.5°C global warming level is reached (50% probability) in categories of modelled pathways considered in WGIII is 2030–2035. By 2030, global surface temperature in any individual year could exceed 1.5°C relative to 1850–1900 with a probability between 40% and 60%, across the five scenarios assessed in WGI (*medium confidence*). In all scenarios considered in WGI except the very high emissions scenario (SSP5-8.5), the midpoint of the first 20-year running average period during which the assessed average global surface temperature change reaches 1.5°C lies in the first half of the 2030s. In the very high GHG emissions scenario, the midpoint is in the late 2020s. {3.1.1, 3.3.1, 4.3} (Box SPM.1)

³⁰ The best estimates [and *very likely* ranges] for the different scenarios are: 1.4 [1.0 to 1.8]°C (SSP1-1.9); 1.8 [1.3 to 2.4]°C (SSP1-2.6); 2.7 [2.1 to 3.5]°C (SSP2-4.5); 3.6 [2.8 to 4.6]°C (SSP3-7.0); and 4.4 [3.3 to 5.7]°C (SSP5-8.5). {3.1.1} (Box SPM.1)

³¹ Assessed future changes in global surface temperature have been constructed, for the first time, by combining multi-model projections with observational constraints and the assessed equilibrium climate sensitivity and transient climate response. The uncertainty range is narrower than in the AR5 thanks to improved knowledge of climate processes, paleoclimate evidence and model-based emergent constraints. {3.1.1}

³² See Annex I: Glossary. Natural variability includes natural drivers and internal variability. The main internal variability phenomena include El Niño-Southern Oscillation, Pacific Decadal Variability and Atlantic Multi-decadal Variability. {4.3}

³³ Based on additional scenarios.

climate events and seasons (*high confidence*). In scenarios with increasing CO₂ emissions, natural land and ocean carbon sinks are projected to take up a decreasing proportion of these emissions (*high confidence*). Other projected changes include further reduced extents and/or volumes of almost all cryospheric elements³⁴ (*high confidence*), further global mean sea level rise (*virtually certain*), and increased ocean acidification (*virtually certain*) and deoxygenation (*high confidence*). {3.1.1, 3.3.1, Figure 3.4} (Figure SPM.2)

- B.1.4 With further warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. Compound heatwaves and droughts are projected to become more frequent, including concurrent events across multiple locations (*high confidence*). Due to relative sea level rise, current 1-in-100 year extreme sea level events are projected to occur at least annually in more than half of all tide gauge locations by 2100 under all considered scenarios (*high confidence*). Other projected regional changes include intensification of tropical cyclones and/or extratropical storms (*medium confidence*), and increases in aridity and fire weather (*medium to high confidence*). {3.1.1, 3.1.3}
- B.1.5 Natural variability will continue to modulate human-caused climate changes, either attenuating or amplifying projected changes, with little effect on centennial-scale global warming (*high confidence*). These modulations are important to consider in adaptation planning, especially at the regional scale and in the near term. If a large explosive volcanic eruption were to occur³⁵, it would temporarily and partially mask human-caused climate change by reducing global surface temperature and precipitation for one to three years (*medium confidence*). {4.3}

³⁴ Permafrost, seasonal snow cover, glaciers, the Greenland and Antarctic Ice Sheets, and Arctic sea ice.

³⁵ Based on 2500-year reconstructions, eruptions with a radiative forcing more negative than -1 W m^{-2} , related to the radiative effect of volcanic stratospheric aerosols in the literature assessed in this report, occur on average twice per century. {4.3}

With every increment of global warming, regional changes in mean climate and extremes become more widespread and pronounced

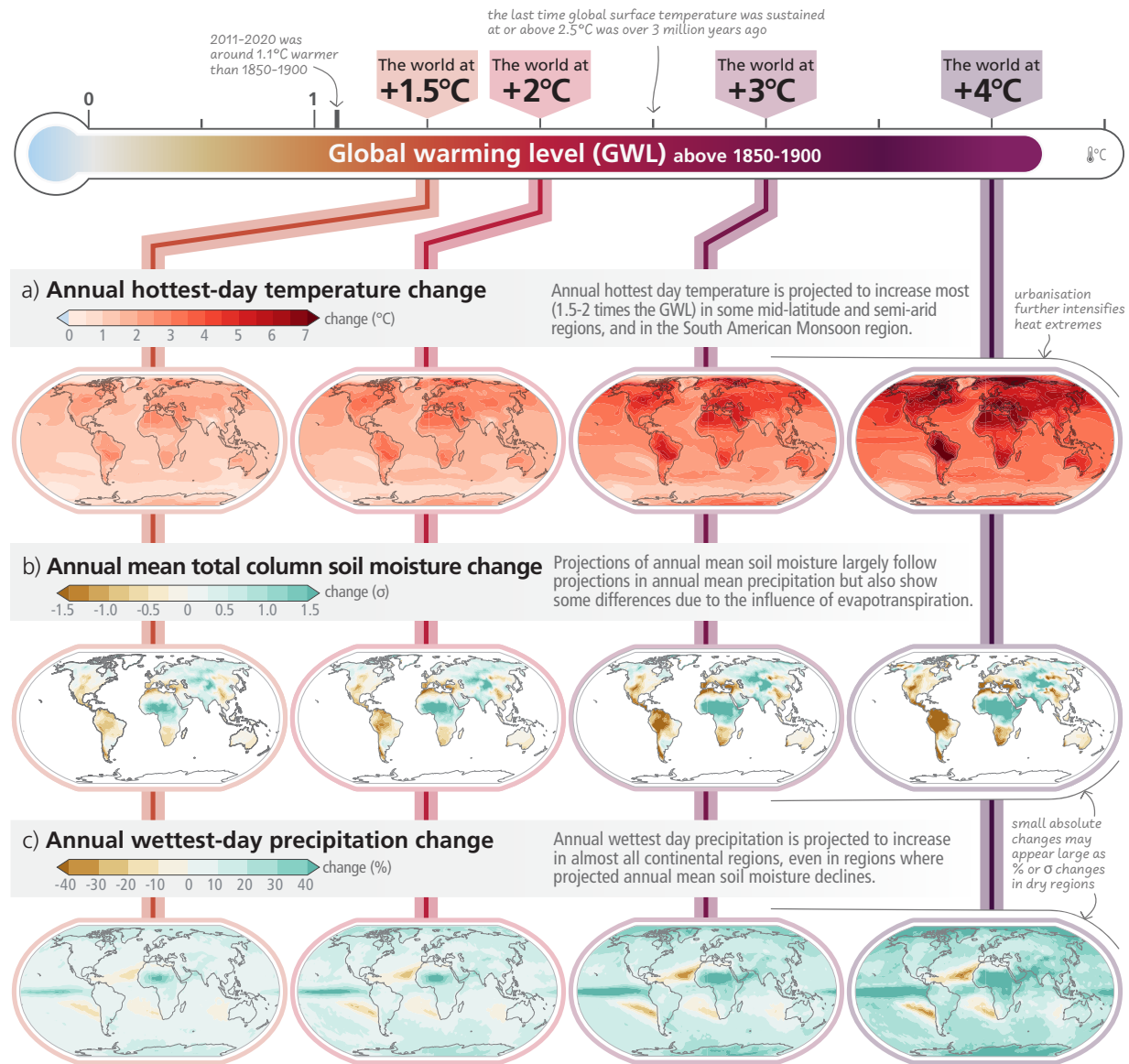


Figure SPM.2: Projected changes of annual maximum daily maximum temperature, annual mean total column soil moisture and annual maximum 1-day precipitation at global warming levels of 1.5°C, 2°C, 3°C, and 4°C relative to 1850–1900. Projected (a) annual maximum daily temperature change (°C), (b) annual mean total column soil moisture change (standard deviation), (c) annual maximum 1-day precipitation change (%). The panels show CMIP6 multi-model median changes. In panels (b) and (c), large positive relative changes in dry regions may correspond to small absolute changes. In panel (b), the unit is the standard deviation of interannual variability in soil moisture during 1850–1900. Standard deviation is a widely used metric in characterising drought severity. A projected reduction in mean soil moisture by one standard deviation corresponds to soil moisture conditions typical of droughts that occurred about once every six years during 1850–1900. The WGI Interactive Atlas (<https://interactive-atlas.ipcc.ch/>) can be used to explore additional changes in the climate system across the range of global warming levels presented in this figure. {Figure 3.1, Cross-Section Box.2}

Climate Change Impacts and Climate-Related Risks

B.2 For any given future warming level, many climate-related risks are higher than assessed in AR5, and projected long-term impacts are up to multiple times higher than currently observed (*high confidence*). Risks and projected adverse impacts and related losses and damages from climate change escalate with every increment of global warming (*very high confidence*). Climatic and non-climatic risks will increasingly interact, creating compound and cascading risks that are more complex and difficult to manage (*high confidence*). {Cross-Section Box.2, 3.1, 4.3, Figure 3.3, Figure 4.3} (Figure SPM.3, Figure SPM.4)

- B.2.1 In the near term, every region in the world is projected to face further increases in climate hazards (*medium to high confidence*, depending on region and hazard), increasing multiple risks to ecosystems and humans (*very high confidence*). Hazards and associated risks expected in the near term include an increase in heat-related human mortality and morbidity (*high confidence*), food-borne, water-borne, and vector-borne diseases (*high confidence*), and mental health challenges³⁶ (*very high confidence*), flooding in coastal and other low-lying cities and regions (*high confidence*), biodiversity loss in land, freshwater and ocean ecosystems (*medium to very high confidence*, depending on ecosystem), and a decrease in food production in some regions (*high confidence*). Cryosphere-related changes in floods, landslides, and water availability have the potential to lead to severe consequences for people, infrastructure and the economy in most mountain regions (*high confidence*). The projected increase in frequency and intensity of heavy precipitation (*high confidence*) will increase rain-generated local flooding (*medium confidence*). {Figure 3.2, Figure 3.3, 4.3, Figure 4.3} (Figure SPM.3, Figure SPM.4)
- B.2.2 Risks and projected adverse impacts and related losses and damages from climate change will escalate with every increment of global warming (*very high confidence*). They are higher for global warming of 1.5°C than at present, and even higher at 2°C (*high confidence*). Compared to the AR5, global aggregated risk levels³⁷ (Reasons for Concern³⁸) are assessed to become high to very high at lower levels of global warming due to recent evidence of observed impacts, improved process understanding, and new knowledge on exposure and vulnerability of human and natural systems, including limits to adaptation (*high confidence*). Due to unavoidable sea level rise (see also B.3), risks for coastal ecosystems, people and infrastructure will continue to increase beyond 2100 (*high confidence*). {3.1.2, 3.1.3, Figure 3.4, Figure 4.3} (Figure SPM.3, Figure SPM.4)
- B.2.3 With further warming, climate change risks will become increasingly complex and more difficult to manage. Multiple climatic and non-climatic risk drivers will interact, resulting in compounding overall risk and risks cascading across sectors and regions. Climate-driven food insecurity and supply instability, for example, are projected to increase with increasing global warming, interacting with non-climatic risk drivers such as competition for land between urban expansion and food production, pandemics and conflict. (*high confidence*) {3.1.2, 4.3, Figure 4.3}
- B.2.4 For any given warming level, the level of risk will also depend on trends in vulnerability and exposure of humans and ecosystems. Future exposure to climatic hazards is increasing globally due to socio-economic development trends including migration, growing inequality and urbanisation. Human vulnerability will concentrate in informal settlements and rapidly growing smaller settlements. In rural areas vulnerability will be heightened by high reliance on climate-sensitive livelihoods. Vulnerability of ecosystems will be strongly influenced by past, present, and future patterns of unsustainable consumption and production, increasing demographic pressures, and persistent unsustainable use and management of land, ocean, and water. Loss of ecosystems and their services has cascading and long-term impacts on people globally, especially for Indigenous Peoples and local communities who are directly dependent on ecosystems to meet basic needs. (*high confidence*) {Cross-Section Box.2 Figure 1c, 3.1.2, 4.3}

³⁶ In all assessed regions.

³⁷ Undetectable risk level indicates no associated impacts are detectable and attributable to climate change; moderate risk indicates associated impacts are both detectable and attributable to climate change with at least *medium confidence*, also accounting for the other specific criteria for key risks; high risk indicates severe and widespread impacts that are judged to be high on one or more criteria for assessing key risks; and very high risk level indicates very high risk of severe impacts and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks. {3.1.2}

³⁸ The Reasons for Concern (RFC) framework communicates scientific understanding about accrual of risk for five broad categories. RFC1: Unique and threatened systems: ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. RFC2: Extreme weather events: risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events. RFC3: Distribution of impacts: risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability. RFC4: Global aggregate impacts: impacts to socio-ecological systems that can be aggregated globally into a single metric. RFC5: Large-scale singular events: relatively large, abrupt and sometimes irreversible changes in systems caused by global warming. See also Annex I: Glossary. {3.1.2, Cross-Section Box.2}

Future climate change is projected to increase the severity of impacts across natural and human systems and will increase regional differences

Examples of impacts without additional adaptation

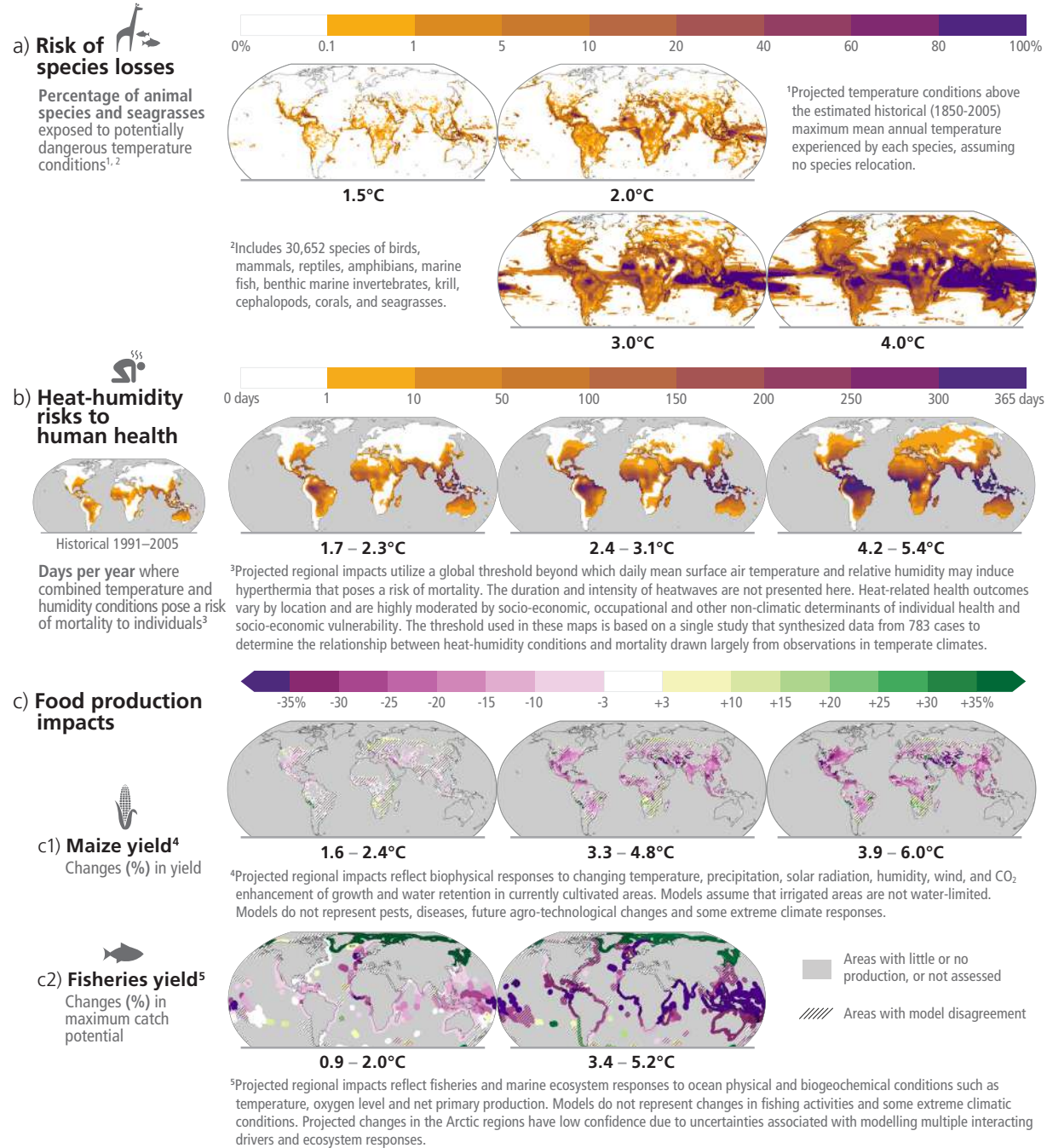


Figure SPM.3: Projected risks and impacts of climate change on natural and human systems at different global warming levels (GWs) relative to 1850–1900 levels. Projected risks and impacts shown on the maps are based on outputs from different subsets of Earth system and impact models that were used to project each impact indicator without additional adaptation. WGII provides further assessment of the impacts on human and natural systems using these projections and additional lines of evidence. **(a)** Risks of species losses as indicated by the percentage of assessed species exposed to potentially dangerous temperature conditions, as defined by conditions beyond the estimated historical (1850–2005) maximum mean annual temperature experienced by each species, at GWs of 1.5°C, 2°C, 3°C and 4°C. Underpinning projections of temperature are from 21 Earth system models and do not consider extreme events impacting ecosystems such as the Arctic. **(b)** Risks to human health as indicated by the days per year of population exposure to hyperthermic conditions that pose a risk of mortality from surface air temperature and humidity conditions for historical period (1991–2005) and at GWs of 1.7°C–2.3°C (mean = 1.9°C; 13 climate models), 2.4°C–3.1°C (2.7°C; 16 climate models) and 4.2°C–5.4°C (4.7°C; 15 climate models). Interquartile ranges of GWs by 2081–2100 under RCP2.6, RCP4.5 and RCP8.5. The presented index is consistent with common features found in many indices included within WGI and WGII assessments. **(c)** Impacts on food production: (c1) Changes in maize yield by 2080–2099 relative to 1986–2005 at projected GWs of 1.6°C–2.4°C (2.0°C), 3.3°C–4.8°C (4.1°C) and 3.9°C–6.0°C (4.9°C). Median yield changes from an ensemble of 12 crop models, each driven by bias-adjusted outputs from 5 Earth system models, from the Agricultural Model Intercomparison and Improvement Project (AgMIP) and the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP). Maps depict

2080–2099 compared to 1986–2005 for current growing regions (>10 ha), with the corresponding range of future global warming levels shown under SSP1-2.6, SSP3-7.0 and SSP5-8.5, respectively. Hatching indicates areas where <70% of the climate-crop model combinations agree on the sign of impact. (c2) Change in maximum fisheries catch potential by 2081–2099 relative to 1986–2005 at projected GWLs of 0.9°C–2.0°C (1.5°C) and 3.4°C–5.2°C (4.3°C). GWLs by 2081–2100 under RCP2.6 and RCP8.5. Hatching indicates where the two climate-fisheries models disagree in the direction of change. Large relative changes in low yielding regions may correspond to small absolute changes. Biodiversity and fisheries in Antarctica were not analysed due to data limitations. Food security is also affected by crop and fishery failures not presented here. {3.1.2, Figure 3.2, Cross-Section Box.2} (Box SPM.1)

Risks are increasing with every increment of warming

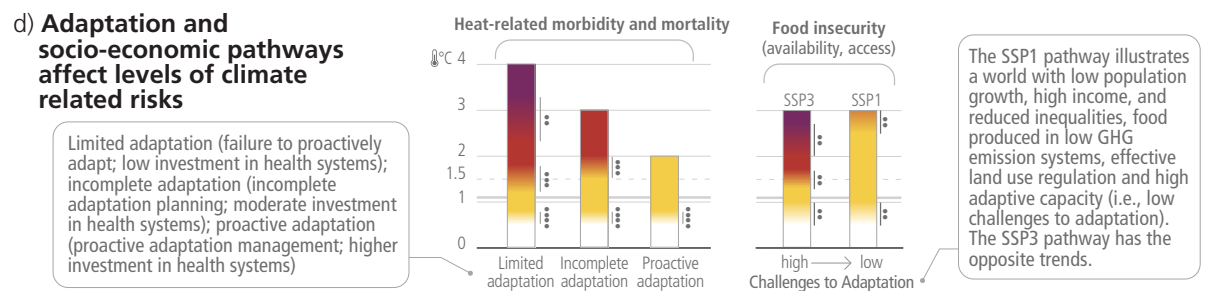
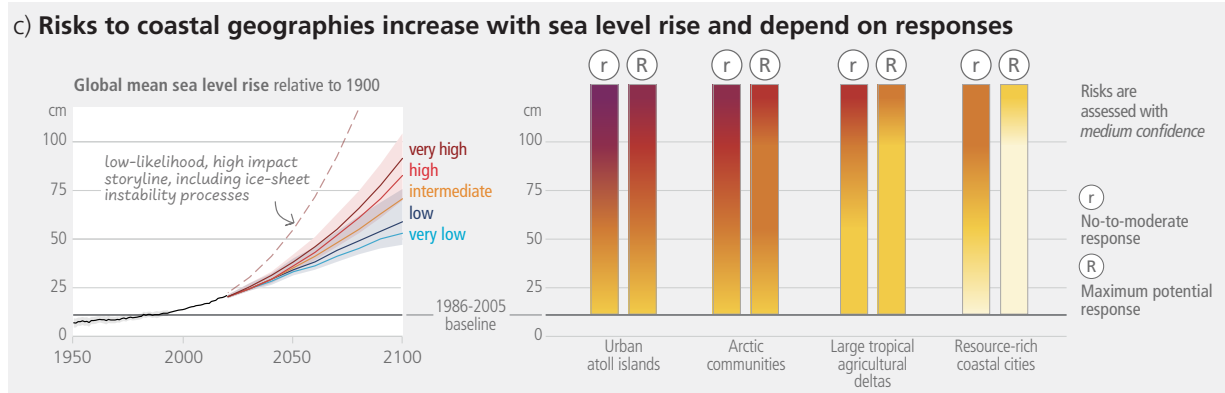
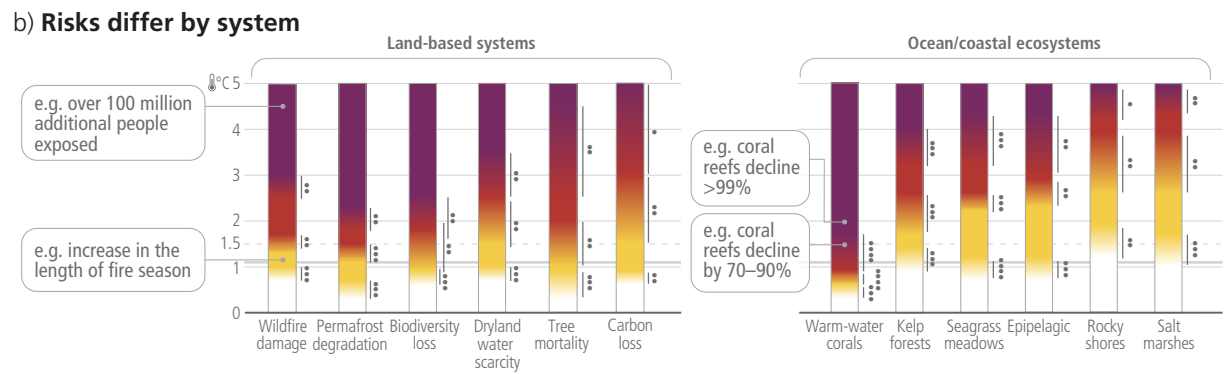
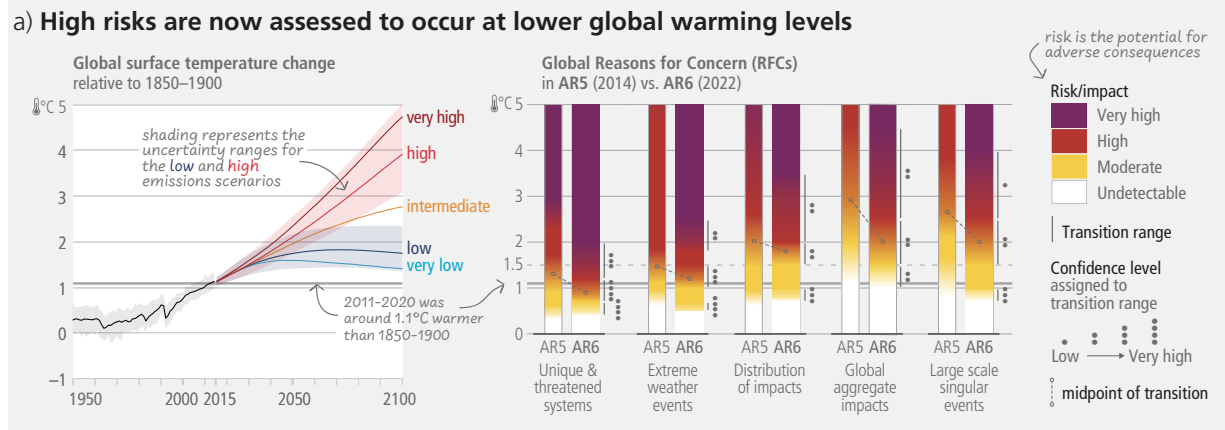


Figure SPM.4: Subset of assessed climate outcomes and associated global and regional climate risks. The burning embers result from a literature based expert elicitation. **Panel (a): Left** – Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining CMIP6 model simulations with observational constraints based on past simulated warming, as well as an updated assessment of equilibrium climate sensitivity. *Very likely* ranges are shown for the low and high GHG emissions scenarios (SSP1-2.6 and SSP3-7.0) (Cross-Section Box.2). **Right** – Global Reasons for Concern (RFC), comparing AR6 (thick embers) and AR5 (thin embers) assessments. Risk transitions have generally shifted towards lower temperatures with updated scientific understanding. Diagrams are shown for each RFC, assuming low to no adaptation. Lines connect the midpoints of the transitions from moderate to high risk across AR5 and AR6. **Panel (b):** Selected global risks for land and ocean ecosystems, illustrating general increase of risk with global warming levels with low to no adaptation. **Panel (c): Left** - Global mean sea level change in centimetres, relative to 1900. The historical changes (black) are observed by tide gauges before 1992 and altimeters afterwards. The future changes to 2100 (coloured lines and shading) are assessed consistently with observational constraints based on emulation of CMIP, ice-sheet, and glacier models, and *likely* ranges are shown for SSP1-2.6 and SSP3-7.0. **Right** - Assessment of the combined risk of coastal flooding, erosion and salinization for four illustrative coastal geographies in 2100, due to changing mean and extreme sea levels, under two response scenarios, with respect to the SROCC baseline period (1986–2005). The assessment does not account for changes in extreme sea level beyond those directly induced by mean sea level rise; risk levels could increase if other changes in extreme sea levels were considered (e.g., due to changes in cyclone intensity). “No-to-moderate response” describes efforts as of today (i.e., no further significant action or new types of actions). “Maximum potential response” represent a combination of responses implemented to their full extent and thus significant additional efforts compared to today, assuming minimal financial, social and political barriers. (In this context, ‘today’ refers to 2019.) The assessment criteria include exposure and vulnerability, coastal hazards, in-situ responses and planned relocation. Planned relocation refers to managed retreat or resettlements. The term response is used here instead of adaptation because some responses, such as retreat, may or may not be considered to be adaptation. **Panel (d):** Selected risks under different socio-economic pathways, illustrating how development strategies and challenges to adaptation influence risk. **Left** - Heat-sensitive human health outcomes under three scenarios of adaptation effectiveness. The diagrams are truncated at the nearest whole °C within the range of temperature change in 2100 under three SSP scenarios. **Right** - Risks associated with food security due to climate change and patterns of socio-economic development. Risks to food security include availability and access to food, including population at risk of hunger, food price increases and increases in disability adjusted life years attributable to childhood underweight. Risks are assessed for two contrasted socio-economic pathways (SSP1 and SSP3) excluding the effects of targeted mitigation and adaptation policies. {Figure 3.3} (Box SPM.1)

Likelihood and Risks of Unavoidable, Irreversible or Abrupt Changes

B.3 Some future changes are unavoidable and/or irreversible but can be limited by deep, rapid, and sustained global greenhouse gas emissions reductions. The likelihood of abrupt and/or irreversible changes increases with higher global warming levels. Similarly, the probability of low-likelihood outcomes associated with potentially very large adverse impacts increases with higher global warming levels. (high confidence) {3.1}

- B.3.1** Limiting global surface temperature does not prevent continued changes in climate system components that have multi-decadal or longer timescales of response (*high confidence*). Sea level rise is unavoidable for centuries to millennia due to continuing deep ocean warming and ice sheet melt, and sea levels will remain elevated for thousands of years (*high confidence*). However, deep, rapid, and sustained GHG emissions reductions would limit further sea level rise acceleration and projected long-term sea level rise commitment. Relative to 1995–2014, the *likely* global mean sea level rise under the SSP1-1.9 GHG emissions scenario is 0.15–0.23 m by 2050 and 0.28–0.55 m by 2100; while for the SSP5-8.5 GHG emissions scenario it is 0.20–0.29 m by 2050 and 0.63–1.01 m by 2100 (*medium confidence*). Over the next 2000 years, global mean sea level will rise by about 2–3 m if warming is limited to 1.5°C and 2–6 m if limited to 2°C (*low confidence*). {3.1.3, Figure 3.4} (Box SPM.1)
- B.3.2** The likelihood and impacts of abrupt and/or irreversible changes in the climate system, including changes triggered when tipping points are reached, increase with further global warming (*high confidence*). As warming levels increase, so do the risks of species extinction or irreversible loss of biodiversity in ecosystems including forests (*medium confidence*), coral reefs (*very high confidence*) and in Arctic regions (*high confidence*). At sustained warming levels between 2°C and 3°C, the Greenland and West Antarctic ice sheets will be lost almost completely and irreversibly over multiple millennia, causing several metres of sea level rise (*limited evidence*). The probability and rate of ice mass loss increase with higher global surface temperatures (*high confidence*). {3.1.2, 3.1.3}
- B.3.3** The probability of low-likelihood outcomes associated with potentially very large impacts increases with higher global warming levels (*high confidence*). Due to deep uncertainty linked to ice-sheet processes, global mean sea level rise above the *likely* range – approaching 2 m by 2100 and in excess of 15 m by 2300 under the very high GHG emissions scenario (SSP5-8.5) (*low confidence*) – cannot be excluded. There is *medium confidence* that the Atlantic Meridional Overturning Circulation will not collapse abruptly before 2100, but if it were to occur, it would *very likely* cause abrupt shifts in regional weather patterns, and large impacts on ecosystems and human activities. {3.1.3} (Box SPM.1)

Adaptation Options and their Limits in a Warmer World

B.4 Adaptation options that are feasible and effective today will become constrained and less effective with increasing global warming. With increasing global warming, losses and damages will increase and additional human and natural systems will reach adaptation limits. Maladaptation can be avoided by flexible, multi-sectoral, inclusive, long-term planning and implementation of adaptation actions, with co-benefits to many sectors and systems. (high confidence) {3.2, 4.1, 4.2, 4.3}

- B.4.1 The effectiveness of adaptation, including ecosystem-based and most water-related options, will decrease with increasing warming. The feasibility and effectiveness of options increase with integrated, multi-sectoral solutions that differentiate responses based on climate risk, cut across systems and address social inequities. As adaptation options often have long implementation times, long-term planning increases their efficiency. (high confidence) {3.2, Figure 3.4, 4.1, 4.2}
- B.4.2 With additional global warming, limits to adaptation and losses and damages, strongly concentrated among vulnerable populations, will become increasingly difficult to avoid (high confidence). Above 1.5°C of global warming, limited freshwater resources pose potential hard adaptation limits for small islands and for regions dependent on glacier and snow melt (medium confidence). Above that level, ecosystems such as some warm-water coral reefs, coastal wetlands, rainforests, and polar and mountain ecosystems will have reached or surpassed hard adaptation limits and as a consequence, some Ecosystem-based Adaptation measures will also lose their effectiveness (high confidence). {2.3.2, 3.2, 4.3}
- B.4.3 Actions that focus on sectors and risks in isolation and on short-term gains often lead to maladaptation over the long term, creating lock-ins of vulnerability, exposure and risks that are difficult to change. For example, seawalls effectively reduce impacts to people and assets in the short term but can also result in lock-ins and increase exposure to climate risks in the long term unless they are integrated into a long-term adaptive plan. Maladaptive responses can worsen existing inequities especially for Indigenous Peoples and marginalised groups and decrease ecosystem and biodiversity resilience. Maladaptation can be avoided by flexible, multi-sectoral, inclusive, long-term planning and implementation of adaptation actions, with co-benefits to many sectors and systems. (high confidence) {2.3.2, 3.2}

Carbon Budgets and Net Zero Emissions

B.5 Limiting human-caused global warming requires net zero CO₂ emissions. Cumulative carbon emissions until the time of reaching net zero CO₂ emissions and the level of greenhouse gas emission reductions this decade largely determine whether warming can be limited to 1.5°C or 2°C (high confidence). Projected CO₂ emissions from existing fossil fuel infrastructure without additional abatement would exceed the remaining carbon budget for 1.5°C (50%) (high confidence). {2.3, 3.1, 3.3, Table 3.1}

- B.5.1 From a physical science perspective, limiting human-caused 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. Reaching net zero GHG emissions primarily requires deep reductions in CO₂, methane, and other GHG emissions, and implies net negative CO₂ emissions³⁹. Carbon dioxide removal (CDR) will be necessary to achieve net negative CO₂ emissions (see B.6). Net zero GHG emissions, if sustained, are projected to result in a gradual decline in global surface temperatures after an earlier peak. (high confidence) {3.1.1, 3.3.1, 3.3.2, 3.3.3, Table 3.1, Cross-Section Box.1}
- B.5.2 For every 1000 GtCO₂ emitted by human activity, global surface temperature rises by 0.45°C (best estimate, with a likely range from 0.27°C to 0.63°C). The best estimates of the remaining carbon budgets from the beginning of 2020 are 500 GtCO₂ for a 50% likelihood of limiting global warming to 1.5°C and 1150 GtCO₂ for a 67% likelihood of limiting warming to 2°C⁴⁰. The stronger the reductions in non-CO₂ emissions, the lower the resulting temperatures are for a given remaining carbon budget or the larger remaining carbon budget for the same level of temperature change⁴¹. {3.3.1}

³⁹ Net zero GHG emissions defined by the 100-year global warming potential. See footnote 9.

⁴⁰ Global databases make different choices about which emissions and removals occurring on land are considered anthropogenic. Most countries report their anthropogenic land CO₂ fluxes including fluxes due to human-caused environmental change (e.g., CO₂ fertilisation) on 'managed' land in their national GHG inventories. Using emissions estimates based on these inventories, the remaining carbon budgets must be correspondingly reduced. {3.3.1}

⁴¹ For example, remaining carbon budgets could be 300 or 600 GtCO₂ for 1.5°C (50%), respectively for high and low non-CO₂ emissions, compared to 500 GtCO₂ in the central case. {3.3.1}

- B.5.3 If the annual CO₂ emissions between 2020–2030 stayed, on average, at the same level as 2019, the resulting cumulative emissions would almost exhaust the remaining carbon budget for 1.5°C (50%), and deplete more than a third of the remaining carbon budget for 2°C (67%). Estimates of future CO₂ emissions from existing fossil fuel infrastructures without additional abatement⁴² already exceed the remaining carbon budget for limiting warming to 1.5°C (50%) (*high confidence*). Projected cumulative future CO₂ emissions over the lifetime of existing and planned fossil fuel infrastructure, if historical operating patterns are maintained and without additional abatement⁴³, are approximately equal to the remaining carbon budget for limiting warming to 2°C with a likelihood of 83%⁴⁴ (*high confidence*). {2.3.1, 3.3.1, Figure 3.5}
- B.5.4 Based on central estimates only, historical cumulative net CO₂ emissions between 1850 and 2019 amount to about four fifths⁴⁵ of the total carbon budget for a 50% probability of limiting global warming to 1.5°C (central estimate about 2900 GtCO₂), and to about two thirds⁴⁶ of the total carbon budget for a 67% probability to limit global warming to 2°C (central estimate about 3550 GtCO₂). {3.3.1, Figure 3.5}

Mitigation Pathways

B.6 All global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, and those that limit warming to 2°C (>67%), involve rapid and deep and, in most cases, immediate greenhouse gas emissions reductions in all sectors this decade. Global net zero CO₂ emissions are reached for these pathway categories, in the early 2050s and around the early 2070s, respectively. (*high confidence*) {3.3, 3.4, 4.1, 4.5, Table 3.1} (Figure SPM.5, Box SPM.1)

- B.6.1 Global modelled pathways provide information on limiting warming to different levels; these pathways, particularly their sectoral and regional aspects, depend on the assumptions described in Box SPM.1. Global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot or limit warming to 2°C (>67%) are characterized by deep, rapid, and, in most cases, immediate GHG emissions reductions. Pathways that limit warming to 1.5°C (>50%) with no or limited overshoot reach net zero CO₂ in the early 2050s, followed by net negative CO₂ emissions. Those pathways that reach net zero GHG emissions do so around the 2070s. Pathways that limit warming to 2°C (>67%) reach net zero CO₂ emissions in the early 2070s. Global GHG emissions are projected to peak between 2020 and at the latest before 2025 in global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot and in those that limit warming to 2°C (>67%) and assume immediate action. (*high confidence*) {3.3.2, 3.3.4, 4.1, Table 3.1, Figure 3.6} (Table SPM.1)

⁴² Abatement here refers to human interventions that reduce the amount of greenhouse gases that are released from fossil fuel infrastructure to the atmosphere.

⁴³ Ibid.

⁴⁴ WGI provides carbon budgets that are in line with limiting global warming to temperature limits with different likelihoods, such as 50%, 67% or 83%. {3.3.1}

⁴⁵ Uncertainties for total carbon budgets have not been assessed and could affect the specific calculated fractions.

⁴⁶ Ibid.

Table SPM.1: Greenhouse gas and CO₂ emission reductions from 2019, median and 5-95 percentiles. {3.3.1, 4.1, Table 3.1, Figure 2.5, Box SPM.1}

	Reductions from 2019 emission levels (%)				
		2030	2035	2040	2050
Limit warming to 1.5°C (>50%) with no or limited overshoot	GHG	43 [34-60]	60 [49-77]	69 [58-90]	84 [73-98]
	CO ₂	48 [36-69]	65 [50-96]	80 [61-109]	99 [79-119]
Limit warming to 2°C (>67%)	GHG	21 [1-42]	35 [22-55]	46 [34-63]	64 [53-77]
	CO ₂	22 [1-44]	37 [21-59]	51 [36-70]	73 [55-90]

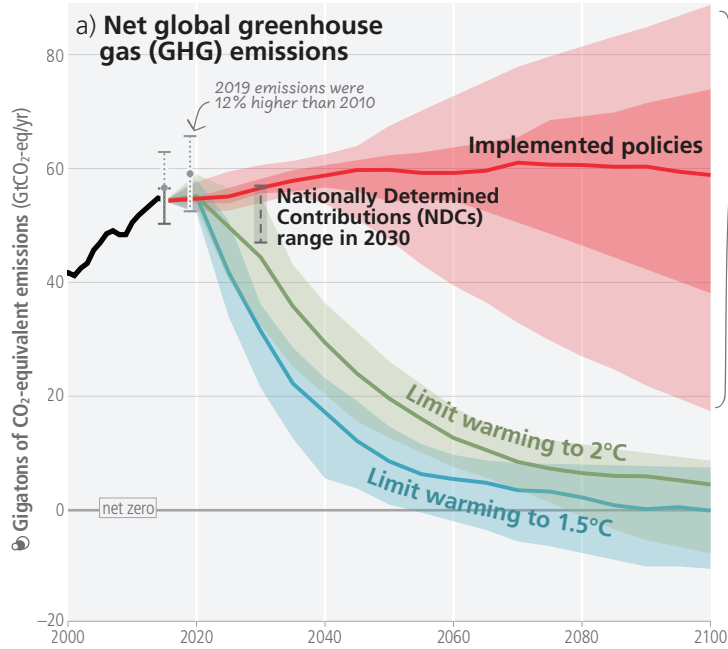
- B.6.2 Reaching net zero CO₂ or GHG emissions primarily requires deep and rapid reductions in gross emissions of CO₂, as well as substantial reductions of non-CO₂ GHG emissions (*high confidence*). For example, in modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, global methane emissions are reduced by 34 [21–57]% by 2030 relative to 2019. However, some hard-to-abate residual GHG emissions (e.g., some emissions from agriculture, aviation, shipping, and industrial processes) remain and would need to be counterbalanced by deployment of CDR methods to achieve net zero CO₂ or GHG emissions (*high confidence*). As a result, net zero CO₂ is reached earlier than net zero GHGs (*high confidence*). {3.3.2, 3.3.3, Table 3.1, Figure 3.5} (Figure SPM.5)
- B.6.3 Global modelled mitigation pathways reaching net zero CO₂ and GHG emissions include transitioning from fossil fuels without carbon capture and storage (CCS) to very low- or zero-carbon energy sources, such as renewables or fossil fuels with CCS, demand-side measures and improving efficiency, reducing non-CO₂ GHG emissions, and CDR⁴⁷. In most global modelled pathways, land-use change and forestry (via reforestation and reduced deforestation) and the energy supply sector reach net zero CO₂ emissions earlier than the buildings, industry and transport sectors. (*high confidence*) {3.3.3, 4.1, 4.5, Figure 4.1} (Figure SPM.5, Box SPM.1)
- B.6.4 Mitigation options often have synergies with other aspects of sustainable development, but some options can also have trade-offs. There are potential synergies between sustainable development and, for instance, energy efficiency and renewable energy. Similarly, depending on the context⁴⁸, biological CDR methods like reforestation, improved forest management, soil carbon sequestration, peatland restoration and coastal blue carbon management can enhance biodiversity and ecosystem functions, employment and local livelihoods. However, afforestation or production of biomass crops can have adverse socio-economic and environmental impacts, including on biodiversity, food and water security, local livelihoods and the rights of Indigenous Peoples, especially if implemented at large scales and where land tenure is insecure. Modelled pathways that assume using resources more efficiently or that shift global development towards sustainability include fewer challenges, such as less dependence on CDR and pressure on land and biodiversity. (*high confidence*) {3.4.1}

⁴⁷ CCS is an option to reduce emissions from large-scale fossil-based energy and industry sources provided geological storage is available. When CO₂ is captured directly from the atmosphere (DACCS), or from biomass (BECCS), CCS provides the storage component of these CDR methods. CO₂ capture and subsurface injection is a mature technology for gas processing and enhanced oil recovery. In contrast to the oil and gas sector, CCS is less mature in the power sector, as well as in cement and chemicals production, where it is a critical mitigation option. The technical geological storage capacity is estimated to be on the order of 1000 GtCO₂, which is more than the CO₂ storage requirements through 2100 to limit global warming to 1.5°C, although the regional availability of geological storage could be a limiting factor. If the geological storage site is appropriately selected and managed, it is estimated that the CO₂ can be permanently isolated from the atmosphere. Implementation of CCS currently faces technological, economic, institutional, ecological-environmental and socio-cultural barriers. Currently, global rates of CCS deployment are far below those in modelled pathways limiting global warming to 1.5°C to 2°C. Enabling conditions such as policy instruments, greater public support and technological innovation could reduce these barriers. (*high confidence*) {3.3.3}

⁴⁸ The impacts, risks, and co-benefits of CDR deployment for ecosystems, biodiversity and people will be highly variable depending on the method, site-specific context, implementation and scale (*high confidence*).

Limiting warming to 1.5°C and 2°C involves rapid, deep and in most cases immediate greenhouse gas emission reductions

Net zero CO₂ and net zero GHG emissions can be achieved through strong reductions across all sectors



Implemented policies result in projected emissions that lead to warming of 3.2°C, with a range of 2.2°C to 3.5°C (medium confidence)

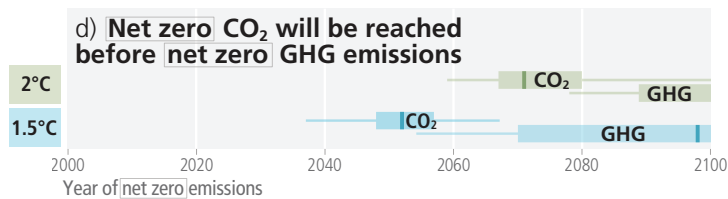
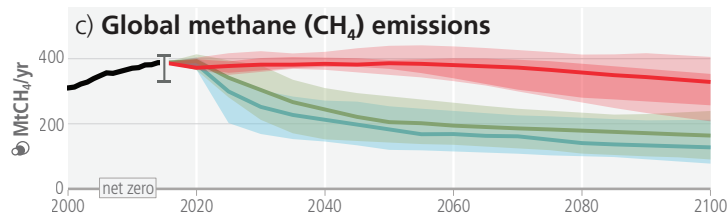
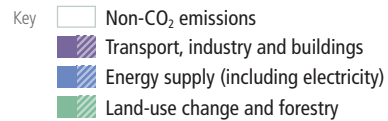
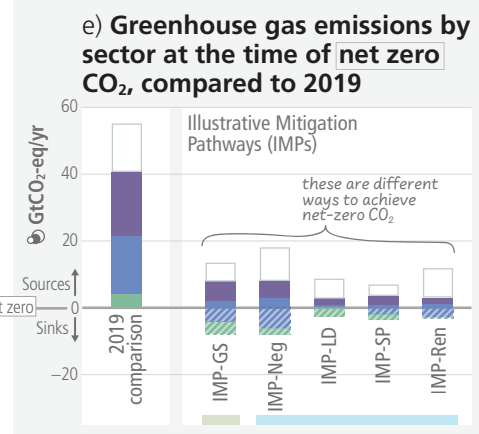
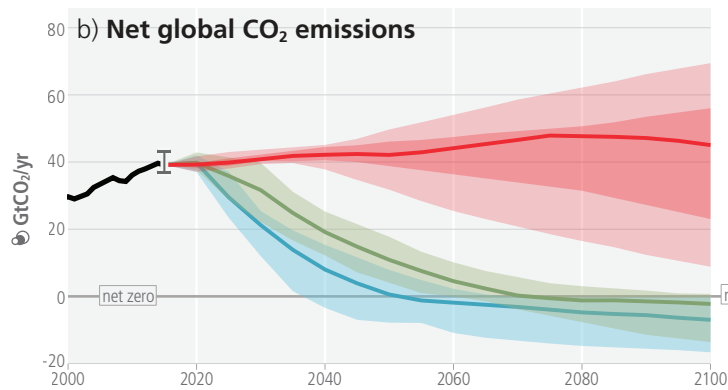
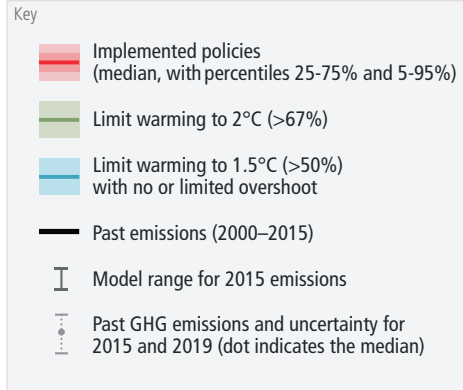


Figure SPM.5: Global emissions pathways consistent with implemented policies and mitigation strategies. Panels (a), (b) and (c) show the development of global GHG, CO₂ and methane emissions in modelled pathways, while panel (d) shows the associated timing of when GHG and CO₂ emissions reach net zero. Coloured ranges denote the 5th to 95th percentile across the global modelled pathways falling within a given category as described in Box SPM.1. The red ranges depict emissions pathways assuming policies that were implemented by the end of 2020. Ranges of modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot are shown in light blue (category C1) and pathways that limit warming to 2°C (>67%) are shown in green (category C3). Global emission pathways that would limit warming to 1.5°C (>50%) with no or limited overshoot and also reach net zero GHG in the second half of the century do so between 2070–2075. Panel (e) shows the sectoral contributions of CO₂ and non-CO₂ emissions sources and sinks at the time when net zero CO₂ emissions are reached in illustrative mitigation pathways (IMPs) consistent with limiting warming to 1.5°C with a high reliance on net negative emissions (IMP-Neg) (“high overshoot”), high resource efficiency (IMP-LD), a focus on sustainable development (IMP-SP), renewables (IMP-Ren) and limiting warming to 2°C with less rapid mitigation initially followed by a gradual strengthening (IMP-GS). Positive and negative emissions for different IMPs are compared to GHG emissions from the year 2019. Energy supply (including electricity) includes bioenergy with carbon dioxide capture and storage and direct air carbon dioxide capture and storage. CO₂ emissions from land-use change and forestry can only be shown as a net number as many models do not report emissions and sinks of this category separately. {Figure 3.6, 4.1} (Box SPM.1)

Overshoot: Exceeding a Warming Level and Returning

B.7 If warming exceeds a specified level such as 1.5°C, it could gradually be reduced again by achieving and sustaining net negative global CO₂ emissions. This would require additional deployment of carbon dioxide removal, compared to pathways without overshoot, leading to greater feasibility and sustainability concerns. Overshoot entails adverse impacts, some irreversible, and additional risks for human and natural systems, all growing with the magnitude and duration of overshoot. (high confidence) {3.1, 3.3, 3.4, Table 3.1, Figure 3.6}

- B.7.1 Only a small number of the most ambitious global modelled pathways limit global warming to 1.5°C (>50%) by 2100 without exceeding this level temporarily. Achieving and sustaining net negative global CO₂ emissions, with annual rates of CDR greater than residual CO₂ emissions, would gradually reduce the warming level again (*high confidence*). Adverse impacts that occur during this period of overshoot and cause additional warming via feedback mechanisms, such as increased wildfires, mass mortality of trees, drying of peatlands, and permafrost thawing, weakening natural land carbon sinks and increasing releases of GHGs would make the return more challenging (*medium confidence*). {3.3.2, 3.3.4, Table 3.1, Figure 3.6} (Box SPM.1)
- B.7.2 The higher the magnitude and the longer the duration of overshoot, the more ecosystems and societies are exposed to greater and more widespread changes in climatic impact-drivers, increasing risks for many natural and human systems. Compared to pathways without overshoot, societies would face higher risks to infrastructure, low-lying coastal settlements, and associated livelihoods. Overshooting 1.5°C will result in irreversible adverse impacts on certain ecosystems with low resilience, such as polar, mountain, and coastal ecosystems, impacted by ice-sheet melt, glacier melt, or by accelerating and higher committed sea level rise. (*high confidence*) {3.1.2, 3.3.4}
- B.7.3 The larger the overshoot, the more net negative CO₂ emissions would be needed to return to 1.5°C by 2100. Transitioning towards net zero CO₂ emissions faster and reducing non-CO₂ emissions such as methane more rapidly would limit peak warming levels and reduce the requirement for net negative CO₂ emissions, thereby reducing feasibility and sustainability concerns, and social and environmental risks associated with CDR deployment at large scales. (*high confidence*) {3.3.3, 3.3.4, 3.4.1, Table 3.1}

C. Responses in the Near Term

Urgency of Near-Term Integrated Climate Action

- C.1 Climate change is a threat to human well-being and planetary health (*very high confidence*). There is a rapidly closing window of opportunity to secure a liveable and sustainable future for all (*very high confidence*). Climate resilient development integrates adaptation and mitigation to advance sustainable development for all, and is enabled by increased international cooperation including improved access to adequate financial resources, particularly for vulnerable regions, sectors and groups, and inclusive governance and coordinated policies (*high confidence*). The choices and actions implemented in this decade will have impacts now and for thousands of years (*high confidence*). {3.1, 3.3, 4.1, 4.2, 4.3, 4.4, 4.7, 4.8, 4.9, Figure 3.1, Figure 3.3, Figure 4.2} (Figure SPM.1, Figure SPM.6)**
- C.1.1 Evidence of observed adverse impacts and related losses and damages, projected risks, levels and trends in vulnerability and adaptation limits, demonstrate that worldwide climate resilient development action is more urgent than previously assessed in AR5. Climate resilient development integrates adaptation and GHG mitigation to advance sustainable development for all. Climate resilient development pathways have been constrained by past development, emissions and climate change and are progressively constrained by every increment of warming, in particular beyond 1.5°C. (*very high confidence*) {3.4, 3.4.2, 4.1}
- C.1.2 Government actions at sub-national, national and international levels, with civil society and the private sector, play a crucial role in enabling and accelerating shifts in development pathways towards sustainability and climate resilient development (*very high confidence*). Climate resilient development is enabled when governments, civil society and the private sector make inclusive development choices that prioritize risk reduction, equity and justice, and when decision-making processes, finance and actions are integrated across governance levels, sectors, and timeframes (*very high confidence*). Enabling conditions are differentiated by national, regional and local circumstances and geographies, according to capabilities, and include: political commitment and follow-through, coordinated policies, social and international cooperation, ecosystem stewardship, inclusive governance, knowledge diversity, technological innovation, monitoring and evaluation, and improved access to adequate financial resources, especially for vulnerable regions, sectors and communities (*high confidence*). {3.4, 4.2, 4.4, 4.5, 4.7, 4.8} (Figure SPM.6)
- C.1.3 Continued emissions will further affect all major climate system components, and many changes will be irreversible on centennial to millennial time scales and become larger with increasing global warming. Without urgent, effective, and equitable mitigation and adaptation actions, climate change increasingly threatens ecosystems, biodiversity, and the livelihoods, health and well-being of current and future generations. (*high confidence*) {3.1.3, 3.3.3, 3.4.1, Figure 3.4, 4.1, 4.2, 4.3, 4.4} (Figure SPM.1, Figure SPM.6)

There is a rapidly narrowing window of opportunity to enable climate resilient development

Multiple interacting choices and actions can shift development pathways towards sustainability

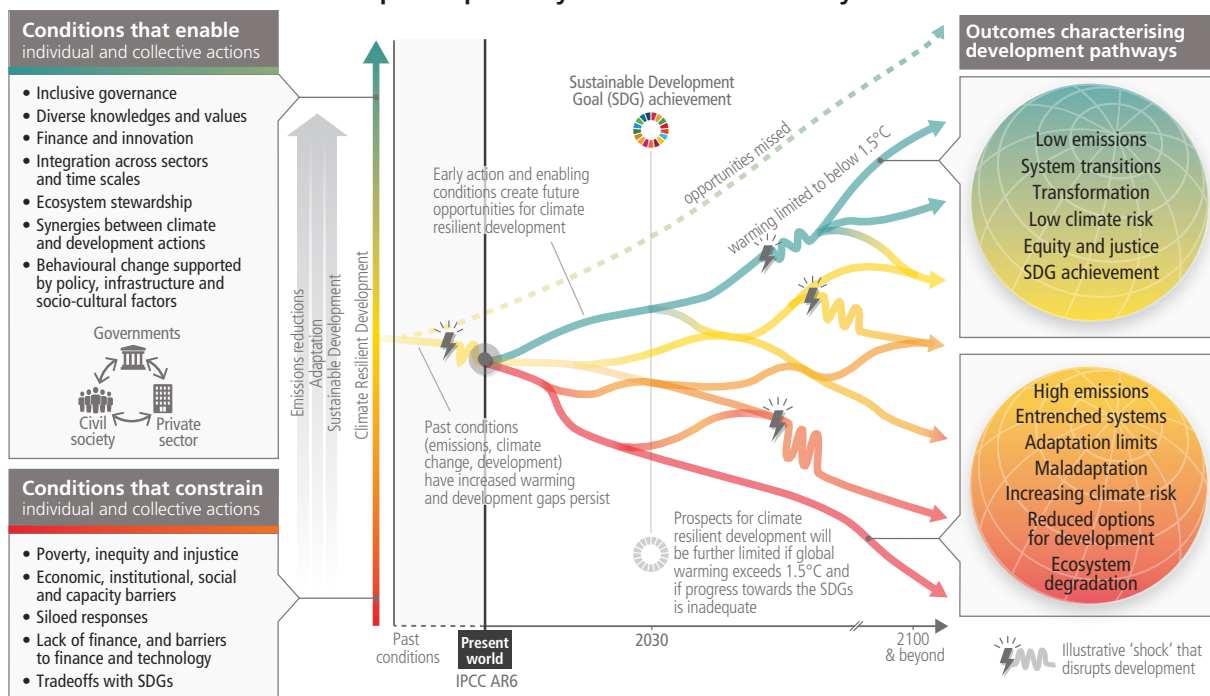


Figure SPM.6: The illustrative development pathways (red to green) and associated outcomes (right panel) show that there is a rapidly narrowing window of opportunity to secure a liveable and sustainable future for all. Climate resilient development is the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development. Diverging pathways illustrate that interacting choices and actions made by diverse government, private sector and civil society actors can advance climate resilient development, shift pathways towards sustainability, and enable lower emissions and adaptation. Diverse knowledge and values include cultural values, Indigenous Knowledge, local knowledge, and scientific knowledge. Climatic and non-climatic events, such as droughts, floods or pandemics, pose more severe shocks to pathways with lower climate resilient development (red to yellow) than to pathways with higher climate resilient development (green). There are limits to adaptation and adaptive capacity for some human and natural systems at global warming of 1.5°C, and with every increment of warming, losses and damages will increase. The development pathways taken by countries at all stages of economic development impact GHG emissions and mitigation challenges and opportunities, which vary across countries and regions. Pathways and opportunities for action are shaped by previous actions (or inactions and opportunities missed; dashed pathway) and enabling and constraining conditions (left panel), and take place in the context of climate risks, adaptation limits and development gaps. The longer emissions reductions are delayed, the fewer effective adaptation options. {Figure 4.2, 3.1, 3.2, 3.4, 4.2, 4.4, 4.5, 4.6, 4.9}

The Benefits of Near-Term Action

C.2 Deep, rapid, and sustained mitigation and accelerated implementation of adaptation actions in this decade would reduce projected losses and damages for humans and ecosystems (very high confidence), and deliver many co-benefits, especially for air quality and health (high confidence). Delayed mitigation and adaptation action would lock in high-emissions infrastructure, raise risks of stranded assets and cost-escalation, reduce feasibility, and increase losses and damages (high confidence). Near-term actions involve high up-front investments and potentially disruptive changes that can be lessened by a range of enabling policies (high confidence). {2.1, 2.2, 3.1, 3.2, 3.3, 3.4, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8}

C.2.1 Deep, rapid, and sustained mitigation and accelerated implementation of adaptation actions in this decade would reduce future losses and damages related to climate change for humans and ecosystems (very high confidence). As adaptation options often have long implementation times, accelerated implementation of adaptation in this decade is important to close adaptation gaps (high confidence). Comprehensive, effective, and innovative responses integrating adaptation and mitigation can harness synergies and reduce trade-offs between adaptation and mitigation (high confidence). {4.1, 4.2, 4.3}

- C.2.2 Delayed mitigation action will further increase global warming and losses and damages will rise and additional human and natural systems will reach adaptation limits. Challenges from delayed adaptation and mitigation actions include the risk of cost escalation, lock-in of infrastructure, stranded assets, and reduced feasibility and effectiveness of adaptation and mitigation options. Without rapid, deep and sustained mitigation and accelerated adaptation actions, losses and damages will continue to increase, including projected adverse impacts in Africa, LDCs, SIDS, Central and South America⁴⁹, Asia and the Arctic, and will disproportionately affect the most vulnerable populations. (*high confidence*) {2.1.2, 3.1.2, 3.2, 3.3.1, 3.3.3, 4.1, 4.2, 4.3} (Figure SPM.3, Figure SPM.4)
- C.2.3 Accelerated climate action can also provide co-benefits (see also C.4) (*high confidence*). Many mitigation actions would have benefits for health through lower air pollution, active mobility (e.g., walking, cycling), and shifts to sustainable healthy diets (*high confidence*). Strong, rapid and sustained reductions in methane emissions can limit near-term warming and improve air quality by reducing global surface ozone (*high confidence*). Adaptation can generate multiple additional benefits such as improving agricultural productivity, innovation, health and well-being, food security, livelihood, and biodiversity conservation (*very high confidence*). {4.2, 4.5.4, 4.5.5, 4.6}
- C.2.4 Cost-benefit analysis remains limited in its ability to represent all avoided damages from climate change (*high confidence*). The economic benefits for human health from air quality improvement arising from mitigation action can be of the same order of magnitude as mitigation costs, and potentially even larger (*medium confidence*). Even without accounting for all the benefits of avoiding potential damages, the global economic and social benefit of limiting global warming to 2°C exceeds the cost of mitigation in most of the assessed literature (*medium confidence*)⁵⁰. More rapid climate change mitigation, with emissions peaking earlier, increases co-benefits and reduces feasibility risks and costs in the long-term, but requires higher up-front investments (*high confidence*). {3.4.1, 4.2}
- C.2.5 Ambitious mitigation pathways imply large and sometimes disruptive changes in existing economic structures, with significant distributional consequences within and between countries. To accelerate climate action, the adverse consequences of these changes can be moderated by fiscal, financial, institutional and regulatory reforms and by integrating climate actions with macroeconomic policies through (i) economy-wide packages, consistent with national circumstances, supporting sustainable low-emission growth paths; (ii) climate resilient safety nets and social protection; and (iii) improved access to finance for low-emissions infrastructure and technologies, especially in developing countries. (*high confidence*) {4.2, 4.4, 4.7, 4.8.1}

⁴⁹ The southern part of Mexico is included in the climatic subregion South Central America (SCA) for WGI. Mexico is assessed as part of North America for WGII. The climate change literature for the SCA region occasionally includes Mexico, and in those cases WGII assessment makes reference to Latin America. Mexico is considered part of Latin America and the Caribbean for WGIII.

⁵⁰ The evidence is too limited to make a similar robust conclusion for limiting warming to 1.5°C. Limiting global warming to 1.5°C instead of 2°C would increase the costs of mitigation, but also increase the benefits in terms of reduced impacts and related risks, and reduced adaptation needs (*high confidence*).

There are multiple opportunities for scaling up climate action

a) Feasibility of climate responses and adaptation, and potential of mitigation options in the near term

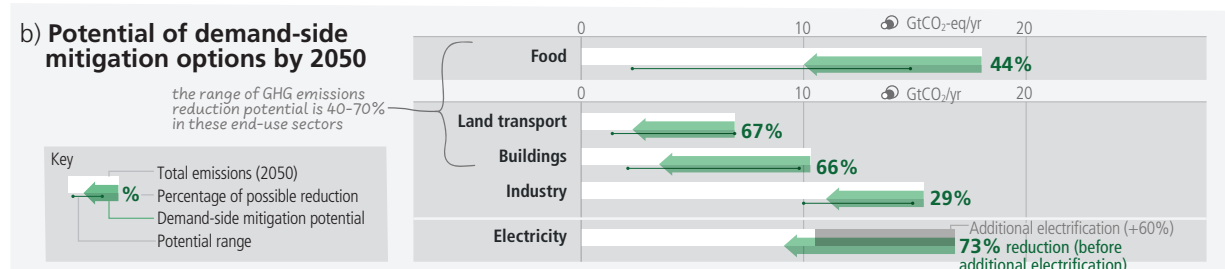
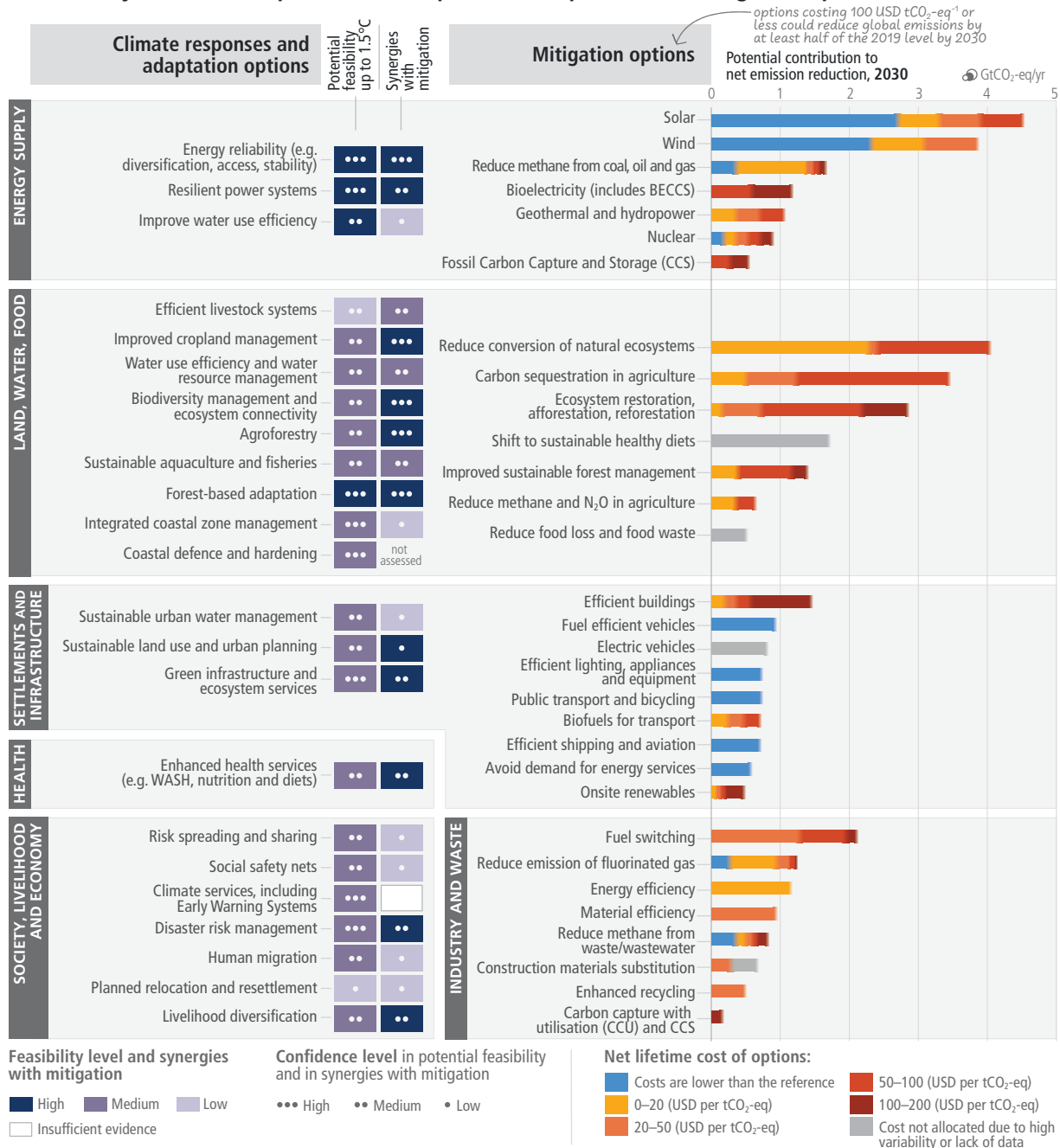


Figure SPM.7: Multiple Opportunities for scaling up climate action. Panel (a) presents selected mitigation and adaptation options across different systems. The left-hand side of panel a shows climate responses and adaptation options assessed for their multidimensional feasibility at global scale, in the near term and up to 1.5°C global warming. As literature above 1.5°C is limited, feasibility at higher levels of warming may change, which is currently not possible to assess robustly. The term response is used here in addition to adaptation because some responses, such as migration, relocation and resettlement may or may not be considered to be adaptation. Forest based adaptation includes sustainable forest management, forest conservation and restoration, reforestation

and afforestation. WASH refers to water, sanitation and hygiene. Six feasibility dimensions (economic, technological, institutional, social, environmental and geophysical) were used to calculate the potential feasibility of climate responses and adaptation options, along with their synergies with mitigation. For potential feasibility and feasibility dimensions, the figure shows high, medium, or low feasibility. Synergies with mitigation are identified as high, medium, and low. The right-hand side of Panel a provides an overview of selected mitigation options and their estimated costs and potentials in 2030. Costs are net lifetime discounted monetary costs of avoided GHG emissions calculated relative to a reference technology. Relative potentials and costs will vary by place, context and time and in the longer term compared to 2030. The potential (horizontal axis) is the net GHG emission reduction (sum of reduced emissions and/or enhanced sinks) broken down into cost categories (coloured bar segments) relative to an emission baseline consisting of current policy (around 2019) reference scenarios from the AR6 scenarios database. The potentials are assessed independently for each option and are not additive. Health system mitigation options are included mostly in settlement and infrastructure (e.g., efficient healthcare buildings) and cannot be identified separately. Fuel switching in industry refers to switching to electricity, hydrogen, bioenergy and natural gas. Gradual colour transitions indicate uncertain breakdown into cost categories due to uncertainty or heavy context dependency. The uncertainty in the total potential is typically 25–50%. **Panel (b)** displays the indicative potential of demand-side mitigation options for 2050. Potentials are estimated based on approximately 500 bottom-up studies representing all global regions. The baseline (white bar) is provided by the sectoral mean GHG emissions in 2050 of the two scenarios (IEA-STEPS and IP_ModAct) consistent with policies announced by national governments until 2020. The green arrow represents the demand-side emissions reductions potentials. The range in potential is shown by a line connecting dots displaying the highest and the lowest potentials reported in the literature. Food shows demand-side potential of socio-cultural factors and infrastructure use, and changes in land-use patterns enabled by change in food demand. Demand-side measures and new ways of end-use service provision can reduce global GHG emissions in end-use sectors (buildings, land transport, food) by 40–70% by 2050 compared to baseline scenarios, while some regions and socioeconomic groups require additional energy and resources. The last row shows how demand-side mitigation options in other sectors can influence overall electricity demand. The dark grey bar shows the projected increase in electricity demand above the 2050 baseline due to increasing electrification in the other sectors. Based on a bottom-up assessment, this projected increase in electricity demand can be avoided through demand-side mitigation options in the domains of infrastructure use and socio-cultural factors that influence electricity usage in industry, land transport, and buildings (green arrow). (Figure 4.4)

Mitigation and Adaptation Options across Systems

C.3 Rapid and far-reaching transitions across all sectors and systems are necessary to achieve deep and sustained emissions reductions and secure a liveable and sustainable future for all. These system transitions involve a significant upscaling of a wide portfolio of mitigation and adaptation options. Feasible, effective, and low-cost options for mitigation and adaptation are already available, with differences across systems and regions. (high confidence) {4.1, 4.5, 4.6} (Figure SPM.7)

C.3.1 The systemic change required to achieve rapid and deep emissions reductions and transformative adaptation to climate change is unprecedented in terms of scale, but not necessarily in terms of speed (*medium confidence*). Systems transitions include: deployment of low- or zero-emission technologies; reducing and changing demand through infrastructure design and access, socio-cultural and behavioural changes, and increased technological efficiency and adoption; social protection, climate services or other services; and protecting and restoring ecosystems (*high confidence*). Feasible, effective, and low-cost options for mitigation and adaptation are already available (*high confidence*). The availability, feasibility and potential of mitigation and adaptation options in the near term differs across systems and regions (*very high confidence*). {4.1, 4.5.1 to 4.5.6} (Figure SPM.7)

Energy Systems

C.3.2 Net zero CO₂ energy systems entail: a substantial reduction in overall fossil fuel use, minimal use of unabated fossil fuels⁵¹, and use of carbon capture and storage in the remaining fossil fuel systems; electricity systems that emit no net CO₂; widespread electrification; alternative energy carriers in applications less amenable to electrification; energy conservation and efficiency; and greater integration across the energy system (*high confidence*). Large contributions to emissions reductions with costs less than USD 20 tCO₂-eq⁻¹ come from solar and wind energy, energy efficiency improvements, and methane emissions reductions (coal mining, oil and gas, waste) (*medium confidence*). There are feasible adaptation options that support infrastructure resilience, reliable power systems and efficient water use for existing and new energy generation systems (*very high confidence*). Energy generation diversification (e.g., via wind, solar, small scale hydropower) and demand-side management (e.g., storage and energy efficiency improvements) can increase energy reliability and reduce vulnerabilities to climate change (*high confidence*). Climate responsive energy markets, updated design standards on energy assets according to current and projected climate change, smart-grid technologies, robust transmission systems and improved capacity to respond to supply deficits have high feasibility in the medium to long term, with mitigation co-benefits (*very high confidence*). {4.5.1} (Figure SPM.7)

⁵¹ In this context, ‘unabated fossil fuels’ refers to fossil fuels produced and used without interventions that substantially reduce the amount of GHG emitted throughout the life cycle; for example, capturing 90% or more CO₂ from power plants, or 50–80% of fugitive methane emissions from energy supply.

Industry and Transport

C.3.3 Reducing industry GHG emissions entails coordinated action throughout value chains to promote all mitigation options, including demand management, energy and materials efficiency, circular material flows, as well as abatement technologies and transformational changes in production processes (*high confidence*). In transport, sustainable biofuels, low-emissions hydrogen, and derivatives (including ammonia and synthetic fuels) can support mitigation of CO₂ emissions from shipping, aviation, and heavy-duty land transport but require production process improvements and cost reductions (*medium confidence*). Sustainable biofuels can offer additional mitigation benefits in land-based transport in the short and medium term (*medium confidence*). Electric vehicles powered by low-GHG emissions electricity have large potential to reduce land-based transport GHG emissions, on a life cycle basis (*high confidence*). Advances in battery technologies could facilitate the electrification of heavy-duty trucks and complement conventional electric rail systems (*medium confidence*). The environmental footprint of battery production and growing concerns about critical minerals can be addressed by material and supply diversification strategies, energy and material efficiency improvements, and circular material flows (*medium confidence*). {4.5.2, 4.5.3} (Figure SPM.7)

Cities, Settlements and Infrastructure

C.3.4 Urban systems are critical for achieving deep emissions reductions and advancing climate resilient development (*high confidence*). Key adaptation and mitigation elements in cities include considering climate change impacts and risks (e.g., through climate services) in the design and planning of settlements and infrastructure; land use planning to achieve compact urban form, co-location of jobs and housing; supporting public transport and active mobility (e.g., walking and cycling); the efficient design, construction, retrofit, and use of buildings; reducing and changing energy and material consumption; sufficiency⁵²; material substitution; and electrification in combination with low emissions sources (*high confidence*). Urban transitions that offer benefits for mitigation, adaptation, human health and well-being, ecosystem services, and vulnerability reduction for low-income communities are fostered by inclusive long-term planning that takes an integrated approach to physical, natural and social infrastructure (*high confidence*). Green/natural and blue infrastructure supports carbon uptake and storage and either singly or when combined with grey infrastructure can reduce energy use and risk from extreme events such as heatwaves, flooding, heavy precipitation and droughts, while generating co-benefits for health, well-being and livelihoods (*medium confidence*). {4.5.3}

Land, Ocean, Food, and Water

C.3.5 Many agriculture, forestry, and other land use (AFOLU) options provide adaptation and mitigation benefits that could be upscaled in the near term across most regions. Conservation, improved management, and restoration of forests and other ecosystems offer the largest share of economic mitigation potential, with reduced deforestation in tropical regions having the highest total mitigation potential. Ecosystem restoration, reforestation, and afforestation can lead to trade-offs due to competing demands on land. Minimizing trade-offs requires integrated approaches to meet multiple objectives including food security. Demand-side measures (shifting to sustainable healthy diets⁵³ and reducing food loss/waste) and sustainable agricultural intensification can reduce ecosystem conversion, and methane and nitrous oxide emissions, and free up land for reforestation and ecosystem restoration. Sustainably sourced agricultural and forest products, including long-lived wood products, can be used instead of more GHG-intensive products in other sectors. Effective adaptation options include cultivar improvements, agroforestry, community-based adaptation, farm and landscape diversification, and urban agriculture. These AFOLU response options require integration of biophysical, socioeconomic and other enabling factors. Some options, such as conservation of high-carbon ecosystems (e.g., peatlands, wetlands, rangelands, mangroves and forests), deliver immediate benefits, while others, such as restoration of high-carbon ecosystems, take decades to deliver measurable results. (*high confidence*) {4.5.4} (Figure SPM.7)

C.3.6 Maintaining the resilience of biodiversity and ecosystem services at a global scale depends on effective and equitable conservation of approximately 30% to 50% of Earth's land, freshwater and ocean areas, including currently near-natural ecosystems (*high confidence*). Conservation, protection and restoration of terrestrial, freshwater, coastal and

⁵² A set of measures and daily practices that avoid demand for energy, materials, land, and water while delivering human well-being for all within planetary boundaries. {4.5.3}

⁵³ 'Sustainable healthy diets' promote all dimensions of individuals' health and well-being; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable, as described in FAO and WHO. The related concept of 'balanced diets' refers to diets that feature plant-based foods, such as those based on coarse grains, legumes, fruits and vegetables, nuts and seeds, and animal-sourced food produced in resilient, sustainable and low-GHG emission systems, as described in SRCCL.

ocean ecosystems, together with targeted management to adapt to unavoidable impacts of climate change reduces the vulnerability of biodiversity and ecosystem services to climate change (*high confidence*), reduces coastal erosion and flooding (*high confidence*), and could increase carbon uptake and storage if global warming is limited (*medium confidence*). Rebuilding overexploited or depleted fisheries reduces negative climate change impacts on fisheries (*medium confidence*) and supports food security, biodiversity, human health and well-being (*high confidence*). Land restoration contributes to climate change mitigation and adaptation with synergies via enhanced ecosystem services and with economically positive returns and co-benefits for poverty reduction and improved livelihoods (*high confidence*). Cooperation, and inclusive decision making, with Indigenous Peoples and local communities, as well as recognition of inherent rights of Indigenous Peoples, is integral to successful adaptation and mitigation across forests and other ecosystems (*high confidence*). {4.5.4, 4.6} (Figure SPM.7)

Health and Nutrition

C.3.7 Human health will benefit from integrated mitigation and adaptation options that mainstream health into food, infrastructure, social protection, and water policies (*very high confidence*). Effective adaptation options exist to help protect human health and well-being, including: strengthening public health programs related to climate-sensitive diseases, increasing health systems resilience, improving ecosystem health, improving access to potable water, reducing exposure of water and sanitation systems to flooding, improving surveillance and early warning systems, vaccine development (*very high confidence*), improving access to mental healthcare, and Heat Health Action Plans that include early warning and response systems (*high confidence*). Adaptation strategies which reduce food loss and waste or support balanced, sustainable healthy diets contribute to nutrition, health, biodiversity and other environmental benefits (*high confidence*). {4.5.5} (Figure SPM.7)

Society, Livelihoods, and Economies

C.3.8 Policy mixes that include weather and health insurance, social protection and adaptive social safety nets, contingent finance and reserve funds, and universal access to early warning systems combined with effective contingency plans, can reduce vulnerability and exposure of human systems. Disaster risk management, early warning systems, climate services and risk spreading and sharing approaches have broad applicability across sectors. Increasing education including capacity building, climate literacy, and information provided through climate services and community approaches can facilitate heightened risk perception and accelerate behavioural changes and planning. (*high confidence*) {4.5.6}

Synergies and Trade-Offs with Sustainable Development

C.4 Accelerated and equitable action in mitigating and adapting to climate change impacts is critical to sustainable development. Mitigation and adaptation actions have more synergies than trade-offs with Sustainable Development Goals. Synergies and trade-offs depend on context and scale of implementation. (*high confidence*) {3.4, 4.2, 4.4, 4.5, 4.6, 4.9, Figure 4.5}

C.4.1 Mitigation efforts embedded within the wider development context can increase the pace, depth and breadth of emission reductions (*medium confidence*). Countries at all stages of economic development seek to improve the well-being of people, and their development priorities reflect different starting points and contexts. Different contexts include but are not limited to social, economic, environmental, cultural, political circumstances, resource endowment, capabilities, international environment, and prior development (*high confidence*). In regions with high dependency on fossil fuels for, among other things, revenue and employment generation, mitigating risk for sustainable development requires policies that promote economic and energy sector diversification and considerations of just transitions principles, processes and practices (*high confidence*). Eradicating extreme poverty, energy poverty, and providing decent living standards in low-emitting countries / regions in the context of achieving sustainable development objectives, in the near term, can be achieved without significant global emissions growth (*high confidence*). {4.4, 4.6, Annex I: Glossary}

C.4.2 Many mitigation and adaptation actions have multiple synergies with Sustainable Development Goals (SDGs) and sustainable development generally, but some actions can also have trade-offs. Potential synergies with SDGs exceed potential trade-offs; synergies and trade-offs depend on the pace and magnitude of change and the development context including inequalities with consideration of climate justice. Trade-offs can be evaluated and minimised by giving emphasis to capacity building, finance, governance, technology transfer, investments, development, context specific gender-based and other social equity considerations with meaningful participation of Indigenous Peoples, local communities and vulnerable populations. (*high confidence*) {3.4.1, 4.6, Figure 4.5, 4.9}

- C.4.3 Implementing both mitigation and adaptation actions together and taking trade-offs into account supports co-benefits and synergies for human health and well-being. For example, improved access to clean energy sources and technologies generates health benefits especially for women and children; electrification combined with low-GHG energy, and shifts to active mobility and public transport can enhance air quality, health, employment, and can elicit energy security and deliver equity. *(high confidence)* {4.2, 4.5.3, 4.5.5, 4.6, 4.9}

Equity and Inclusion

C.5 Prioritising equity, climate justice, social justice, inclusion and just transition processes can enable adaptation and ambitious mitigation actions and climate resilient development. Adaptation outcomes are enhanced by increased support to regions and people with the highest vulnerability to climatic hazards. Integrating climate adaptation into social protection programs improves resilience. Many options are available for reducing emission-intensive consumption, including through behavioural and lifestyle changes, with co-benefits for societal well-being. *(high confidence)* {4.4, 4.5}

- C.5.1 Equity remains a central element in the UN climate regime, notwithstanding shifts in differentiation between states over time and challenges in assessing fair shares. Ambitious mitigation pathways imply large and sometimes disruptive changes in economic structure, with significant distributional consequences, within and between countries. Distributional consequences within and between countries include shifting of income and employment during the transition from high- to low-emissions activities. *(high confidence)* {4.4}
- C.5.2 Adaptation and mitigation actions that prioritise equity, social justice, climate justice, rights-based approaches, and inclusivity, lead to more sustainable outcomes, reduce trade-offs, support transformative change and advance climate resilient development. Redistributive policies across sectors and regions that shield the poor and vulnerable, social safety nets, equity, inclusion and just transitions, at all scales can enable deeper societal ambitions and resolve trade-offs with sustainable development goals. Attention to equity and broad and meaningful participation of all relevant actors in decision making at all scales can build social trust which builds on equitable sharing of benefits and burdens of mitigation that deepen and widen support for transformative changes. *(high confidence)* {4.4}
- C.5.3 Regions and people (3.3 to 3.6 billion in number) with considerable development constraints have high vulnerability to climatic hazards (see A.2.2). Adaptation outcomes for the most vulnerable within and across countries and regions are enhanced through approaches focusing on equity, inclusivity and rights-based approaches. Vulnerability is exacerbated by inequity and marginalisation linked to e.g., gender, ethnicity, low incomes, informal settlements, disability, age, and historical and ongoing patterns of inequity such as colonialism, especially for many Indigenous Peoples and local communities. Integrating climate adaptation into social protection programs, including cash transfers and public works programs, is highly feasible and increases resilience to climate change, especially when supported by basic services and infrastructure. The greatest gains in well-being in urban areas can be achieved by prioritising access to finance to reduce climate risk for low-income and marginalised communities including people living in informal settlements. *(high confidence)* {4.4, 4.5.3, 4.5.5, 4.5.6}
- C.5.4 The design of regulatory instruments and economic instruments and consumption-based approaches, can advance equity. Individuals with high socio-economic status contribute disproportionately to emissions, and have the highest potential for emissions reductions. Many options are available for reducing emission-intensive consumption while improving societal well-being. Socio-cultural options, behaviour and lifestyle changes supported by policies, infrastructure, and technology can help end-users shift to low-emissions-intensive consumption, with multiple co-benefits. A substantial share of the population in low-emitting countries lack access to modern energy services. Technology development, transfer, capacity building and financing can support developing countries / regions leapfrogging or transitioning to low-emissions transport systems thereby providing multiple co-benefits. Climate resilient development is advanced when actors work in equitable, just and inclusive ways to reconcile divergent interests, values and worldviews, toward equitable and just outcomes. *(high confidence)* {2.1, 4.4}

Governance and Policies

C.6 Effective climate action is enabled by political commitment, well-aligned multilevel governance, institutional frameworks, laws, policies and strategies and enhanced access to finance and technology. Clear goals, coordination across multiple policy domains, and inclusive governance processes facilitate effective climate action. Regulatory and economic instruments can support deep emissions reductions and climate resilience if scaled up and applied widely. Climate resilient development benefits from drawing on diverse knowledge. (*high confidence*) {2.2, 4.4, 4.5, 4.7}

- C.6.1 Effective climate governance enables mitigation and adaptation. Effective governance provides overall direction on setting targets and priorities and mainstreaming climate action across policy domains and levels, based on national circumstances and in the context of international cooperation. It enhances monitoring and evaluation and regulatory certainty, prioritising inclusive, transparent and equitable decision-making, and improves access to finance and technology (see C.7). (*high confidence*) {2.2.2, 4.7}
- C.6.2 Effective local, municipal, national and subnational institutions build consensus for climate action among diverse interests, enable coordination and inform strategy setting but require adequate institutional capacity. Policy support is influenced by actors in civil society, including businesses, youth, women, labour, media, Indigenous Peoples, and local communities. Effectiveness is enhanced by political commitment and partnerships between different groups in society. (*high confidence*) {2.2, 4.7}
- C.6.3 Effective multilevel governance for mitigation, adaptation, risk management, and climate resilient development is enabled by inclusive decision processes that prioritise equity and justice in planning and implementation, allocation of appropriate resources, institutional review, and monitoring and evaluation. Vulnerabilities and climate risks are often reduced through carefully designed and implemented laws, policies, participatory processes, and interventions that address context specific inequities such as those based on gender, ethnicity, disability, age, location and income. (*high confidence*) {4.4, 4.7}
- C.6.4 Regulatory and economic instruments could support deep emissions reductions if scaled up and applied more widely (*high confidence*). Scaling up and enhancing the use of regulatory instruments can improve mitigation outcomes in sectoral applications, consistent with national circumstances (*high confidence*). Where implemented, carbon pricing instruments have incentivized low-cost emissions reduction measures but have been less effective, on their own and at prevailing prices during the assessment period, to promote higher-cost measures necessary for further reductions (*medium confidence*). Equity and distributional impacts of such carbon pricing instruments, e.g., carbon taxes and emissions trading, can be addressed by using revenue to support low-income households, among other approaches. Removing fossil fuel subsidies would reduce emissions⁵⁴ and yield benefits such as improved public revenue, macroeconomic and sustainability performance; subsidy removal can have adverse distributional impacts, especially on the most economically vulnerable groups which, in some cases can be mitigated by measures such as redistributing revenue saved, all of which depend on national circumstances (*high confidence*). Economy-wide policy packages, such as public spending commitments and pricing reforms, can meet short-term economic goals while reducing emissions and shifting development pathways towards sustainability (*medium confidence*). Effective policy packages would be comprehensive, consistent, balanced across objectives, and tailored to national circumstances (*high confidence*). {2.2.2, 4.7}
- C.6.5 Drawing on diverse knowledges and cultural values, meaningful participation and inclusive engagement processes—including Indigenous Knowledge, local knowledge, and scientific knowledge—facilitates climate resilient development, builds capacity and allows locally appropriate and socially acceptable solutions. (*high confidence*) {4.4, 4.5.6, 4.7}

⁵⁴ Fossil fuel subsidy removal is projected by various studies to reduce global CO₂ emission by 1 to 4%, and GHG emissions by up to 10% by 2030, varying across regions (*medium confidence*).

Finance, Technology and International Cooperation

- C.7 Finance, technology and international cooperation are critical enablers for accelerated climate action. If climate goals are to be achieved, both adaptation and mitigation financing would need to increase many-fold. There is sufficient global capital to close the global investment gaps but there are barriers to redirect capital to climate action. Enhancing technology innovation systems is key to accelerate the widespread adoption of technologies and practices. Enhancing international cooperation is possible through multiple channels. (*high confidence*) {2.3, 4.8}**
- C.7.1 Improved availability of and access to finance⁵⁵ would enable accelerated climate action (*very high confidence*). Addressing needs and gaps and broadening equitable access to domestic and international finance, when combined with other supportive actions, can act as a catalyst for accelerating adaptation and mitigation, and enabling climate resilient development (*high confidence*). If climate goals are to be achieved, and to address rising risks and accelerate investments in emissions reductions, both adaptation and mitigation finance would need to increase many-fold (*high confidence*). {4.8.1}
- C.7.2 Increased access to finance can build capacity and address soft limits to adaptation and avert rising risks, especially for developing countries, vulnerable groups, regions and sectors (*high confidence*). Public finance is an important enabler of adaptation and mitigation, and can also leverage private finance (*high confidence*). Average annual modelled mitigation investment requirements for 2020 to 2030 in scenarios that limit warming to 2°C or 1.5°C are a factor of three to six greater than current levels⁵⁶, and total mitigation investments (public, private, domestic and international) would need to increase across all sectors and regions (*medium confidence*). Even if extensive global mitigation efforts are implemented, there will be a need for financial, technical, and human resources for adaptation (*high confidence*). {4.3, 4.8.1}
- C.7.3 There is sufficient global capital and liquidity to close global investment gaps, given the size of the global financial system, but there are barriers to redirect capital to climate action both within and outside the global financial sector and in the context of economic vulnerabilities and indebtedness facing developing countries. Reducing financing barriers for scaling up financial flows would require clear signalling and support by governments, including a stronger alignment of public finances in order to lower real and perceived regulatory, cost and market barriers and risks and improving the risk-return profile of investments. At the same time, depending on national contexts, financial actors, including investors, financial intermediaries, central banks and financial regulators can shift the systemic underpricing of climate-related risks, and reduce sectoral and regional mismatches between available capital and investment needs. (*high confidence*) {4.8.1}
- C.7.4 Tracked financial flows fall short of the levels needed for adaptation and to achieve mitigation goals across all sectors and regions. These gaps create many opportunities and the challenge of closing gaps is largest in developing countries. Accelerated financial support for developing countries from developed countries and other sources is a critical enabler to enhance adaptation and mitigation actions and address inequities in access to finance, including its costs, terms and conditions, and economic vulnerability to climate change for developing countries. Scaled-up public grants for mitigation and adaptation funding for vulnerable regions, especially in Sub-Saharan Africa, would be cost-effective and have high social returns in terms of access to basic energy. Options for scaling up mitigation in developing countries include: increased levels of public finance and publicly mobilised private finance flows from developed to developing countries in the context of the USD 100 billion-a-year goal; increased use of public guarantees to reduce risks and leverage private flows at lower cost; local capital markets development; and building greater trust in international cooperation processes. A coordinated effort to make the post-pandemic recovery sustainable over the longer-term can accelerate climate action, including in developing regions and countries facing high debt costs, debt distress and macroeconomic uncertainty. (*high confidence*) {4.8.1}
- C.7.5 Enhancing technology innovation systems can provide opportunities to lower emissions growth, create social and environmental co-benefits, and achieve other SDGs. Policy packages tailored to national contexts and technological characteristics have been effective in supporting low-emission innovation and technology diffusion. Public policies can

⁵⁵ Finance originates from diverse sources: public or private, local, national or international, bilateral or multilateral, and alternative sources. It can take the form of grants, technical assistance, loans (concessional and non-concessional), bonds, equity, risk insurance and financial guarantees (of different types).

⁵⁶ These estimates rely on scenario assumptions.

support training and R&D, complemented by both regulatory and market-based instruments that create incentives and market opportunities. Technological innovation can have trade-offs such as new and greater environmental impacts, social inequalities, overdependence on foreign knowledge and providers, distributional impacts and rebound effects⁵⁷, requiring appropriate governance and policies to enhance potential and reduce trade-offs. Innovation and adoption of low-emission technologies lags in most developing countries, particularly least developed ones, due in part to weaker enabling conditions, including limited finance, technology development and transfer, and capacity building. (*high confidence*) {4.8.3}

- C.7.6 International cooperation is a critical enabler for achieving ambitious climate change mitigation, adaptation, and climate resilient development (*high confidence*). Climate resilient development is enabled by increased international cooperation including mobilising and enhancing access to finance, particularly for developing countries, vulnerable regions, sectors and groups and aligning finance flows for climate action to be consistent with ambition levels and funding needs (*high confidence*). Enhancing international cooperation on finance, technology and capacity building can enable greater ambition and can act as a catalyst for accelerating mitigation and adaptation, and shifting development pathways towards sustainability (*high confidence*). This includes support to NDCs and accelerating technology development and deployment (*high confidence*). Transnational partnerships can stimulate policy development, technology diffusion, adaptation and mitigation, though uncertainties remain over their costs, feasibility and effectiveness (*medium confidence*). International environmental and sectoral agreements, institutions and initiatives are helping, and in some cases may help, to stimulate low GHG emissions investments and reduce emissions (*medium confidence*). {2.2.2, 4.8.2}

⁵⁷ Leading to lower net emission reductions or even emission increases.

Climate Change 2023 Synthesis Report

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Section 1

Introduction



1. Introduction

This Synthesis Report (SYR) of the IPCC Sixth Assessment Report (AR6) summarises the state of knowledge of climate change, its widespread impacts and risks, and climate change mitigation and adaptation, based on the peer-reviewed scientific, technical and socio-economic literature since the publication of the IPCC's Fifth Assessment Report (AR5) in 2014.

The assessment is undertaken within the context of the evolving international landscape, in particular, developments in the UN Framework Convention on Climate Change (UNFCCC) process, including the outcomes of the Kyoto Protocol and the adoption of the Paris Agreement. It reflects the increasing diversity of those involved in climate action.

This report integrates the main findings of the AR6 Working Group reports⁵⁸ and the three AR6 Special Reports⁵⁹. It recognizes the interdependence of climate, ecosystems and biodiversity, and human societies; the value of diverse forms of knowledge; and the close linkages between climate change adaptation, mitigation, ecosystem health, human well-being and sustainable development. Building on multiple analytical frameworks, including those from the physical and social sciences, this report identifies opportunities for transformative action which are effective, feasible, just and equitable using concepts of systems transitions and resilient development pathways⁶⁰. Different regional classification schemes⁶¹ are used for physical, social and economic aspects, reflecting the underlying literature.

After this introduction, Section 2, '*Current Status and Trends*', opens with the assessment of observational evidence for our changing climate, historical and current drivers of human-induced climate change, and its impacts. It assesses the current implementation of adaptation and mitigation response options. Section 3, '*Long-Term Climate and Development Futures*', provides a long-term assessment of climate change to 2100 and beyond in a broad range of socio-economic

futures. It considers long-term characteristics, impacts, risks and costs in adaptation and mitigation pathways in the context of sustainable development. Section 4, '*Near-Term Responses in a Changing Climate*', assesses opportunities for scaling up effective action in the period up to 2040, in the context of climate pledges, and commitments, and the pursuit of sustainable development.

Based on scientific understanding, key findings can be formulated as statements of fact or associated with an assessed level of confidence using the IPCC calibrated language⁶². The scientific findings are drawn from the underlying reports and arise from their Summary for Policymakers (hereafter SPM), Technical Summary (hereafter TS), and underlying chapters and are indicated by {} brackets. Figure 1.1 shows the Synthesis Report Figures Key, a guide to visual icons that are used across multiple figures within this report.

⁵⁸ The three Working Group contributions to AR6 are: Climate Change 2021: The Physical Science Basis; Climate Change 2022: Impacts, Adaptation and Vulnerability; and Climate Change 2022: Mitigation of Climate Change, respectively. Their assessments cover scientific literature accepted for publication respectively by 31 January 2021, 1 September 2021 and 11 October 2021.

⁵⁹ The three Special Reports are: Global Warming of 1.5°C (2018): an IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (SR1.5); Climate Change and Land (2019): an IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL); and The Ocean and Cryosphere in a Changing Climate (2019) (SROCC). The Special Reports cover scientific literature accepted for publication respectively by 15 May 2018, 7 April 2019 and 15 May 2019.


⁶⁰ The Glossary (Annex I) includes definitions of these, and other terms and concepts used in this report drawn from the AR6 joint Working Group Glossary.

⁶¹ Depending on the climate information context, geographical regions in AR6 may refer to larger areas, such as sub-continent and oceanic regions, or to typological regions, such as monsoon regions, coastlines, mountain ranges or cities. A new set of standard AR6 WGI reference land and ocean regions have been defined. WGIII allocates countries to geographical regions, based on the UN Statistics Division Classification {WGI 1.4.5, WGI 10.1, WGI 11.9, WGI 12.1–12.4, WGI Atlas.1.3.3–1.3.4}.


⁶² Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or result: virtually certain 99–100% probability; very likely 90–100%; likely 66–100%; more likely than not >50–100%; about as likely as not 33–66%; unlikely 0–33%; very unlikely 0–10%; and exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100% and extremely unlikely 0–5%) are also used when appropriate. Assessed likelihood also is typeset in italics: for example, very likely. This is consistent with AR5. In this Report, unless stated otherwise, square brackets [x to y] are used to provide the assessed *very likely* range, or 90% interval.

Synthesis Report
figures key

Axis labels

 GHG emissions

 °C Temperature

 Cost or budget

 Net zero

*these help non-experts
navigate complex content* → **Italicized 'annotations'**
Simple explanations written
in non-technical language

Figure 1.1: The Synthesis Report figures key.

Section 2

Current Status and Trends



Section 2: Current Status and Trends

2.1 Observed Changes, Impacts and Attribution

Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020. Global greenhouse gas emissions have continued to increase over 2010–2019, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and between individuals (*high confidence*). Human-caused climate change is already affecting many weather and climate extremes in every region across the globe. This has led to widespread adverse impacts on food and water security, human health and on economies and society and related losses and damages⁶³ to nature and people (*high confidence*). Vulnerable communities who have historically contributed the least to current climate change are disproportionately affected (*high confidence*).

2.1.1. Observed Warming and its Causes

Global surface temperature was around 1.1°C above 1850–1900 in 2011–2020 (1.09 [0.95 to 1.20]°C)⁶⁴, with larger increases over land (1.59 [1.34 to 1.83]°C) than over the ocean (0.88 [0.68 to 1.01]°C)⁶⁵. Observed warming is human-caused, with warming from greenhouse gases (GHG), dominated by CO₂ and methane (CH₄), partly masked by aerosol cooling (Figure 2.1). Global surface temperature in the first two decades of the 21st century (2001–2020) was 0.99 [0.84 to 1.10]°C higher than 1850–1900. Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years (*high confidence*). The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019⁶⁶ is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is *likely* that well-mixed GHGs⁶⁷ contributed a warming of 1.0°C to 2.0°C, and other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural (solar and volcanic) drivers changed global surface temperature by ±0.1°C and internal variability changed it by ±0.2°C. {WGI SPM A.1, WGI SPM A.1.2, WGI SPM A.1.3, WGI SPM A.2.2, WGI Figure SPM.2; SRCCL TS.2}

Observed increases in well-mixed GHG concentrations since around 1750 are unequivocally caused by GHG emissions from human activities. Land and ocean sinks have taken up a near-constant proportion (globally about 56% per year) of CO₂ emissions from human activities over

the past six decades, with regional differences (*high confidence*). In 2019, atmospheric CO₂ concentrations reached 410 parts per million (ppm), CH₄ reached 1866 parts per billion (ppb) and nitrous oxide (N₂O) reached 332 ppb⁶⁸. Other major contributors to warming are tropospheric ozone (O₃) and halogenated gases. Concentrations of CH₄ and N₂O have increased to levels unprecedented in at least 800,000 years (*very high confidence*), and there is *high confidence* that current CO₂ concentrations are higher than at any time over at least the past two million years. Since 1750, increases in CO₂ (47%) and CH₄ (156%) concentrations far exceed – and increases in N₂O (23%) are similar to – the natural multi-millennial changes between glacial and interglacial periods over at least the past 800,000 years (*very high confidence*). The net cooling effect which arises from anthropogenic aerosols peaked in the late 20th century (*high confidence*). {WGI SPM A1.1, WGI SPM A1.3, WGI SPM A.2.1, WGI Figure SPM.2, WGI TS 2.2, WGI 2ES, WGI Figure 6.1}

⁶³ In this report, the term 'losses and damages' refers to adverse observed impacts and/or projected risks and can be economic and/or non-economic. (See Annex I: Glossary)

⁶⁴ The estimated increase in global surface temperature since AR5 is principally due to further warming since 2003–2012 (+0.19 [0.16 to 0.22]°C). Additionally, methodological advances and new datasets have provided a more complete spatial representation of changes in surface temperature, including in the Arctic. These and other improvements have also increased the estimate of global surface temperature change by approximately 0.1°C, but this increase does not represent additional physical warming since AR5 {WGI SPM A1.2 and footnote 10}

⁶⁵ For 1850–1900 to 2013–2022 the updated calculations are 1.15 [1.00 to 1.25]°C for global surface temperature, 1.65 [1.36 to 1.90]°C for land temperatures and 0.93 [0.73 to 1.04]°C for ocean temperatures above 1850–1900 using the exact same datasets (updated by 2 years) and methods as employed in WGI.

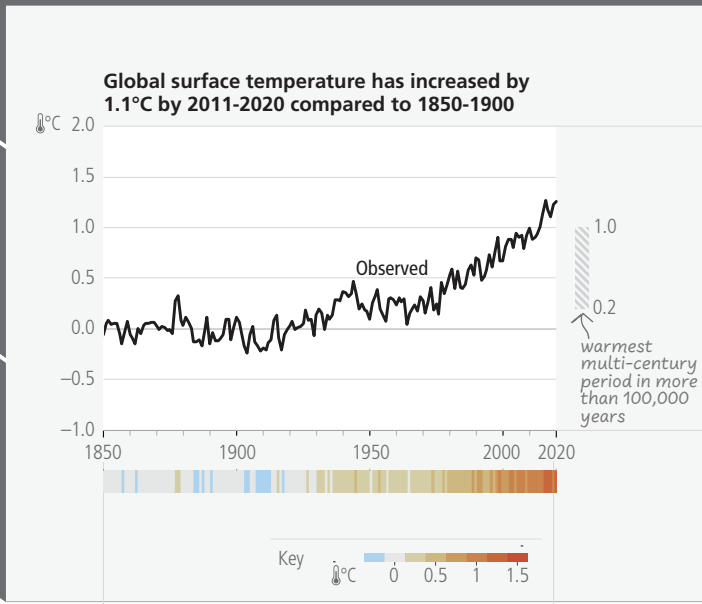
⁶⁶ The period distinction with the observed assessment arises because the attribution studies consider this slightly earlier period. The observed warming to 2010–2019 is 1.06 [0.88 to 1.21]°C. {WGI SPM footnote 11}

⁶⁷ Contributions from emissions to the 2010–2019 warming relative to 1850–1900 assessed from radiative forcing studies are: CO₂ 0.8 [0.5 to 1.2]°C; methane 0.5 [0.3 to 0.8]°C; nitrous oxide 0.1 [0.0 to 0.2]°C and fluorinated gases 0.1 [0.0 to 0.2]°C.

⁶⁸ For 2021 (the most recent year for which final numbers are available) concentrations using the same observational products and methods as in AR6 WGI are: 415 ppm CO₂; 1896 ppb CH₄; and 335 ppb N₂O. Note that the CO₂ is reported here using the WMO-CO₂-X2007 scale to be consistent with WGI. Operational CO₂ reporting has since been updated to use the WMO-CO₂-X2019 scale.

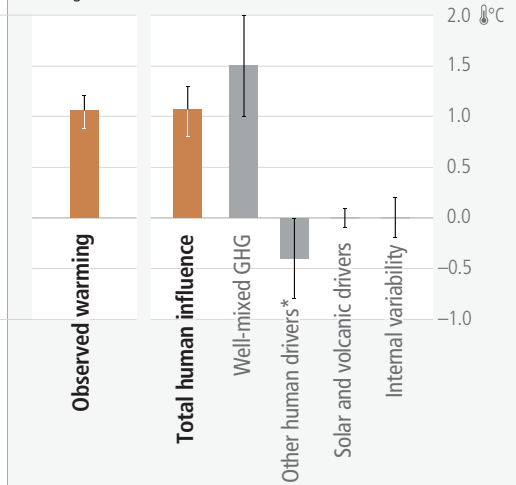
Human activities are responsible for global warming

c) Changes in global surface temperature



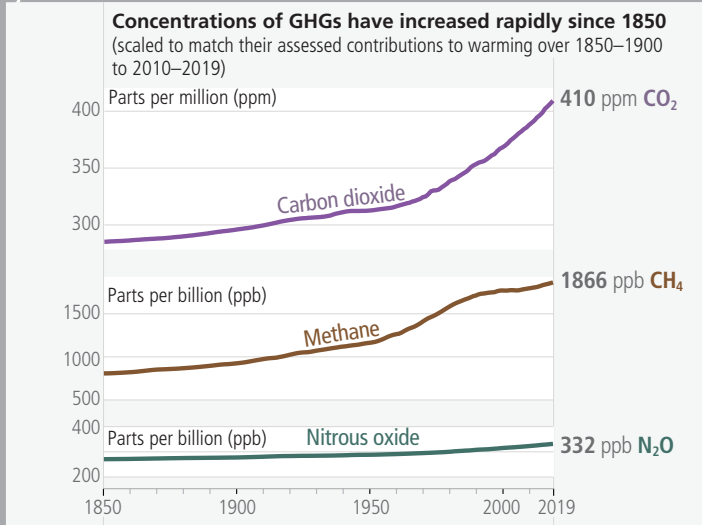
d) Humans are responsible

Observed warming is driven by emissions from human activities with GHG warming partly masked by aerosol cooling 2010-2019 (change from 1850-1900)



*Other human drivers are predominantly cooling aerosols, but also warming aerosols, land-use change (land-use reflectance) and ozone.

b) Increased concentrations of GHGs in the atmosphere



a) Increased emissions of greenhouse gases (GHGs)

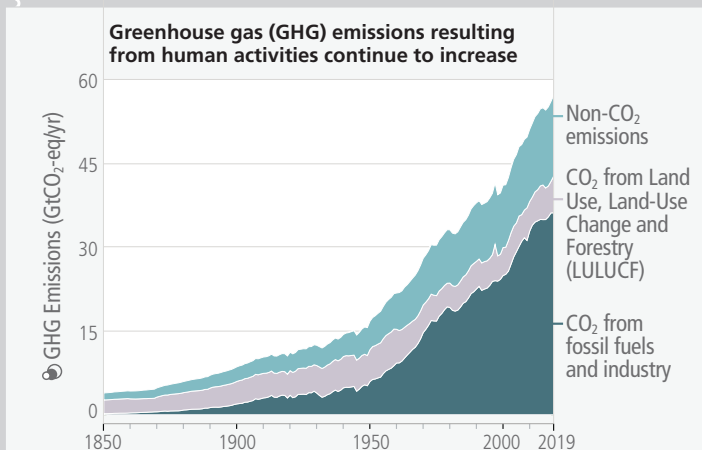


Figure 2.1: The causal chain from emissions to resulting warming of the climate system. Emissions of GHG have increased rapidly over recent decades (panel (a)). Global net anthropogenic GHG emissions include CO₂ from fossil fuel combustion and industrial processes (CO₂-FFI) (dark green); net CO₂ from land use, land-use change and forestry (CO₂-LULUCF) (green); CH₄; N₂O; and fluorinated gases (HFCs, PFCs, SF₆, NF₃) (light blue). These emissions have led to increases in the atmospheric concentrations of several GHGs including the three major well-mixed GHGs CO₂, CH₄ and N₂O (panel (b)), annual values). To indicate their relative importance each subpanel's vertical extent for CO₂, CH₄ and N₂O is scaled to match the assessed individual direct effect (and, in the case of CH₄ indirect effect via atmospheric chemistry impacts on tropospheric ozone) of historical emissions on temperature change from 1850-1900 to 2010-2019. This estimate arises from an assessment of effective radiative forcing and climate sensitivity. The global surface temperature (shown as annual anomalies from a 1850-1900 baseline) has increased by around 1.1°C since 1850-1900 (panel (c)). The vertical bar on the right shows the estimated temperature (*very likely range*) during the warmest multi-century period in at least the last 100,000 years, which occurred around 6500 years ago during the current interglacial period (Holocene). Prior to that, the next most recent warm period was about 125,000 years ago, when the assessed multi-century temperature range [0.5°C to 1.5°C] overlaps the observations of the most recent decade. These past warm periods were caused by slow (multi-millennial) orbital variations. Formal detection and attribution studies synthesise information from climate models and observations and show that the best estimate is that all the warming observed between 1850-1900 and 2010-2019 is caused by humans (panel (d)). The panel shows temperature change attributed to: total human influence; its decomposition into changes in GHG concentrations and other human drivers (aerosols, ozone and land-use change (land-use reflectance)); solar and volcanic drivers; and internal climate variability. Whiskers show *likely ranges*. [WGI SPM A.2.2, WGI Figure SPM.1, WGI Figure SPM.2, WGI TS2.2, WGI 2.1; WGIII Figure SPM.1, WGIII A.III.II.2.5.1]

Average annual GHG emissions during 2010–2019 were higher than in any previous decade, but the rate of growth between 2010 and 2019 (1.3% yr⁻¹) was lower than that between 2000 and 2009 (2.1% yr⁻¹)⁶⁹. Historical cumulative net CO₂ emissions from 1850 to 2019 were 2400 ±240 GtCO₂. Of these, more than half (58%) occurred between 1850 and 1989 [1400 ±195 GtCO₂], and about 42% between 1990 and 2019 [1000 ±90 GtCO₂]. Global net anthropogenic GHG emissions have been estimated to be 59±6.6 GtCO₂-eq in 2019, about 12% (6.5 GtCO₂-eq) higher than in 2010 and 54% (21 GtCO₂-eq) higher than in 1990. By 2019, the largest growth in gross emissions occurred in CO₂ from fossil fuels and industry (CO₂-FFI) followed by CH₄, whereas the highest relative growth occurred in fluorinated gases (F-gases), starting from low levels in 1990. (*high confidence*) {WGIII SPM B.1.1, WGIII SPM B.1.2, WGIII SPM B.1.3, WGIII Figure SPM.1, WGIII Figure SPM.2}

Regional contributions to global human-caused GHG emissions continue to differ widely. Historical contributions of CO₂ emissions vary substantially across regions in terms of total magnitude, but also in terms of contributions to CO₂-FFI (1650 ± 73 GtCO₂-eq) and net CO₂-LULUCF (760 ± 220 GtCO₂-eq) emissions (Figure 2.2). Variations in regional and national per capita emissions partly reflect different development stages, but they also vary widely at similar income levels. Average per capita net anthropogenic GHG emissions in 2019 ranged from 2.6 tCO₂-eq to 19 tCO₂-eq across regions (Figure 2.2). Least Developed Countries (LDCs) and Small Island Developing States (SIDS) have much lower per capita emissions (1.7 tCO₂-eq and 4.6 tCO₂-eq, respectively) than the global average (6.9 tCO₂-eq), excluding CO₂-LULUCF. Around 48% of the global population in 2019 lives in countries emitting on average more than 6 tCO₂-eq per capita, 35% of the global population live in countries emitting more than 9 tCO₂-eq per capita⁷⁰ (excluding CO₂-LULUCF) while another 41% live in countries emitting less than 3 tCO₂-eq per capita. A substantial share of the population in these low-emitting countries lack access to modern energy services. (*high confidence*) {WGIII SPM B.3, WGIII SPM B.3.1, WGIII SPM B.3.2, WGIII SPM B.3.3}

Net GHG emissions have increased since 2010 across all major sectors (*high confidence*). In 2019, approximately 34% (20 GtCO₂-eq) of net global GHG emissions came from the energy sector, 24% (14 GtCO₂-eq) from industry, 22% (13 GtCO₂-eq) from AFOLU, 15% (8.7 GtCO₂-eq) from transport and 6% (3.3 GtCO₂-eq) from buildings⁷¹ (*high confidence*). Average annual GHG emissions growth between

2010 and 2019 slowed compared to the previous decade in energy supply (from 2.3% to 1.0%) and industry (from 3.4% to 1.4%) but remained roughly constant at about 2% yr⁻¹ in the transport sector (*high confidence*). About half of total net AFOLU emissions are from CO₂ LULUCF, predominantly from deforestation (*medium confidence*). Land overall constituted a net sink of -6.6 (±4.6) GtCO₂ yr⁻¹ for the period 2010–2019⁷² (*medium confidence*). {WGIII SPM B.2, WGIII SPM B.2.1, WGIII SPM B.2.2, WGIII TS 5.6.1}

Human-caused climate change is a consequence of more than a century of net GHG emissions from energy use, land-use and land use change, lifestyle and patterns of consumption, and production. Emissions reductions in CO₂ from fossil fuels and industrial processes (CO₂-FFI), due to improvements in energy intensity of GDP and carbon intensity of energy, have been less than emissions increases from rising global activity levels in industry, energy supply, transport, agriculture and buildings. The 10% of households with the highest per capita emissions contribute 34–45% of global consumption-based household GHG emissions, while the middle 40% contribute 40–53%, and the bottom 50% contribute 13–15%. An increasing share of emissions can be attributed to urban areas (a rise from about 62% to 67–72% of the global share between 2015 and 2020). The drivers of urban GHG emissions⁷³ are complex and include population size, income, state of urbanisation and urban form. (*high confidence*) {WGIII SPM B.2, WGIII SPM B.2.3, WGIII SPM B.3.4, WGIII SPM D.1.1}

⁶⁹ GHG emission metrics are used to express emissions of different GHGs in a common unit. Aggregated GHG emissions in this report are stated in CO₂-equivalents (CO₂-eq) using the Global Warming Potential with a time horizon of 100 years (GWP100) with values based on the contribution of Working Group I to the AR6. The AR6 WGI and WGIII reports contain updated emission metric values, evaluations of different metrics with regard to mitigation objectives, and assess new approaches to aggregating gases. The choice of metric depends on the purpose of the analysis and all GHG emission metrics have limitations and uncertainties, given that they simplify the complexity of the physical climate system and its response to past and future GHG emissions. {WGI SPM D.1.8, WGI 7.6; WGIII SPM B.1, WGIII Cross-Chapter Box 2.2} (Annex I: Glossary)

⁷⁰ Territorial emissions

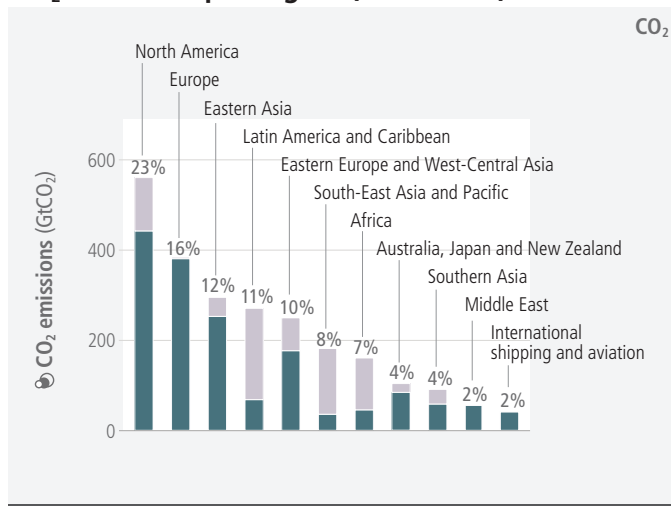
⁷¹ GHG emission levels are rounded to two significant digits; as a consequence, small differences in sums due to rounding may occur. {WGIII SPM footnote 8}

⁷² Comprising a gross sink of -12.5 (±3.2) GtCO₂ yr⁻¹ resulting from responses of all land to both anthropogenic environmental change and natural climate variability, and net anthropogenic CO₂-LULUCF emissions +5.9 (±4.1) GtCO₂ yr⁻¹ based on book-keeping models. {WGIII SPM Footnote 14}

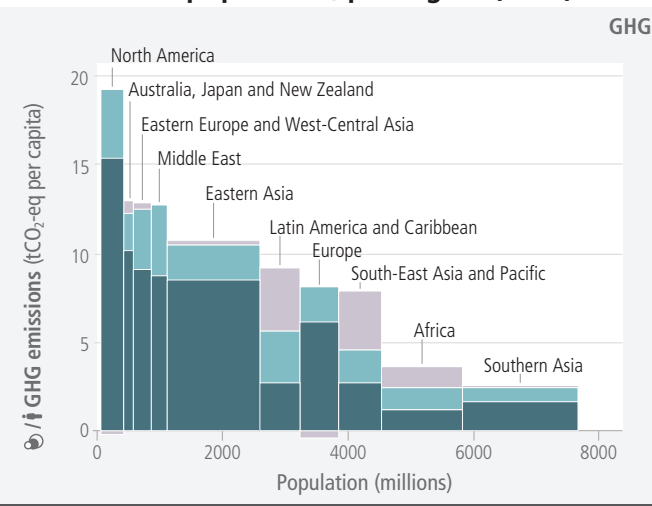
⁷³ This estimate is based on consumption-based accounting, including both direct emissions from within urban areas, and indirect emissions from outside urban areas related to the production of electricity, goods and services consumed in cities. These estimates include all CO₂ and CH₄ emission categories except for aviation and marine bunker fuels, land-use change, forestry and agriculture. {WGIII SPM footnote 15}

Emissions have grown in most regions but are distributed unevenly, both in the present day and cumulatively since 1850

a) Historical cumulative net anthropogenic CO₂ emissions per region (1850–2019)



b) Net anthropogenic GHG emissions per capita and for total population, per region (2019)



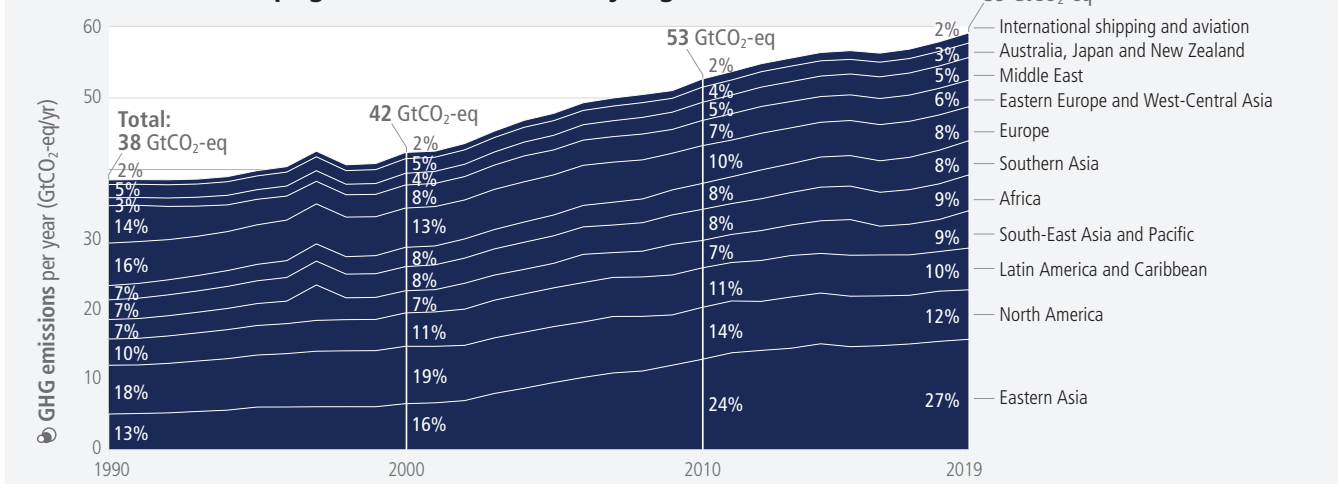
Key

Timeframes represented in these graphs



- Net CO₂ from land use, land use change, forestry (CO₂LULUCF)
- Other GHG emissions
- Fossil fuel and industry (CO₂FFI)
- All GHG emissions

c) Global net anthropogenic GHG emissions by region (1990–2019)



d) Regional indicators (2019) and regional production vs consumption accounting (2018)

	Africa	Australia, Japan, New Zealand	Eastern Asia	Eastern Europe, West-Central Asia	Europe	Latin America and Caribbean	Middle East	North America	South-East Asia and Pacific	Southern Asia
Population (million persons, 2019)	1292	157	1471	291	620	646	252	366	674	1836
GDP per capita (USD1000 _{PPP} 2017 per person) ¹	5.0	43	17	20	43	15	20	61	12	6.2
Net GHG 2019² (production basis)										
GHG emissions intensity (tCO ₂ -eq / USD1000 _{PPP} 2017)	0.78	0.30	0.62	0.64	0.18	0.61	0.64	0.31	0.65	0.42
GHG per capita (tCO ₂ -eq per person)	3.9	13	11	13	7.8	9.2	13	19	7.9	2.6
CO₂FFI, 2018, per person										
Production-based emissions (tCO ₂ FFI per person, based on 2018 data)	1.2	10	8.4	9.2	6.5	2.8	8.7	16	2.6	1.6
Consumption-based emissions (tCO ₂ FFI per person, based on 2018 data)	0.84	11	6.7	6.2	7.8	2.8	7.6	17	2.5	1.5

¹ GDP per capita in 2019 in USD2017 currency purchasing power basis.

² Includes CO₂FFI, CO₂LULUCF and Other GHGs, excluding international aviation and shipping.

The regional groupings used in this figure are for statistical purposes only and are described in WGIII Annex II, Part I.

Figure 2.2: Regional GHG emissions, and the regional proportion of total cumulative production-based CO₂ emissions from 1850 to 2019. Panel (a) shows the share of historical cumulative net anthropogenic CO₂ emissions per region from 1850 to 2019 in GtCO₂. This includes CO₂-FFI and CO₂-LULUCF. Other GHG emissions are not included. CO₂-LULUCF emissions are subject to high uncertainties, reflected by a global uncertainty estimate of ±70% (90% confidence interval). Panel (b) shows the distribution of regional GHG emissions in tonnes CO₂-eq per capita by region in 2019. GHG emissions are categorised into: CO₂-FFI; net CO₂-LULUCF; and other GHG emissions (CH₄, N₂O, fluorinated gases, expressed in CO₂-eq using GWP100-AR6). The height of each rectangle shows per capita emissions, the width shows the population of the region, so that the area of the rectangles refers to the total emissions for each region. Emissions from international aviation and shipping are not included. In the case of two regions, the area for CO₂-LULUCF is below the axis, indicating net CO₂ removals rather than emissions. Panel (c) shows global net anthropogenic GHG emissions by region (in GtCO₂-eq yr⁻¹ (GWP100-AR6)) for the time period 1990–2019. Percentage values refer to the contribution of each region to total GHG emissions in each respective time period. The single-year peak of emissions in 1997 was due to higher CO₂-LULUCF emissions from a forest and peat fire event in South East Asia. Regions are as grouped in Annex II of WGIII. Panel (d) shows population, gross domestic product (GDP) per person, emission indicators by region in 2019 for total GHG per person, and total GHG emissions intensity, together with production-based and consumption-based CO₂-FFI data, which is assessed in this report up to 2018. Consumption-based emissions are emissions released to the atmosphere in order to generate the goods and services consumed by a certain entity (e.g., region). Emissions from international aviation and shipping are not included. {WGIII Figure SPM.2}

2.1.2. Observed Climate System Changes and Impacts to Date

It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred (Table 2.1). 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. It is *very likely* that GHG emissions were the main driver⁷⁴ of tropospheric warming and *extremely likely* that human-caused stratospheric ozone depletion was the main driver of stratospheric cooling between 1979 and the mid-1990s. It is *virtually certain* that the global upper ocean (0–700m) has warmed since the 1970s and *extremely likely* that human influence is the main driver. Ocean warming accounted for 91% of the heating in the climate system, with land warming, ice loss and atmospheric warming accounting for about 5%, 3% and 1%, respectively (*high confidence*). Global mean sea level increased by 0.20 [0.15 to 0.25] m between 1901 and 2018. The average rate of sea level rise was 1.3 [0.6 to 2.1] mm yr⁻¹ between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm yr⁻¹ between 1971 and 2006, and further increasing to 3.7 [3.2 to –4.2] mm yr⁻¹ between 2006 and 2018 (*high confidence*). Human influence was *very likely* the main driver of these increases since at least 1971 (Figure 3.4). Human influence is *very likely* the main driver of the global retreat of glaciers since the 1990s and the decrease in Arctic sea ice area between 1979–1988 and 2010–2019. Human influence has also *very likely* contributed to decreased Northern Hemisphere spring snow cover and surface melting of the Greenland ice sheet. It is *virtually certain* that human-caused CO₂ emissions are the main driver of current global acidification of the surface open ocean. {WGI SPM A.1, WGI SPM A.1.3, WGI SPM A.1.5, WGI SPM A.1.6, WGI SPM A.1.7, WGI SPM A.2, WGI SPM A.4.2; SROCC SPM A.1, SROCC SPM A.2}

Human-caused climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since AR5 (Figure 2.3). It is *virtually certain* that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s (Figure 2.3), while cold extremes (including cold waves) have become less frequent and less severe, with *high confidence* that human-caused climate change is the main driver of these changes. Marine heatwaves have approximately doubled

in frequency since the 1980s (*high confidence*), and human influence has *very likely* contributed to most of them since at least 2006. The frequency and intensity of heavy precipitation events have increased since the 1950s over most land areas for which observational data are sufficient for trend analysis (*high confidence*), and human-caused climate change is *likely* the main driver (Figure 2.3). Human-caused climate change has contributed to increases in agricultural and ecological droughts in some regions due to increased land evapotranspiration (*medium confidence*) (Figure 2.3). It is *likely* that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades. {WGI SPM A.3, WGI SPM A.3.1, WGI SPM A.3.2; WGI SPM A.3.4; SRCCL SPM A.2.2; SROCC SPM A.2}







Climate change has caused substantial damages, and increasingly irreversible⁷⁵ losses, in terrestrial, freshwater, cryospheric and coastal and open ocean ecosystems (*high confidence*). The extent and magnitude of climate change impacts are larger than estimated in previous assessments (*high confidence*). Approximately half of the species assessed globally have shifted polewards or, on land, also to higher elevations (*very high confidence*). Biological responses including changes in geographic placement and shifting seasonal timing are often not sufficient to cope with recent climate change (*very high confidence*). Hundreds of local losses of species have been driven by increases in the magnitude of heat extremes (*high confidence*) and mass mortality events on land and in the ocean (*very high confidence*). Impacts on some ecosystems are approaching irreversibility such as the impacts of hydrological changes resulting from the retreat of glaciers, or the changes in some mountain (*medium confidence*) and Arctic ecosystems driven by permafrost thaw (*high confidence*). Impacts in ecosystems from slow-onset processes such as ocean acidification, sea level rise or regional decreases in precipitation have also been attributed to human-caused climate change (*high confidence*). Climate change has contributed to desertification and exacerbated land degradation, particularly in low lying coastal areas, river deltas, drylands and in permafrost areas (*high confidence*). Nearly 50% of coastal wetlands have been lost over the last 100 years, as a result of the combined effects of localised human pressures, sea level rise, warming and extreme climate events (*high confidence*). {WGII SPM B.1.1, WGII SPM B.1.2, WGII Figure SPM.2.A, WGII TS.B.1; SRCCL SPM A.1.5, SRCCL SPM A.2, SRCCL SPM A.2.6, SRCCL Figure SPM.1; SROCC SPM A.6.1, SROCC SPM A.6.4, SROCC SPM A.7}

⁷⁴ 'Main driver' means responsible for more than 50% of the change. {WGI SPM footnote 12}

⁷⁵ See Annex I: Glossary.

Table 2.1: Assessment of observed changes in large-scale indicators of mean climate across climate system components, and their attribution to human influence. The colour coding indicates the assessed confidence in / likelihood⁷⁶ of the observed change and the human contribution as a driver or main driver (specified in that case) where available (see colour key). Otherwise, explanatory text is provided. {WGI Table TS.1}

Change in indicator	Observed change assessment	Human contribution assessment
Atmosphere and water cycle	Warming of global mean surface air temperature since 1850-1900	<i>likely</i> range of human contribution ((0.8-1.3°C)) encompasses the very likely range of observed warming ((0.9-1.2°C))
	Warming of the troposphere since 1979	Main driver
	Cooling of the lower stratosphere since the mid-20th century	Main driver 1979 - mid-1990s
	Large-scale precipitation and upper troposphere humidity changes since 1979	
	Expansion of the zonal mean Hadley Circulation since the 1980s	Southern Hemisphere
Ocean	Ocean heat content increase since the 1970s	Main driver
	Salinity changes since the mid-20th century	
	Global mean sea level rise since 1970	Main driver
Cryosphere	Arctic sea ice loss since 1979	Main driver
	Reduction in Northern Hemisphere springtime snow cover since 1950	
	Greenland ice sheet mass loss since 1990s	
	Antarctic ice sheet mass loss since 1990s	<i>Limited evidence & medium agreement</i>
	Retreat of glaciers	Main driver
Carbon cycle	Increased amplitude of the seasonal cycle of atmospheric CO ₂ since the early 1960s	Main driver
	Acidification of the global surface ocean	Main driver
Land climate	Mean surface air temperature over land (about 40% larger than global mean warming)	Main driver
Synthesis	Warming of the global climate system since preindustrial times	

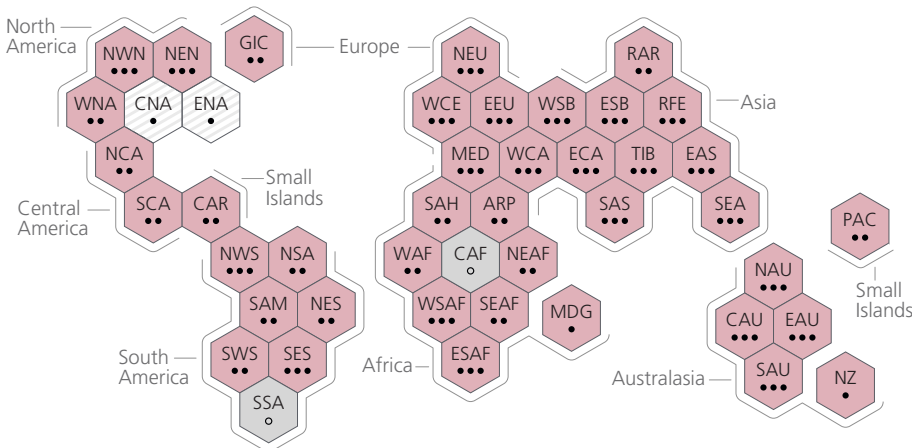
Key						
	medium confidence	likely / high confidence	very likely	extremely likely	virtually certain	fact

⁷⁶ Based on scientific understanding, key findings can be formulated as statements of fact or associated with an assessed level of confidence indicated using the IPCC calibrated language.

Climate change has impacted human and natural systems across the world with those who have generally least contributed to climate change being most vulnerable

a) Synthesis of assessment of observed change in hot extremes, heavy precipitation and drought, and confidence in human contribution to the observed changes in the world's regions

Hot extremes ← including heatwaves



Dimension of Risk: Hazard

Key

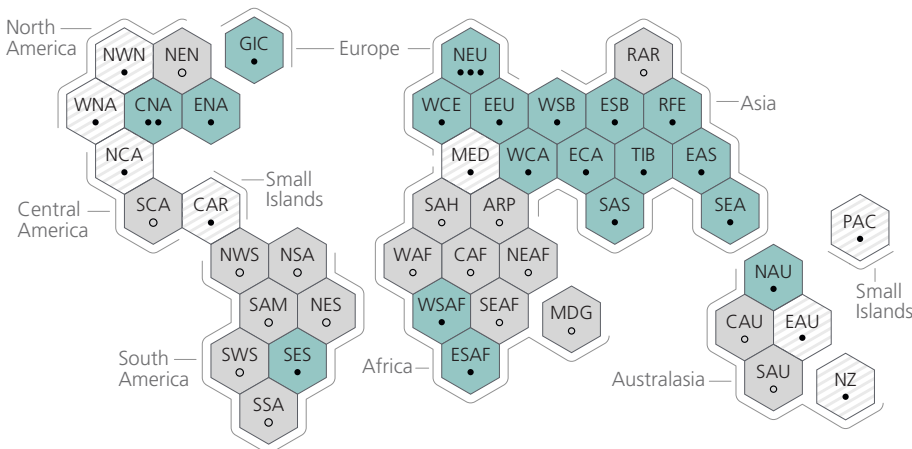
Type of observed change since the 1950s

- Increase (Red hexagon)
- Decrease (Blue hexagon)
- Limited data and/or literature (Grey hexagon)
- Low agreement in the type of change (White hexagon with diagonal lines)

Confidence in human contribution to the observed change

- High (3 dots)
- Medium (2 dots)
- Low due to limited agreement (1 dot)
- Low due to limited evidence (0 dots)

Heavy precipitation

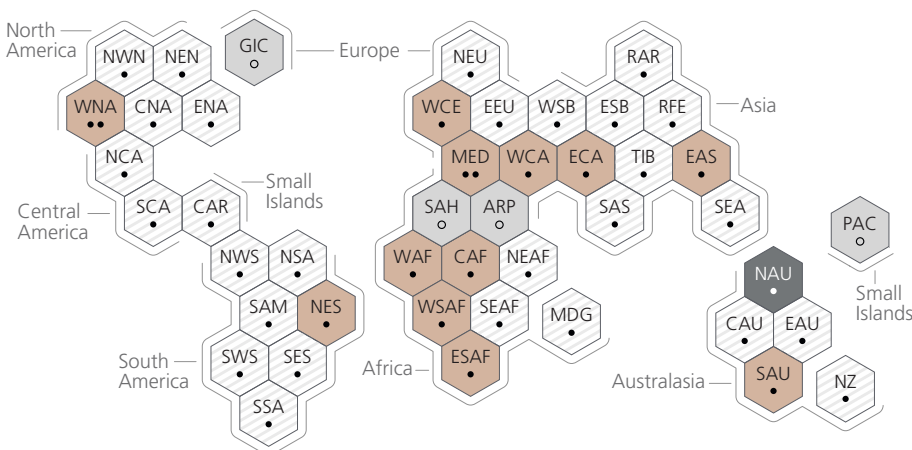


Each hexagon corresponds to a region

North-Western North America

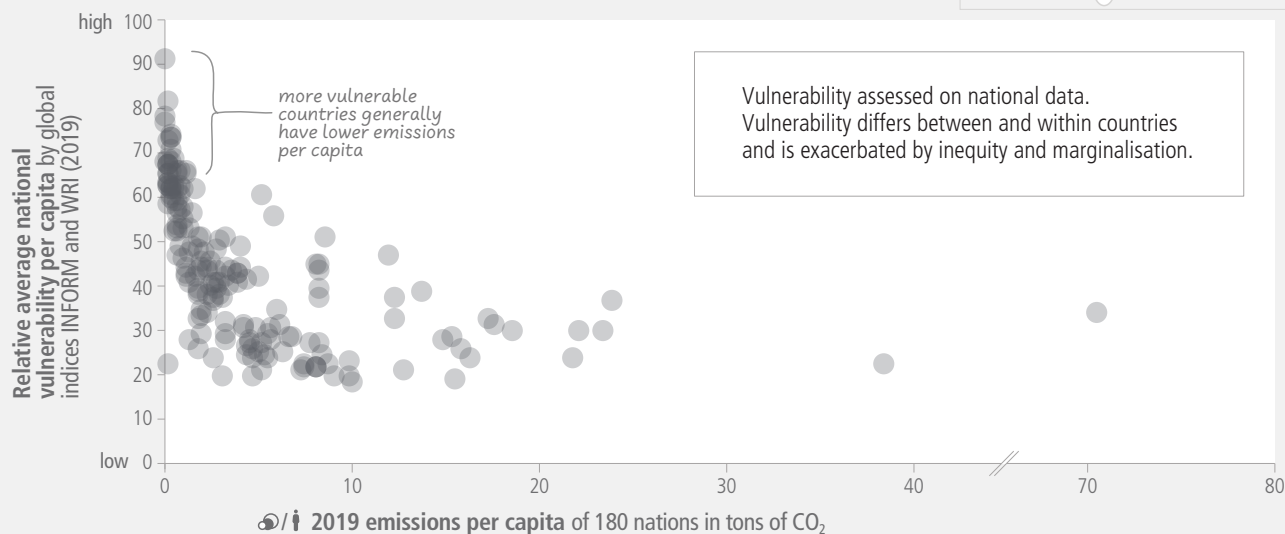
IPCC AR6 WGI reference regions:
North America: **NWN** (North-Western North America), **NEN** (North-Eastern North America), **WNA** (Western North America), **ENA** (Eastern North America), **Central America:** **NCA** (Northern Central America), **SCA** (Southern Central America), **CAR** (Caribbean), **South America:** **NWS** (North-Western South America), **NSA** (Northern South America), **NES** (North-Eastern South America), **SAM** (South American Monsoon), **SWS** (South-Western South America), **SES** (South-Eastern South America), **SSA** (Southern South America), **Europe:** **GIC** (Greenland/Iceland), **NEU** (Northern Europe), **WCE** (Western and Central Europe), **EEU** (Eastern Europe), **MED** (Mediterranean), **Africa:** **MED** (Mediterranean), **SAH** (Sahara), **WAF** (Western Africa), **CAF** (Central Africa), **NEAF** (North Eastern Africa), **SEAF** (South Eastern Africa), **WSAF** (West Southern Africa), **ESAF** (East Southern Africa), **MDG** (Madagascar), **Asia:** **RAR** (Russian Arctic), **WSB** (West Siberia), **ESB** (East Siberia), **RFE** (Russian Far East), **WCA** (West Central Asia), **ECA** (East Central Asia), **TIB** (Tibetan Plateau), **EAS** (East Asia), **ARP** (Arabian Peninsula), **SAS** (South Asia), **SEA** (South East Asia), **Australasia:** **NAU** (Northern Australia), **CAU** (Central Australia), **EAU** (Eastern Australia), **SAU** (Southern Australia), **NZ** (New Zealand), **Small Islands:** **CAR** (Caribbean), **PAC** (Pacific Small Islands)

Agricultural and ecological drought



b) Vulnerability of population & per capita emissions per country in 2019

Dimension of Risk: Vulnerability



c) Observed impacts and related losses and damages of climate change

		Global	Africa	Asia	Australasia	Central & South America	Europe	North America	Small Islands
HUMAN SYSTEMS	Water availability and food production	Physical water availability	•••	••	•••	•••	•••	•••	•••
	Agriculture/crop production	•••	•••	•••	•••	•••	•••	•••	•••
	Animal and livestock health and productivity	•••	••	••	•••	•••	•••	•••	•••
	Fisheries yields and aquaculture production	•••	••	••	•••	•••	•••	•••	•••
	Health and wellbeing	Infectious diseases	•••	•••	••	••	••	•••	•••
Heat, malnutrition and harm from wildfire	•••	•••	•••	••	••	••	•••	•••	
Mental health	•••	-	•••	••	/	•••	•••	-	
Displacement	•••	•••	•••	/	••	••	•••	••	
Cities, settlements and infrastructure	Inland flooding and associated damages	•••	••	••	••	••	••	•••	•••
	Flood/storm induced damages in coastal areas	•••	••	•••	•••	••	••	•••	•••
	Damages to infrastructure	•••	••	••	•••	••	••	•••	•••
	Damages to key economic sectors	•••	•••	••	•••	••	••	•••	•••
ECOSYSTEMS	Changes in ecosystem structure	Terrestrial	•••	•••	•••	•••	•••	•••	•••
	Freshwater	•••	•••	••	-	•••	•••	•••	•••
	Ocean	•••	•••	•••	•••	•••	•••	•••	•••
	Species range shifts	Terrestrial	•••	•••	••	•••	•••	•••	•••
	Freshwater	•••	-	••	-	•••	•••	•••	•••
	Ocean	•••	•••	-	•••	•••	•••	•••	•••
	Changes in seasonal timing (phenology)	Terrestrial	•••	-	••	•••	-	•••	•••
	Freshwater	•••	••	••	-	-	•••	•••	-
	Ocean	•••	••	••	••	••	•••	•••	••

Dimension of Risk: Impact

Key

Increased climate impacts

HUMAN SYSTEMS

- Adverse impacts
- Adverse and positive impacts

ECOSYSTEMS

- Climate-driven changes observed, no assessment of impact direction

Confidence in attribution to climate change

- High or very high
- Medium
- Low
- Evidence limited, insufficient
- / Not assessed

Figure 2.3: Both vulnerability to current climate extremes and historical contribution to climate change are highly heterogeneous with many of those who have least contributed to climate change to date being most vulnerable to its impacts. Panel (a) The IPCC AR6 WGI inhabited regions are displayed as hexagons with identical size in their approximate geographical location (see legend for regional acronyms). All assessments are made for each region as a whole and for the 1950s to the present. Assessments made on different time scales or more local spatial scales might differ from what is shown in the figure. The colours in each panel represent the four outcomes of the assessment on observed changes. Striped hexagons (white and light-grey) are used where there is *low agreement* in the type of change for the region as a whole, and grey hexagons are used when there is limited data and/or literature that prevents an assessment of the region as a whole. Other colours indicate at least *medium confidence* in the observed change. The confidence level for the human influence on these observed changes is based on assessing trend detection and attribution and event attribution literature, and it is indicated by the number of dots: three dots for *high confidence*, two dots for *medium confidence* and one dot for *low confidence* (single, filled dot: *limited agreement*; single, empty dot: *limited evidence*). For hot extremes, the evidence is mostly drawn from changes in metrics based on daily maximum temperatures; regional studies using other indices (heatwave duration, frequency and intensity) are used in addition. For heavy precipitation, the evidence is mostly drawn from changes in indices based on one-day or five-day precipitation amounts using global and regional studies. Agricultural and ecological droughts are assessed based on observed and simulated changes in total column soil moisture, complemented by evidence on changes in surface soil moisture, water balance (precipitation minus evapotranspiration) and indices driven by precipitation and atmospheric evaporative demand. Panel (b) shows the average level of vulnerability amongst a country's population against 2019 CO₂-FFI emissions per-capita per country for the 180 countries for which both sets of metrics are available. Vulnerability information is based on two global indicator systems, namely INFORM and World Risk Index. Countries with a relatively low average vulnerability often have groups with high vulnerability within their population and vice versa. The underlying data includes, for example, information on poverty, inequality, health care infrastructure or insurance coverage. Panel (c) Observed impacts on ecosystems and human systems attributed to climate change at global and regional scales. Global assessments focus on large studies, multi-species, meta-analyses and large reviews. Regional assessments consider evidence on impacts across an entire region and do not focus on any country in particular. For human systems, the direction of impacts is assessed and both adverse and positive impacts have been observed e.g., adverse impacts in one area or food item may occur with positive impacts in another area or food item (for more details and methodology see WGII SMTS.1). Physical water availability includes balance of water available from various sources including ground water, water quality and demand for water. Global mental health and displacement assessments reflect only assessed regions. Confidence levels reflect the assessment of attribution of the observed impact to climate change. {WGI Figure SPM.3, Table TS.5, Interactive Atlas; WGII Figure SPM.2, WGII SMTS.1, WGII 8.3.1, Figure 8.5; ; WGIII 2.2.3}

Climate change has reduced food security and affected water security due to warming, changing precipitation patterns, reduction and loss of cryospheric elements, and greater frequency and intensity of climatic extremes, thereby hindering efforts to meet Sustainable Development Goals (*high confidence*). Although overall agricultural productivity has increased, climate change has slowed this growth in agricultural productivity over the past 50 years globally (*medium confidence*), with related negative crop yield impacts mainly recorded in mid- and low latitude regions, and some positive impacts in some high latitude regions (*high confidence*). Ocean warming in the 20th century and beyond has contributed to an overall decrease in maximum catch potential (*medium confidence*), compounding the impacts from overfishing for some fish stocks (*high confidence*). Ocean warming and ocean acidification have adversely affected food production from shellfish aquaculture and fisheries in some oceanic regions (*high confidence*). Current levels of global warming are associated with moderate risks from increased dryland water scarcity (*high confidence*). Roughly half of the world's population currently experiences severe water scarcity for at least some part of the year due to a combination of climatic and non-climatic drivers (*medium confidence*) (Figure 2.3). Unsustainable agricultural expansion, driven in part by unbalanced diets⁷⁷, increases ecosystem and human vulnerability and leads to competition for land and/or water resources (*high confidence*). Increasing weather and climate extreme events have exposed millions of people to acute food insecurity⁷⁸ and reduced water security, with the largest impacts observed in many locations and/or communities in Africa, Asia, Central and South America, LDCs, Small Islands and the Arctic, and for small-scale food producers, low-income households and Indigenous Peoples globally (*high confidence*). {WGII SPM B.1.3, WGII SPM.B.2.3, WGII Figure SPM.2, WGII TS B.2.3, WGII TS Figure TS. 6; SRCL SPM A.2.8, SRCL SPM A.5.3; SROCC SPM A.5.4, SROCC SPM A.7.1, SROCC SPM A.8.1, SROCC Figure SPM.2}

In urban settings, climate change has caused adverse impacts on human health, livelihoods and key infrastructure (*high confidence*). Hot extremes including heatwaves have intensified in cities (*high confidence*), where they have also worsened air pollution events (*medium confidence*) and limited functioning of key infrastructure (*high confidence*). Urban infrastructure, including transportation, water, sanitation and energy systems have been compromised by extreme and slow-onset events⁷⁹, with resulting economic losses, disruptions of services and impacts to well-being (*high confidence*). Observed impacts are concentrated amongst economically and socially marginalised urban residents, e.g., those living in informal settlements (*high confidence*). Cities intensify human-caused warming locally (*very high confidence*), while urbanisation also increases mean and heavy precipitation over and/or downwind of cities (*medium confidence*) and resulting runoff intensity (*high confidence*). {WGI SPM C.2.6; WGII SPM B.1.5, WGII Figure TS.9, WGII 6 E5}

Climate change has adversely affected human physical health globally and mental health in assessed regions (*very high confidence*), and is contributing to humanitarian crises where climate hazards interact with high vulnerability (*high confidence*). In all regions increases in extreme heat events have resulted in human mortality and morbidity (*very high confidence*). The occurrence of climate-related food-borne and water-borne diseases has increased (*very high confidence*). The incidence of vector-borne diseases has increased from range expansion and/or increased reproduction of disease vectors (*high confidence*). Animal and human diseases, including zoonoses, are emerging in new areas (*high confidence*). In assessed regions, some mental health challenges are associated with increasing temperatures (*high confidence*), trauma from extreme events (*very high confidence*), and loss of livelihoods and culture

⁷⁷ Balanced diets feature plant-based foods, such as those based on coarse grains, legumes fruits and vegetables, nuts and seeds, and animal-source foods produced in resilient, sustainable and low-GHG emissions systems, as described in SRCL. {WGII SPM Footnote 32}

⁷⁸ Acute food insecurity can occur at any time with a severity that threatens lives, livelihoods or both, regardless of the causes, context or duration, as a result of shocks risking determinants of food security and nutrition, and is used to assess the need for humanitarian action. {WGII SPM, footnote 30}

⁷⁹ Slow-onset events are described among the climatic-impact drivers of the AR6 WGI and refer to the risks and impacts associated with e.g., increasing temperature means, desertification, decreasing precipitation, loss of biodiversity, land and forest degradation, glacial retreat and related impacts, ocean acidification, sea level rise and salinization. {WGII SPM footnote 29}

(*high confidence*) (Figure 2.3). Climate change impacts on health are mediated through natural and human systems, including economic and social conditions and disruptions (*high confidence*). Climate and weather extremes are increasingly driving displacement in Africa, Asia, North America (*high confidence*), and Central and South America (*medium confidence*) (Figure 2.3), with small island states in the Caribbean and South Pacific being disproportionately affected relative to their small population size (*high confidence*). Through displacement and involuntary migration from extreme weather and climate events, climate change has generated and perpetuated vulnerability (*medium confidence*). {WGII SPM B.1.4, WGII SPM B.1.7}

Human influence has likely increased the chance of compound extreme events⁸⁰ since the 1950s. Concurrent and repeated climate hazards have occurred in all regions, increasing impacts and risks to health, ecosystems, infrastructure, livelihoods and food (*high confidence*). Compound extreme events include increases in the frequency of concurrent heatwaves and droughts (*high confidence*); fire weather in some regions (*medium confidence*); and compound flooding in some locations (*medium confidence*). Multiple risks interact, generating new sources of vulnerability to climate hazards, and compounding overall risk (*high confidence*). Compound climate hazards can overwhelm adaptive capacity and substantially increase damage (*high confidence*). {WGI SPM A.3.5; WGII SPM B.5.1, WGII TS.C.11.3}

Economic impacts attributable to climate change are increasingly affecting peoples' livelihoods and are causing economic and societal impacts across national boundaries (*high confidence*). Economic damages from climate change have been detected in climate-exposed sectors, with regional effects to agriculture, forestry, fishery, energy, and tourism, and through outdoor labour productivity (*high confidence*) with some exceptions of positive impacts in regions with low energy demand and comparative advantages in agricultural markets and tourism (*high confidence*). Individual livelihoods have been affected through changes in agricultural productivity, impacts on human health and food security, destruction of homes and infrastructure, and loss of property and income, with adverse effects on gender and social equity (*high confidence*). Tropical cyclones have reduced economic growth in the short-term (*high confidence*). Event attribution studies and physical understanding indicate that human-caused climate change increases heavy precipitation associated with tropical cyclones (*high confidence*). Wildfires in many regions have affected built assets, economic activity, and health (*medium to high confidence*). In cities and settlements, climate impacts to key infrastructure are leading to losses and damages across water and food systems, and affect economic activity, with impacts extending beyond the area directly impacted by the climate hazard (*high confidence*). {WGI SPM A.3.4; WGII SPM B.1.6, WGII SPM B.5.2, WGII SPM B.5.3}

Climate change has caused widespread adverse impacts and related losses and damages to nature and people (*high confidence*). Losses and damages are unequally distributed across systems, regions and sectors (*high confidence*). Cultural losses, related

to tangible and intangible heritage, threaten adaptive capacity and may result in irrevocable losses of sense of belonging, valued cultural practices, identity and home, particularly for Indigenous Peoples and those more directly reliant on the environment for subsistence (*medium confidence*). For example, changes in snow cover, lake and river ice, and permafrost in many Arctic regions, are harming the livelihoods and cultural identity of Arctic residents including Indigenous populations (*high confidence*). Infrastructure, including transportation, water, sanitation and energy systems have been compromised by extreme and slow-onset events, with resulting economic losses, disruptions of services and impacts to well-being (*high confidence*). {WGII SPM B.1, WGII SPM B.1.2, WGII SPM B.1.5, WGII SPM C.3.5, WGII TS.B.1.6; SROCC SPM A.7.1}

Across sectors and regions, the most vulnerable people and systems have been disproportionately affected by the impacts of climate change (*high confidence*). LDCs and SIDS who have much lower per capita emissions (1.7 tCO₂-eq, 4.6 tCO₂-eq, respectively) than the global average (6.9 tCO₂-eq) excluding CO₂-LULUCF, also have high vulnerability to climatic hazards, with global hotspots of high human vulnerability observed in West-, Central- and East Africa, South Asia, Central and South America, SIDS and the Arctic (*high confidence*). Regions and people with considerable development constraints have high vulnerability to climatic hazards (*high confidence*). Vulnerability is higher in locations with poverty, governance challenges and limited access to basic services and resources, violent conflict and high levels of climate-sensitive livelihoods (e.g., smallholder farmers, pastoralists, fishing communities) (*high confidence*). Vulnerability at different spatial levels is exacerbated by inequity and marginalisation linked to gender, ethnicity, low income or combinations thereof (*high confidence*), especially for many Indigenous Peoples and local communities (*high confidence*). Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change (*high confidence*). Between 2010 and 2020, human mortality from floods, droughts and storms was 15 times higher in highly vulnerable regions, compared to regions with very low vulnerability (*high confidence*). In the Arctic and in some high mountain regions, negative impacts of cryosphere change have been especially felt among Indigenous Peoples (*high confidence*). Human and ecosystem vulnerability are interdependent (*high confidence*). Vulnerability of ecosystems and people to climate change differs substantially among and within regions (*very high confidence*), driven by patterns of intersecting socio-economic development, unsustainable ocean and land use, inequity, marginalisation, historical and ongoing patterns of inequity such as colonialism, and governance⁸¹ (*high confidence*). {WGII SPM B.1, WGII SPM B.2, WGII SPM B.2.4; WGIII SPM B.3.1; SROCC SPM A.7.1, SROCC SPM A.7.2}

⁸⁰ See Annex 1: Glossary.

⁸¹ Governance: 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. {WGII SPM Footnote 31}

2.2 Responses Undertaken to Date

International climate agreements, rising national ambitions for climate action, along with rising public awareness are accelerating efforts to address climate change at multiple levels of governance. Mitigation policies have contributed to a decrease in global energy and carbon intensity, with several countries achieving GHG emission reductions for over a decade. Low-emission technologies are becoming more affordable, with many low or zero emissions options now available for energy, buildings, transport, and industry. Adaptation planning and implementation progress has generated multiple benefits, with effective adaptation options having the potential to reduce climate risks and contribute to sustainable development. Global tracked finance for mitigation and adaptation has seen an upward trend since AR5, but falls short of needs. (*high confidence*)

2.2.1. Global Policy Setting

The United Nations Framework Convention on Climate Change (UNFCCC), Kyoto Protocol, and Paris Agreement are supporting rising levels of national ambition and encouraging the development and implementation of climate policies at multiple levels of governance (*high confidence*). The Kyoto Protocol led to reduced emissions in some countries and was instrumental in building national and international capacity for GHG reporting, accounting and emissions markets (*high confidence*). The Paris Agreement, adopted under the UNFCCC, with near universal participation, has led to policy development and target-setting at national and sub-national levels, particularly in relation to mitigation but also for adaptation, as well as enhanced transparency of climate action and support (*medium confidence*). Nationally Determined Contributions (NDCs), required under the Paris Agreement, have required countries to articulate their priorities and ambition with respect to climate action. {WGII 17.4, WGII TS D.1.1; WGIII SPM B.5.1, WGIII SPM E.6}

Loss & Damage⁸² was formally recognized in 2013 through establishment of the Warsaw International Mechanism on Loss and Damage (WIM), and in 2015, Article 8 of the Paris Agreement provided a legal basis for the WIM. There is improved understanding of both economic and non-economic losses and damages, which is informing international climate policy and which has highlighted that losses and damages are not comprehensively addressed by current financial, governance and institutional arrangements, particularly in vulnerable developing countries (*high confidence*). {WGII SPM C.3.5, WGII Cross-Chapter Box LOSS}

Other recent global agreements that influence responses to climate change include the Sendai Framework for Disaster Risk Reduction (2015-2030), the finance-oriented Addis Ababa Action Agenda (2015) and the New Urban Agenda (2016), and the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (2016), among others. In addition, the 2030 Agenda for Sustainable Development, adopted in 2015 by UN member states, sets out 17 Sustainable Development Goals (SDGs) and seeks to align efforts globally to prioritise ending extreme poverty, protect the planet and promote more peaceful, prosperous and inclusive societies. If achieved, these agreements would reduce climate change, and the impacts on health, well-being, migration, and conflict, among others (*very high confidence*). {WGII TS.A.1, WGII 7 ES}

Since AR5, rising public awareness and an increasing diversity of actors, have overall helped accelerate political commitment and global efforts to address climate change (*medium*

confidence). Mass social movements have emerged as catalysing agents in some regions, often building on prior movements including Indigenous Peoples-led movements, youth movements, human rights movements, gender activism, and climate litigation, which is raising awareness and, in some cases, has influenced the outcome and ambition of climate governance (*medium confidence*). Engaging Indigenous Peoples and local communities using just-transition and rights-based decision-making approaches, implemented through collective and participatory decision-making processes has enabled deeper ambition and accelerated action in different ways, and at all scales, depending on national circumstances (*medium confidence*). The media helps shape the public discourse about climate change. This can usefully build public support to accelerate climate action (*medium evidence, high agreement*). In some instances, public discourses of media and organised counter movements have impeded climate action, exacerbating helplessness and disinformation and fuelling polarisation, with negative implications for climate action (*medium confidence*). {WGII SPM C.5.1, WGII SPM D.2, WGII TS.D.9, WGII TS.D.9.7, WGII TS.E.2.1, WGII 18.4; WGIII SPM D.3.3, WGIII SPM E.3.3, WGIII TS.6.1, WGIII 6.7, WGIII 13 ES, WGIII Box.13.7}

2.2.2. Mitigation Actions to Date

There has been a consistent expansion of policies and laws addressing mitigation since AR5 (*high confidence*). Climate governance supports mitigation by providing frameworks through which diverse actors interact, and a basis for policy development and implementation (*medium confidence*). Many regulatory and economic instruments have already been deployed successfully (*high confidence*). By 2020, laws primarily focussed on reducing GHG emissions existed in 56 countries covering 53% of global emissions (*medium confidence*). The application of diverse policy instruments for mitigation at the national and sub-national levels has grown consistently across a range of sectors (*high confidence*). Policy coverage is uneven across sectors and remains limited for emissions from agriculture, and from industrial materials and feedstocks (*high confidence*). {WGIII SPM B.5, WGIII SPM B.5.2, WGIII SPM E.3, WGIII SPM E.4}

Practical experience has informed economic instrument design and helped to improve predictability, environmental effectiveness, economic efficiency, alignment with distributional goals, and social acceptance (*high confidence*). Low-emission technological innovation is strengthened through the combination of technology-push policies, together with policies that create incentives for behaviour change and market opportunities (*high confidence*) (Section 4.8.3). Comprehensive and consistent policy packages have been found to be more effective

⁸² See Annex I: Glossary.

than single policies (*high confidence*). Combining mitigation with policies to shift development pathways, policies that induce lifestyle or behaviour changes, for example, measures promoting walkable urban areas combined with electrification and renewable energy can create health co-benefits from cleaner air and enhanced active mobility (*high confidence*). Climate governance enables mitigation by providing an overall direction, setting targets, mainstreaming climate action across policy domains and levels, based on national circumstances and in the context of international cooperation. Effective governance enhances regulatory certainty, creating specialised organisations and creating the context to mobilise finance (*medium confidence*). These functions can be promoted by climate-relevant laws, which are growing in number, or climate strategies, among others, based on national and sub-national context (*medium confidence*). Effective and equitable climate governance builds on engagement with civil society actors, political actors, businesses, youth, labour, media, Indigenous Peoples and local communities (*medium confidence*). {WGIII SPM E.2.2, WGIII SPM E.3, WGIII SPM E.3.1, WGIII SPM E.4.2, WGIII SPM E.4.3, WGIII SPM E.4.4}

The unit costs of several low-emission technologies, including solar, wind and lithium-ion batteries, have fallen consistently since 2010 (Figure 2.4). Design and process innovations in combination with the use of digital technologies have led to near-commercial availability of many low or zero emissions options in buildings, transport and industry. From 2010-2019, there have been sustained decreases in the unit costs of solar energy (by 85%), wind energy (by 55%), and lithium-ion batteries (by 85%), and large increases in their deployment, e.g., >10× for solar and >100× for electric vehicles (EVs), albeit varying widely across regions (Figure 2.4). Electricity from PV and wind is now cheaper than electricity from fossil sources in many regions, electric vehicles are increasingly competitive with internal combustion engines, and large-scale battery storage on electricity grids is increasingly viable. In comparison to modular small-unit size technologies, the empirical record shows that multiple large-scale mitigation technologies, with fewer opportunities for learning, have seen minimal cost reductions and their adoption has grown slowly. Maintaining emission-intensive systems may, in some regions and sectors, be more expensive than transitioning to low emission systems. (*high confidence*) {WGIII SPM B.4, WGIII SPM B.4.1, WGIII SPM C.4.2, WGIII SPM C.5.2, WGIII SPM C.7.2, WGIII SPM C.8, WGIII Figure SPM.3, WGIII Figure SPM.3}

For almost all basic materials – primary metals, building materials and chemicals – many low- to zero-GHG intensity production processes are at the pilot to near-commercial and in some cases commercial stage but they are not yet established industrial practice. Integrated design in construction and retrofit of buildings has led to increasing examples of zero energy or zero carbon buildings. Technological innovation made possible the widespread adoption of LED lighting. Digital technologies including sensors, the internet of things, robotics, and artificial intelligence can improve energy management in all sectors; they can increase energy efficiency, and promote the adoption of many low-emission technologies, including decentralised renewable energy, while creating economic opportunities. However, some of these climate change mitigation gains can be reduced or counterbalanced by growth in demand for goods and services due to the use of digital devices. Several mitigation options, notably solar energy, wind energy, electrification of urban systems, urban green infrastructure, energy efficiency, demand side management, improved forest- and crop/grassland management, and reduced food waste and loss, are technically viable, are becoming

increasingly cost effective and are generally supported by the public, and this enables expanded deployment in many regions. (*high confidence*) {WGIII SPM B.4.3, WGIII SPM C.5.2, WGIII SPM C.7.2, WGIII SPM E.1.1, WGIII TS.6.5}

The magnitude of global climate finance flows has increased and financing channels have broadened (*high confidence*). Annual tracked total financial flows for climate mitigation and adaptation increased by up to 60% between 2013/14 and 2019/20, but average growth has slowed since 2018 (*medium confidence*) and most climate finance stays within national borders (*high confidence*). Markets for green bonds, environmental, social and governance and sustainable finance products have expanded significantly since AR5 (*high confidence*). Investors, central banks, and financial regulators are driving increased awareness of climate risk to support climate policy development and implementation (*high confidence*). Accelerated international financial cooperation is a critical enabler of low-GHG and just transitions (*high confidence*). {WGIII SPM B.5.4, WGIII SPM E.5, WGIII TS.6.3, WGIII TS.6.4}

Economic instruments have been effective in reducing emissions, complemented by regulatory instruments mainly at the national and also sub-national and regional level (*high confidence*). By 2020, over 20% of global GHG emissions were covered by carbon taxes or emissions trading systems, although coverage and prices have been insufficient to achieve deep reductions (*medium confidence*). Equity and distributional impacts of carbon pricing instruments can be addressed by using revenue from carbon taxes or emissions trading to support low-income households, among other approaches (*high confidence*). The mix of policy instruments which reduced costs and stimulated adoption of solar energy, wind energy and lithium-ion batteries includes public R&D, funding for demonstration and pilot projects, and demand-pull instruments such as deployment subsidies to attain scale (*high confidence*) (Figure 2.4). {WGIII SPM B.4.1, WGIII SPM B.5.2, WGIII SPM E.4.2, WG III TS.3}

Mitigation actions, supported by policies, have contributed to a decrease in global energy and carbon intensity between 2010 and 2019, with a growing number of countries achieving absolute GHG emission reductions for more than a decade (*high confidence*). While global net GHG emissions have increased since 2010, global energy intensity (total primary energy per unit GDP) decreased by 2% yr⁻¹ between 2010 and 2019. Global carbon intensity (CO₂-FFI per unit primary energy) also decreased by 0.3% yr⁻¹, mainly due to fuel switching from coal to gas, reduced expansion of coal capacity, and increased use of renewables, and with large regional variations over the same period. In many countries, policies have enhanced energy efficiency, reduced rates of deforestation and accelerated technology deployment, leading to avoided and in some cases reduced or removed emissions (*high confidence*). At least 18 countries have sustained production-based CO₂ and GHG and consumption-based CO₂ absolute emission reductions for longer than 10 years since 2005 through energy supply decarbonization, energy efficiency gains, and energy demand reduction, which resulted from both policies and changes in economic structure (*high confidence*). Some countries have reduced production-based GHG emissions by a third or more since peaking, and some have achieved reduction rates of around 4% yr⁻¹ for several years consecutively (*high confidence*). Multiple lines of evidence suggest that mitigation policies have led to avoided global emissions of several GtCO₂-eq yr⁻¹ (*medium confidence*).

Renewable electricity generation is increasingly price-competitive and some sectors are electrifying

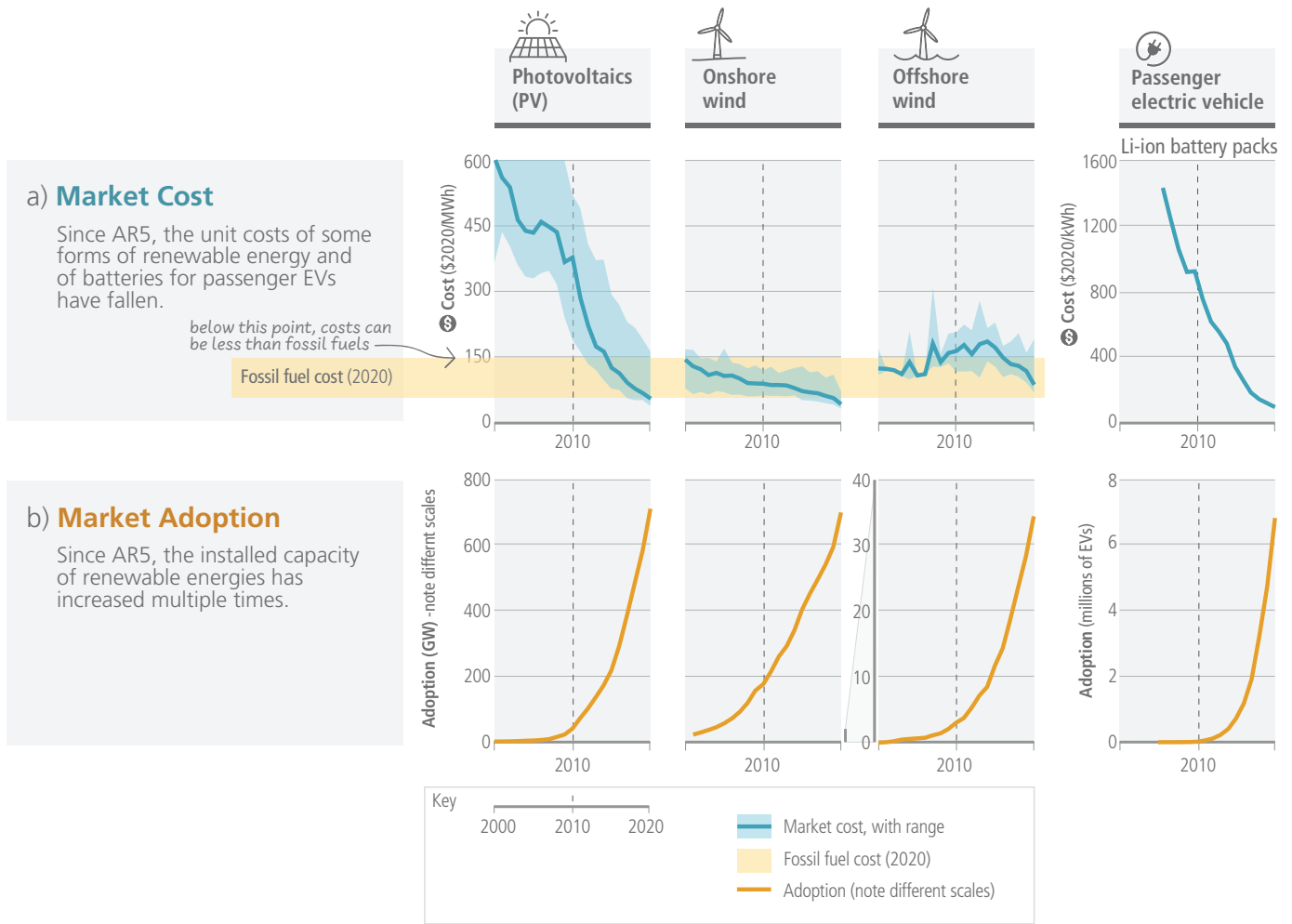


Figure 2.4: Unit cost reductions and use in some rapidly changing mitigation technologies. The **top panel (a)** shows global costs per unit of energy (USD per MWh) for some rapidly changing mitigation technologies. Solid blue lines indicate average unit cost in each year. Light blue shaded areas show the range between the 5th and 95th percentiles in each year. Yellow shading indicates the range of unit costs for new fossil fuel (coal and gas) power in 2020 (corresponding to USD 55 to 148 per MWh). In 2020, the levelised costs of energy (LCOE) of the three renewable energy technologies could compete with fossil fuels in many places. For batteries, costs shown are for 1 kWh of battery storage capacity; for the others, costs are LCOE, which includes installation, capital, operations, and maintenance costs per MWh of electricity produced. The literature uses LCOE because it allows consistent comparisons of cost trends across a diverse set of energy technologies to be made. However, it does not include the costs of grid integration or climate impacts. Further, LCOE does not take into account other environmental and social externalities that may modify the overall (monetary and non-monetary) costs of technologies and alter their deployment. The **bottom panel (b)** shows cumulative global adoption for each technology, in GW of installed capacity for renewable energy and in millions of vehicles for battery-electric vehicles. A vertical dashed line is placed in 2010 to indicate the change over the past decade. The electricity production share reflects different capacity factors; for example, for the same amount of installed capacity, wind produces about twice as much electricity as solar PV. Renewable energy and battery technologies were selected as illustrative examples because they have recently shown rapid changes in costs and adoption, and because consistent data are available. Other mitigation options assessed in the WGIII report are not included as they do not meet these criteria. {WGIII Figure SPM.3, WGIII 2.5, 6.4}

At least 1.8 GtCO₂-eq yr⁻¹ of avoided emissions can be accounted for by aggregating separate estimates for the effects of economic and regulatory instruments (*medium confidence*). Growing numbers of laws and executive orders have impacted global emissions and are estimated to have resulted in 5.9 GtCO₂-eq yr⁻¹ of avoided emissions in 2016 (*medium confidence*). These reductions have only partly offset global emissions growth (*high confidence*). {WGIII SPM B.1, WGIII SPM B.2.4, WGIII SPM B.3.5, WGIII SPM B.5.1, WGIII SPM B.5.3, WGIII 1.3.2, WGIII 2.2.3}

2.2.3. Adaptation Actions to Date

Progress in adaptation planning and implementation has been observed across all sectors and regions, generating multiple benefits (*very high confidence*). The ambition, scope and progress on adaptation have risen among governments at the local, national and international levels, along with businesses, communities and civil society (*high confidence*). Various tools, measures and processes are available that can enable, accelerate and sustain adaptation implementation (*high confidence*). Growing public and political awareness of climate impacts and risks has resulted in at least 170 countries and many cities including adaptation in their climate policies and planning processes (*high confidence*). Decision support tools and climate services are increasingly being used (*very high confidence*) and pilot projects and local experiments are being implemented in different sectors (*high confidence*). {WGII SPM C.1, WGII SPM.C.1.1, WGII TS.D.1.3, WGII TS.D.10}

Adaptation to water-related risks and impacts make up the majority (~60%) of all documented⁸³ adaptation (*high confidence*). A large number of these adaptation responses are in the agriculture sector and these include on-farm water management, water storage, soil moisture conservation, and irrigation. Other adaptations in agriculture include cultivar improvements, agroforestry, community-based adaptation and farm and landscape diversification among others (*high confidence*). For inland flooding, combinations of non-structural measures like early warning systems, enhancing natural water retention such as by restoring wetlands and rivers, and land use planning such as no build zones or upstream forest management, can reduce flood risk (*medium confidence*). Some land-related adaptation actions such as sustainable food production, improved and sustainable forest management, soil organic carbon management, ecosystem conservation and land restoration, reduced deforestation and degradation, and reduced food loss and waste are being undertaken, and can have mitigation co-benefits (*high confidence*). Adaptation actions that increase the resilience of biodiversity and ecosystem services to climate change include responses like minimising additional stresses or disturbances, reducing fragmentation, increasing natural habitat extent, connectivity and heterogeneity, and protecting small-scale refugia where microclimate conditions can allow species to persist (*high confidence*). Most innovations in urban adaptation have occurred through advances

in disaster risk management, social safety nets and green/blue infrastructure (*medium confidence*). Many adaptation measures that benefit health and well-being are found in other sectors (e.g., food, livelihoods, social protection, water and sanitation, infrastructure) (*high confidence*). {WGII SPM C.2.1, WGII SPM C.2.2, WGII TS.D.1.2, WGII TS.D.1.4, WGII TS.D.4.2, WGII TS.D.8.3, WGII 4 ES; SRCCL SPM B.1.1}

Adaptation can generate multiple additional benefits such as improving agricultural productivity, innovation, health and well-being, food security, livelihood, and biodiversity conservation as well as reduction of risks and damages (*very high confidence*). {WGII SPM C1.1}

Globally tracked adaptation finance has shown an upward trend since AR5, but represents only a small portion of total climate finance, is uneven and has developed heterogeneously across regions and sectors (*high confidence*). Adaptation finance has come predominantly from public sources, largely through grants, concessional and non-concessional instruments (*very high confidence*). Globally, private-sector financing of adaptation from a variety of sources such as commercial financial institutions, institutional investors, other private equity, non-financial corporations, as well as communities and households has been limited, especially in developing countries (*high confidence*). Public mechanisms and finance can leverage private sector finance for adaptation by addressing real and perceived regulatory, cost and market barriers, for example via public-private partnerships (*high confidence*). Innovations in adaptation and resilience finance, such as forecast-based/anticipatory financing systems and regional risk insurance pools, have been piloted and are growing in scale (*high confidence*). {WGII SPM C.3.2, WGII SPM C.5.4; WGII TS.D.1.6, WGII Cross-Chapter Box FINANCE; WGIII SPM E.5.4}

There are adaptation options which are effective⁸⁴ in reducing climate risks⁸⁵ for specific contexts, sectors and regions and contribute positively to sustainable development and other societal goals. In the agriculture sector, cultivar improvements, on-farm water management and storage, soil moisture conservation, irrigation⁸⁶, agroforestry, community-based adaptation, and farm and landscape level diversification, and sustainable land management approaches, provide multiple benefits and reduce climate risks. Reduction of food loss and waste, and adaptation measures in support of balanced diets contribute to nutrition, health, and biodiversity benefits. (*high confidence*) {WGII SPM C.2, WGII SPM C.2.1, WGII SPM C.2.2; SRCCL B.2, SRCCL SPM C.2.1}

Ecosystem-based Adaptation⁸⁷ approaches such as urban greening, restoration of wetlands and upstream forest ecosystems reduce a range of climate change risks, including flood risks, urban heat and provide multiple co-benefits. Some land-based adaptation options provide immediate benefits (e.g., conservation of peatlands,

⁸³ Documented adaptation refers to published literature on adaptation policies, measures and actions that has been implemented and documented in peer reviewed literature, as opposed to adaptation that may have been planned, but not implemented.

⁸⁴ Effectiveness refers here to the extent to which an adaptation option is anticipated or observed to reduce climate-related risk.

⁸⁵ See Annex I: Glossary.

⁸⁶ Irrigation is effective in reducing drought risk and climate impacts in many regions and has several livelihood benefits, but needs appropriate management to avoid potential adverse outcomes, which can include accelerated depletion of groundwater and other water sources and increased soil salinization (*medium confidence*).

⁸⁷ EbA is recognised internationally under the Convention on Biological Diversity (CBD14/5). A related concept is Nature-based Solutions (NbS), see Annex I: Glossary.

Section 2

wetlands, rangelands, mangroves and forests); while afforestation and reforestation, restoration of high-carbon ecosystems, agroforestry, and the reclamation of degraded soils take more time to deliver measurable results. Significant synergies exist between adaptation and mitigation, for example through sustainable land management approaches. Agroecological principles and practices and other approaches that work with natural processes support food security, nutrition, health and well-being, livelihoods and biodiversity, sustainability and ecosystem services. (*high confidence*) {WGII SPM C.2.1, WGII SPM C.2.2, WGII SPM C.2.5, WGII TS.D.4.1; SRCCL SPM B.1.2, SRCCL SPM.B.6.1; SROCC SPM C.2}

Combinations of non-structural measures like early warning systems and structural measures like levees have reduced loss of lives in case of inland flooding (*medium confidence*) and early warning systems along with flood-proofing of buildings have proven to be cost-effective in the context of coastal flooding under current sea level rise (*high confidence*). Heat Health Action Plans that include early warning and response systems are effective adaptation options for extreme heat (*high confidence*). Effective adaptation options for water, food and vector-borne diseases include improving access to potable water, reducing exposure of water and sanitation systems to extreme weather events, and improved early warning systems, surveillance, and vaccine development (*very high confidence*). Adaptation options such as disaster risk management, early warning systems, climate services and social safety nets have broad applicability across multiple sectors (*high confidence*). {WGII SPM C.2.1, WGII SPM C.2.5, WGII SPM C.2.9, WGII SPM C.2.11, WGII SPM C.2.13; SROCC SPM C.3.2}

Integrated, multi-sectoral solutions that address social inequities, differentiate responses based on climate risk and cut across systems, increase the feasibility and effectiveness of adaptation in multiple sectors (*high confidence*). {WGII SPM C.2}

2.3 Current Mitigation and Adaptation Actions and Policies are not Sufficient

At the time of the present assessment⁸⁸ there are gaps between global ambitions and the sum of declared national ambitions. These are further compounded by gaps between declared national ambitions and current implementation for all aspects of climate action. For mitigation, global GHG emissions in 2030 implied by NDCs announced by October 2021 would make it *likely* that warming will exceed 1.5°C during the 21st century and would make it harder to limit warming below 2°C.⁸⁹ Despite progress, adaptation gaps⁹⁰ persist, with many initiatives prioritising short-term risk reduction, hindering transformational adaptation. Hard and soft limits to adaptation are being reached in some sectors and regions, while maladaptation is also increasing and disproportionately affecting vulnerable groups. Systemic barriers such as funding, knowledge, and practice gaps, including lack of climate literacy and data hinders adaptation progress. Insufficient financing, especially for adaptation, constraints climate action in particular in developing countries. (*high confidence*)

2.3.1. The Gap Between Mitigation Policies, Pledges and Pathways that Limit Warming to 1.5°C or Below 2°C

Global GHG emissions in 2030 associated with the implementation of NDCs announced prior to COP26⁹¹ would make it *likely* that warming will exceed 1.5°C during the 21st century and would make it harder to limit warming below 2°C – if no additional commitments are made or actions taken (Figure 2.5, Table 2.2). A substantial ‘emissions gap’ exists as global GHG emissions in 2030 associated with the implementation of NDCs announced prior to COP26 would be similar to or only slightly below 2019 emission levels and higher than those associated with modelled mitigation pathways that limit warming to 1.5°C (>50%) with no or limited overshoot or to 2°C (>67%), assuming immediate action, which implies deep, rapid, and sustained global GHG emission reductions this decade (*high confidence*) (Table 2.2, Table 3.1, 4.1).⁹² The magnitude of the emissions gap depends on the global warming level considered and whether only unconditional or also conditional elements of NDCs⁹³ are considered (*high confidence*) (Table 2.2). Modelled pathways that are consistent with NDCs announced prior to COP26 until 2030 and assume no increase in ambition thereafter have higher emissions, leading

to a median global warming of 2.8 [2.1 to 3.4]°C by 2100 (*medium confidence*). If the ‘emission gap’ is not reduced, global GHG emissions in 2030 consistent with NDCs announced prior to COP26 make it *likely* that warming will exceed 1.5°C during the 21st century, while limiting warming to 2°C (>67%) would imply an unprecedented acceleration of mitigation efforts during 2030–2050 (*medium confidence*) (see Section 4.1, Cross-Section Box.2). {WGIII SPM B.6, WGIII SPM B.6.1, WGIII SPM B.6.3, WGIII SPM B.6.4, WGIII SPM C.1.1}

Policies implemented by the end of 2020 are projected to result in higher global GHG emissions in 2030 than those implied by NDCs, indicating an ‘implementation gap’⁹⁴ (*high confidence*) (Table 2.2, Figure 2.5). Projected global emissions implied by policies implemented by the end of 2020 are 57 (52–60) GtCO₂-eq in 2030 (Table 2.2). This points to an implementation gap compared with the NDCs of 4 to 7 GtCO₂-eq in 2030 (Table 2.2); without a strengthening of policies, emissions are projected to rise, leading to a median global warming of 2.2°C to 3.5°C (*very likely range*) by 2100 (*medium confidence*) (see Section 3.1.1). {WGIII SPM B.6.1, WGIII SPM C.1}

⁸⁸ The timing of various cut-offs for assessment differs by WG report and the aspect assessed. See footnote 58 in Section 1.

⁸⁹ See CSB.2 for a discussion of scenarios and pathways.

⁹⁰ See Annex I: Glossary.

⁹¹ NDCs announced prior to COP26 refer to the most recent NDCs submitted to the UNFCCC up to the literature cut-off date of the WGIII report, 11 October 2021, and revised NDCs announced by China, Japan and the Republic of Korea prior to October 2021 but only submitted thereafter. 25 NDC updates were submitted between 12 October 2021 and the start of COP26. {WGIII SPM footnote 24}

⁹² Immediate action in modelled global pathways refers to the adoption between 2020 and at latest before 2025 of climate policies intended to limit global warming to a given level. Modelled pathways that limit warming to 2°C (>67%) based on immediate action are summarised in category C3a in Table 3.1. All assessed modelled global pathways that limit warming to 1.5°C (>50%) with no or limited overshoot assume immediate action as defined here (Category C1 in Table 3.1). {WGIII SPM footnote 26}

⁹³ In this report, ‘unconditional’ elements of NDCs refer to mitigation efforts put forward without any conditions. ‘Conditional’ elements refer to mitigation efforts that are contingent on international cooperation, for example bilateral and multilateral agreements, financing or monetary and/or technological transfers. This terminology is used in the literature and the UNFCCC’s NDC Synthesis Reports, not by the Paris Agreement. {WGIII SPM footnote 27}

⁹⁴ Implementation gaps refer to how far currently enacted policies and actions fall short of reaching the pledges. The policy cut-off date in studies used to project GHG emissions of ‘policies implemented by the end of 2020’ varies between July 2019 and November 2020. {WGIII Table 4.2, WGIII SPM footnote 25}

Projected cumulative future CO₂ emissions over the lifetime of existing fossil fuel infrastructure without additional abatement⁹⁵ exceed the total cumulative net CO₂ emissions in pathways that limit warming to 1.5°C (>50%) with no or limited overshoot. They are approximately equal to total cumulative net CO₂ emissions in pathways that limit warming to 2°C with a likelihood of 83%⁹⁶ (see Figure 3.5). Limiting warming to 2°C (>67%) or lower will result in stranded assets. About 80% of coal, 50% of gas, and 30% of oil reserves cannot be burned and emitted if warming is limited to 2°C. Significantly more reserves are expected to remain unburned if warming is limited to 1.5°C. (*high confidence*) {WGIII SPM B.7, WGIII Box 6.3}

Table 2.2 Projected global emissions in 2030 associated with policies implemented by the end of 2020 and NDCs announced prior to COP26, and associated emissions gaps. Emissions projections for 2030 and gross differences in emissions are based on emissions of 52–56 GtCO₂-eq yr⁻¹ in 2019 as assumed in underlying model studies⁹⁷. (*medium confidence*) {WGIII Table SPM.1} (Table 3.1, Cross-Section Box.2)

Emission and implementation gaps associated with projected global emissions in 2030 under Nationally Determined Contributions (NDCs) and implemented policies

	Implied by policies implemented by the end of 2020 (GtCO ₂ -eq/yr)	Implied by Nationally Determined Contributions (NDCs) announced prior to COP26	
		Unconditional elements (GtCO ₂ -eq/yr)	Including conditional elements (GtCO ₂ -eq/yr)
Median projected global emissions (min–max)*	57 [52–60]	53 [50–57]	50 [47–55]
Implementation gap between implemented policies and NDCs (median)	–	4	7
Emissions gap between NDCs and pathways that limit warming to 2°C (>67%) with immediate action	–	10–16	6–14
Emissions gap between NDCs and pathways that limit warming to 1.5°C (>50%) with no or limited overshoot with immediate action	–	19–26	16–23

*Emissions projections for 2030 and gross differences in emissions are based on emissions of 52–56 GtCO₂-eq/yr in 2019 as assumed in underlying model studies. (*medium confidence*)

⁹⁵ Abatement here refers to human interventions that reduce the amount of GHGs that are released from fossil fuel infrastructure to the atmosphere. {WGIII SPM footnote 34}

⁹⁶ WGI provides carbon budgets that are in line with limiting global warming to temperature limits with different likelihoods, such as 50%, 67% or 83%. {WGI Table SPM.2}

⁹⁷ The 2019 range of harmonised GHG emissions across the pathways [53–58 GtCO₂-eq] is within the uncertainty ranges of 2019 emissions assessed in WGIII Chapter 2 [53–66 GtCO₂-eq].

Projected global GHG emissions from NDCs announced prior to COP26 would make it *likely* that warming will exceed 1.5°C and also make it harder after 2030 to limit warming to below 2°C

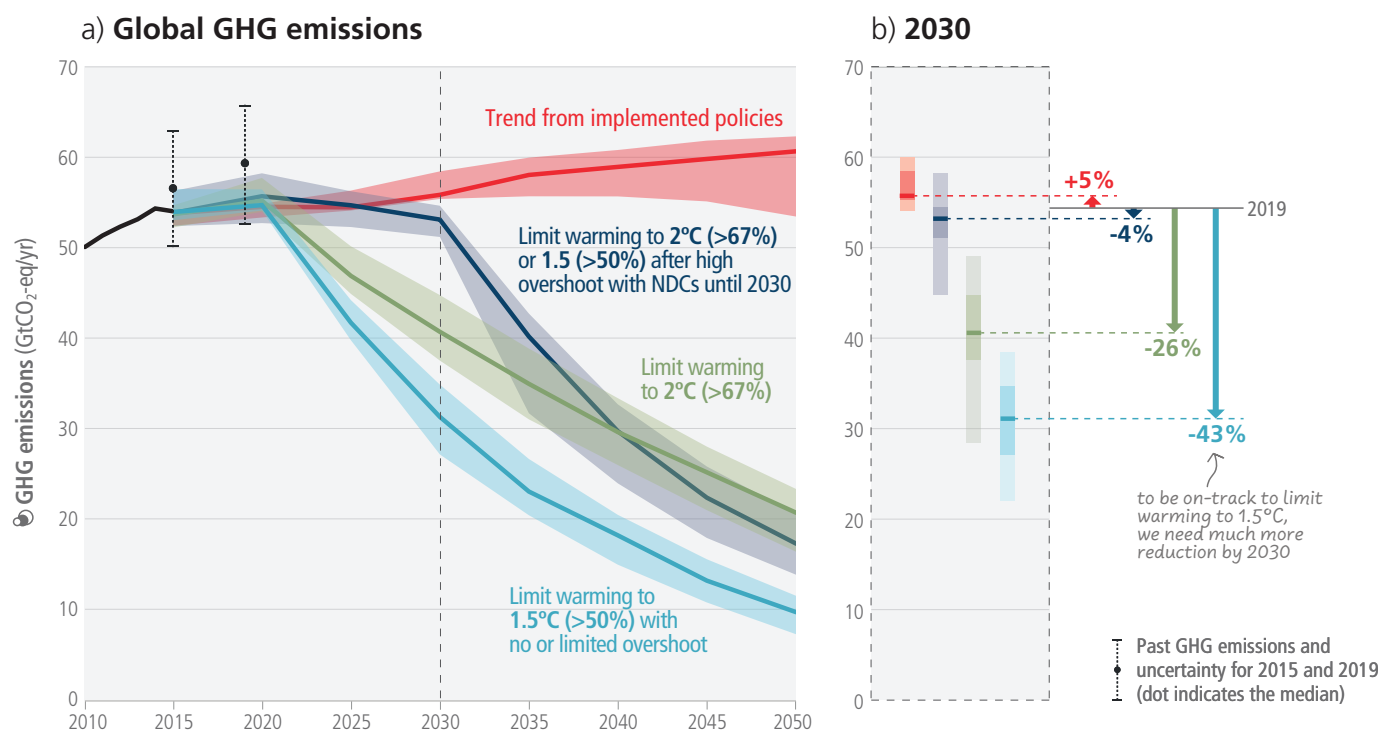


Figure 2.5 Global GHG emissions of modelled pathways (funnels in Panel a), and projected emission outcomes from near-term policy assessments for 2030 (Panel b). Panel a shows global GHG emissions over 2015-2050 for four types of assessed modelled global pathways:

- Trend from implemented policies: Pathways with projected near-term GHG emissions in line with policies implemented until the end of 2020 and extended with comparable ambition levels beyond 2030 (29 scenarios across categories C5–C7, WGIII Table SPM.2).
- Limit to 2°C (>67%) or return warming to 1.5°C (>50%) after a high overshoot, NDCs until 2030: Pathways with GHG emissions until 2030 associated with the implementation of NDCs announced prior to COP26, followed by accelerated emissions reductions *likely* to limit warming to 2°C (C3b, WGIII Table SPM.2) or to return warming to 1.5°C with a probability of 50% or greater after high overshoot (subset of 42 scenarios from C2, WGIII Table SPM.2).
- Limit to 2°C (>67%) with immediate action: Pathways that limit warming to 2°C (>67%) with immediate action after 2020 (C3a, WGIII Table SPM.2).
- Limit to 1.5°C (>50%) with no or limited overshoot: Pathways limiting warming to 1.5°C with no or limited overshoot (C1, WGIII Table SPM.2 C1).

All these pathways assume immediate action after 2020. Past GHG emissions for 2010-2015 used to project global warming outcomes of the modelled pathways are shown by a black line. Panel b shows a snapshot of the GHG emission ranges of the modelled pathways in 2030 and projected emissions outcomes from near-term policy assessments in 2030 from WGIII Chapter 4.2 (Tables 4.2 and 4.3; median and full range). GHG emissions are CO₂-equivalent using GWP100 from AR6 WGI. (WGIII Figure SPM.4, WGIII 3.5, 4.2, Table 4.2, Table 4.3, Cross-Chapter Box 4 in Chapter 4) (Table 3.1, Cross-Section Box.2)

Cross-Section Box.1: Understanding Net Zero CO₂ and Net Zero GHG Emissions

Limiting human-caused global warming to a specific level requires limiting cumulative CO₂ emissions, reaching net zero or net negative CO₂ emissions, along with strong reductions in other GHG emissions (see 3.3.2). Future additional warming will depend on future emissions, with total warming dominated by past and future cumulative CO₂ emissions. {WGI SPM D.1.1, WGI Figure SPM.4; SR1.5 SPM A.2.2}

Reaching net zero CO₂ emissions is different from reaching net zero GHG emissions. The timing of net zero for a basket of GHGs depends on the emissions metric, such as global warming potential over a 100-year period, chosen to convert non-CO₂ emissions into CO₂-equivalent (*high confidence*). However, for a given emissions pathway, the physical climate response is independent of the metric chosen (*high confidence*). {WGI SPM D.1.8; WGIII Box TS.6, WGIII Cross-Chapter Box 2}

Achieving global net zero GHG emissions requires all remaining CO₂ and metric-weighted⁹⁸ non-CO₂ GHG emissions to be counterbalanced by durably stored CO₂ removals (*high confidence*). Some non-CO₂ emissions, such as CH₄ and N₂O from agriculture, cannot be fully eliminated using existing and anticipated technical measures. {WGIII SPM C.2.4, WGIII SPM C.11.4, WGIII Cross-Chapter Box 3}

Global net zero CO₂ or GHG emissions can be achieved even if some sectors and regions are net emitters, provided that others reach net negative emissions (see Figure 4.1). The potential and cost of achieving net zero or even net negative emissions vary by sector and region. If and when net zero emissions for a given sector or region are reached depends on multiple factors, including the potential to reduce GHG emissions and undertake carbon dioxide removal, the associated costs, and the availability of policy mechanisms to balance emissions and removals between sectors and countries. (*high confidence*) {WGIII Box TS.6, WGIII Cross-Chapter Box 3}

The adoption and implementation of net zero emission targets by countries and regions also depend on equity and capacity considerations (*high confidence*). The formulation of net zero pathways by countries will benefit from clarity on scope, plans-of-action, and fairness. Achieving net zero emission targets relies on policies, institutions, and milestones against which to track progress. Least-cost global modelled pathways have been shown to distribute the mitigation effort unevenly, and the incorporation of equity principles could change the country-level timing of net zero (*high confidence*). The Paris Agreement also recognizes that peaking of emissions will occur later in developing countries than developed countries (Article 4.1). {WGIII Box TS.6, WGIII Cross-Chapter Box 3, WGIII 14.3}

More information on country-level net zero pledges is provided in Section 2.3.1, on the timing of global net zero emissions in Section 3.3.2, and on sectoral aspects of net zero in Section 4.1.

⁹⁸ See footnote 12 above.

Many countries have signalled an intention to achieve net zero GHG or net zero CO₂ emissions by around mid-century (Cross-Section Box.1). More than 100 countries have either adopted, announced or are discussing net zero GHG or net zero CO₂ emissions commitments, covering more than two-thirds of global GHG emissions. A growing number of cities are setting climate targets, including net zero GHG targets. Many companies and institutions have also announced net zero emissions targets in recent years. The various net zero emission pledges differ across countries in terms of scope and specificity, and limited policies are to date in place to deliver on them. {WGIII SPM C.6.4, WGIII TS.4.1, WGIII Table TS.1, WGIII 13.9, WGIII 14.3, WGIII 14.5}

All mitigation strategies face implementation challenges, including technology risks, scaling, and costs (high confidence). Almost all mitigation options also face institutional barriers that need to be addressed to enable their application at scale (medium confidence). Current development pathways may create behavioural, spatial, economic and social barriers to accelerated mitigation at all scales (high confidence). Choices made by policymakers, citizens, the private sector and other stakeholders influence societies' development pathways (high confidence). Structural factors of national circumstances and capabilities (e.g., economic and natural endowments, political systems and cultural factors and gender considerations) affect the breadth and depth of climate governance (medium confidence). The extent to which civil society actors, political actors, businesses, youth, labour, media, Indigenous Peoples, and local communities are engaged influences political support for climate change mitigation and eventual policy outcomes (medium confidence). {WGIII SPM C.3.6, WGIII SPM E.1.1, WGIII SPM E.2.1, WGIII SPM E.3.3}

The adoption of low-emission technologies lags in most developing countries, particularly least developed ones, due in part to weaker enabling conditions, including limited finance, technology development and transfer, and capacity (medium confidence). In many countries, especially those with limited institutional capacity, several adverse side-effects have been observed as a result of diffusion of low-emission technology, e.g., low-value employment, and dependency on foreign knowledge and suppliers (medium confidence). Low-emission innovation along with strengthened enabling conditions can reinforce development benefits, which can, in turn, create feedbacks towards greater public support for policy (medium confidence). Persistent and region-specific barriers also continue to hamper the economic and political feasibility of deploying AFOLU mitigation options (medium confidence). Barriers to implementation of AFOLU mitigation include insufficient institutional and financial support, uncertainty over long-term additionality and trade-offs, weak governance, insecure land ownership, low incomes and the lack of access to alternative sources of income, and the risk of reversal (high confidence). {WGIII SPM B.4.2, WGIII SPM C.9.1, WGIII SPM C.9.3}

⁹⁹ See Annex I: Glossary.

¹⁰⁰ Adaptation limit: The point at which an actor's objectives (or system needs) cannot be secured from intolerable risks through adaptive actions. Hard adaptation limit - No adaptive actions are possible to avoid intolerable risks. Soft adaptation limit - Options are currently not available to avoid intolerable risks through adaptive action.

¹⁰¹ Maladaptation refers to actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas emissions, increased or shifted vulnerability to climate change, more inequitable outcomes, or diminished welfare, now or in the future. Most often, maladaptation is an unintended consequence. See Annex I: Glossary.

2.3.2. Adaptation Gaps and Barriers

Despite progress, adaptation gaps exist between current levels of adaptation and levels needed to respond to impacts and reduce climate risks (high confidence). While progress in adaptation implementation is observed across all sectors and regions (very high confidence), many adaptation initiatives prioritise immediate and near-term climate risk reduction, e.g., through hard flood protection, which reduces the opportunity for transformational adaptation⁹⁹ (high confidence). Most observed adaptation is fragmented, small in scale, incremental, sector-specific, and focused more on planning rather than implementation (high confidence). Further, observed adaptation is unequally distributed across regions and the largest adaptation gaps exist among lower population income groups (high confidence). In the urban context, the largest adaptation gaps exist in projects that manage complex risks, for example in the food–energy–water–health nexus or the inter-relationships of air quality and climate risk (high confidence). Many funding, knowledge and practice gaps remain for effective implementation, monitoring and evaluation and current adaptation efforts are not expected to meet existing goals (high confidence). At current rates of adaptation planning and implementation the adaptation gap will continue to grow (high confidence). {WGII SPM C.1, WGII SPM C.1.2, WGII SPM C.4.1, WGII TS.D.1.3, WGII TS.D.1.4}

Soft and hard adaptation limits¹⁰⁰ have already been reached in some sectors and regions, in spite of adaptation having buffered some climate impacts (high confidence). Ecosystems already reaching hard adaptation limits include some warm water coral reefs, some coastal wetlands, some rainforests, and some polar and mountain ecosystems (high confidence). Individuals and households in low lying coastal areas in Australasia and Small Islands and smallholder farmers in Central and South America, Africa, Europe and Asia have reached soft limits (medium confidence), resulting from financial, governance, institutional and policy constraints and can be overcome by addressing these constraints (high confidence). Transitioning from incremental to transformational adaptation can help overcome soft adaptation limits (high confidence). {WGII SPM C.3, WGII SPM C.3.1, WGII SPM C.3.2, WGII SPM C.3.3, WGII SPM.C.3.4, WGII 16 ES}

Adaptation does not prevent all losses and damages, even with effective adaptation and before reaching soft and hard limits. Losses and damages are unequally distributed across systems, regions and sectors and are not comprehensively addressed by current financial, governance and institutional arrangements, particularly in vulnerable developing countries. (high confidence) {WGII SPM.C.3.5}

There is increased evidence of maladaptation¹⁰¹ in various sectors and regions. Examples of maladaptation are observed in urban areas (e.g., new urban infrastructure that cannot be adjusted easily or affordably), agriculture (e.g., using high-cost irrigation in areas projected to have more intense drought conditions), ecosystems (e.g. fire suppression in naturally

fire-adapted ecosystems, or hard defences against flooding) and human settlements (e.g. stranded assets and vulnerable communities that cannot afford to shift away or adapt and require an increase in social safety nets). Maladaptation especially affects marginalised and vulnerable groups adversely (e.g., Indigenous Peoples, ethnic minorities, low-income households, people living in informal settlements), reinforcing and entrenching existing inequities. Maladaptation can be avoided by flexible, multi-sectoral, inclusive and long-term planning and implementation of adaptation actions with benefits to many sectors and systems. (*high confidence*) {WGII SPM C.4, WGII SPM C.4.3, WGII TS.D.3.1}

Systemic barriers constrain the implementation of adaptation options in vulnerable sectors, regions and social groups (*high confidence*). Key barriers include limited resources, lack of private-sector and civic engagement, insufficient mobilisation of finance, lack of political commitment, limited research and/or slow and low uptake of adaptation science and a low sense of urgency. Inequity and poverty also constrain adaptation, leading to soft limits and resulting in disproportionate exposure and impacts for most vulnerable groups (*high confidence*). The largest adaptation gaps exist among lower income population groups (*high confidence*). As adaptation options often have long implementation times, long-term planning and accelerated implementation, particularly in this decade, is important to close adaptation gaps, recognising that constraints remain for some regions (*high confidence*). Prioritisation of options and transitions from incremental to transformational adaptation are limited due to vested interests, economic lock-ins, institutional path dependencies and prevalent practices, cultures, norms and belief systems (*high confidence*). Many funding, knowledge and practice gaps remain for effective implementation, monitoring and evaluation of adaptation (*high confidence*), including, lack of climate literacy at all levels and limited availability of data and information (*medium confidence*); for example for Africa, severe climate data constraints and inequities in research funding and leadership reduce adaptive capacity (*very high confidence*). {WGII SPM C.1.2, WGII SPM C.3.1, WGII TS.D.1.3, WGII TS.D.1.5, WGII TS.D.2.4}

2.3.3. Lack of Finance as a Barrier to Climate Action

Insufficient financing, and a lack of political frameworks and incentives for finance, are key causes of the implementation gaps for both mitigation and adaptation (*high confidence*). Financial flows remained heavily focused on mitigation, are uneven, and have developed heterogeneously across regions and sectors (*high confidence*). In 2018, public and publicly mobilised private climate finance flows from developed to developing countries were below the collective goal under the UNFCCC and Paris Agreement to mobilise USD 100 billion per year by 2020 in the context of meaningful mitigation action and transparency on implementation (*medium confidence*). Public and private finance flows for fossil fuels are still greater than those for climate adaptation and mitigation (*high confidence*). The overwhelming majority of tracked climate finance is directed towards mitigation (*very high confidence*). Nevertheless, average annual modelled investment requirements for 2020 to 2030 in scenarios that limit warming to 2°C or 1.5°C are a factor of three to six greater than current levels, and total mitigation investments (public, private, domestic and international) would need to increase across all sectors and regions (*medium confidence*). Challenges remain for green bonds and similar products, in particular around

integrity and additionality, as well as the limited applicability of these markets to many developing countries (*high confidence*). {WGII SPM C.3.2, WGII SPM C.5.4; WGIII SPM B.5.4, WGIII SPM E.5.1}

Current global financial flows for adaptation including from public and private finance sources, are insufficient for and constrain implementation of adaptation options, especially in developing countries (*high confidence*). There are widening disparities between the estimated costs of adaptation and the documented finance allocated to adaptation (*high confidence*). Adaptation finance needs are estimated to be higher than those assessed in AR5, and the enhanced mobilisation of and access to financial resources are essential for implementation of adaptation and to reduce adaptation gaps (*high confidence*). Annual finance flows targeting adaptation for Africa, for example, are billions of USD less than the lowest adaptation cost estimates for near-term climate change (*high confidence*). Adverse climate impacts can further reduce the availability of financial resources by causing losses and damages and impeding national economic growth, thereby further increasing financial constraints for adaptation particularly for developing countries and LDCs (*medium confidence*). {WGII SPM C.1.2, WGII SPM C.3.2, WGII SPM C.5.4, WGII TS.D.1.6}

Without effective mitigation and adaptation, losses and damages will continue to disproportionately affect the poorest and most vulnerable populations. Accelerated financial support for developing countries from developed countries and other sources is a critical enabler to enhance mitigation action {WGIII SPM. E.5.3}. Many developing countries lack comprehensive data at the scale needed and lack adequate financial resources needed for adaptation for reducing associated economic and non-economic losses and damages. (*high confidence*) {WGII Cross-Chapter Box LOSS, WGII SPM C.3.1, WGII SPM C.3.2, WGII TS.D.1.3, WGII TS.D.1.5; WGIII SPM E.5.3}

There are barriers to redirecting capital towards climate action both within and outside the global financial sector. These barriers include: the inadequate assessment of climate-related risks and investment opportunities, regional mismatch between available capital and investment needs, home bias factors, country indebtedness levels, economic vulnerability, and limited institutional capacities. Challenges from outside the financial sector include: limited local capital markets; unattractive risk-return profiles, in particular due to missing or weak regulatory environments that are inconsistent with ambition levels; limited institutional capacity to ensure safeguards; standardisation, aggregation, scalability and replicability of investment opportunities and financing models; and, a pipeline ready for commercial investments. (*high confidence*) {WGII SPM C.5.4; WGIII SPM E.5.2; SR1.5 SPM D.5.2}

Cross-Section Box.2: Scenarios, Global Warming Levels, and Risks

Modelled scenarios and pathways¹⁰² are used to explore future emissions, climate change, related impacts and risks, and possible mitigation and adaptation strategies and are based on a range of assumptions, including socio-economic variables and mitigation options. These are quantitative projections and are neither predictions nor forecasts. Global modelled emission pathways, including those based on cost effective approaches contain regionally differentiated assumptions and outcomes, and have to be assessed with the careful recognition of these assumptions. Most do not make explicit assumptions about global equity, environmental justice or intra-regional income distribution. IPCC is neutral with regard to the assumptions underlying the scenarios in the literature assessed in this report, which do not cover all possible futures¹⁰³. {WGI Box SPM.1; WGII Box SPM.1; WGIII Box SPM.1; SROCC Box SPM.1; SRCCL Box SPM.1}

Socio-economic Development, Scenarios, and Pathways

The five Shared Socio-economic Pathways (SSP1 to SSP5) were designed to span a range of challenges to climate change mitigation and adaptation. For the assessment of climate impacts, risk and adaptation, the SSPs are used for future exposure, vulnerability and challenges to adaptation. Depending on levels of GHG mitigation, modelled emissions scenarios based on the SSPs can be consistent with low or high warming levels¹⁰⁴. There are many different mitigation strategies that could be consistent with different levels of global warming in 2100 (see Figure 4.1). {WGI Box SPM.1; WGII Box SPM.1; WGIII Box SPM.1, WGIII Box TS.5, WGIII Annex III; SRCCL Box SPM.1, SRCCL Figure SPM.2}

WGI assessed the climate response to five illustrative scenarios based on SSPs¹⁰⁵ that cover the range of possible future development of anthropogenic drivers of climate change found in the literature. These scenarios combine socio-economic assumptions, levels of climate mitigation, land use and air pollution controls for aerosols and non-CH₄ ozone precursors. The high and very high GHG emissions scenarios (SSP3-7.0 and SSP5-8.5) have CO₂ emissions that roughly double from current levels by 2100 and 2050, respectively¹⁰⁶. The intermediate GHG emissions scenario (SSP2-4.5) has CO₂ emissions remaining around current levels until the middle of the century. The very low and low GHG emissions scenarios (SSP1-1.9 and SSP1-2.6) have CO₂ emissions declining to net zero around 2050 and 2070, respectively, followed by varying levels of net negative CO₂ emissions. In addition, Representative Concentration Pathways (RCPs)¹⁰⁷ were used by WGI and WGII to assess regional climate changes, impacts and risks. {WGI Box SPM.1} (Cross-Section Box.2 Figure 1)

In WGIII, a large number of global modelled emissions pathways were assessed, of which 1202 pathways were categorised based on their projected global warming over the 21st century, with categories ranging from pathways that limit warming to 1.5°C with more than 50% likelihood¹⁰⁸ with no or limited overshoot (C1) to pathways that exceed 4°C (C8). Methods to project global warming associated with the modelled pathways were updated to ensure consistency with the AR6 WGI assessment of the climate system response¹⁰⁹. {WGIII Box SPM.1, WGIII Table 3.1} (Table 3.1, Cross-Section Box.2 Figure 1)

¹⁰² In the literature, the terms pathways and scenarios are used interchangeably, with the former more frequently used in relation to climate goals. WGI primarily used the term scenarios and WGIII mostly used the term modelled emissions and mitigation pathways. The SYR primarily uses scenarios when referring to WGI and modelled emissions and mitigation pathways when referring to WGIII. {WGI Box SPM.1; WGIII footnote 44}

¹⁰³ Around half of all modelled global emissions pathways assume cost-effective approaches that rely on least-cost mitigation/abatement options globally. The other half look at existing policies and regionally and sectorally differentiated actions. The underlying population assumptions range from 8.5 to 9.7 billion in 2050 and 7.4 to 10.9 billion in 2100 (5–95th percentile) starting from 7.6 billion in 2019. The underlying assumptions on global GDP growth range from 2.5 to 3.5% per year in the 2019–2050 period and 1.3 to 2.1% per year in the 2050–2100 (5–95th percentile). {WGIII Box SPM.1}

¹⁰⁴ High mitigation challenges, for example, due to assumptions of slow technological change, high levels of global population growth, and high fragmentation as in the Shared Socio-economic Pathway SSP3, may render modelled pathways that limit warming to 2°C (> 67%) or lower infeasible (*medium confidence*). {WGIII SPM C.1.4; SRCCL Box SPM.1}

¹⁰⁵ SSP-based scenarios are referred to as SSPx-y, where 'SSPx' refers to the Shared Socio-economic Pathway describing the socioeconomic trends underlying the scenarios, and 'y' refers to the level of radiative forcing (in watts per square metre, or Wm⁻²) resulting from the scenario in the year 2100. {WGI SPM footnote 22}

¹⁰⁶ Very high emission scenarios have become less *likely* but cannot be ruled out. Temperature levels > 4°C may result from very high emission scenarios, but can also occur from lower emission scenarios if climate sensitivity or carbon cycle feedbacks are higher than the best estimate. {WGIII SPM C.1.3}

¹⁰⁷ RCP-based scenarios are referred to as RCPy, where 'y' refers to the approximate level of radiative forcing (in watts per square metre, or Wm⁻²) resulting from the scenario in the year 2100. {WGII SPM footnote 21}

¹⁰⁸ Denoted '>50%' in this report.

¹⁰⁹ The climate response to emissions is investigated with climate models, paleoclimatic insights and other lines of evidence. The assessment outcomes are used to categorise thousands of scenarios via simple physically-based climate models (emulators). {WGI TS.1.2.2}

Global Warming Levels (GWLs)

For many climate and risk variables, the geographical patterns of changes in climatic impact-drivers¹¹⁰ and climate impacts for a level of global warming¹¹¹ are common to all scenarios considered and independent of timing when that level is reached. This motivates the use of GWLs as a dimension of integration. {*WGI Box SPM.1.4, WGI TS.1.3.2; WGII Box SPM.1*} (Figure 3.1, Figure 3.2)

Risks

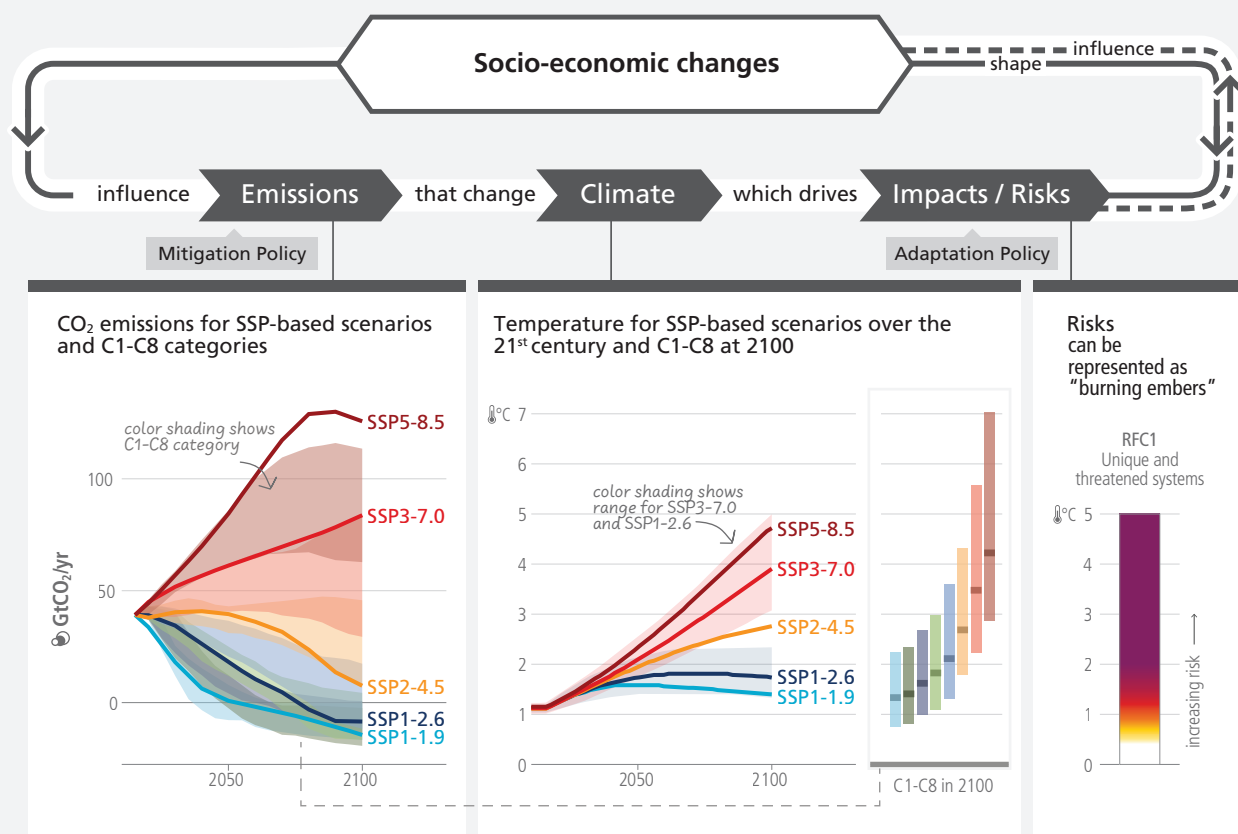
Dynamic interactions between climate-related hazards, exposure and vulnerability of the affected human society, species, or ecosystems result in risks arising from climate change. AR6 assesses key risks across sectors and regions as well as providing an updated assessment of the Reasons for Concern (RFCs) – five globally aggregated categories of risk that evaluate risk accrual with increasing global surface temperature. Risks can also arise from climate change mitigation or adaptation responses when the response does not achieve its intended objective, or when it results in adverse effects for other societal objectives. {*WGII SPM A, WGII Figure SPM.3, WGII Box TS.1, WGII Figure TS.4; SR1.5 Figure SPM.2; SROCC Errata Figure SPM.3; SRCCL Figure SPM.2*} (3.1.2, Cross-Section Box.2 Figure 1, Figure 3.3)

¹¹⁰ See Annex I: Glossary

¹¹¹ See Annex I: Glossary. Here, global warming is the 20-year average global surface temperature relative to 1850–1900. The assessed time of when a certain global warming level is reached under a particular scenario is defined here as the mid-point of the first 20-year running average period during which the assessed average global surface temperature change exceeds the level of global warming. {*WGI SPM footnote 26, Cross-Section Box TS.1*}

Scenarios and warming levels structure our understanding across the cause-effect chain from emissions to climate change and risks

a) AR6 integrated assessment framework on future climate, impacts and mitigation



b) Scenarios and pathways across AR6 Working Group reports

Category in WGIII	Category description	GHG emissions scenarios (SSPx-y*) in WGI & WGII	RCPy** in WGI & WGII
C1	limit warming to 1.5°C (>50%) with no or limited overshoot	Very low (SSP1-1.9)	
C2	return warming to 1.5°C (>50%) after a high overshoot		
C3	limit warming to 2°C (>67%)	Low (SSP1-2.6)	RCP2.6
C4	limit warming to 2°C (>50%)		
C5	limit warming to 2.5°C (>50%)		
C6	limit warming to 3°C (>50%)	Intermediate (SSP2-4.5)	RCP 4.5
C7	limit warming to 4°C (>50%)	High (SSP3-7.0)	
C8	exceed warming of 4°C (>50%)	Very high (SSP5-8.5)	RCP 8.5

c) Determinants of risk



* The terminology SSPx-y is used, where 'SSPx' refers to the Shared Socio-economic Pathway or 'SSP' describing the socio-economic trends underlying the scenario, and 'y' refers to the approximate level of radiative forcing (in watts per square metre, or Wm⁻²) resulting from the scenario in the year 2100.

** The AR5 scenarios (RCPy), which partly inform the AR6 WGI and WGII assessments, are indexed to a similar set of approximate 2100 radiative forcing levels (in W m⁻²). The SSP scenarios cover a broader range of GHG and air pollutant futures than the RCPs. They are similar but not identical, with differences in concentration trajectories for different GHGs. The overall radiative forcing tends to be higher for the SSPs compared to the RCPs with the same label (*medium confidence*). {WGI TS.1.3.1}

*** Limited overshoot refers to exceeding 1.5°C global warming by up to about 0.1°C, high overshoot by 0.1°C-0.3°C, in both cases for up to several decades.

Cross-Section Box.2 Figure 1: Schematic of the AR6 framework for assessing future greenhouse gas emissions, climate change, risks, impacts and mitigation. Panel (a) The integrated framework encompasses socio-economic development and policy, emissions pathways and global surface temperature responses to the five scenarios considered by WGI (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) and eight global mean temperature change categorisations (C1–C8) assessed by WGIII, and the WGII risk assessment. The dashed arrow indicates that the influence from impacts/risks to socio-economic changes is not yet considered in the scenarios assessed in the AR6. Emissions include GHGs, aerosols, and ozone precursors. CO₂ emissions are shown as an example on the left. The assessed global surface temperature changes across the 21st century relative to 1850-1900 for the five GHG emissions scenarios are shown as an example in the centre. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0. Projected temperature outcomes at 2100 relative to 1850-1900 are shown for C1 to C8 categories with median (line) and the combined *very likely* range across scenarios (bar). On the right, future risks due to increasing warming are represented by an example 'burning ember' figure (see 3.1.2 for the definition of RFC1). Panel (b) Description and relationship of scenarios considered across AR6 Working Group reports. Panel (c) Illustration of risk arising from the interaction of hazard (driven by changes in climatic impact-drivers) with vulnerability, exposure and response to climate change. {WGI TS1.4, Figure 4.11; WGII Figure 1.5, WGII Figure 14.8; WGIII Table SPM.2, WGIII Figure 3.11}

Section 3

Long-Term Climate and Development Futures

Section 3: Long-Term Climate and Development Futures

3.1 Long-Term Climate Change, Impacts and Related Risks

Future warming will be driven by future emissions and will affect all major climate system components, with every region experiencing multiple and co-occurring changes. Many climate-related risks are assessed to be higher than in previous assessments, and projected long-term impacts are up to multiple times higher than currently observed. Multiple climatic and non-climatic risks will interact, resulting in compounding and cascading risks across sectors and regions. Sea level rise, as well as other irreversible changes, will continue for thousands of years, at rates depending on future emissions. (*high confidence*)

3.1.1. Long-term Climate Change

The uncertainty range on assessed future changes in global surface temperature is narrower than in the AR5. For the first time in an IPCC assessment cycle, multi-model projections of global surface temperature, ocean warming and sea level are constrained using observations and the assessed climate sensitivity. The *likely* range of equilibrium climate sensitivity has been narrowed to 2.5°C to 4.0°C (with a best estimate of 3.0°C) based on multiple lines of evidence¹¹², including improved understanding of cloud feedbacks. For related emissions scenarios, this leads to narrower uncertainty ranges for long-term projected global temperature change than in AR5. {WGI A.4, WGI Box SPM.1, WGI TS.3.2, WGI 4.3}

Future warming depends on future GHG emissions, with cumulative net CO₂ dominating. The assessed best estimates and *very likely* ranges of warming for 2081–2100 with respect to 1850–1900 vary from 1.4 [1.0 to 1.8]°C in the very low GHG emissions scenario (SSP1-1.9) to 2.7 [2.1 to 3.5]°C in the intermediate GHG emissions scenario (SSP2-4.5) and 4.4 [3.3 to 5.7]°C in the very high GHG emissions scenario (SSP5-8.5)¹¹³. {WGI SPM B.1.1, WGI Table SPM.1, WGI Figure SPM.4} (Cross-Section Box.2 Figure 1)

Modelled pathways consistent with the continuation of policies implemented by the end of 2020 lead to global warming of 3.2 [2.2 to 3.5]°C (5–95% range) by 2100 (*medium confidence*) (see also Section 2.3.1). Pathways of >4°C (≥50%) by 2100 would imply a reversal of current technology and/or mitigation policy trends (*medium confidence*). However, such warming could occur in emissions pathways consistent with policies implemented by the end of 2020 if climate sensitivity or carbon cycle feedbacks are higher than the best estimate (*high confidence*). {WGIII SPM C.1.3}

Global warming will continue to increase in the near term in nearly all considered scenarios and modelled pathways. Deep, rapid, and sustained GHG emissions reductions, reaching net zero CO₂ emissions and including strong emissions reductions of other GHGs, in particular CH₄, are necessary to limit warming to 1.5°C (>50%) or less than 2°C (>67%) by the end of century (*high confidence*). The best estimate of reaching 1.5°C of global warming lies in the first half of the 2030s in most of the considered scenarios and modelled pathways¹¹⁴. In the very low GHG emissions scenario (SSP1-1.9), CO₂ emissions reach net zero around 2050 and the best-estimate end-of-century warming is 1.4°C, after a temporary overshoot (see Section 3.3.4) of no more than 0.1°C above 1.5°C global warming. Global warming of 2°C will be exceeded during the 21st century unless deep reductions in CO₂ and other GHG emissions occur in the coming decades. Deep, rapid, and sustained reductions in GHG emissions would lead to improvements in air quality within a few years, to reductions in trends of global surface temperature discernible after around 20 years, and over longer time periods for many other climate impact-drivers¹¹⁵ (*high confidence*). Targeted reductions of air pollutant emissions lead to more rapid improvements in air quality compared to reductions in GHG emissions only, but in the long term, further improvements are projected in scenarios that combine efforts to reduce air pollutants as well as GHG emissions (*high confidence*)¹¹⁶. {WGI SPM B.1, WGI SPM B.1.3, WGI SPM D.1, WGI SPM D.2, WGI Figure SPM.4, WGI Table SPM.1, WGI Cross-Section Box TS.1; WGIII SPM C.3, WGIII Table SPM.2, WGIII Figure SPM.5, WGIII Box SPM.1 Figure 1, WGIII Table 3.2} (Table 3.1, Cross-Section Box.2 Figure 1)

Changes in short-lived climate forcers (SLCF) resulting from the five considered scenarios lead to an additional net global warming in the near and long term (*high confidence*). Simultaneous stringent climate change mitigation and air pollution control

¹¹² Understanding of climate processes, the instrumental record, paleoclimates and model-based emergent constraints (see Annex I: Glossary). {WGI SPM footnote 21}

¹¹³ The best estimates [and *very likely* ranges] for the different scenarios are: 1.4 [1.0 to 1.8]°C (SSP1-1.9); 1.8 [1.3 to 2.4]°C (SSP1-2.6); 2.7 [2.1 to 3.5]°C (SSP2-4.5); 3.6 [2.8 to 4.6]°C (SSP3-7.0); and 4.4 [3.3 to 5.7]°C (SSP5-8.5). {WGI Table SPM.1} (Cross-Section Box.2)

¹¹⁴ In the near term (2021–2040), the 1.5°C global warming level is *very likely* to be exceeded under the very high GHG emissions scenario (SSP5-8.5), *likely* to be exceeded under the intermediate and high GHG emissions scenarios (SSP2-4.5, SSP3-7.0), *more likely than not* to be exceeded under the low GHG emissions scenario (SSP1-2.6) and *more likely than not* to be reached under the very low GHG emissions scenario (SSP1-1.9). In all scenarios considered by WGI except the very high emissions scenario, the midpoint of the first 20-year running average period during which the assessed global warming reaches 1.5°C lies in the first half of the 2030s. In the very high GHG emissions scenario, this mid-point is in the late 2020s. The median five-year interval at which a 1.5°C global warming level is reached (50% probability) in categories of modelled pathways considered in WGIII is 2030–2035. {WGI SPM B.1.3, WGI Cross-Section Box TS.1, WGIII Table 3.2} (Cross-Section Box.2)

¹¹⁵ See Cross-Section Box.2.

¹¹⁶ Based on additional scenarios.

policies limit this additional warming and lead to strong benefits for air quality (high confidence). In high and very high GHG emissions scenarios (SSP3-7.0 and SSP5-8.5), combined changes in SLCF emissions, such as CH₄, aerosol and ozone precursors, lead to a net global warming by 2100 of *likely* 0.4°C to 0.9°C relative to 2019. This is due to projected increases in atmospheric concentration of CH₄, tropospheric ozone, hydrofluorocarbons and, when strong air pollution control is considered, reductions of cooling aerosols. In low and very low GHG emissions scenarios (SSP1-1.9 and SSP1-2.6), air pollution control policies, reductions in CH₄ and other ozone precursors lead to a net cooling, whereas reductions in anthropogenic cooling aerosols lead to a net warming (*high confidence*). Altogether, this causes a *likely* net warming of 0.0°C to 0.3°C due to SLCF changes in 2100 relative to 2019 and strong reductions in global surface ozone and particulate matter (*high confidence*). {WGI SPM D.1.7, WGI Box TS.7} (Cross-Section Box.2)

Continued GHG emissions will further affect all major climate system components, and many changes will be irreversible on centennial to millennial time scales. Many changes in the climate system become larger in direct relation to increasing global warming. With every additional increment of global warming, changes in extremes continue to become larger. Additional warming will lead to more frequent and intense marine heatwaves and is projected to further amplify permafrost thawing and loss of seasonal snow cover, glaciers, land ice and Arctic sea ice (*high confidence*). Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation¹¹⁷, and very wet and very dry weather and climate events and seasons (*high confidence*). The portion of global land experiencing detectable changes in seasonal mean precipitation is projected to increase (*medium confidence*) with more variable precipitation and surface water flows over most land regions within seasons (*high confidence*) and from year to year (*medium confidence*). Many changes due to past and future GHG emissions are irreversible¹¹⁸ on centennial to millennial time scales, especially in the ocean, ice sheets and global sea level (see 3.1.3). Ocean acidification (*virtually certain*), ocean deoxygenation (*high confidence*) and global mean sea level (*virtually certain*) will continue to increase in the 21st century, at rates dependent on future emissions. {WGI SPM B.2, WGI SPM B.2.2, WGI SPM B.2.3, WGI SPM B.2.5, WGI SPM B.3, WGI SPM B.3.1, WGI SPM B.3.2, WGI SPM B.4, WGI SPM B.5, WGI SPM B.5.1, WGI SPM B.5.3, WGI Figure SPM.8} (Figure 3.1)

With further global warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. Increases in hot and decreases in cold climatic impact-drivers, such as temperature extremes, are projected in all regions (*high confidence*). At 1.5°C global warming, heavy precipitation and flooding events are projected to intensify and become more frequent in most regions in Africa, Asia (*high confidence*), North America (*medium to high confidence*) and Europe (*medium confidence*). At 2°C or above, these changes expand to more regions and/or become more significant (*high confidence*), and more frequent and/or severe agricultural and ecological droughts are projected in Europe, Africa, Australasia and North, Central and South America (*medium to high confidence*). Other projected regional changes include

intensification of tropical cyclones and/or extratropical storms (*medium confidence*), and increases in aridity and fire weather¹¹⁹ (*medium to high confidence*). Compound heatwaves and droughts become *likely* more frequent, including concurrently at multiple locations (*high confidence*). {WGI SPM C.2, WGI SPM C.2.1, WGI SPM C.2.2, WGI SPM C.2.3, WGI SPM C.2.4, WGI SPM C.2.7}

¹¹⁷ Particularly over South and South East Asia, East Asia and West Africa apart from the far west Sahel. {WGI SPM B.3.3}

¹¹⁸ See Annex I: Glossary.

¹¹⁹ See Annex I: Glossary.

With every increment of global warming, regional changes in mean climate and extremes become more widespread and pronounced

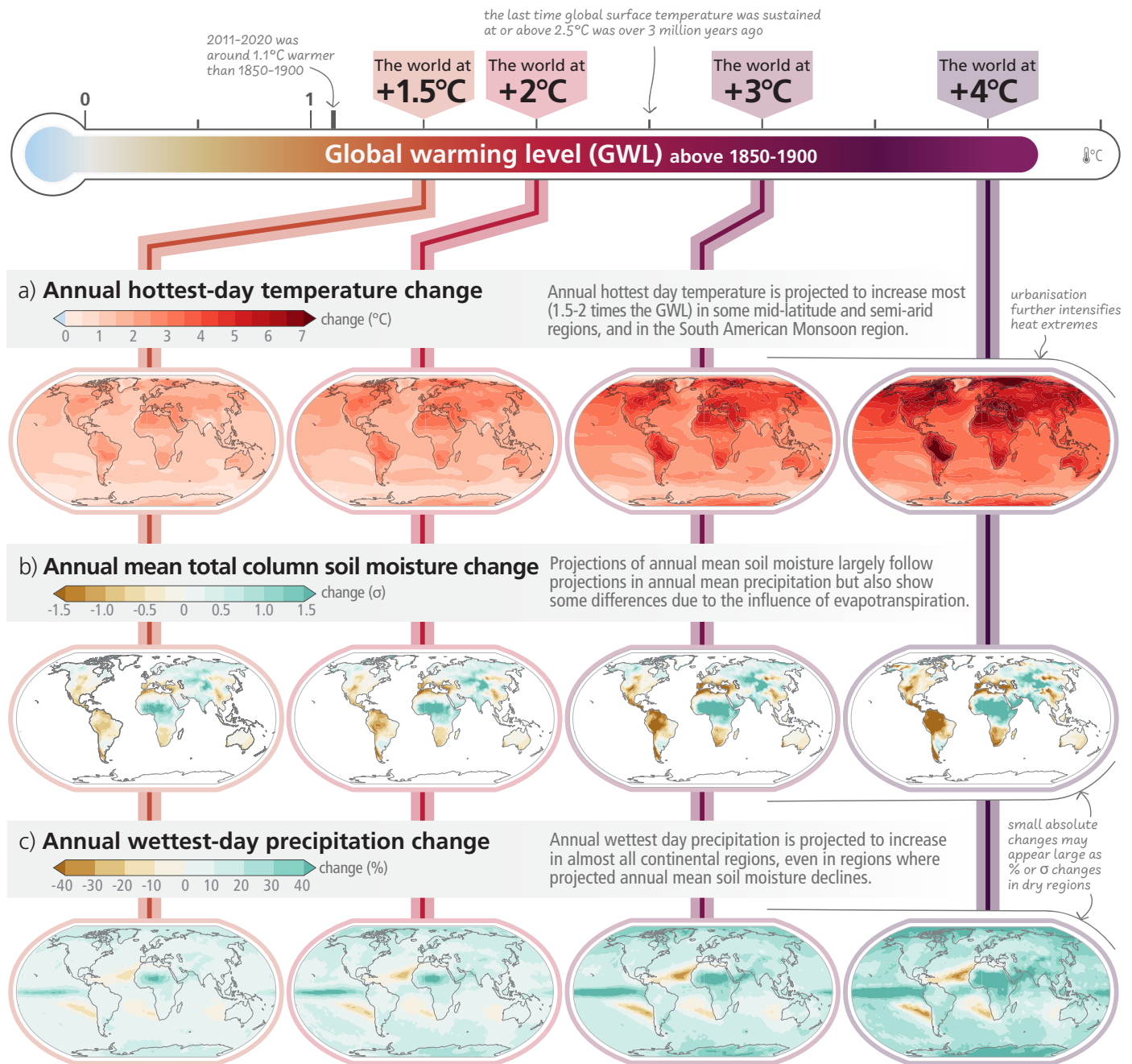


Figure 3.1: Projected changes of annual maximum daily temperature, annual mean total column soil moisture and annual maximum daily precipitation at global warming levels of 1.5°C, 2°C, 3°C, and 4°C relative to 1850-1900. Simulated (a) annual maximum temperature change (°C), (b) annual mean total column soil moisture (standard deviation), (c) annual maximum daily precipitation change (%). Changes correspond to CMIP6 multi-model median changes. In panels (b) and (c), large positive relative changes in dry regions may correspond to small absolute changes. In panel (b), the unit is the standard deviation of interannual variability in soil moisture during 1850-1900. Standard deviation is a widely used metric in characterising drought severity. A projected reduction in mean soil moisture by one standard deviation corresponds to soil moisture conditions typical of droughts that occurred about once every six years during 1850-1900. The WGI Interactive Atlas (<https://interactive-atlas.ipcc.ch/>) can be used to explore additional changes in the climate system across the range of global warming levels presented in this figure. [WGI Figure SPM.5, WGI Figure TS.5, WGI Figure 11.11, WGI Figure 11.16, WGI Figure 11.19] (Cross-Section Box.2)

3.1.2 Impacts and Related Risks

For a given level of warming, many climate-related risks are assessed to be higher than in AR5 (*high confidence*). Levels of risk¹²⁰ for all Reasons for Concern¹²¹ (RFCs) are assessed to become high to very high at lower global warming levels compared to what was assessed in AR5 (*high confidence*). This is based upon recent evidence of observed impacts, improved process understanding, and new knowledge on exposure and vulnerability of human and natural systems, including limits to adaptation. Depending on the level of global warming, the assessed long-term impacts will be up to multiple times higher than currently observed (*high confidence*) for 127 identified key risks, e.g., in terms of the number of affected people and species. Risks, including cascading risks (see 3.1.3) and risks from overshoot (see 3.3.4), are projected to become increasingly severe with every increment of global warming (*very high confidence*). {WGII SPM B.3.3, WGII SPM B.4, WGII SPM B.5, WGII 16.6.3; SRCL SPM A5.3} (Figure 3.2, Figure 3.3)

Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present (1.1°C) but lower than at 2°C (*high confidence*) (see Section 2.1.2). Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5°C. In terrestrial ecosystems, 3 to 14% of the tens of thousands of species assessed will *likely* face a very high risk of extinction at a GWL of 1.5°C. Coral reefs are projected to decline by a further 70–90% at 1.5°C of global warming (*high confidence*). At this GWL, many low-elevation and small glaciers around the world would lose most of their mass or disappear within decades to centuries (*high confidence*). Regions at disproportionately higher risk include Arctic ecosystems, dryland regions, small island developing states and Least Developed Countries (*high confidence*). {WGII SPM B.3, WGII SPM B.4.1, WGII TS.C.4.2; SR1.5 SPM A.3, SR1.5 SPM B.4.2, SR1.5 SPM B.5, SR1.5 SPM B.5.1} (Figure 3.3)

At 2°C of global warming, overall risk levels associated with the unequal distribution of impacts (RFC3), global aggregate impacts (RFC4) and large-scale singular events (RFC5) would be transitioning to high (*medium confidence*), those associated with extreme weather events (RFC2) would be transitioning to very high (*medium confidence*), and those associated with unique and threatened systems (RFC1) would be very high (*high confidence*) (Figure 3.3, panel a). With about 2°C warming, climate-related

changes in food availability and diet quality are estimated to increase nutrition-related diseases and the number of undernourished people, affecting tens (under low vulnerability and low warming) to hundreds of millions of people (under high vulnerability and high warming), particularly among low-income households in low- and middle-income countries in sub-Saharan Africa, South Asia and Central America (*high confidence*). For example, snowmelt water availability for irrigation is projected to decline in some snowmelt dependent river basins by up to 20% (*medium confidence*). Climate change risks to cities, settlements and key infrastructure will rise sharply in the mid and long term with further global warming, especially in places already exposed to high temperatures, along coastlines, or with high vulnerabilities (*high confidence*). {WGII SPM B.3.3, WGII SPM B.4.2, WGII SPM B.4.5, WGII TS C.3.3, WGII TS.C.12.2} (Figure 3.3)

At global warming of 3°C, additional risks in many sectors and regions reach high or very high levels, implying widespread systemic impacts, irreversible change and many additional adaptation limits (see Section 3.2) (*high confidence*). For example, very high extinction risk for endemic species in biodiversity hotspots is projected to increase at least tenfold if warming rises from 1.5°C to 3°C (*medium confidence*). Projected increases in direct flood damages are higher by 1.4 to 2 times at 2°C and 2.5 to 3.9 times at 3°C, compared to 1.5°C global warming without adaptation (*medium confidence*). {WGII SPM B.4.1, WGII SPM B.4.2, WGII Figure SPM.3, WGII TS Appendix All, WGII Appendix I Global to Regional Atlas Figure AI.46} (Figure 3.2, Figure 3.3)

Global warming of 4°C and above is projected to lead to far-reaching impacts on natural and human systems (*high confidence*). Beyond 4°C of warming, projected impacts on natural systems include local extinction of ~50% of tropical marine species (*medium confidence*) and biome shifts across 35% of global land area (*medium confidence*). At this level of warming, approximately 10% of the global land area is projected to face both increasing high and decreasing low extreme streamflow, affecting, without additional adaptation, over 2.1 billion people (*medium confidence*) and about 4 billion people are projected to experience water scarcity (*medium confidence*). At 4°C of warming, the global burned area is projected to increase by 50 to 70% and the fire frequency by ~30% compared to today (*medium confidence*). {WGII SPM B.4.1, WGII SPM B.4.2, WGII TS.C.1.2, WGII TS.C.2.3, WGII TS.C.4.1, WGII TS.C.4.4} (Figure 3.2, Figure 3.3)

¹²⁰ Undetectable risk level indicates no associated impacts are detectable and attributable to climate change; moderate risk indicates associated impacts are both detectable and attributable to climate change with at least *medium confidence*, also accounting for the other specific criteria for key risks; high risk indicates severe and widespread impacts that are judged to be high on one or more criteria for assessing key risks; and very high risk level indicates very high risk of severe impacts and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks. {WGII Figure SPM.3}

¹²¹ The Reasons for Concern (RFC) framework communicates scientific understanding about accrual of risk for five broad categories (WGII Figure SPM.3). RFC1: Unique and threatened systems: ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its Indigenous Peoples, mountain glaciers and biodiversity hotspots. RFC2: Extreme weather events: risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events such as heatwaves, heavy rain, drought and associated wildfires, and coastal flooding. RFC3: Distribution of impacts: risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability. RFC4: Global aggregate impacts: impacts to socio-ecological systems that can be aggregated globally into a single metric, such as monetary damages, lives affected, species lost or ecosystem degradation at a global scale. RFC5: Large-scale singular events: relatively large, abrupt and sometimes irreversible changes in systems caused by global warming, such as ice sheet instability or thermohaline circulation slowing. Assessment methods include a structured expert elicitation based on the literature described in WGII SM16.6 and are identical to AR5 but are enhanced by a structured approach to improve robustness and facilitate comparison between AR5 and AR6. For further explanations of global risk levels and Reasons for Concern, see WGII TS.All. {WGII Figure SPM.3}

Projected adverse impacts and related losses and damages from climate change escalate with every increment of global warming (*very high confidence*), but they will also strongly depend on socio-economic development trajectories and adaptation actions to reduce vulnerability and exposure (*high confidence*). For example, development pathways with higher demand for food, animal feed, and water, more resource-intensive consumption and production, and limited technological improvements result in higher risks from water scarcity in drylands, land degradation and food insecurity (*high confidence*). Changes in, for example, demography or investments in health systems have effect on a variety of health-related outcomes including heat-related morbidity and mortality (Figure 3.3 Panel d). {*WGII SPM B.3, WGII SPM B.4, WGII Figure SPM.3; SRCCL SPM A.6*}

With every increment of warming, climate change impacts and risks will become increasingly complex and more difficult to manage. Many regions are projected to experience an increase in the probability of compound events with higher global warming, such as concurrent heatwaves and droughts, compound flooding and fire weather. In addition, multiple climatic and non-climatic risk drivers such as biodiversity loss or violent conflict will interact, resulting in compounding overall risk and risks cascading across sectors and regions. Furthermore, risks can arise from some responses that are intended to reduce the risks of climate change, e.g., adverse side effects of some emission reduction and carbon dioxide removal (CDR) measures (see 3.4.1). (*high confidence*) {*WGI SPM C.2.7, WGI Figure SPM.6, WGI TS.4.3; WGII SPM B.1.7, WGII B.2.2, WGII SPM B.5, WGII SPM B.5.4, WGII SPM C.4.2, WGII SPM B.5, WGII CCB2*}

Solar Radiation Modification (SRM) approaches, if they were to be implemented, introduce a widespread range of new risks to people and ecosystems, which are not well understood. SRM has the potential to offset warming within one or two decades and ameliorate some climate hazards but would not restore climate to a previous state, and substantial residual or overcompensating climate change would occur at regional and seasonal scales (*high confidence*). Effects of SRM would depend on the specific approach used¹²², and a sudden and sustained termination of SRM in a high CO₂ emissions scenario would cause rapid climate change (*high confidence*). SRM would not stop atmospheric CO₂ concentrations from increasing nor reduce resulting ocean acidification under continued anthropogenic emissions (*high confidence*). Large uncertainties and knowledge gaps are associated with the potential of SRM approaches to reduce climate change risks. Lack of robust and formal SRM governance poses risks as deployment by a limited number of states could create international tensions. {*WGI 4.6; WGII SPM B.5.5; WGIII 14.4.5.1; WGIII 14 Cross-Working Group Box Solar Radiation Modification; SR1.5 SPM C.1.4*}

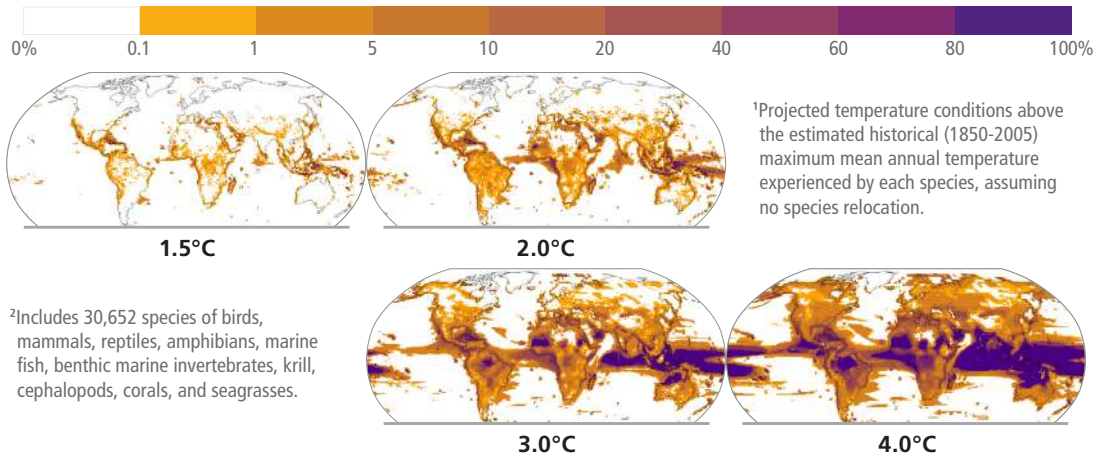
¹²² Several SRM approaches have been proposed, including stratospheric aerosol injection, marine cloud brightening, ground-based albedo modifications, and ocean albedo change. See Annex I: Glossary.

Future climate change is projected to increase the severity of impacts across natural and human systems and will increase regional differences

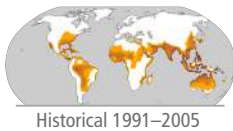
Examples of impacts without additional adaptation

a) Risk of species losses

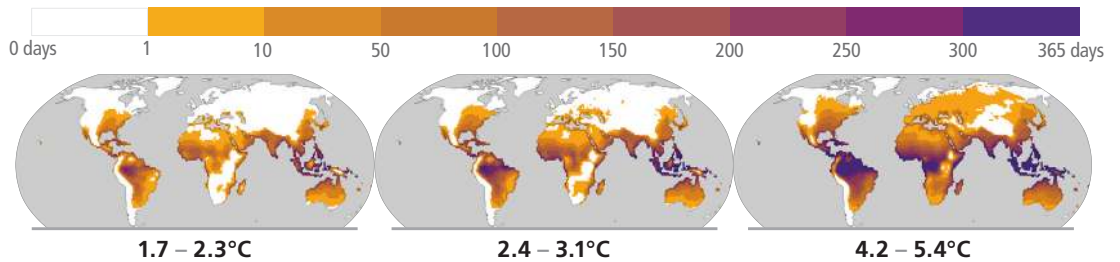
Percentage of animal species and seagrasses exposed to potentially dangerous temperature conditions^{1, 2}



b) Heat-humidity risks to human health



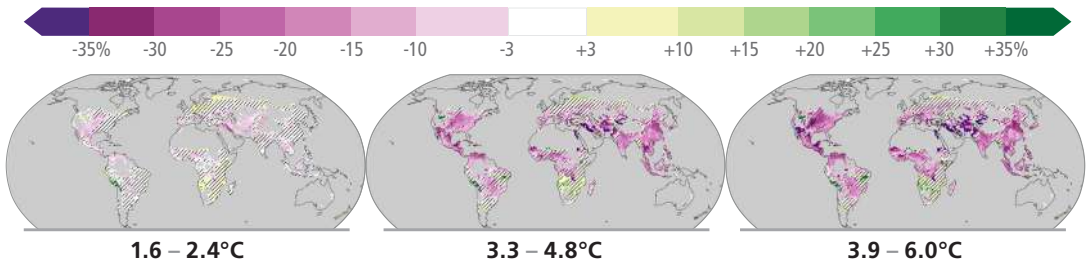
Days per year where combined temperature and humidity conditions pose a risk of mortality to individuals³



c) Food production impacts

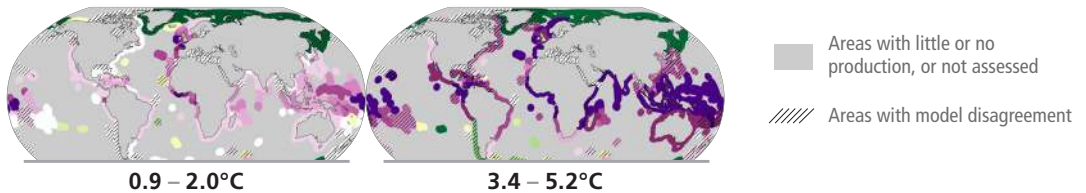
c1) Maize yield⁴

Changes (%) in yield



c2) Fisheries yield⁵

Changes (%) in maximum catch potential

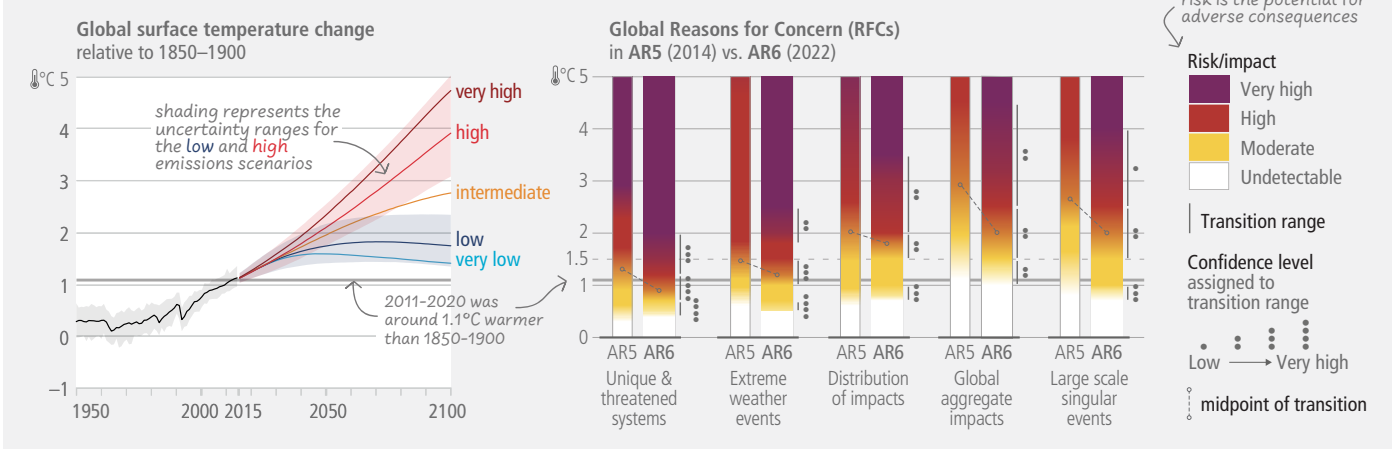


⁵Projected regional impacts reflect fisheries and marine ecosystem responses to ocean physical and biogeochemical conditions such as temperature, oxygen level and net primary production. Models do not represent changes in fishing activities and some extreme climatic conditions. Projected changes in the Arctic regions have low confidence due to uncertainties associated with modelling multiple interacting drivers and ecosystem responses.

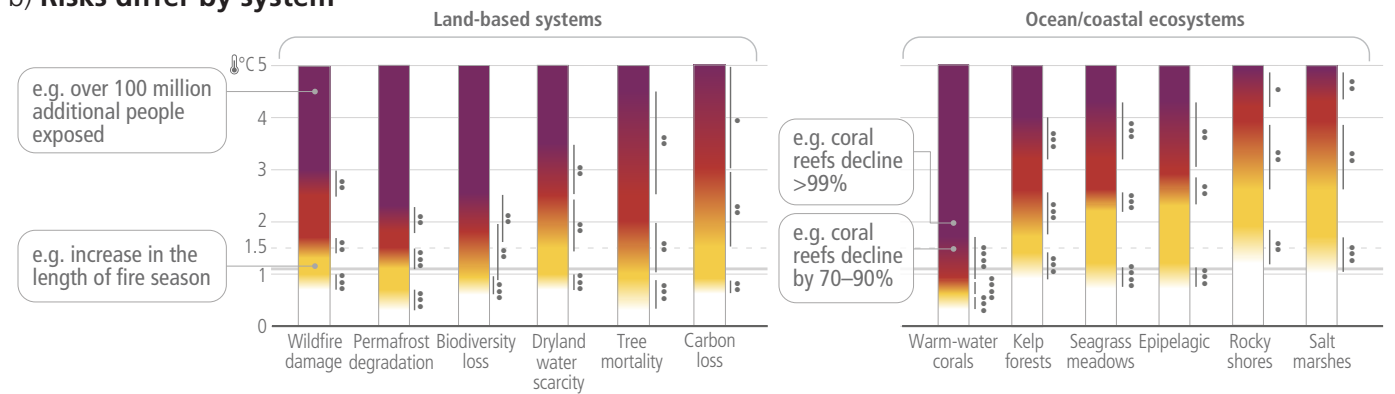
Figure 3.2: Projected risks and impacts of climate change on natural and human systems at different global warming levels (GWLs) relative to 1850-1900 levels. Projected risks and impacts shown on the maps are based on outputs from different subsets of Earth system models that were used to project each impact indicator without additional adaptation. WGII provides further assessment of the impacts on human and natural systems using these projections and additional lines of evidence. **(a)** Risks of species losses as indicated by the percentage of assessed species exposed to potentially dangerous temperature conditions, as defined by conditions beyond the estimated historical (1850–2005) maximum mean annual temperature experienced by each species, at GWLs of 1.5°C, 2°C, 3°C and 4°C. Underpinning projections of temperature are from 21 Earth system models and do not consider extreme events impacting ecosystems such as the Arctic. **(b)** Risk to human health as indicated by the days per year of population exposure to hyperthermic conditions that pose a risk of mortality from surface air temperature and humidity conditions for historical period (1991–2005) and at GWLs of 1.7°C to 2.3°C (mean = 1.9°C; 13 climate models), 2.4°C to 3.1°C (2.7°C; 16 climate models) and 4.2°C to 5.4°C (4.7°C; 15 climate models). Interquartile ranges of GWLs by 2081–2100 under RCP2.6, RCP4.5 and RCP8.5. The presented index is consistent with common features found in many indices included within WGI and WGII assessments. **(c)** Impacts on food production: (c1) Changes in maize yield at projected GWLs of 1.6°C to 2.4°C (2.0°C), 3.3°C to 4.8°C (4.1°C) and 3.9°C to 6.0°C (4.9°C). Median yield changes from an ensemble of 12 crop models, each driven by bias-adjusted outputs from 5 Earth system models from the Agricultural Model Intercomparison and Improvement Project (AgMIP) and the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP). Maps depict 2080–2099 compared to 1986–2005 for current growing regions (>10 ha), with the corresponding range of future global warming levels shown under SSP1-2.6, SSP3-7.0 and SSP5-8.5, respectively. Hatching indicates areas where <70% of the climate-crop model combinations agree on the sign of impact. (c2) Changes in maximum fisheries catch potential by 2081–2099 relative to 1986-2005 at projected GWLs of 0.9°C to 2.0°C (1.5°C) and 3.4°C to 5.2°C (4.3°C). GWLs by 2081–2100 under RCP2.6 and RCP8.5. Hatching indicates where the two climate-fisheries models disagree in the direction of change. Large relative changes in low yielding regions may correspond to small absolute changes. Biodiversity and fisheries in Antarctica were not analysed due to data limitations. Food security is also affected by crop and fishery failures not presented here. {WGII Fig. TS.5, WGII Fig TS.9, WGII Annex I: Global to Regional Atlas Figure AI.15, Figure AI.22, Figure AI.23, Figure AI.29; WGII 7.3.1.2, 7.2.4.1, SROCC Figure SPM.3} (3.1.2, Cross-Section Box.2)

Risks are increasing with every increment of warming

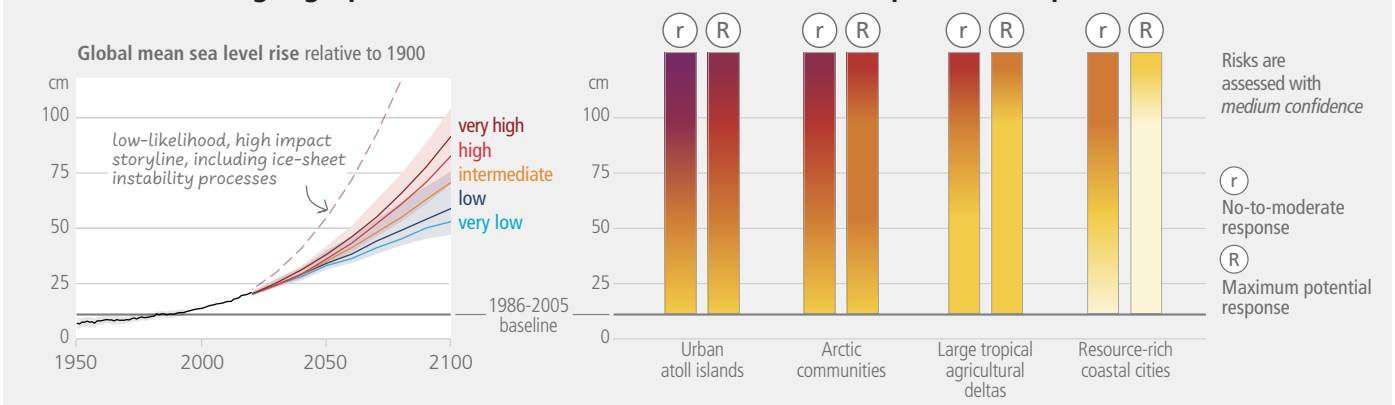
a) High risks are now assessed to occur at lower global warming levels



b) Risks differ by system

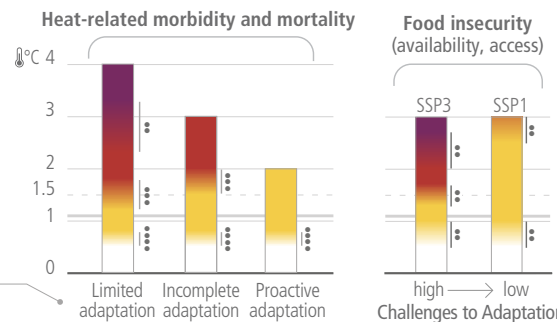


c) Risks to coastal geographies increase with sea level rise and depend on responses



d) Adaptation and socio-economic pathways affect levels of climate related risks

Limited adaptation (failure to proactively adapt; low investment in health systems); incomplete adaptation (incomplete adaptation planning; moderate investment in health systems); proactive adaptation (proactive adaptation management; higher investment in health systems)



The SSP1 pathway illustrates a world with low population growth, high income, and reduced inequalities, food produced in low GHG emission systems, effective land use regulation and high adaptive capacity (i.e., low challenges to adaptation). The SSP3 pathway has the opposite trends.

e) Examples of key risks in different regions

Absence of risk diagrams does not imply absence of risks within a region. The development of synthetic diagrams for Small Islands, Asia and Central and South America was limited due to the paucity of adequately downscaled climate projections, with uncertainty in the direction of change, the diversity of climatologies and socioeconomic contexts across countries within a region, and the resulting few numbers of impact and risk projections for different warming levels.

The risks listed are of at least *medium confidence* level:

Small Islands	<ul style="list-style-type: none"> - Loss of terrestrial, marine and coastal biodiversity and ecosystem services - Loss of lives and assets, risk to food security and economic disruption due to destruction of settlements and infrastructure - Economic decline and livelihood failure of fisheries, agriculture, tourism and from biodiversity loss from traditional agroecosystems - Reduced habitability of reef and non-reef islands leading to increased displacement - Risk to water security in almost every small island
North America	<ul style="list-style-type: none"> - Climate-sensitive mental health outcomes, human mortality and morbidity due to increasing average temperature, weather and climate extremes, and compound climate hazards - Risk of degradation of marine, coastal and terrestrial ecosystems, including loss of biodiversity, function, and protective services - Risk to freshwater resources with consequences for ecosystems, reduced surface water availability for irrigated agriculture, other human uses, and degraded water quality - Risk to food and nutritional security through changes in agriculture, livestock, hunting, fisheries, and aquaculture productivity and access - Risks to well-being, livelihoods and economic activities from cascading and compounding climate hazards, including risks to coastal cities, settlements and infrastructure from sea level rise
Europe	<ul style="list-style-type: none"> - Risks to people, economies and infrastructures due to coastal and inland flooding - Stress and mortality to people due to increasing temperatures and heat extremes - Marine and terrestrial ecosystems disruptions - Water scarcity to multiple interconnected sectors - Losses in crop production, due to compound heat and dry conditions, and extreme weather
Central and South America	<ul style="list-style-type: none"> - Risk to water security - Severe health effects due to increasing epidemics, in particular vector-borne diseases - Coral reef ecosystems degradation due to coral bleaching - Risk to food security due to frequent/extreme droughts - Damages to life and infrastructure due to floods, landslides, sea level rise, storm surges and coastal erosion
Australasia	<ul style="list-style-type: none"> - Degradation of tropical shallow coral reefs and associated biodiversity and ecosystem service values - Loss of human and natural systems in low-lying coastal areas due to sea level rise - Impact on livelihoods and incomes due to decline in agricultural production - Increase in heat-related mortality and morbidity for people and wildlife - Loss of alpine biodiversity in Australia due to less snow
Asia	<ul style="list-style-type: none"> - Urban infrastructure damage and impacts on human well-being and health due to flooding, especially in coastal cities and settlements - Biodiversity loss and habitat shifts as well as associated disruptions in dependent human systems across freshwater, land, and ocean ecosystems - More frequent, extensive coral bleaching and subsequent coral mortality induced by ocean warming and acidification, sea level rise, marine heat waves and resource extraction - Decline in coastal fishery resources due to sea level rise, decrease in precipitation in some parts and increase in temperature - Risk to food and water security due to increased temperature extremes, rainfall variability and drought
Africa	<ul style="list-style-type: none"> - Species extinction and reduction or irreversible loss of ecosystems and their services, including freshwater, land and ocean ecosystems - Risk to food security, risk of malnutrition (micronutrient deficiency), and loss of livelihood due to reduced food production from crops, livestock and fisheries - Risks to marine ecosystem health and to livelihoods in coastal communities - Increased human mortality and morbidity due to increased heat and infectious diseases (including vector-borne and diarrhoeal diseases) - Reduced economic output and growth, and increased inequality and poverty rates - Increased risk to water and energy security due to drought and heat

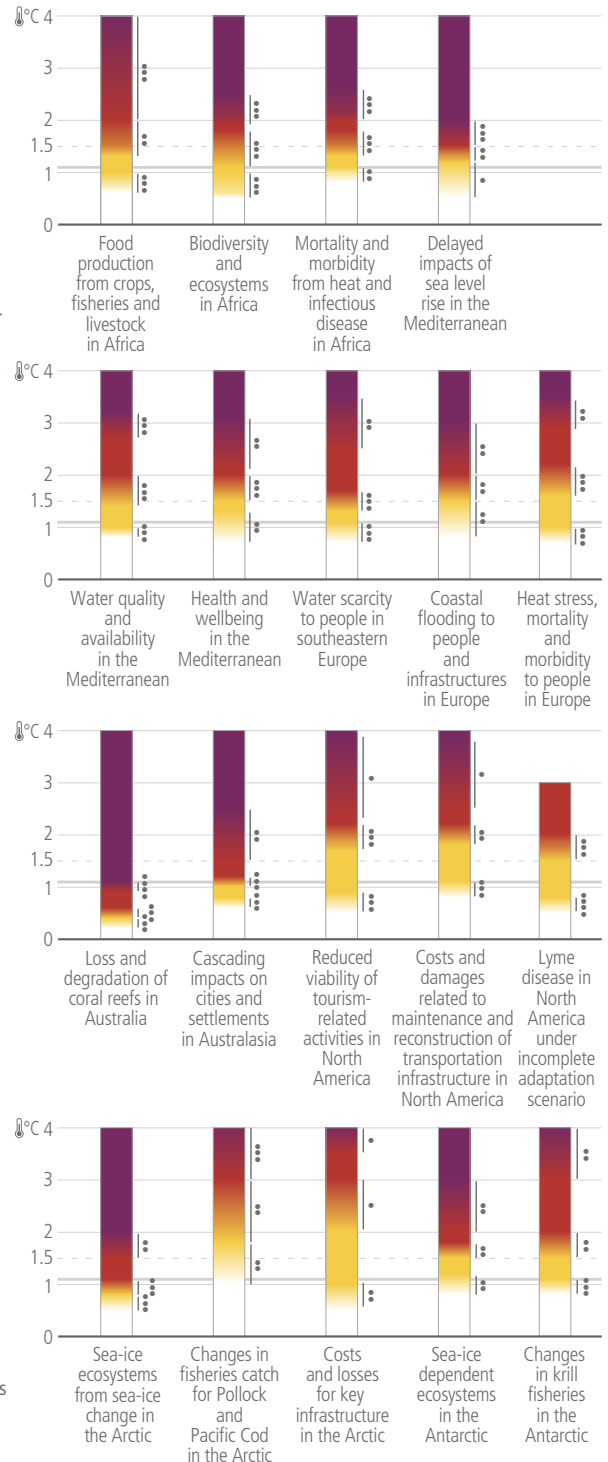


Figure 3.3: Synthetic risk diagrams of global and sectoral assessments and examples of regional key risks. The burning embers result from a literature based expert elicitation. **Panel (a): Left** - Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining CMIP6 model simulations with observational constraints based on past simulated warming, as well as an updated assessment of equilibrium climate sensitivity. *Very likely* ranges are shown for the low and high GHG emissions scenarios (SSP1-2.6 and SSP3-7.0). **Right** - Global Reasons for Concern, comparing AR6 (thick embers) and AR5 (thin embers) assessments. Diagrams are shown for each RFC, assuming low to no adaptation (i.e., adaptation is fragmented, localised and comprises incremental adjustments to existing practices). However, the transition to a very high-risk level has an emphasis on irreversibility and adaptation limits. The horizontal line denotes the present global warming of 1.1°C which is used to separate the observed, past impacts below the line from the future projected risks above it. Lines connect the midpoints of the transition from moderate to high risk across AR5 and AR6. **Panel (b):** Risks for land-based systems and ocean/coastal ecosystems. Diagrams shown for each risk assume low to no adaptation. Text bubbles indicate examples of impacts at a given warming level. **Panel (c): Left** - Global mean sea level change in centimetres, relative to 1900. The historical changes (black) are observed by tide gauges before 1992 and altimeters afterwards. The future changes to 2100 (coloured lines and shading) are assessed consistently with observational constraints based on emulation of CMIP, ice-sheet, and glacier models, and *likely* ranges are shown for SSP1-2.6 and SSP3-7.0. **Right** - Assessment of the combined risk of coastal flooding, erosion and salinization for four illustrative coastal geographies in 2100, due to changing mean and extreme sea levels, under two response scenarios, with respect to the SROCC baseline period (1986–2005) and indicating the IPCC AR6 baseline period (1995–2014). The assessment does not account for changes in extreme sea level beyond those directly induced by mean sea level rise; risk levels could increase if other changes in extreme sea levels were considered (e.g., due to changes in cyclone intensity). “No-to-moderate response” describes efforts as of today (i.e., no further significant action or new types of actions). “Maximum potential response” represents a combination of responses implemented to their full extent and thus significant additional efforts compared to today, assuming minimal financial, social and political barriers. The assessment criteria include exposure and vulnerability (density of assets, level of degradation of terrestrial and marine buffer ecosystems), coastal hazards (flooding, shoreline erosion, salinization), in-situ responses (hard engineered coastal defences, ecosystem restoration or creation of new natural buffers areas, and subsidence management) and planned relocation. Planned relocation refers to managed retreat or resettlement. Forced displacement is not considered in this assessment. The term response is used here instead of adaptation because some responses, such as retreat, may or may not be considered to be adaptation. **Panel (d): Left** - Heat-sensitive human health outcomes under three scenarios of adaptation effectiveness. The diagrams are truncated at the nearest whole °C within the range of temperature change in 2100 under three SSP scenarios. **Right** - Risks associated with food security due to climate change and patterns of socio-economic development. Risks to food security include availability and access to food, including population at risk of hunger, food price increases and increases in disability adjusted life years attributable to childhood underweight. Risks are assessed for two contrasted socio-economic pathways (SSP1 and SSP3) excluding the effects of targeted mitigation and adaptation policies. **Panel (e):** Examples of regional key risks. Risks identified are of at least *medium confidence* level. Key risks are identified based on the magnitude of adverse consequences (pervasiveness of the consequences, degree of change, irreversibility of consequences, potential for impact thresholds or tipping points, potential for cascading effects beyond system boundaries); likelihood of adverse consequences; temporal characteristics of the risk; and ability to respond to the risk, e.g., by adaptation. {WGI Figure SPM.8; WGII SPM B.3.3, WGII Figure SPM.3, WGII SM 16.6, WGII SM 16.7.4; SROCC Figure SPM.3d, SROCC SPM.5a, SROCC 4SM; SRCLL Figure SPM.2, SRCLL 7.3.1, SRCLL 7 SM} (Cross-Section Box.2)

3.1.3 The Likelihood and Risks of Abrupt and Irreversible Change

The likelihood of abrupt and irreversible changes and their impacts increase with higher global warming levels (*high confidence*).

As warming levels increase, so do the risks of species extinction or irreversible loss of biodiversity in ecosystems such as forests (*medium confidence*), coral reefs (*very high confidence*) and in Arctic regions (*high confidence*). Risks associated with large-scale singular events or tipping points, such as ice sheet instability or ecosystem loss from tropical forests, transition to high risk between 1.5°C to 2.5°C (*medium confidence*) and to very high risk between 2.5°C to 4°C (*low confidence*). The response of biogeochemical cycles to anthropogenic perturbations can be abrupt at regional scales and irreversible on decadal to century time scales (*high confidence*). The probability of crossing uncertain regional thresholds increases with further warming (*high confidence*). {WGI SPM C.3.2, WGI Box TS.9, WGI TS.2.6; WGII Figure SPM.3, WGII SPM B.3.1, WGII SPM B.4.1, WGII SPM B.5.2, WGII Table TS.1, WGII TS.C.1, WGII TS.C.13.3; SROCC SPM B.4}

Sea level rise is unavoidable for centuries to millennia due to continuing deep ocean warming and ice sheet melt, and sea levels will remain elevated for thousands of years (*high confidence*). Global mean sea level rise will continue in the 21st century (*virtually certain*), with projected regional relative sea level rise within 20% of the global mean along two-thirds of the global coastline (*medium confidence*). The magnitude, the rate, the timing of threshold exceedances, and the long-term commitment of sea level rise depend on emissions, with higher emissions leading to greater and faster rates of sea level rise. Due to relative sea level rise, extreme sea level events that occurred once per century in the recent past are projected to occur at least annually at more than half of all tide gauge locations by 2100

and risks for coastal ecosystems, people and infrastructure will continue to increase beyond 2100 (*high confidence*). At sustained warming levels between 2°C and 3°C, the Greenland and West Antarctic ice sheets will be lost almost completely and irreversibly over multiple millennia (*limited evidence*). The probability and rate of ice mass loss increase with higher global surface temperatures (*high confidence*). Over the next 2000 years, global mean sea level will rise by about 2 to 3 m if warming is limited to 1.5°C and 2 to 6 m if limited to 2°C (*low confidence*). Projections of multi-millennial global mean sea level rise are consistent with reconstructed levels during past warm climate periods: global mean sea level was *very likely* 5 to 25 m higher than today roughly 3 million years ago, when global temperatures were 2.5°C to 4°C higher than 1850–1900 (*medium confidence*). Further examples of unavoidable changes in the climate system due to multi-decadal or longer response timescales include continued glacier melt (*very high confidence*) and permafrost carbon loss (*high confidence*). {WGI SPM B.5.2, WGI SPM B.5.3, WGI SPM B.5.4, WGI SPM C.2.5, WGI Box TS.4, WGI Box TS.9, WGI 9.5.1; WGII TS C.5; SROCC SPM B.3, SROCC SPM B.6, SROCC SPM B.9} (Figure 3.4)

The probability of low-likelihood outcomes associated with potentially very large impacts increases with higher global warming levels (*high confidence*). Warming substantially above the assessed *very likely* range for a given scenario cannot be ruled out, and there is *high confidence* this would lead to regional changes greater than assessed in many aspects of the climate system. Low-likelihood, high-impact outcomes could occur at regional scales even for global warming within the *very likely* assessed range for a given GHG emissions scenario. Global mean sea level rise above the *likely* range – approaching 2 m by 2100 and in excess of 15 m by 2300 under a very high GHG emissions scenario (SSP5-8.5) (*low confidence*) – cannot be ruled out due to deep uncertainty in ice-sheet processes¹²³ and would have severe

¹²³ This outcome is characterised by deep uncertainty: Its likelihood defies quantitative assessment but is considered due to its high potential impact. {WGI Box TS.1; WGII Cross-Chapter Box DEEP}

impacts on populations in low elevation coastal zones. If global warming increases, some compound extreme events¹²⁴ will become more frequent, with higher likelihood of unprecedented intensities, durations or spatial extent (*high confidence*). The Atlantic Meridional Overturning Circulation is *very likely* to weaken over the 21st century for all considered scenarios (*high confidence*), however an abrupt collapse is not expected before 2100 (*medium confidence*). If such a low probability event were to occur, it would *very likely* cause abrupt shifts in regional weather patterns and water cycle,

such as a southward shift in the tropical rain belt, and large impacts on ecosystems and human activities. A sequence of large explosive volcanic eruptions within decades, as have occurred in the past, is a low-likelihood high-impact event that would lead to substantial cooling globally and regional climate perturbations over several decades. {WGI SPM B.5.3, WGI SPM C.3, WGI SPM C.3.1, WGI SPM C.3.2, WGI SPM C.3.3, WGI SPM C.3.4, WGI SPM C.3.5, WGI Figure SPM.8, WGI Box TS.3, WGI Figure TS.6, WGI Box 9.4; WGII SPM B.4.5, WGII SPM C.2.8; SROCC SPM B.2.7} (Figure 3.4, Cross-Section Box.2)

3.2 Long-term Adaptation Options and Limits

With increasing warming, adaptation options will become more constrained and less effective. At higher levels of warming, losses and damages will increase, and additional human and natural systems will reach adaptation limits. Integrated, cross-cutting multi-sectoral solutions increase the effectiveness of adaptation. Maladaptation can create lock-ins of vulnerability, exposure and risks but can be avoided by long-term planning and the implementation of adaptation actions that are flexible, multi-sectoral and inclusive. (*high confidence*)

The effectiveness of adaptation to reduce climate risk is documented for specific contexts, sectors and regions and will decrease with increasing warming (*high confidence*)¹²⁵. For example, common adaptation responses in agriculture – adopting improved cultivars and agronomic practices, and changes in cropping patterns and crop systems – will become less effective from 2°C to higher levels of warming (*high confidence*). The effectiveness of most water-related adaptation options to reduce projected risks declines with increasing warming (*high confidence*). Adaptations for hydropower and thermo-electric power generation are effective in most regions up to 1.5°C to 2°C, with decreasing effectiveness at higher levels of warming (*medium confidence*). Ecosystem-based Adaptation is vulnerable to climate change impacts, with effectiveness declining with increasing global warming (*high confidence*). Globally, adaptation options related to agroforestry and forestry have a sharp decline in effectiveness at 3°C, with a substantial increase in residual risk (*medium confidence*). {WGII SPM C.2, WGII SPM C.2.1, WGII SPM C.2.5, WGII SPM C.2.10, WGII Figure TS.6 Panel (e), 4.7.2}

With increasing global warming, more limits to adaptation will be reached and losses and damages, strongly concentrated among the poorest vulnerable populations, will increase (*high confidence*). Already below 1.5°C, autonomous and evolutionary adaptation responses by terrestrial and aquatic ecosystems will increasingly face hard limits (*high confidence*) (Section 2.1.2). Above 1.5°C, some ecosystem-based adaptation measures will lose their effectiveness in providing benefits to people as these ecosystems will reach hard adaptation limits (*high confidence*). Adaptation to address the risks of heat stress, heat mortality and reduced capacities for outdoor work for humans face soft and hard limits across regions that become significantly more severe at 1.5°C, and are particularly relevant for regions with warm climates (*high confidence*). Above 1.5°C global warming level, limited freshwater resources pose potential hard limits for small islands and for regions dependent on glacier and snow melt

(*medium confidence*). By 2°C, soft limits are projected for multiple staple crops, particularly in tropical regions (*high confidence*). By 3°C, soft limits are projected for some water management measures for many regions, with hard limits projected for parts of Europe (*medium confidence*). {WGII SPM C.3, WGII SPM C.3.3, WGII SPM C.3.4, WGII SPM C.3.5, WGII TS.D.2.2, WGII TS.D.2.3; SR1.5 SPM B.6; SROCC SPM C.1}

Integrated, cross-cutting multi-sectoral solutions increase the effectiveness of adaptation. For example, inclusive, integrated and long-term planning at local, municipal, sub-national and national scales, together with effective regulation and monitoring systems and financial and technological resources and capabilities foster urban and rural system transition. There are a range of cross-cutting adaptation options, such as disaster risk management, early warning systems, climate services and risk spreading and sharing that have broad applicability across sectors and provide greater benefits to other adaptation options when combined. Transitioning from incremental to transformational adaptation, and addressing a range of constraints, primarily in the financial, governance, institutional and policy domains, can help overcome soft adaptation limits. However, adaptation does not prevent all losses and damages, even with effective adaptation and before reaching soft and hard limits. (*high confidence*) {WGII SPM C.2, WGII SPM C.2.6, WGII SPM C.2.13, WGII SPM C.3.1, WGII SPM C.3.4, WGII SPM C.3.5, WGII Figure TS.6 Panel (e)}

Maladaptive responses to climate change can create lock-ins of vulnerability, exposure and risks that are difficult and expensive to change and exacerbate existing inequalities. Actions that focus on sectors and risks in isolation and on short-term gains often lead to maladaptation. Adaptation options can become maladaptive due to their environmental impacts that constrain ecosystem services and decrease biodiversity and ecosystem resilience to climate change or by causing adverse outcomes for different groups, exacerbating inequity. Maladaptation can be avoided by flexible, multi-sectoral, inclusive and

¹²⁴ See Annex I: Glossary. Examples of compound extreme events are concurrent heatwaves and droughts or compound flooding. {WGI SPM Footnote 18}

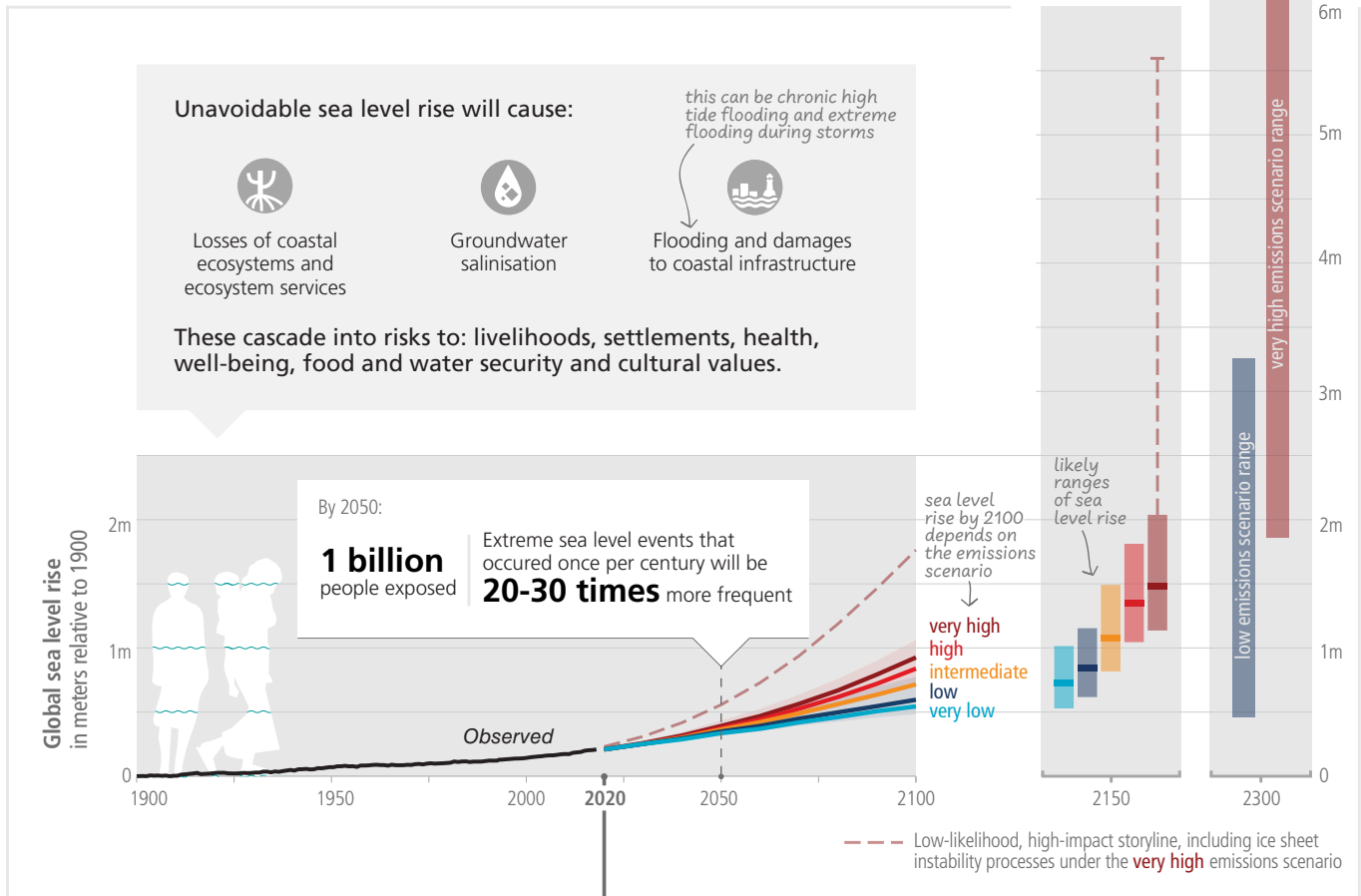
¹²⁵ There are limitations to assessing the full scope of adaptation options available in the future since not all possible future adaptation responses can be incorporated in climate impact models, and projections of future adaptation depend on currently available technologies or approaches. {WGII 4.7.2}

long-term planning and implementation of adaptation actions with benefits to many sectors and systems. (*high confidence*) {*WGII SPM C.4, WGII SPM.C.4.1, WGII SPM C.4.2, WGII SPM C.4.3*}

Sea level rise poses a distinctive and severe adaptation challenge as it implies both dealing with slow onset changes and increases in the frequency and magnitude of extreme sea level events (*high confidence*). Such adaptation challenges would occur much earlier under high rates of sea level rise (*high confidence*). Responses to ongoing sea level rise and land subsidence include protection, accommodation, advance and planned relocation (*high confidence*). These responses are more effective if combined and/or sequenced, planned well ahead, aligned with sociocultural values and underpinned by inclusive community engagement processes (*high confidence*). Ecosystem-based solutions such as wetlands provide co-benefits for the environment and climate mitigation, and reduce costs for flood defences (*medium confidence*), but have site-specific physical limits, at least above 1.5°C of global warming (*high confidence*) and lose effectiveness at high rates of sea level rise beyond 0.5 to 1 cm yr⁻¹ (*medium confidence*). Seawalls can be maladaptive as they effectively reduce impacts in the short term but can also result in lock-ins and increase exposure to climate risks in the long term unless they are integrated into a long-term adaptive plan (*high confidence*). {*WGI SPM C.2.5; WGII SPM C.2.8, WGII SPM C.4.1; WGII 13.10, WGII Cross-Chapter Box SLR; SROCC SPM B.9, SROCC SPM C.3.2, SROCC Figure SPM.4, SROCC Figure SPM.5c*} (Figure 3.4)

Sea level rise will continue for millennia, but how fast and how much depends on future emissions

a) Sea level rise: observations and projections 2020-2100, 2150, 2300 (relative to 1900)



Responding to sea level rise requires long-term planning

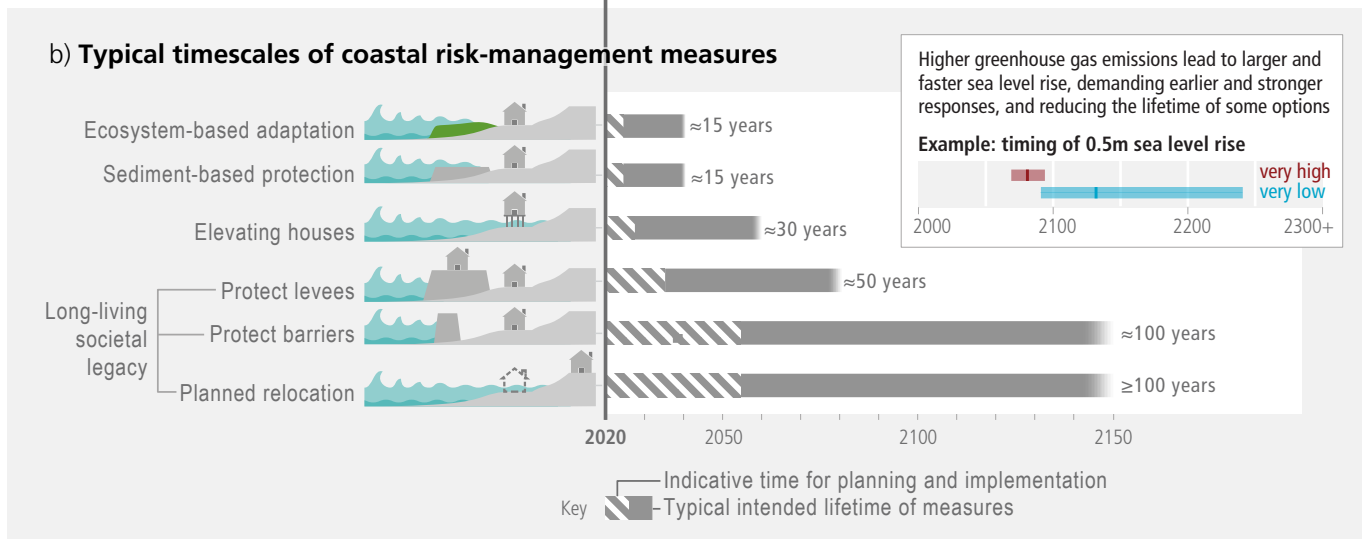


Figure 3.4: Observed and projected global mean sea level change and its impacts, and time scales of coastal risk management. Panel (a): Global mean sea level change in metres relative to 1900. The historical changes (black) are observed by tide gauges before 1992 and altimeters afterwards. The future changes to 2100 and for 2150 (coloured lines and shading) are assessed consistently with observational constraints based on emulation of CMIP, ice-sheet, and glacier models, and median values and *likely* ranges are shown for the considered scenarios. Relative to 1995-2014, the *likely* global mean sea level rise by 2050 is between 0.15 to 0.23 m in the very low GHG emissions scenario (SSP1-1.9) and 0.20 to 0.29 m in the very high GHG emissions scenario (SSP5-8.5); by 2100 between 0.28 to 0.55 m under SSP1-1.9 and 0.63 to 1.01 m under SSP5-8.5; and by 2150 between 0.37 to 0.86 m under SSP1-1.9 and 0.98 to 1.88 m under SSP5-8.5 (*medium confidence*). Changes relative to 1900 are calculated by adding 0.158 m (observed global mean sea level rise from 1900 to 1995-2014) to simulated changes relative to 1995-2014. The future changes to 2300 (bars) are based on literature assessment, representing the 17th–83rd percentile range for SSP1-2.6 (0.3 to 3.1 m) and SSP5-8.5 (1.7 to 6.8 m). Red dashed lines: Low-likelihood, high-impact storyline, including ice sheet instability processes. These indicate the potential impact of deeply uncertain processes, and show the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact processes that cannot be ruled out; because of *low confidence* in projections of these processes, this is not part of a *likely* range. IPCC AR6 global and regional sea level projections are hosted at <https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool>. The low-lying coastal zone is currently home to around 896 million people (nearly 11% of the 2020 global population), projected to reach more than one billion by 2050 across all five SSPs. Panel (b): Typical time scales for the planning, implementation (dashed bars) and operational lifetime of current coastal risk-management measures (blue bars). Higher rates of sea level rise demand earlier and stronger responses and reduce the lifetime of measures (inset). As the scale and pace of sea level rise accelerates beyond 2050, long-term adjustments may in some locations be beyond the limits of current adaptation options and for some small islands and low-lying coasts could be an existential risk. {WGI SPM B.5, WGI C.2.5, WGI Figure SPM.8, WGI 9.6; WGII SPM B.4.5, WGII B.5.2, WGII C.2.8, WGII D.3.3, WGII TS.D.7, WGII Cross-Chapter Box SLR} (Cross-Section Box.2)

3.3 Mitigation Pathways

Limiting human-caused global warming requires net zero anthropogenic CO₂ emissions. Pathways consistent with 1.5°C and 2°C carbon budgets imply rapid, deep, and in most cases immediate GHG emission reductions in all sectors (*high confidence*). Exceeding a warming level and returning (i.e. overshoot) implies increased risks and potential irreversible impacts; achieving and sustaining global net negative CO₂ emissions would reduce warming (*high confidence*).

3.3.1 Remaining Carbon Budgets

Limiting global temperature increase to a specific level requires limiting cumulative net CO₂ emissions to within a finite carbon budget¹²⁶, along with strong reductions in other GHGs. For every 1000 GtCO₂ emitted by human activity, global mean temperature rises by *likely* 0.27°C to 0.63°C (best estimate of 0.45°C). This relationship implies that there is a finite carbon budget that cannot be exceeded in order to limit warming to any given level. {WGI SPM D.1, WGI SPM D.1.1; SR1.5 SPM C.1.3} (Figure 3.5)

The best estimates of the remaining carbon budget (RCB) from the beginning of 2020 for limiting warming to 1.5°C with a 50% likelihood¹²⁷ is estimated to be 500 GtCO₂; for 2°C (67% likelihood) this is 1150 GtCO₂.¹²⁸ Remaining carbon budgets have been quantified based on the assessed value of TCRE and its uncertainty, estimates of historical warming, climate system feedbacks such as emissions from thawing permafrost, and the global surface temperature change after global anthropogenic CO₂ emissions reach net zero, as well as variations in projected warming from non-CO₂ emissions due in part to mitigation action. The stronger the reductions in non-CO₂ emissions the lower the resulting temperatures are for a given RCB or the larger RCB for the same level of temperature change. For instance, the RCB for limiting warming to 1.5°C with a 50% likelihood could vary between 300 to 600 GtCO₂ depending on non-CO₂ warming¹²⁹. Limiting warming to 2°C with a 67% (or 83%) likelihood would imply a RCB of 1150 (900) GtCO₂ from the beginning of 2020. To stay below 2°C with a 50% likelihood, the RCB is higher, i.e., 1350 GtCO₂¹³⁰. {WGI SPM D.1.2, WGI Table SPM.2; WGIII Box SPM.1, WGIII Box 3.4; SR1.5 SPM C.1.3}

If the annual CO₂ emissions between 2020–2030 stayed, on average, at the same level as 2019, the resulting cumulative emissions would almost exhaust the remaining carbon budget for 1.5°C (50%), and exhaust more than a third of the remaining carbon budget for 2°C (67%) (Figure 3.5). Based on central estimates only, historical cumulative net CO₂ emissions between 1850 and 2019 (2400 ±240 GtCO₂) amount to about four-fifths¹³¹ of the total carbon budget for a 50% probability of limiting global warming to 1.5°C (central estimate about 2900 GtCO₂) and to about two-thirds¹³² of the total carbon budget for a 67% probability to limit global warming to 2°C (central estimate about 3550 GtCO₂). {WGI Table SPM.2; WGIII SPM B.1.3, WGIII Table 2.1}

In scenarios with increasing CO₂ emissions, the land and ocean carbon sinks are projected to be less effective at slowing the accumulation of CO₂ in the atmosphere (*high confidence*). While natural land and ocean carbon sinks are projected to take up, in absolute terms, a progressively larger amount of CO₂ under higher compared to lower CO₂ emissions scenarios, they become less effective, that is, the proportion of emissions taken up by land and ocean decreases with increasing cumulative net CO₂ emissions (*high confidence*). Additional ecosystem responses to warming not yet fully included in climate models, such as GHG fluxes from wetlands, permafrost thaw, and wildfires, would further increase concentrations of these gases in the atmosphere (*high confidence*). In scenarios where CO₂ concentrations peak and decline during the 21st century, the land and ocean begin to take up less carbon in response to declining atmospheric CO₂ concentrations (*high confidence*) and turn into a weak net source by 2100 in the very low GHG emissions scenario (*medium confidence*)¹³³. {WGI SPM B.4, WGI SPM B.4.1, WGI SPM B.4.2, WGI SPM B.4.3}

¹²⁶ See Annex I: Glossary.

¹²⁷ This likelihood is based on the uncertainty in transient climate response to cumulative net CO₂ emissions and additional Earth system feedbacks and provides the probability that global warming will not exceed the temperature levels specified. {WGI Table SPM.1}

¹²⁸ Global databases make different choices about which emissions and removals occurring on land are considered anthropogenic. Most countries report their anthropogenic land CO₂ fluxes including fluxes due to human-caused environmental change (e.g., CO₂ fertilisation) on 'managed' land in their National GHG inventories. Using emissions estimates based on these inventories, the remaining carbon budgets must be correspondingly reduced. {WGIII SPM Footnote 9, WGIII TS.3, WGIII Cross-Chapter Box 6}

¹²⁹ The central case RCB assumes future non-CO₂ warming (the net additional contribution of aerosols and non-CO₂ GHG) of around 0.1°C above 2010–2019 in line with stringent mitigation scenarios. If additional non-CO₂ warming is higher, the RCB for limiting warming to 1.5°C with a 50% likelihood shrinks to around 300 GtCO₂. If, however, additional non-CO₂ warming is limited to only 0.05°C (via stronger reductions of CH₄ and N₂O through a combination of deep structural and behavioural changes, e.g., dietary changes), the RCB could be around 600 GtCO₂ for 1.5°C warming. {WGI Table SPM.2, WGI Box TS.7; WGIII Box 3.4}

¹³⁰ When adjusted for emissions since previous reports, these RCB estimates are similar to SR1.5 but larger than AR5 values due to methodological improvements. {WGI SPM D.1.3}

¹³¹ Uncertainties for total carbon budgets have not been assessed and could affect the specific calculated fractions.

¹³² See footnote 131.

¹³³ These projected adjustments of carbon sinks to stabilisation or decline of atmospheric CO₂ concentrations are accounted for in calculations of remaining carbon budgets. {WGI SPM footnote 32}

Remaining carbon budgets to limit warming to 1.5°C could soon be exhausted, and those for 2°C largely depleted

Remaining carbon budgets are similar to emissions from use of existing and planned fossil fuel infrastructure, without additional abatement

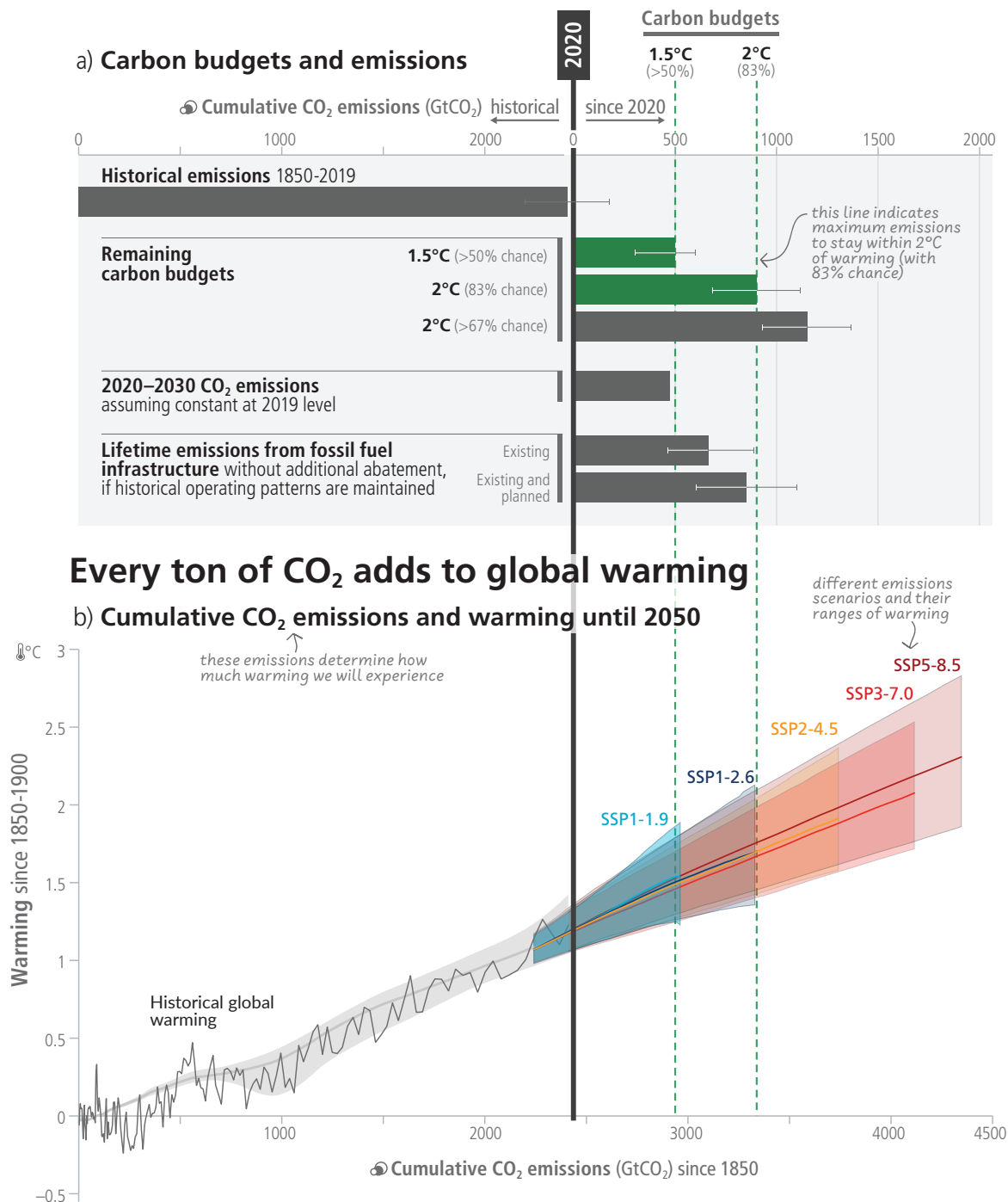


Figure 3.5: Cumulative past, projected, and committed emissions, and associated global temperature changes. Panel (a) Assessed remaining carbon budgets to limit warming *more likely than not* to 1.5°C, to 2°C with a 83% and 67% likelihood, compared to cumulative emissions corresponding to constant 2019 emissions until 2030, existing and planned fossil fuel infrastructures (in GtCO₂). For remaining carbon budgets, thin lines indicate the uncertainty due to the contribution of non-CO₂ warming. For lifetime emissions from fossil fuel infrastructure, thin lines indicate the assessed sensitivity range. **Panel (b)** Relationship between cumulative CO₂ emissions and the increase in global surface temperature. Historical data (thin black line) shows historical CO₂ emissions versus observed global surface temperature increase relative to the period 1850-1900. The grey range with its central line shows a corresponding estimate of the human-caused share of historical warming. Coloured areas show the assessed *very likely* range of global surface temperature projections, and thick coloured central lines show the median estimate as a function of cumulative CO₂ emissions for the selected scenarios SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5. Projections until 2050 use the cumulative CO₂ emissions of each respective scenario, and the projected global warming includes the contribution from all anthropogenic forcings. {WGI SPM D.1, WGI Figure SPM.10, WGI Table SPM.2; WGIII SPM B.1, WGIII SPM B.7, WGIII 2.7; SR1.5 SPM C.1.3}

Table 3.1: Key characteristics of the modelled global emissions pathways. Summary of projected CO₂ and GHG emissions, projected net zero timings and the resulting global warming outcomes. Pathways are categorised (columns), according to their likelihood of limiting warming to different peak warming levels (if peak temperature occurs before 2100) and 2100 warming levels. Values shown are for the median [p50] and 5–95th percentiles [p5–p95], noting that not all pathways achieve net zero CO₂ or GHGs. {WGIII Table SPM.2}

Category (²) [# pathways]	Modelled global emissions pathways categorised by projected global warming levels (GWL). Detailed likelihood definitions are provided in SPM Box1. The five illustrative scenarios (SSPx-yy) considered by AR6 WGI and the Illustrative (Mitigation) Pathways assessed in WGIII are aligned with the temperature categories and are indicated in a separate column. Global emission pathways contain regionally differentiated information. This assessment focuses on their global characteristics.	C1 [97]			C2 [133]	C3 [311]	C3a [204]		C3b [97]	C4 [159]	C5 [212]	C6 [97]
		C1a [50]	C1b [47]	limit warming to 1.5°C (>50%) with no or limited overshoot	... with net zero GHGs	... without net zero GHGs	return warming to 1.5°C (>50%) after a high overshoot	limit warming to 2°C (>67%)	... with action starting in 2020	... NDCs until 2030	limit warming to 2°C (>50%)	limit warming to 2.5°C (>50%)
GHG emissions reductions from 2019 (%) ⁽³⁾	2030	43 [34-60]	41 [31-59]	48 [35-61]	23 [0-44]	21 [1-42]	27 [13-45]	5 [0-14]	10 [0-27]	6 [-1 to 18]	2 [-10 to 11]	
	2040	69 [58-90]	66 [58-89]	70 [62-87]	55 [40-71]	46 [34-63]	47 [35-63]	46 [34-63]	31 [20-5]	18 [4-33]	3 [-14 to 14]	
	2050	84 [73-98]	85 [72-100]	84 [76-93]	75 [62-91]	64 [53-77]	63 [52-76]	68 [56-83]	49 [35-65]	29 [11-48]	5 [-2 to 18]	
Emissions milestones ⁽⁴⁾	Net zero CO ₂ (% net zero pathways)	2050-2055 (100%) [2035-2070]			2055-2060 (100%) [2045-2070]	2070-2075 (93%) [2055-...]	2070-2075 (91%) [2055-...]	2065-2070 (97%) [2055-2090]	2080-2085 (86%) [2065-...]	...-... (41%) [2080-...]	no net-zero	
	Net zero GHGs (% net zero pathways) ⁽⁵⁾	2095-2100 (52%) [2050-...]	2070-2075 (100%) [2050-2090]	...-... (0%) [...-...]	2070-2075 (87%) [2055-...]	...-... (30%) [2075-...]	...-... (24%) [2080-...]	...-... (41%) [2075-...]	...-... (31%) [2075-...]	...-... (12%) [2090-...]	no net-zero	
Cumulative CO ₂ emissions [Gt CO ₂] ⁽⁶⁾	2020 to net zero CO ₂	510 [330-710]	550 [340-760]	460 [320-590]	720 [530-930]	890 [640-1160]	860 [640-1180]	910 [720-1150]	1210 [970-1490]	1780 [1400-2360]	no net-zero	
	2020–2100	320 [-210-570]	160 [-220-620]	360 [10-540]	400 [-90-620]	800 [510-1140]	790 [480-1150]	800 [560-1050]	1160 [700-1490]	1780 [1260-2360]	2790 [2440-3520]	
Global mean temperature changes 50% probability (°C)	at peak warming	1.6 [1.4-1.6]	1.6 [1.4-1.6]	1.6 [1.5-1.6]	1.7 [1.5-1.8]	1.7 [1.6-1.8]	1.7 [1.6-1.8]	1.8 [1.6-1.8]	1.9 [1.7-2.0]	2.2 [1.9-2.5]	no peaking by 2100	
	2100	1.3 [1.1-1.5]	1.2 [1.1-1.4]	1.4 [1.3-1.5]	1.4 [1.2-1.5]	1.6 [1.5-1.8]	1.6 [1.5-1.8]	1.6 [1.5-1.7]	1.8 [1.5-2.0]	2.1 [1.9-2.5]	2.7 [2.4-2.9]	
Likelihood of peak global warming staying below (%)	<1.5°C	38 [33-58]	38 [34-60]	37 [33-56]	24 [15-42]	20 [13-41]	21 [14-42]	17 [12-35]	11 [7-22]	4 [0-10]	0 [0-0]	
	<2.0°C	90 [86-97]	90 [85-97]	89 [87-96]	82 [71-93]	76 [68-91]	78 [69-91]	73 [67-87]	59 [50-77]	37 [18-59]	8 [2-18]	
	<3.0°C	100 [99-100]	100 [99-100]	100 [99-100]	100 [99-100]	99 [98-100]	100 [98-100]	99 [98-99]	98 [95-99]	91 [83-98]	71 [53-88]	

1 Detailed explanations on the Table are provided in WGIII Box SPM.1 and WGIII Table SPM.2. The relationship between the temperature categories and SSP/RCPs is discussed in Cross-Section Box.2. Values in the table refer to the 50th and [5–95th] percentile values across the pathways falling within a given category as defined in WGIII Box SPM.1. The three dots (...) sign denotes that the value cannot be given (as the value is after 2100 or, for net zero, net zero is not reached). Based on the assessment of climate emulators in AR6 WG I (Chapter 7, Box 7.1), two climate emulators were used for the probabilistic assessment of the resulting warming of the pathways. For the 'Temperature Change' and 'Likelihood' columns, the non-bracketed values represent the 50th percentile across the pathways in that category and the median [50th percentile] across the warming estimates of the probabilistic MAGICC climate model emulator. For the bracketed ranges in the "likelihood" column, the median warming for every pathway in that category is calculated for each of the two climate model emulators (MAGICC and FaIR). These ranges cover both the uncertainty of the emissions pathways as well as the climate emulators' uncertainty. All global warming levels are relative to 1850-1900.

2 C3 pathways are sub-categorised according to the timing of policy action to match the emissions pathways in WGIII Figure SPM.4.

3 Global emission reductions in mitigation pathways are reported on a pathway-by-pathway basis relative to harmonised modelled global emissions in 2019 rather than

the global emissions reported in WGIII SPM Section B and WGIII Chapter 2; this ensures internal consistency in assumptions about emission sources and activities, as well as consistency with temperature projections based on the physical climate science assessment by WGI (see WGIII SPM Footnote 49). Negative values (e.g., in C5, C6) represent an increase in emissions. The modelled GHG emissions in 2019 are 55 [53–58] GtCO₂-eq, thus within the uncertainty ranges of estimates for 2019 emissions [53–66] GtCO₂-eq (see 2.1.1).

4 Emissions milestones are provided for 5-year intervals in order to be consistent with the underlying 5-year time-step data of the modelled pathways. Ranges in square brackets underneath refer to the range across the pathways, comprising the lower bound of the 5th percentile 5-year interval and the upper bound of the 95th percentile 5-year interval. Numbers in round brackets signify the fraction of pathways that reach specific milestones over the 21st century. Percentiles reported across all pathways in that category include those that do not reach net zero before 2100.

5 For cases where models do not report all GHGs, missing GHG species are infilled and aggregated into a Kyoto basket of GHG emissions in CO₂-eq defined by the 100-year global warming potential. For each pathway, reporting of CO₂, CH₄, and N₂O emissions was the minimum required for the assessment of the climate response and the assignment to a climate category. Emissions pathways without climate assessment are not included in the ranges presented here. See WGIII Annex III.II.5.

6 Cumulative emissions are calculated from the start of 2020 to the time of net zero and 2100, respectively. They are based on harmonised net CO₂ emissions, ensuring consistency with the WG I assessment of the remaining carbon budget. {WGIII Box 3.4, WGIII SPM Footnote 50}

3.3.2 Net Zero Emissions: Timing and Implications

From a physical science perspective, limiting human-caused global warming to a specific level requires limiting cumulative CO₂ emissions, reaching net zero or net negative CO₂ emissions, along with strong reductions of other GHG emissions (see Cross-Section Box.1). Global modelled pathways that reach and sustain net zero GHG emissions are projected to result in a gradual decline in surface temperature (*high confidence*). Reaching net zero GHG emissions primarily requires deep reductions in CO₂, methane, and other GHG emissions, and implies net negative CO₂ emissions.¹³⁴ Carbon dioxide removal (CDR) will be necessary to achieve net negative CO₂ emissions¹³⁵. Achieving global net zero CO₂ emissions, with remaining anthropogenic CO₂ emissions balanced by durably stored CO₂ from anthropogenic removal, is a requirement to stabilise CO₂-induced global surface temperature increase (see 3.3.3) (*high confidence*). This is different from achieving net zero GHG emissions, where metric-weighted anthropogenic GHG emissions (see Cross-Section Box.1) equal CO₂ removal (*high confidence*). Emissions pathways that reach and sustain net zero GHG emissions defined by the 100-year global warming potential imply net negative CO₂ emissions and are projected to result in a gradual decline in surface temperature after an earlier peak (*high confidence*). While reaching net zero CO₂ or net zero GHG emissions requires deep and rapid reductions in gross emissions, the deployment of CDR to counterbalance hard-to-abate residual emissions (e.g., some emissions from agriculture, aviation, shipping, and industrial processes) is unavoidable (*high confidence*). {WGI SPM D.1, WGI SPM D.1.1, WGI SPM D.1.8; WGIII SPM C.2, WGIII SPM C.3, WGIII SPM C.11, WGIII Box TS.6; SR1.5 SPMA.2.2}

In modelled pathways, the timing of net zero CO₂ emissions, followed by net zero GHG emissions, depends on several variables, including the desired climate outcome, the mitigation strategy and the gases covered (*high confidence*). Global net zero CO₂ emissions are reached in the early 2050s in pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, and around the early 2070s in pathways that limit warming to 2°C (>67%). While non-CO₂ GHG emissions are strongly reduced in all pathways that limit warming to 2°C (>67%) or lower, residual emissions of CH₄ and N₂O and F-gases of about 8 [5–11] GtCO₂-eq yr⁻¹ remain at the time of

net zero GHG, counterbalanced by net negative CO₂ emissions. As a result, net zero CO₂ would be reached before net zero GHGs (*high confidence*). {WGIII SPM C.2, WGIII SPM C.2.3, WGIII SPM C.2.4, WGIII Table SPM.2, WGIII 3.3} (Figure 3.6)

¹³⁴ Net zero GHG emissions defined by the 100-year global warming potential. See footnote 70.

¹³⁵ See Section 3.3.3 and 3.4.1.

Global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot reach net zero CO₂ emissions around 2050

Total greenhouse gases (GHG) reach net zero later

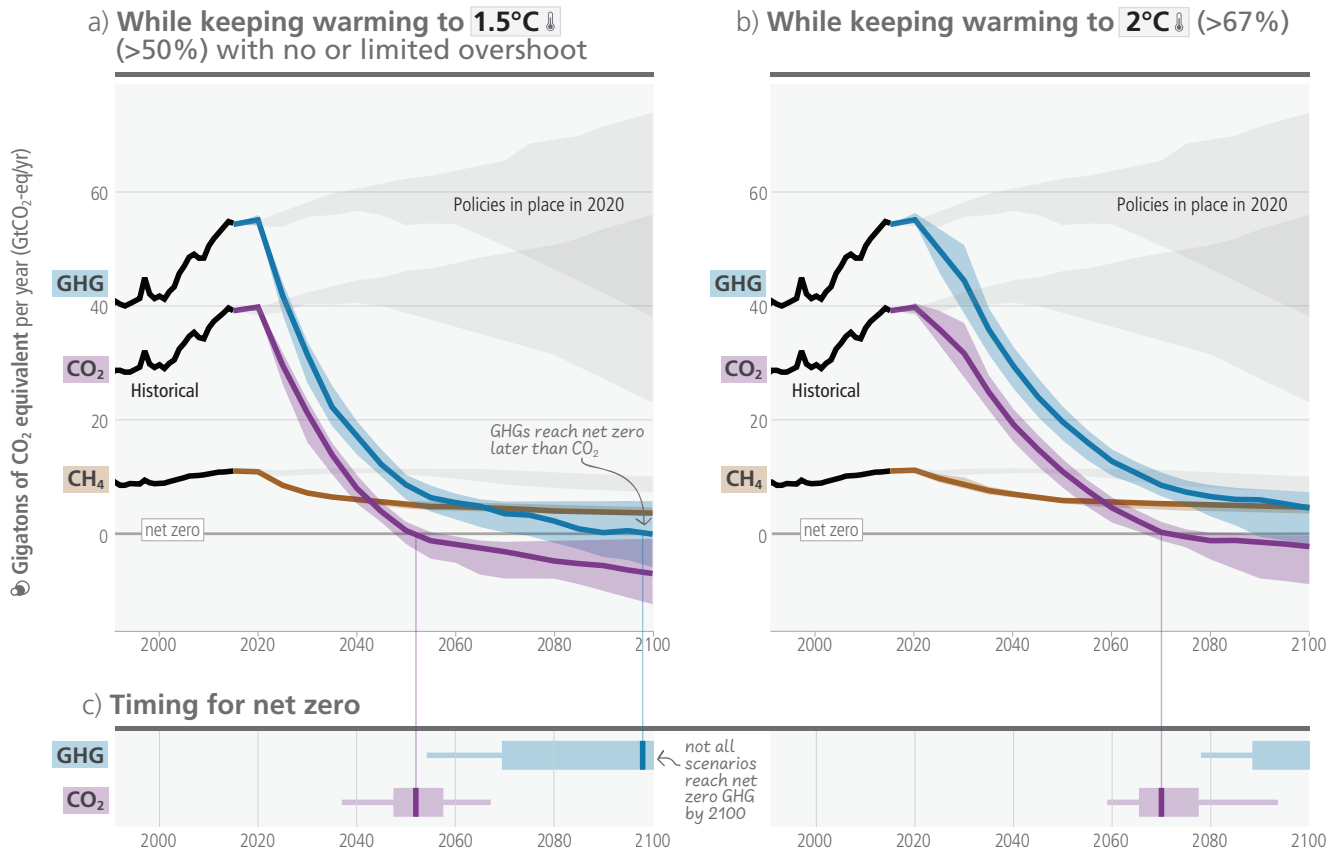


Figure 3.6: Total GHG, CO₂ and CH₄ emissions and timing of reaching net zero in different mitigation pathways. Top row: GHG, CO₂ and CH₄ emissions over time (in GtCO₂eq) with historical emissions, projected emissions in line with policies implemented until the end of 2020 (grey), and pathways consistent with temperature goals in colour (blue, purple, and brown, respectively). Panel (a) (left) shows pathways that limit warming to 1.5°C (>50%) with no or limited overshoot (C1) and Panel (b) (right) shows pathways that limit warming to 2°C (>67%) (C3). Bottom row: Panel (c) shows median (vertical line), likely (bar) and very likely (thin lines) timing of reaching net zero GHG and CO₂ emissions for global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot (C1) (left) or 2°C (>67%) (C3) (right). {WGIII Figure SPM.5}

3.3.3 Sectoral Contributions to Mitigation

All global modelled pathways that limit warming to 2°C (>67%) or lower by 2100 involve rapid and deep and in most cases immediate GHG emissions reductions in all sectors (see also 4.1, 4.5). Reductions in GHG emissions in industry, transport, buildings, and urban areas can be achieved through a combination of energy efficiency and conservation and a transition to low-GHG technologies and energy carriers (see also 4.5, Figure 4.4). Socio-cultural options and behavioural change can reduce global GHG emissions of end-use sectors, with most of the potential in developed countries, if combined with improved

infrastructure design and access. (high confidence) {WGIII SPM C.3, WGIII SPM C.5, WGIII SPM C.6, WGIII SPM C.7.3, WGIII SPM C.8, WGIII SPM C.10.2}

Global modelled mitigation pathways reaching net zero CO₂ and GHG emissions include transitioning from fossil fuels without carbon capture and storage (CCS) to very low- or zero-carbon energy sources, such as renewables or fossil fuels with CCS, demand-side measures and improving efficiency, reducing non-CO₂ GHG emissions, and CDR¹³⁶. In global modelled pathways that limit warming to 2°C or below, almost all electricity is supplied

¹³⁶ CCS is an option to reduce emissions from large-scale fossil-based energy and industry sources provided geological storage is available. When CO₂ is captured directly from the atmosphere (DACCS), or from biomass (BECCS), CCS provides the storage component of these CDR methods. CO₂ capture and subsurface injection is a mature technology for gas processing and enhanced oil recovery. In contrast to the oil and gas sector, CCS is less mature in the power sector, as well as in cement and chemicals production, where it is a critical mitigation option. The technical geological storage capacity is estimated to be on the order of 1000 GtCO₂, which is more than the CO₂ storage requirements through 2100 to limit global warming to 1.5°C, although the regional availability of geological storage could be a limiting factor. If the geological storage site is appropriately selected and managed, it is estimated that the CO₂ can be permanently isolated from the atmosphere. Implementation of CCS currently faces technological, economic, institutional, ecological environmental and socio-cultural barriers. Currently, global rates of CCS deployment are far below those in modelled pathways limiting global warming to 1.5°C to 2°C. Enabling conditions such as policy instruments, greater public support and technological innovation could reduce these barriers. (high confidence) {WGIII SPM C.4.6}

from zero or low-carbon sources in 2050, such as renewables or fossil fuels with CO₂ capture and storage, combined with increased electrification of energy demand. Such pathways meet energy service demand with relatively low energy use, through e.g., enhanced energy efficiency and behavioural changes and increased electrification of energy end use. Modelled global pathways limiting global warming to 1.5°C (>50%) with no or limited overshoot generally implement such changes faster than pathways limiting global warming to 2°C (>67%). (*high confidence*) {*WGIII SPM C.3*, *WGIII SPM C.3.2*, *WGIII SPM C.4*, *WGIII TS.4.2*; *SR1.5 SPM C.2.2*}

AFOLU mitigation options, when sustainably implemented, can deliver large-scale GHG emission reductions and enhanced CO₂ removal; however, barriers to implementation and trade-offs may result from the impacts of climate change, competing demands on land, conflicts with food security and livelihoods, the complexity of land ownership and management systems, and cultural aspects (see 3.4.1). All assessed modelled pathways that limit warming to 2°C (>67%) or lower by 2100 include land-based mitigation and land-use change, with most including different combinations of reforestation, afforestation, reduced deforestation, and bioenergy. However, accumulated carbon in vegetation and soils is at risk from future loss (or sink reversal) triggered by climate change and disturbances such as flood, drought, fire, or pest outbreaks, or future poor management. (*high confidence*) {*WGI SPM B.4.3*; *WGII SPM B.2.3*, *WGII SPM B.5.4*; *WGIII SPM C.9*, *WGIII SPM C.11.3*, *WGIII SPM D.2.3*, *WGIII TS.4.2*, *3.4*; *SR1.5 SPM C.2.5*; *SRCL SPM B.1.4*, *SRCL SPM B.3*, *SRCL SPM B.7*}

In addition to deep, rapid, and sustained emission reductions, CDR can fulfil three complementary roles: lowering net CO₂ or net GHG emissions in the near term; counterbalancing 'hard-to-abate' residual emissions (e.g., some emissions from agriculture, aviation, shipping, industrial processes) to help reach net zero CO₂ or GHG emissions, and achieving net negative CO₂ or GHG emissions if deployed at levels exceeding annual residual emissions (*high confidence*). CDR methods vary in terms of their maturity, removal process, time scale of carbon storage, storage medium, mitigation potential, cost, co-benefits, impacts and risks, and governance requirements (*high confidence*). Specifically, maturity ranges from lower maturity (e.g., ocean alkalisation) to higher maturity (e.g., reforestation); removal and storage potential ranges from lower potential (<1 Gt CO₂ yr⁻¹, e.g., blue carbon management) to higher potential (>3 Gt CO₂ yr⁻¹, e.g., agroforestry); costs range from lower cost (e.g., -45 to 100 USD tCO₂⁻¹ for soil carbon sequestration) to higher cost (e.g., 100 to 300 USD tCO₂⁻¹ for direct air carbon dioxide capture and storage) (*medium confidence*). Estimated storage timescales vary from decades to centuries for methods that store carbon in vegetation and through soil carbon management, to ten thousand years or more for methods that store carbon in geological formations (*high confidence*). Afforestation, reforestation, improved forest management, agroforestry and soil carbon sequestration are currently the only widely practiced CDR methods (*high confidence*). Methods and levels of CDR deployment in global modelled mitigation pathways vary depending on assumptions about costs, availability and constraints (*high confidence*). {*WGIII SPM C.3.5*, *WGIII SPM C.11.1*, *WGIII SPM C.11.4*}

3.3.4 Overshoot Pathways: Increased Risks and Other Implications

Exceeding a specific remaining carbon budget results in higher global warming. Achieving and sustaining net negative global CO₂ emissions could reverse the resulting temperature exceedance (*high confidence*). Continued reductions in emissions of short-lived climate forcers, particularly methane, after peak temperature has been reached, would also further reduce warming (*high confidence*). Only a small number of the most ambitious global modelled pathways limit global warming to 1.5°C (>50%) without overshoot. {*WGI SPM D.1.1*, *WGI SPM D.1.6*, *WGI SPM D.1.7*; *WGIII TS.4.2*}

Overshoot of a warming level results in more adverse impacts, some irreversible, and additional risks for human and natural systems compared to staying below that warming level, with risks growing with the magnitude and duration of overshoot (*high confidence*). Compared to pathways without overshoot, societies and ecosystems would be exposed to greater and more widespread changes in climatic impact-drivers, such as extreme heat and extreme precipitation, with increasing risks to infrastructure, low-lying coastal settlements, and associated livelihoods (*high confidence*). Overshooting 1.5°C will result in irreversible adverse impacts on certain ecosystems with low resilience, such as polar, mountain, and coastal ecosystems, impacted by ice-sheet melt, glacier melt, or by accelerating and higher committed sea level rise (*high confidence*). Overshoot increases the risks of severe impacts, such as increased wildfires, mass mortality of trees, drying of peatlands, thawing of permafrost and weakening natural land carbon sinks; such impacts could increase releases of GHGs making temperature reversal more challenging (*medium confidence*). {*WGI SPM C.2*, *WGI SPM C.2.1*, *WGI SPM C.2.3*; *WGII SPM B.6*, *WGII SPM B.6.1*, *WGII SPM B.6.2*; *SR1.5 3.6*}

The larger the overshoot, the more net negative CO₂ emissions needed to return to a given warming level (*high confidence*). Reducing global temperature by removing CO₂ would require net negative emissions of 220 GtCO₂ (best estimate, with a *likely* range of 160 to 370 GtCO₂) for every tenth of a degree (*medium confidence*). Modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot reach median values of cumulative net negative emissions of 220 GtCO₂ by 2100, pathways that return warming to 1.5°C (>50%) after high overshoot reach median values of 360 GtCO₂ (*high confidence*).¹³⁷ More rapid reduction in CO₂ and non-CO₂ emissions, particularly methane, limits peak warming levels and reduces the requirement for net negative CO₂ emissions and CDR, thereby reducing feasibility and sustainability concerns, and social and environmental risks (*high confidence*). {*WGI SPM D.1.1*; *WGIII SPM B.6.4*, *WGIII SPM C.2*, *WGIII SPM C.2.2*, *WGIII Table SPM.2*}

¹³⁷ Limited overshoot refers to exceeding 1.5°C global warming by up to about 0.1°C, high overshoot by 0.1°C to 0.3°C, in both cases for up to several decades. {*WGIII Box SPM.1*}

3.4 Long-Term Interactions Between Adaptation, Mitigation and Sustainable Development

Mitigation and adaptation can lead to synergies and trade-offs with sustainable development (*high confidence*). Accelerated and equitable mitigation and adaptation bring benefits from avoiding damages from climate change and are critical to achieving sustainable development (*high confidence*). Climate resilient development¹³⁸ pathways are progressively constrained by every increment of further warming (*very high confidence*). There is a rapidly closing window of opportunity to secure a liveable and sustainable future for all (*very high confidence*).

3.4.1 Synergies and trade-offs, costs and benefits

Mitigation and adaptation options can lead to synergies and trade-offs with other aspects of sustainable development (see also Section 4.6, Figure 4.4). Synergies and trade-offs depend on the pace and magnitude of changes and the development context including inequalities, with consideration of climate justice. The potential or effectiveness of some adaptation and mitigation options decreases as climate change intensifies (see also Sections 3.2, 3.3.3, 4.5). (*high confidence*) {WGII SPM C.2, WGII Figure SPM.4b; WGIII SPM D.1, WGIII SPM D.1.2, WGIII TS.5.1, WGIII Figure SPM.8; SR1.5 SPM D.3, SR1.5 SPM D.4; SRCCL SPM B.2, SRCCL SPM B.3, SRCCL SPM D.3.2, SRCCL Figure SPM.3}

In the energy sector, transitions to low-emission systems will have multiple co-benefits, including improvements in air quality and health. There are potential synergies between sustainable development and, for instance, energy efficiency and renewable energy. (*high confidence*) {WGIII SPM C.4.2, WGIII SPM D.1.3}

For agriculture, land, and food systems, many land management options and demand-side response options (e.g., dietary choices, reduced post-harvest losses, reduced food waste) can contribute to eradicating poverty and eliminating hunger while promoting good health and well-being, clean water and sanitation, and life on land (*medium confidence*). In contrast, certain adaptation options that promote intensification of production, such as irrigation, may have negative effects on sustainability (e.g., for biodiversity, ecosystem services, groundwater depletion, and water quality) (*high confidence*). {WGII TS.D.5.5; WGIII SPM D.10; SRCCL SPM B.2.3}

Reforestation, improved forest management, soil carbon sequestration, peatland restoration and coastal blue carbon management are examples of CDR methods that can enhance biodiversity and ecosystem functions, employment and local livelihoods, depending on context¹³⁹. However, afforestation or production of biomass crops for bioenergy with carbon dioxide capture and storage or biochar can have adverse socio-economic and environmental impacts, including on biodiversity, food and water security, local livelihoods and the rights of Indigenous Peoples, especially if implemented at large scales and where land tenure is insecure. (*high confidence*) {WGII SPM B.5.4, WGII SPM C.2.4; WGIII SPM C.11.2; SR1.5 SPM C.3.4, SR1.5 SPM C.3.5; SRCCL SPM B.3, SRCCL SPM B.7.3, SRCCL Figure SPM.3}

¹³⁸ See Annex I: Glossary.

¹³⁹ The impacts, risks, and co-benefits of CDR deployment for ecosystems, biodiversity and people will be highly variable depending on the method, site-specific context, implementation and scale (*high confidence*). {WGIII SPM C.11.2}

¹⁴⁰ The evidence is too limited to make a similar robust conclusion for limiting warming to 1.5°C. {WGIII SPM footnote 68}

Modelled pathways that assume using resources more efficiently or shift global development towards sustainability include fewer challenges, such as dependence on CDR and pressure on land and biodiversity, and have the most pronounced synergies with respect to sustainable development (*high confidence*). {WGIII SPM C.3.6; SR1.5 SPM D.4.2}

Strengthening climate change mitigation action entails more rapid transitions and higher up-front investments, but brings benefits from avoiding damages from climate change and reduced adaptation costs. The aggregate effects of climate change mitigation on global GDP (excluding damages from climate change and adaptation costs) are small compared to global projected GDP growth. Projected estimates of global aggregate net economic damages and the costs of adaptation generally increase with global warming level. (*high confidence*) {WGII SPM B.4.6, WGII TS.C.10; WGIII SPM C.12.2, WGIII SPM C.12.3}

Cost-benefit analysis remains limited in its ability to represent all damages from climate change, including non-monetary damages, or to capture the heterogeneous nature of damages and the risk of catastrophic damages (*high confidence*). Even without accounting for these factors or for the co-benefits of mitigation, the global benefits of limiting warming to 2°C exceed the cost of mitigation (*medium confidence*). This finding is robust against a wide range of assumptions about social preferences on inequalities and discounting over time (*medium confidence*). Limiting global warming to 1.5°C instead of 2°C would increase the costs of mitigation, but also increase the benefits in terms of reduced impacts and related risks (see 3.1.1, 3.1.2) and reduced adaptation needs (*high confidence*)¹⁴⁰. {WGII SPM B.4, WGII SPM B.6; WGIII SPM C.12, WGIII SPM C.12.2, WGIII SPM C.12.3 WGIII Box TS.7; SR1.5 SPM B.3, SR1.5 SPM B.5, SR1.5 SPM B.6}

Considering other sustainable development dimensions, such as the potentially strong economic benefits on human health from air quality improvement, may enhance the estimated benefits of mitigation (*medium confidence*). The economic effects of strengthened mitigation action vary across regions and countries, depending notably on economic structure, regional emissions reductions, policy design and level of international cooperation (*high confidence*). Ambitious mitigation pathways imply large and sometimes disruptive changes in economic structure, with implications for near-term actions (Section 4.2), equity (Section 4.4), sustainability (Section 4.6), and finance (Section 4.8) (*high confidence*). {WGIII SPM C.12.2, WGIII SPM D.3.2, WGIII TS.4.2}

3.4.2 Advancing Integrated Climate Action for Sustainable Development

An inclusive, equitable approach to integrating adaptation, mitigation and development can advance sustainable development in the long term (*high confidence*). Integrated responses can harness synergies for sustainable development and reduce trade-offs (*high confidence*). Shifting development pathways towards sustainability and advancing climate resilient development is enabled when governments, civil society and the private sector make development choices that prioritise risk reduction, equity and justice, and when decision-making processes, finance and actions are integrated across governance levels, sectors and timeframes (*very high confidence*) (see also Figure 4.2). Inclusive processes involving local knowledge and Indigenous Knowledge increase these prospects (*high confidence*). However, opportunities for action differ substantially among and within regions, driven by historical and ongoing patterns of development (*very high confidence*). Accelerated financial support for developing countries is critical to enhance mitigation and adaptation action (*high confidence*). {WGII SPM C.5.4, WGII SPM D.1, WGII SPM D.1.1, WGII SPM D.1.2, WGII SPM D.2, WGII SPM D.3, WGII SPM D.5, WGII SPM D.5.1, WGII SPM D.5.2; WGIII SPM D.1, WGIII SPM D.2, WGIII SPM D.2.4, WGIII SPM E.2.2, WGIII SPM E.2.3, WGIII SPM E.5.3, WGIII Cross-Chapter Box 5}

Policies that shift development pathways towards sustainability can broaden the portfolio of available mitigation and adaptation responses (*medium confidence*). Combining mitigation with action to shift development pathways, such as broader sectoral policies, approaches that induce lifestyle or behaviour changes, financial regulation, or macroeconomic policies can overcome barriers and open up a broader range of mitigation options (*high confidence*). Integrated, inclusive planning and investment in everyday decision-making about urban infrastructure can significantly increase the adaptive capacity of urban and rural settlements. Coastal cities and settlements play an important role in advancing climate resilient development due to the high number of people living in the Low Elevation Coastal Zone, the escalating and climate compounded risk that they face, and their vital role in national economies and beyond (*high confidence*). {WGII SPM D.3, WGII SPM D.3.3; WGIII SPM E.2, WGIII SPM E.2.2; SR1.5 SPM D.6}

Observed adverse impacts and related losses and damages, projected risks, trends in vulnerability, and adaptation limits demonstrate that transformation for sustainability and climate resilient development action is more urgent than previously assessed (*very high confidence*). Climate resilient development integrates adaptation and GHG mitigation to advance sustainable development for all. Climate resilient development pathways have been constrained by past development, emissions and climate change and are progressively constrained by every increment of warming, in particular beyond 1.5°C (*very high confidence*). Climate resilient development will not be possible in some regions and sub-regions if global warming exceeds 2°C (*medium confidence*). Safeguarding biodiversity and ecosystems is fundamental to climate resilient development, but biodiversity and ecosystem services have limited capacity to adapt to increasing global warming levels, making

climate resilient development progressively harder to achieve beyond 1.5°C warming (*very high confidence*). {WGII SPM D.1, WGII SPM D.1.1, WGII SPM D.4, WGII SPM D.4.3, WGII SPM D.5.1; WGIII SPM D.1.1}

The cumulative scientific evidence is unequivocal: climate change is a threat to human well-being and planetary health (*very high confidence*). Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all (*very high confidence*). Opportunities for near-term action are assessed in the following section. {WGII SPM D.5.3; WGIII SPM D.1.1}

Section 4

Near-Term Responses in a Changing Climate



Section 4 : Near-Term Responses in a Changing Climate

4.1 The Timing and Urgency of Climate Action

Deep, rapid, and sustained mitigation and accelerated implementation of adaptation reduces the risks of climate change for humans and ecosystems. In modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot and in those that limit warming to 2°C (>67%) and assume immediate action, global GHG emissions are projected to peak in the early 2020s followed by rapid and deep reductions. As adaptation options often have long implementation times, accelerated implementation of adaptation, particularly in this decade, is important to close adaptation gaps. (high confidence)

The magnitude and rate of climate change and associated risks depend strongly on near-term mitigation and adaptation actions (*very high confidence*). Global warming is *more likely than not* to reach 1.5°C between 2021 and 2040 even under the very low GHG emission scenarios (SSP1-1.9), and *likely* or *very likely* to exceed 1.5°C under higher emissions scenarios¹⁴¹. Many adaptation options have medium or high feasibility up to 1.5°C (*medium* to *high confidence*, depending on option), but hard limits to adaptation have already been reached in some ecosystems and the effectiveness of adaptation to reduce climate risk will decrease with increasing warming (*high confidence*). Societal choices and actions implemented in this decade determine the extent to which medium- and long-term pathways will deliver higher or lower climate resilient development (*high confidence*). Climate resilient development prospects are increasingly limited if current greenhouse gas emissions do not rapidly decline, especially if 1.5°C global warming is exceeded in the near term (*high confidence*). Without urgent, effective and equitable adaptation and mitigation actions, climate change increasingly threatens the health and livelihoods of people around the globe, ecosystem health, and biodiversity, with severe adverse consequences for current and future generations (*high confidence*). {WGI SPM B.1.3, WGI SPM B.5.1, WGI SPM B.5.2; WGII SPM A, WGII SPM B.4, WGII SPM C.2, WGII SPM C.3.3, WGII Figure SPM.4, WGII SPM D.1, WGII SPM D.5, WGIII SPM D.1.1 SR1.5 SPM D.2.2}. (Cross-Section Box.2, Figure 2.1, Figure 2.3)

In modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot and in those that limit warming to 2°C (>67%), assuming immediate actions, global GHG emissions are projected to peak in the early 2020s followed by rapid and deep GHG emissions reductions (*high confidence*)¹⁴². In pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, net global GHG emissions are projected to fall by 43 [34 to 60]%¹⁴³ below 2019 levels by 2030, 60 [49 to 77]% by 2035, 69 [58 to 90]% by 2040 and 84 [73 to 98]% by 2050 (*high confidence*) (Section 2.3.1, Table 2.2, Figure 2.5, Table 3.1)¹⁴⁴. Global modelled pathways that limit warming to 2°C (>67%) have reductions in GHG emissions below 2019 levels of 21 [1 to 42]% by 2030, 35 [22 to 55] % by 2035, 46 [34 to 63] % by 2040 and 64 [53 to 77]% by 2050¹⁴⁵ (*high confidence*). Global GHG emissions associated with NDCs announced prior to COP26 would make it *likely* that warming would exceed 1.5°C (*high confidence*) and limiting warming to 2°C (>67%) would then imply a rapid acceleration of emission reductions during 2030–2050, around 70% faster than in pathways where immediate action is taken to limit warming to 2°C (>67%) (*medium confidence*) (Section 2.3.1) Continued investments in unabated high-emitting infrastructure¹⁴⁶ and limited development and deployment of low-emitting alternatives prior to 2030 would act as barriers to this acceleration and increase feasibility risks (*high confidence*). {WGIII SPM B.6.3, WGIII 3.5.2, WGIII SPM B.6, WGIII SPM B.6., WGIII SPM C.1, WGIII SPM C1.1, WGIII Table SPM.2} (Cross-Section Box.2)

¹⁴¹ In the near term (2021–2040), the 1.5°C global warming level is *very likely* to be exceeded under the very high GHG emissions scenario (SSP5-8.5), *likely* to be exceeded under the intermediate and high GHG emissions scenarios (SSP2-4.5, SSP3-7.0), *more likely than not* to be exceeded under the low GHG emissions scenario (SSP1-2.6) and *more likely than not* to be reached under the very low GHG emissions scenario (SSP1-1.9). The best estimates [and *very likely* ranges] of global warming for the different scenarios in the near term are: 1.5 [1.2 to 1.7]°C (SSP1-1.9); 1.5 [1.2 to 1.8]°C (SSP1-2.6); 1.5 [1.2 to 1.8]°C (SSP2-4.5); 1.5 [1.2 to 1.8]°C (SSP3-7.0); and 1.6 [1.3 to 1.9]°C (SSP5-8.5). {WGI SPM B.1.3, WGI Table SPM.1} (Cross-Section Box.2)

¹⁴² Values in parentheses indicate the likelihood of limiting warming to the level specified (see Cross-Section Box.2).

¹⁴³ Median and *very likely* range [5th to 95th percentile]. {WGIII SPM footnote 30}

¹⁴⁴ These numbers for CO₂ are 48 [36 to 69]% in 2030, 65 [50 to 96] % in 2035, 80 [61 to 109] % in 2040 and 99 [79 to 119]% in 2050.

¹⁴⁵ These numbers for CO₂ are 22 [1 to 44]% in 2030, 37 [21 to 59] % in 2035, 51 [36 to 70] % in 2040 and 73 [55 to 90]% in 2050.

¹⁴⁶ In this context, 'unabated fossil fuels' refers to fossil fuels produced and used without interventions that substantially reduce the amount of GHG emitted throughout the life cycle; for example, capturing 90% or more CO₂ from power plants, or 50 to 80% of fugitive methane emissions from energy supply. {WGIII SPM footnote 54}

All global modelled pathways that limit warming to 2°C (>67%) or lower by 2100 involve reductions in both net CO₂ emissions and non-CO₂ emissions (see Figure 3.6) (high confidence). For example, in pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, global CH₄ (methane) emissions are reduced by 34 [21 to 57]% below 2019 levels by 2030 and by 44 [31 to 63]% in 2040 (high confidence). Global CH₄ emissions are reduced by 24 [9 to 53]% below 2019 levels by 2030 and by 37 [20 to 60]% in 2040 in modelled pathways that limit warming to 2°C with action starting in 2020 (>67%) (high confidence). {WGIII SPM C.1.2, WGIII Table SPM.2, WGIII 3.3; SR1.5 SPM C.1, SR1.5 SPM C.1.2} (Cross-Section Box.2)

All global modelled pathways that limit warming to 2°C (>67%) or lower by 2100 involve GHG emission reductions in all sectors (high confidence). The contributions of different sectors vary across modelled mitigation pathways. In most global modelled mitigation pathways, emissions from land-use, land-use change and forestry, via reforestation and reduced deforestation, and from the energy supply sector reach net zero CO₂ emissions earlier than the buildings, industry and transport sectors (Figure 4.1). Strategies can rely on combinations of different options (Figure 4.1, Section 4.5), but doing less in one sector needs to be compensated by further reductions in other sectors if warming is to be limited. (high confidence) {WGIII SPM C.3, WGIII SPM C.3.1, WGIII SPM 3.2, WGIII SPM C.3.3} (Cross-Section Box.2)

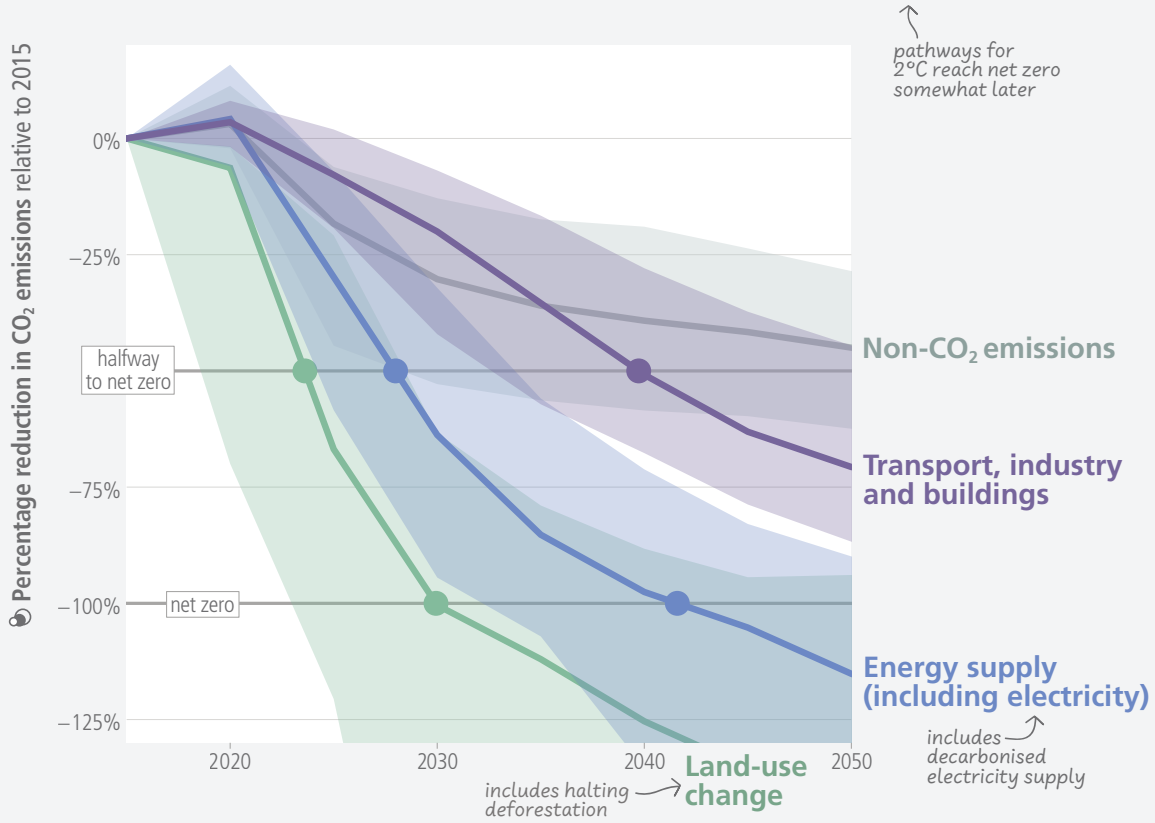
Without rapid, deep and sustained mitigation and accelerated adaptation actions, losses and damages will continue to increase, including projected adverse impacts in Africa, LDCs, SIDS, Central and South America¹⁴⁷, Asia and the Arctic, and will disproportionately affect the most vulnerable populations (high confidence). {WGII SPM C.3.5, WGII SPM B.2.4, WGII 12.2, WGII 10. Box 10.6, WGII TS D.7.5, WGII Cross-Chapter Box 6 ES, WGII Global to Regional Atlas Annex A1.15, WGII Global to Regional Atlas Annex A1.27; SR1.5 SPM B.5.3, SR 1.5 SPM B.5.7; SRCCL A.5.6} (Figure 3.2; Figure 3.3)

¹⁴⁷ The southern part of Mexico is included in the climatic subregion South Central America (SCA) for WGI. Mexico is assessed as part of North America for WGII. The climate change literature for the SCA region occasionally includes Mexico, and in those cases WGII assessment makes reference to Latin America. Mexico is considered part of Latin America and the Caribbean for WGIII. {WGII 12.1.1, WGIII AII.1.1}

The transition towards net zero CO₂ will have different pace across different sectors

CO₂ emissions from the electricity/fossil fuel industries sector and land-use change generally reach net zero earlier than other sectors

a) Sectoral emissions in pathways that limit warming to 1.5°C



b) Greenhouse gas emissions by sector at the time of net zero CO₂, compared to 2019

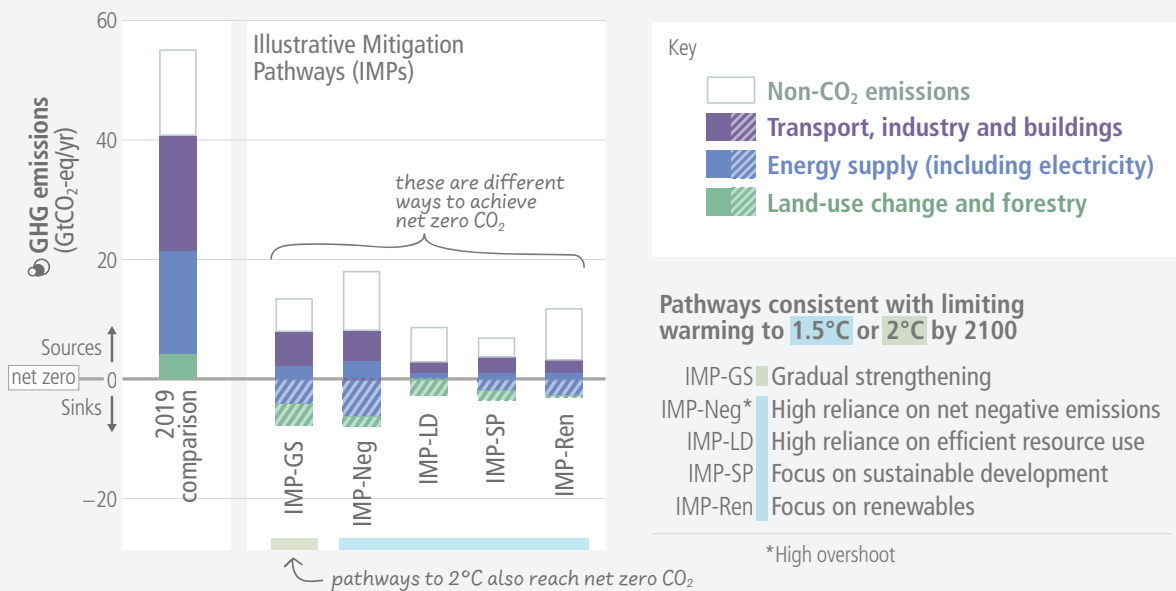


Figure 4.1: Sectoral emissions in pathways that limit warming to 1.5°C. Panel (a) shows sectoral CO₂ and non-CO₂ emissions in global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot. The horizontal lines illustrate halving 2015 emissions (base year of the pathways) (dashed) and reaching net zero emissions (solid line). The range shows the 5–95th percentile of the emissions across the pathways. The timing strongly differs by sector, with the CO₂ emissions from the electricity/fossil fuel industries sector and land-use change generally reaching net zero earlier. Non-CO₂ emissions from agriculture are also substantially reduced compared to pathways without climate policy but do not typically reach zero. Panel (b) Although all pathways include strongly reduced emissions, there are different pathways as indicated by the illustrative mitigation pathways used in IPCC WGIII. The pathways emphasise routes consistent with limiting warming to 1.5°C with a high reliance on net negative emissions (IMP-Neg), high resource efficiency (IMP-LD), a focus on sustainable development (IMP-SP) or renewables (IMP-Ren) and consistent with 2°C based on a less rapid introduction of mitigation measures followed by a subsequent gradual strengthening (IMP-GS). Positive (solid filled bars) and negative emissions (hatched bars) for different illustrative mitigation pathways are compared to GHG emissions from the year 2019. The category “energy supply (including electricity)” includes bioenergy with carbon capture and storage and direct air carbon capture and storage. {WGIII Box TS.5, WGIII 3.3, WGIII 3.4, WGIII 6.6, WGIII 10.3, WGIII 11.3} (Cross-Section Box.2)

4.2 Benefits of Strengthening Near-Term Action

Accelerated implementation of adaptation will improve well-being by reducing losses and damages, especially for vulnerable populations. Deep, rapid, and sustained mitigation actions would reduce future adaptation costs and losses and damages, enhance sustainable development co-benefits, avoid locking-in emission sources, and reduce stranded assets and irreversible climate changes. These near-term actions involve higher up-front investments and disruptive changes, which can be moderated by a range of enabling conditions and removal or reduction of barriers to feasibility. (high confidence)

Accelerated implementation of adaptation responses will bring benefits to human well-being (high confidence) (Section 4.3). As adaptation options often have long implementation times, long-term planning and accelerated implementation, particularly in this decade, is important to close adaptation gaps, recognising that constraints remain for some regions. The benefits to vulnerable populations would be high (see Section 4.4). (high confidence) {WGI SPM B.1, WGI SPM B.1.3, WGI SPM B.2.2, WGI SPM B.3; WGII SPM C.1.1, WGII SPM C.1.2, WGII SPM C.2, WGII SPM C.3.1, WGII Figure SPM.4b; SROCC SPM C.3.4, SROCC Figure 3.4, SROCC Figure SPM.5}

Near-term actions that limit global warming to close to 1.5°C would substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared to higher warming levels, but cannot eliminate them all (very high confidence). The magnitude and rate of climate change and associated risks depend strongly on near-term mitigation and adaptation actions, and projected adverse impacts and related losses and damages escalate with every increment of global warming (very high confidence). Delayed mitigation action will further increase global warming which will decrease the effectiveness of many adaptation options, including Ecosystem-based Adaptation and many water-related options, as well as increasing mitigation feasibility risks, such as for options based on ecosystems (high confidence). Comprehensive, effective, and innovative responses integrating adaptation and mitigation can harness synergies and reduce trade-offs between adaptation and mitigation, as well as in meeting requirements for financing (very high confidence) (see Section 4.5, 4.6, 4.8 and 4.9). {WGII SPM B.3, WGII SPM B.4, WGII SPM B.6.2, WGII SPM C.2, WGII SPM C.3, WGII SPM D.1, WGII SPM D.4.3, WGII SPM D.5, WG II TS D.1.4, WG II TS.D.5, WGII TS D.7.5; WGIII SPM B.6.3, WGIII SPM B.6.4, WGIII SPM C.9, WGIII SPM D.2, WGIII SPM E.13; SR1.5 SPM C.2.7, SR1.5 D.1.3, SR1.5 D.5.2}

Mitigation actions will have other sustainable development co-benefits (high confidence). Mitigation will improve air quality and human health in the near term notably because many air pollutants are

co-emitted by GHG emitting sectors and because methane emissions leads to surface ozone formation (high confidence). The benefits from air quality improvement include prevention of air pollution-related premature deaths, chronic diseases and damages to ecosystems and crops. The economic benefits for human health from air quality improvement arising from mitigation action can be of the same order of magnitude as mitigation costs, and potentially even larger (medium confidence). As methane has a short lifetime but is a potent GHG, strong, rapid and sustained reductions in methane emissions can limit near-term warming and improve air quality by reducing global surface ozone (high confidence). {WGI SPM D.1.7, WGI SPM D.2.2, WGI 6.7, WGI TS Box TS.7, WGI 6 Box 6.2, WGI Figure 6.3, WGI Figure 6.16, WGI Figure 6.17; WGII TS.D.8.3, WGII Cross-Chapter Box HEALTH, WGII 5 ES, WGII 7 ES; WGII 7.3.1.2; WGIII Figure SPM.8, WGIII SPM C.2.3, WGIII SPM C.4.2, WGIII TS.4.2}

Challenges from delayed adaptation and mitigation actions include the risk of cost escalation, lock-in of infrastructure, stranded assets, and reduced feasibility and effectiveness of adaptation and mitigation options (high confidence). The continued installation of unabated fossil fuel¹⁴⁸ infrastructure will ‘lock-in’ GHG emissions (high confidence). Limiting global warming to 2°C or below will leave a substantial amount of fossil fuels unburned and could strand considerable fossil fuel infrastructure (high confidence), with globally discounted value projected to be around USD 1 to 4 trillion from 2015 to 2050 (medium confidence). Early actions would limit the size of these stranded assets, whereas delayed actions with continued investments in unabated high-emitting infrastructure and limited development and deployment of low-emitting alternatives prior to 2030 would raise future stranded assets to the higher end of the range – thereby acting as barriers and increasing political economy feasibility risks that may jeopardise efforts to limit global warming. (high confidence). {WGIII SPM B.6.3, WGIII SPM C.4, WGIII Box TS.8}

¹⁴⁸ In this context, ‘unabated fossil fuels’ refers to fossil fuels produced and used without interventions that substantially reduce the amount of GHG emitted throughout the life cycle; for example, capturing 90% or more CO₂ from power plants, or 50 to 80% of fugitive methane emissions from energy supply. {WGIII SPM footnote 54}

Scaling-up near-term climate actions (Section 4.1) will mobilise a mix of low-cost and high-cost options. High-cost options, as in energy and infrastructure, are needed to avoid future lock-ins, foster innovation and initiate transformational changes (Figure 4.4). Climate resilient development pathways in support of sustainable development for all are shaped by equity, and social and climate justice (*very high confidence*). Embedding effective and equitable adaptation and mitigation in development planning can reduce vulnerability, conserve and restore ecosystems, and enable climate resilient development. This is especially challenging in localities with persistent development gaps and limited resources. (*high confidence*) {WGII SPM C.5, WGII SPM D1; WGIII TS.5.2, WGIII 8.3.1, WGIII 8.3.4, WGIII 8.4.1, WGIII 8.6}

Scaling-up climate action may generate disruptive changes in economic structure with distributional consequences and need to reconcile divergent interests, values and worldviews, within and between countries. Deeper fiscal, financial, institutional and regulatory reforms can offset such adverse effects and unlock mitigation potentials. Societal choices and actions implemented in this decade will determine the extent to which medium and long-term development pathways will deliver higher or lower climate resilient development outcomes. (*high confidence*) {WGII SPM D.2, WGII SPM D.5, WGII Box TS.8; WGIII SPM D.3, WGIII SPM E.2, WGIII SPM E.3, WGIII SPM E.4, WGIII TS.2, WGIII TS.4.1, WGIII TS.6.4, WGIII 15.2, WGIII 15.6}

Enabling conditions would need to be strengthened in the near-term and barriers reduced or removed to realise opportunities for deep and rapid adaptation and mitigation actions and climate resilient development (*high confidence*) (Figure 4.2). These enabling conditions are differentiated by national, regional and local circumstances and geographies, according to capabilities, and include: equity and inclusion in climate action (see Section 4.4), rapid and far-reaching transitions in sectors and system (see Section 4.5), measures to achieve synergies and reduce trade-offs with sustainable development goals (see Section 4.6), governance and policy improvements (see Section 4.7), access to finance, improved international cooperation and technology improvements (see Section 4.8), and integration of near-term actions across sectors, systems and regions (see Section 4.9). {WGII SPM D.2; WGIII SPM E.1, WGIII SPM E.2}

Barriers to feasibility would need to be reduced or removed to deploy mitigation and adaptation options at scale. Many limits to feasibility and effectiveness of responses can be overcome by addressing a range of barriers, including economic, technological, institutional, social, environmental and geophysical barriers. The feasibility and effectiveness of options increase with integrated, multi-sectoral solutions that differentiate responses based on climate risk, cut across systems and address social inequities. Strengthened near-term actions in modelled cost-effective pathways that limit global warming to 2°C or lower, reduce the overall risk to the feasibility of the system transitions, compared to modelled pathways with delayed or uncoordinated action. (*high confidence*) {WGII SPM C.2, WGII SPM C.3, WGII SPM C.5; WGIII SPM E.1, WGIII SPM E.1.3}

Integrating ambitious climate actions with macroeconomic policies under global uncertainty would provide benefits (*high confidence*). This encompasses three main directions:

(a) economy-wide mainstreaming packages supporting options to improved sustainable low-emission economic recovery, development and job creation programs (Sections 4.4, 4.5, 4.6, 4.8, 4.9) (b) safety nets and social protection in the transition (Section 4.4, 4.7); and (c) broadened access to finance, technology and capacity-building and coordinated support to low-emission infrastructure ('leap-frog' potential), especially in developing regions, and under debt stress (*high confidence*). (Section 4.8) {WGII SPM C.2, WGII SPM C.4.1, WGII SPM D.1.3, WGII SPM D.2, WGII SPM D.3.2, WGII SPM E.2.2, WGII SPM E.4, WGII SPM TS.2, WGII SPM TS.5.2, WGII TS.6.4, WGII TS.15, WGII TS Box TS.3; WGIII SPM B.4.2, WGIII SPM C.5.4, WGIII SPM C.6.2, WGIII SPM C.12.2, WGIII SPM D.3.4, WGIII SPM E.4.2, WGIII SPM E.4.5, WGIII SPM E.5.2, WGIII SPM E.5.3, WGIII TS.1, WGIII Box TS.15, WGIII 15.2, WGIII Cross-Chapter Box 1 on COVID in Chapter 1}

There is a rapidly narrowing window of opportunity to enable climate resilient development

Multiple interacting choices and actions can shift development pathways towards sustainability

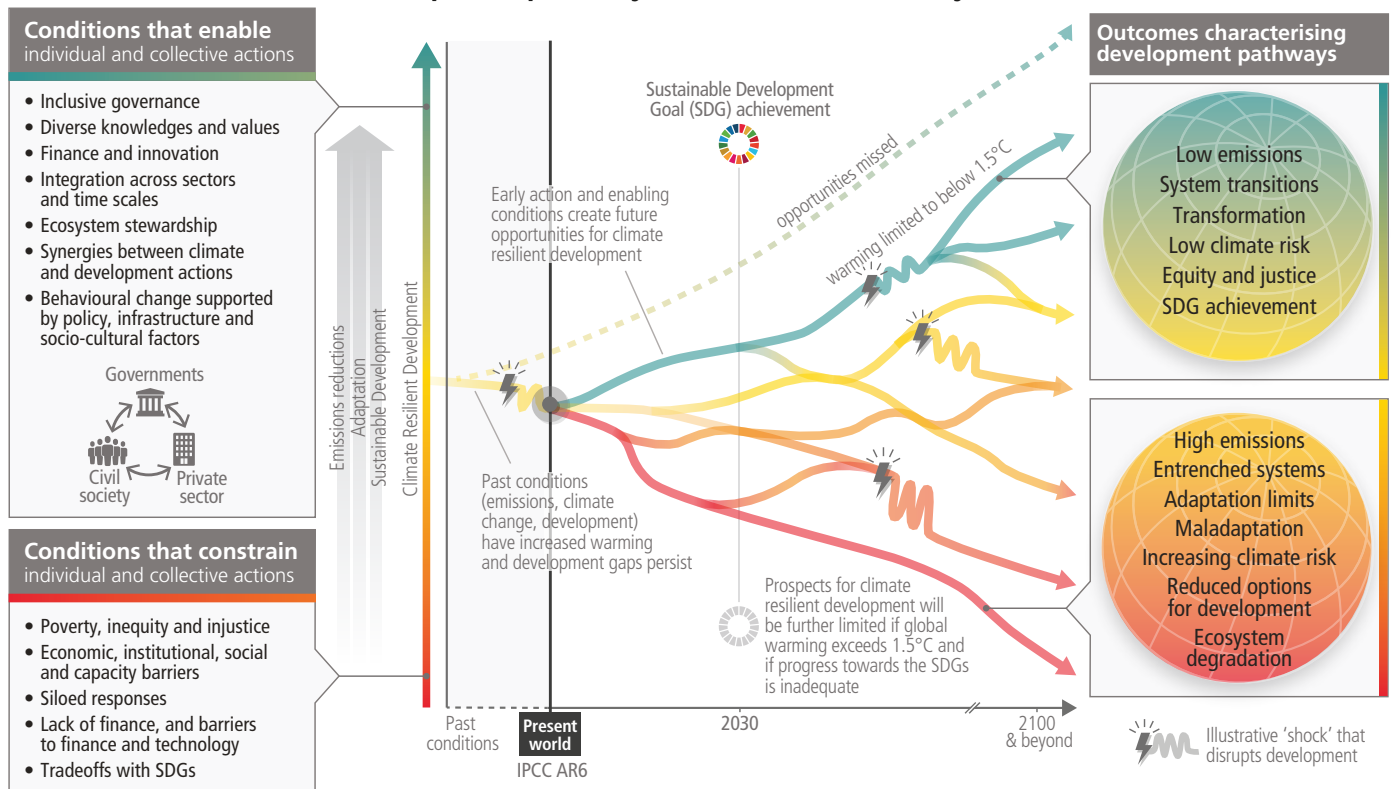


Figure 4.2: The illustrative development pathways (red to green) and associated outcomes (right panel) show that there is a rapidly narrowing window of opportunity to secure a liveable and sustainable future for all. Climate resilient development is the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development. Diverging pathways illustrate that interacting choices and actions made by diverse government, private sector and civil society actors can advance climate resilient development, shift pathways towards sustainability, and enable lower emissions and adaptation. Diverse knowledges and values include cultural values, Indigenous Knowledge, local knowledge, and scientific knowledge. Climatic and non-climatic events, such as droughts, floods or pandemics, pose more severe shocks to pathways with lower climate resilient development (red to yellow) than to pathways with higher climate resilient development (green). There are limits to adaptation and adaptive capacity for some human and natural systems at global warming of 1.5°C, and with every increment of warming, losses and damages will increase. The development pathways taken by countries at all stages of economic development impact GHG emissions and hence shape mitigation challenges and opportunities, which vary across countries and regions. Pathways and opportunities for action are shaped by previous actions (or inactions) and opportunities missed, and enabling and constraining conditions (left panel), and take place in the context of climate risks, adaptation limits and development gaps. The longer emissions reductions are delayed, the fewer effective adaptation options. [WGI SPM B.1; WGII SPM B.1 to B.5, WGII SPM C.2 to 5, WGII SPM D.1 to 5, WGII Figure SPM.3, WGII Figure SPM.4, WGII Figure SPM.5, WGII TS.D.5, WGII 3.1, WGII 3.2, WGII 3.4, WGII 4.2, WGII Figure 4.4, WGII 4.5, WGII 4.6, WGII 4.9; WGIII SPM A, WGIII SPM B.1, WGIII SPM B.3, WGIII SPM B.6, WGIII SPM C.4, WGIII SPM D.1 to 3, WGIII SPM E.1, WGIII SPM E.2, WGIII SPM E.4, WGIII SPM E.5, WGIII Figure TS.1, WGIII Figure TS.7, WGIII Box TS.3, WGIII Box TS.8, Cross-Working Group Box 1 in Chapter 3, WGIII Cross-Chapter Box 5 in Chapter 4; SR1.5 SPM D.1 to 6; SRCL SPM D.3]

4.3 Near-Term Risks

Many changes in the climate system, including extreme events, will become larger in the near term with increasing global warming (*high confidence*). Multiple climatic and non-climatic risks will interact, resulting in increased compounding and cascading impacts becoming more difficult to manage (*high confidence*). Losses and damages will increase with increasing global warming (*very high confidence*), while strongly concentrated among the poorest vulnerable populations (*high confidence*). Continuing with current unsustainable development patterns would increase exposure and vulnerability of ecosystems and people to climate hazards (*high confidence*).

Global warming will continue to increase in the near term (2021–2040) mainly due to increased cumulative CO₂ emissions in nearly all considered scenarios and pathways. In the near term, every region in the world is projected to face further increases in climate hazards (*medium to high confidence, depending on region and hazard*), increasing multiple risks to ecosystems and humans (*very high confidence*). In the near term, natural variability¹⁴⁹ will modulate human-caused changes, either attenuating or amplifying projected changes, especially at regional scales, with little effect on centennial global warming. Those modulations are important to consider in adaptation planning. Global surface temperature in any single year can vary above or below the long-term human-induced trend, due to natural variability. By 2030, global surface temperature in any individual year could exceed 1.5°C relative to 1850–1900 with a probability between 40% and 60%, across the five scenarios assessed in WGI (*medium confidence*). The occurrence of individual years with global surface temperature change above a certain level does not imply that this global warming level has been reached. If a large explosive volcanic eruption were to occur in the near term¹⁵⁰, it would temporarily and partially mask human-caused climate change by reducing global surface temperature and precipitation, especially over land, for one to three years (*medium confidence*). {WGI SPM B.1.3, WGI SPM B.1.4, WGI SPM C.1, WGI SPM C.2, WGI Cross-Section Box TS.1, WGI Cross-Chapter Box 4.1; WGII SPM B.3, WGII SPM B.3.1; WGIII Box SPM.1 Figure 1}

The level of risk for humans and ecosystems will depend on near-term trends in vulnerability, exposure, level of socio-economic development and adaptation (*high confidence*). In the near term, many climate-associated risks to natural and human systems depend more strongly on changes in these systems' vulnerability and exposure than on differences in climate hazards between emissions scenarios (*high confidence*). Future exposure to climatic hazards is increasing globally due to socio-economic development trends including growing inequality, and when urbanisation or migration increase exposure (*high confidence*). Urbanisation increases hot extremes (*very high confidence*) and precipitation runoff intensity (*high confidence*). Increasing urbanisation in low-lying and coastal zones will be a major driver of increasing exposure to extreme riverflow events and sea level rise hazards, increasing risks (*high confidence*) (Figure 4.3). Vulnerability will also rise rapidly in low-lying Small Island Developing States and atolls in the context of sea level rise (*high confidence*) (see Figure 3.4 and Figure 4.3). Human vulnerability will concentrate in informal settlements and rapidly growing smaller settlements; and vulnerability in rural areas will be heightened by reduced habitability and high reliance on climate-sensitive livelihoods (*high confidence*). Human and ecosystem vulnerability are interdependent (*high confidence*). Vulnerability to climate change for ecosystems will be strongly influenced by past, present, and future patterns of human development, including from unsustainable consumption and production, increasing demographic pressures, and persistent unsustainable use and management of

land, ocean, and water (*high confidence*). Several near-term risks can be moderated with adaptation (*high confidence*). {WGI SPM C.2.6; WGII SPM B.2, WGII SPM B.2.3, WGII SPM B.2.5, WGII SPM B.3, WGII SPM B.3.2, WGII TS.C.5.2} (Section 4.5 and 3.2)

Principal hazards and associated risks expected in the near term (at 1.5°C global warming) are:

- Increased intensity and frequency of hot extremes and dangerous heat-humidity conditions, with increased human mortality, morbidity, and labour productivity loss (*high confidence*). {WGI SPM B.2.2, WGI TS Figure TS.6; WGII SPM B.1.4, WGII SPM B.4.4, WGII Figure SPM.2}
- Increasing frequency of marine heatwaves will increase risks of biodiversity loss in the oceans, including from mass mortality events (*high confidence*). {WGI SPM B.2.3; WGII SPM B.1.2, WGII Figure SPM.2; SROCC SPM B.5.1}
- Near-term risks for biodiversity loss are moderate to high in forest ecosystems (*medium confidence*) and kelp and seagrass ecosystems (*high to very high confidence*) and are high to very high in Arctic sea-ice and terrestrial ecosystems (*high confidence*) and warm-water coral reefs (*very high confidence*). {WGII SPM B.3.1}
- More intense and frequent extreme rainfall and associated flooding in many regions including coastal and other low-lying cities (*medium to high confidence*), and increased proportion of and peak wind speeds of intense tropical cyclones (*high confidence*). {WGI SPM B.2.4, WGI SPM C.2.2, WGI SPM C.2.6, WGI 11.7}
- High risks from dryland water scarcity, wildfire damage, and permafrost degradation (*medium confidence*). {SRCCL SPM A.5.3}
- Continued sea level rise and increased frequency and magnitude of extreme sea level events encroaching on coastal human settlements and damaging coastal infrastructure (*high confidence*), committing low-lying coastal ecosystems to submergence and loss (*medium confidence*), expanding land salinization (*very high confidence*), with cascading to risks to livelihoods, health, well-being, cultural values, food and water security (*high confidence*). {WGI SPM C.2.5, WGI SPM C.2.6; WGII SPM B.3.1, WGII SPM B.5.2; SRCCL SPM A.5.6; SROCC SPM B.3.4, SROCC SPM 3.6, SROCC SPM B.9.1} (Figure 3.4, 4.3)
- Climate change will significantly increase ill health and premature deaths from the near to long term (*high confidence*). Further warming will increase climate-sensitive food-borne, water-borne, and vector-borne disease risks (*high confidence*), and mental health challenges including anxiety and stress (*very high confidence*). {WGII SPM B.4.4}

¹⁴⁹ See Annex I: Glossary. The main internal variability phenomena include El Niño–Southern Oscillation, Pacific Decadal Variability and Atlantic Multi-decadal Variability through their regional influence. The internal variability of global surface temperature in any single year is estimated to be about ±0.25°C (5 to 95% range, *high confidence*). {WGI SPM footnote 29, WGI SPM footnote 37}

¹⁵⁰ Based on 2500-year reconstructions, eruptions with a radiative forcing more negative than -1 Wm^{-2} , related to the radiative effect of volcanic stratospheric aerosols in the literature assessed in this report, occur on average twice per century. {WGI SPM footnote 38}

- Cryosphere-related changes in floods, landslides, and water availability have the potential to lead to severe consequences for people, infrastructure and the economy in most mountain regions (*high confidence*). {WGII TS C.4.2}
- The projected increase in frequency and intensity of heavy precipitation (*high confidence*) will increase rain-generated local flooding (*medium confidence*). {WGI Figure SPM.6, WGI SPM B.2.2; WGII TS C.4.5}

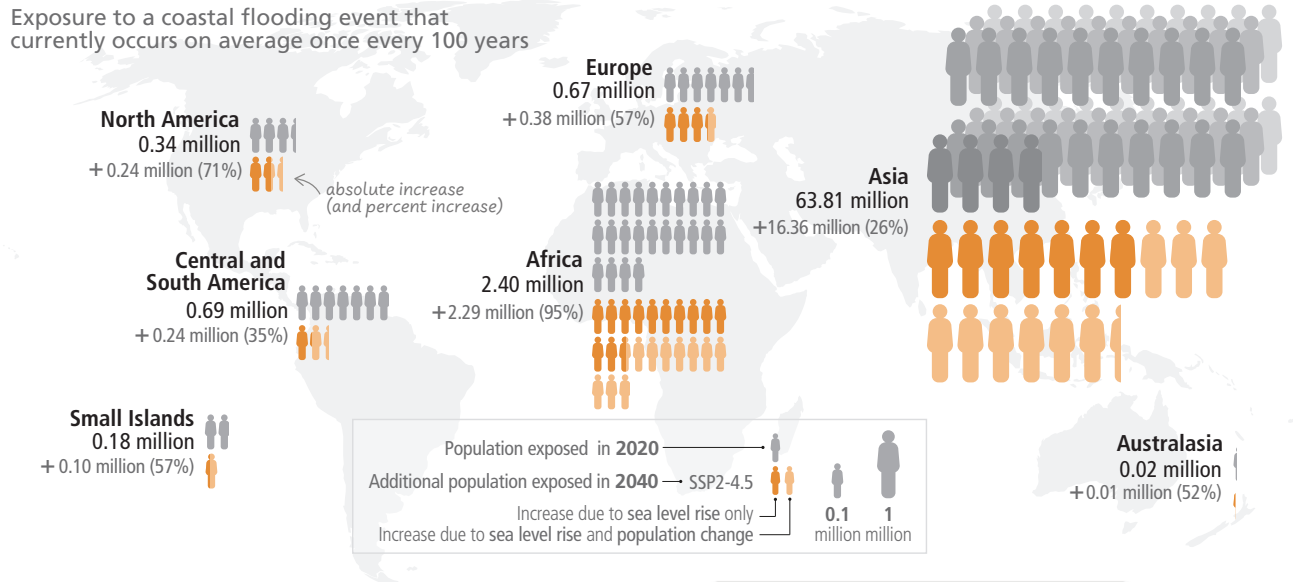
Multiple climate change risks will increasingly compound and cascade in the near term (*high confidence*). Many regions are projected to experience an increase in the probability of compound events with higher global warming (*high confidence*) including concurrent heatwaves and drought. Risks to health and food production will be made more severe from the interaction of sudden food production losses from heat and drought, exacerbated by heat-induced labour productivity losses (*high confidence*) (Figure 4.3). These interacting impacts will increase food prices, reduce household incomes, and lead to health risks of malnutrition and climate-related mortality with no or low levels of adaptation, especially in tropical regions (*high confidence*). Concurrent and cascading risks from climate change to food systems, human settlements, infrastructure and health will make these risks more severe and more difficult to manage, including when interacting with non-climatic risk drivers such as competition for land between urban expansion and food production, and pandemics (*high confidence*). Loss of ecosystems and their services has cascading and long-term impacts on people globally, especially for Indigenous Peoples and local communities who are directly dependent on ecosystems, to meet basic needs (*high confidence*). Increasing transboundary risks are projected across the food, energy and water sectors as impacts from weather and climate extremes propagate through supply-chains, markets, and natural resource flows (*high confidence*) and may interact with impacts from other crises such as pandemics. Risks also arise from some responses intended to reduce the risks of climate change, including risks from maladaptation and adverse side effects of some emissions reduction and carbon dioxide removal measures, such as afforestation of naturally unforested land or poorly implemented bioenergy compounding climate-related risks to biodiversity, food and water security, and livelihoods (*high confidence*) (see Section 3.4.1 and 4.5). {WGI SPM.2.7; WGII SPM B.2.1, WGII SPM B.5, WGII SPM B.5.1, WGII SPM B.5.2, WGII SPM B.5.3, WGII SPM B.5.4, WGII Cross-Chapter Box COVID in Chapter 7; WGIII SPM C.11.2; SRCCL SPM A.5, SRCCL SPM A.6.5} (Figure 4.3)

With every increment of global warming losses and damages will increase (*very high confidence*), become increasingly difficult to avoid and be strongly concentrated among the poorest vulnerable populations (*high confidence*). Adaptation does not prevent all losses and damages, even with effective adaptation and before reaching soft and hard limits. Losses and damages will be unequally distributed across systems, regions and sectors and are not comprehensively addressed by current financial, governance and institutional arrangements, particularly in vulnerable developing countries. (*high confidence*). {WGII SPM B.4, WGII SPM C.3, WGII SPM C.3.5}

Every region faces more severe and/or frequent compound and cascading climate risks

a) Increase in the population exposed to sea level rise from 2020 to 2040

Exposure to a coastal flooding event that currently occurs on average once every 100 years

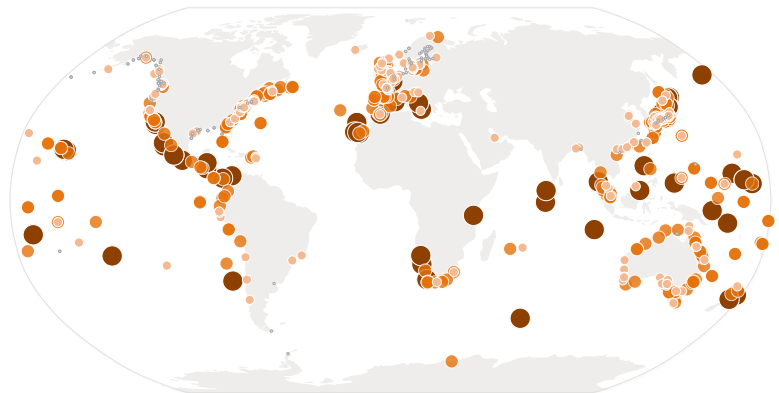
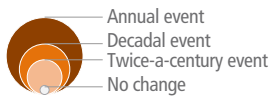


b) Increased frequency of extreme sea level events by 2040

Frequency of events that currently occur on average once every 100 years

The absence of a circle indicates an inability to perform an assessment due to a lack of data.

Projected change to 1-in-100 year events under the intermediate SSP2-4.5 scenario



c) Example of complex risk, where impacts from climate extreme events have cascading effects on food, nutrition, livelihoods and well-being of smallholder farmers

Multiple climate change risks will increasingly compound and cascade in the near term

More frequent and more intense
Extreme heat and drought

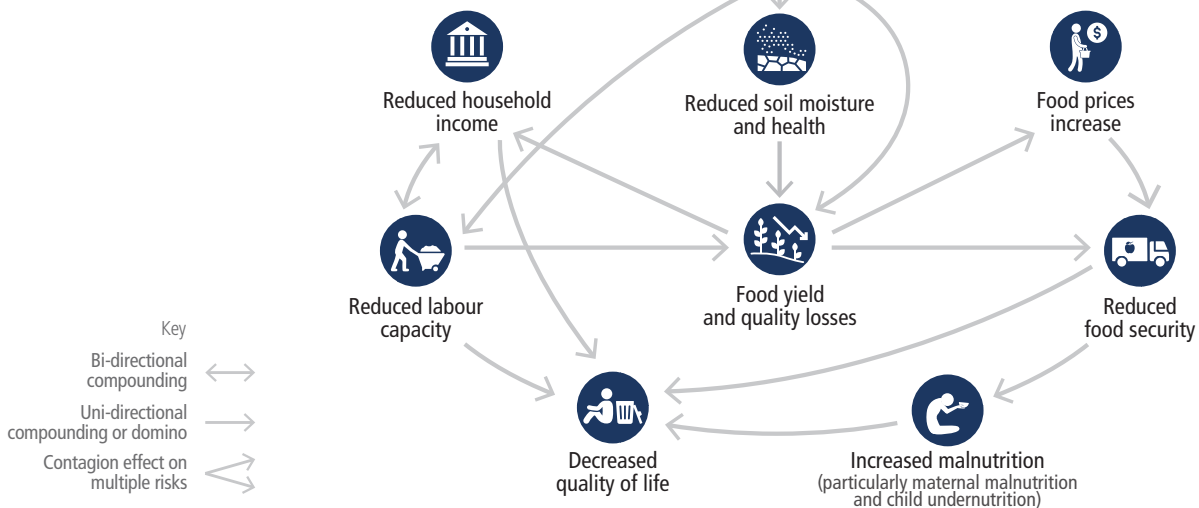


Figure 4.3: Every region faces more severe or frequent compound and/or cascading climate risks in the near term. Changes in risk result from changes in the degree of the hazard, the population exposed, and the degree of vulnerability of people, assets, or ecosystems. **Panel (a)** Coastal flooding events affect many of the highly populated regions of the world where large percentages of the population are exposed. The panel shows near-term projected increase of population exposed to 100-year flooding events depicted as the increase from the year 2020 to 2040 (due to sea level rise and population change), based on the intermediate GHG emissions scenario (SSP2-4.5) and current adaptation measures. Out-migration from coastal areas due to future sea level rise is not considered in the scenario. **Panel (b)** projected median probability in the year 2040 for extreme water levels resulting from a combination of mean sea level rise, tides and storm surges, which have a historical 1% average annual probability. A peak-over-threshold (99.7%) method was applied to the historical tide gauge observations available in the Global Extreme Sea Level Analysis version 2 database, which is the same information as WGI Figure 9.32, except here the panel uses relative sea level projections under SSP2-4.5 for the year 2040 instead of 2050. The absence of a circle indicates an inability to perform an assessment due to a lack of data, but does not indicate absence of increasing frequencies. **Panel (c)** Climate hazards can initiate risk cascades that affect multiple sectors and propagate across regions following complex natural and societal connections. This example of a compound heat wave and a drought event striking an agricultural region shows how multiple risks are interconnected and lead to cascading biophysical, economic, and societal impacts even in distant regions, with vulnerable groups such as smallholder farmers, children and pregnant women particularly impacted. {WGI Figure 9.32; WGII SPM B.4.3, WGII SPM B.1.3, WGII SPM B.5.1, WGII TS Figure TS.9, WGII TS Figure TS.10 (c), WGII Fig 5.2, WGII TS.B.2.3, WGII TS.B.2.3, WGII TS.B.3.3, WGII 9.11.1.2}

4.4 Equity and Inclusion in Climate Change Action

Actions that prioritise equity, climate justice, social justice and inclusion lead to more sustainable outcomes, co-benefits, reduce trade-offs, support transformative change and advance climate resilient development. Adaptation responses are immediately needed to reduce rising climate risks, especially for the most vulnerable. Equity, inclusion and just transitions are key to progress on adaptation and deeper societal ambitions for accelerated mitigation. (high confidence)

Adaptation and mitigation actions, across scales, sectors and regions, that prioritise equity, climate justice, rights-based approaches, social justice and inclusivity, lead to more sustainable outcomes, reduce trade-offs, support transformative change and advance climate resilient development (*high confidence*). Redistributive policies across sectors and regions that shield the poor and vulnerable, social safety nets, equity, inclusion and just transitions, at all scales can enable deeper societal ambitions and resolve trade-offs with sustainable development goals (SDGs), particularly education, hunger, poverty, gender and energy access (*high confidence*). Mitigation efforts embedded within the wider development context can increase the pace, depth and breadth of emission reductions (*medium confidence*). Equity, inclusion and just transitions at all scales enable deeper societal ambitions for accelerated mitigation, and climate action more broadly (*high confidence*). The complexity in risk of rising food prices, reduced household incomes, and health and climate-related malnutrition (particularly maternal malnutrition and child undernutrition) and mortality increases with little or low levels of adaptation (*high confidence*). {WGII SPM B.5.1, WGII SPM C.2.9, WGII SPM D.2.1, WGII TS Box TS.4; WGIII SPM D.3, WGIII SPM D.3.3, WGIII SPM WGIII SPM E.3, SR1.5 SPM D.4.5} (Figure 4.3c)

Regions and people with considerable development constraints have high vulnerability to climatic hazards. Adaptation outcomes for the most vulnerable within and across countries and regions are enhanced through approaches focusing on equity, inclusivity, and rights-based approaches, including 3.3 to 3.6 billion people living in contexts that are highly vulnerable to climate change (*high confidence*). Vulnerability is higher in locations with poverty, governance challenges and limited access to basic services and resources, violent conflict and high levels of climate-sensitive livelihoods (e.g., smallholder farmers, pastoralists, fishing communities) (*high confidence*). Several risks can be moderated with adaptation (*high confidence*). The largest adaptation gaps exist among lower income population groups (*high confidence*) and adaptation progress is unevenly distributed with observed adaptation gaps (*high confidence*). Present development challenges causing high

vulnerability are influenced by historical and ongoing patterns of inequity such as colonialism, especially for many Indigenous Peoples and local communities (*high confidence*). Vulnerability is exacerbated by inequity and marginalisation linked to gender, ethnicity, low income or combinations thereof, especially for many Indigenous Peoples and local communities (*high confidence*). {WGII SPM B.2, WGII SPM B.2.4, WGII SPM B.3.2, WGII SPM B.3.3, WGII SPM C.1, WGII SPM C.1.2, WGII SPM C.2.9}

Meaningful participation and inclusive planning, informed by cultural values, Indigenous Knowledge, local knowledge, and scientific knowledge can help address adaptation gaps and avoid maladaptation (high confidence). Such actions with flexible pathways may encourage low-regret and timely actions (*very high confidence*). Integrating climate adaptation into social protection programmes, including cash transfers and public works programmes, would increase resilience to climate change, especially when supported by basic services and infrastructure (*high confidence*). {WGII SPM C.2.3, WGII SPM C.4.3, WGII SPM C.4.4, WGII SPM C.2.9, WGII WPM D.3}

Equity, inclusion, just transitions, broad and meaningful participation of all relevant actors in decision making at all scales enable deeper societal ambitions for accelerated mitigation, and climate action more broadly, and build social trust, support transformative changes and an equitable sharing of benefits and burdens (high confidence). Equity remains a central element in the UN climate regime, notwithstanding shifts in differentiation between states over time and challenges in assessing fair shares. Ambitious mitigation pathways imply large and sometimes disruptive changes in economic structure, with significant distributional consequences, within and between countries, including shifting of income and employment during the transition from high to low emissions activities (*high confidence*). While some jobs may be lost, low-emissions development can also open up opportunities to enhance skills and create jobs (*high confidence*). Broadening equitable access to finance, technologies and governance that facilitate mitigation, and consideration of climate justice can help equitable sharing of benefits

and burdens, especially for vulnerable countries and communities. {WGIII SPM D.3, WGIII SPM D.3.2, WGIII SPM D.3.3, WGIII SPM D.3.4, WGIII TS Box TS.4}

Development priorities among countries also reflect different starting points and contexts, and enabling conditions for shifting development pathways towards increased sustainability will therefore differ, giving rise to different needs (*high confidence*). Implementing just transition principles through collective and participatory decision-making processes is an effective way of integrating equity principles into policies at all scales depending on national circumstances, while in several countries just transition commissions, task forces and national policies have been established (*medium confidence*). {WGIII SPM D.3.1, WGIII SPM D.3.3}

Many economic and regulatory instruments have been effective in reducing emissions and practical experience has informed instrument design to improve them while addressing distributional goals and social acceptance (*high confidence*). The design of behavioural interventions, including the way that choices are presented to consumers work synergistically with price signals, making the combination more effective (*medium confidence*). Individuals with high socio-economic status contribute disproportionately to emissions, and have the highest potential for emissions reductions, e.g., as

citizens, investors, consumers, role models, and professionals (*high confidence*). There are options on design of instruments such as taxes, subsidies, prices, and consumption-based approaches, complemented by regulatory instruments to reduce high-emissions consumption while improving equity and societal well-being (*high confidence*). Behaviour and lifestyle changes to help end-users adopt low-GHG-intensive options can be supported by policies, infrastructure and technology with multiple co-benefits for societal well-being (*high confidence*). Broadening equitable access to domestic and international finance, technologies and capacity can also act as a catalyst for accelerating mitigation and shifting development pathways in low-income contexts (*high confidence*). Eradicating extreme poverty, energy poverty, and providing decent living standards to all in these regions in the context of achieving sustainable development objectives, in the near term, can be achieved without significant global emissions growth (*high confidence*). Technology development, transfer, capacity building and financing can support developing countries/ regions leapfrogging or transitioning to low-emissions transport systems thereby providing multiple co-benefits (*high confidence*). Climate resilient development is advanced when actors work in equitable, just and enabling ways to reconcile divergent interests, values and worldviews, toward equitable and just outcomes (*high confidence*). {WGII D.2.1, WGIII SPM B.3.3, WGIII SPM C.8.5, WGIII SPM C.10.2, WGIII SPM C.10.4, WGIII SPM D.3.4, WGIII SPM E.4.2, WGIII TS.5.1, WGIII 5.4, WGIII 5.8, WGIII 15.2}

4.5 Near-Term Mitigation and Adaptation Actions

Rapid and far-reaching transitions across all sectors and systems are necessary to achieve deep and sustained emissions reductions and secure a liveable and sustainable future for all. These system transitions involve a significant upscaling of a wide portfolio of mitigation and adaptation options. Feasible, effective and low-cost options for mitigation and adaptation are already available, with differences across systems and regions. (*high confidence*)

Rapid and far-reaching transitions across all sectors and systems are necessary to achieve deep emissions reductions and secure a liveable and sustainable future for all (*high confidence*). System transitions¹⁵¹ consistent with pathways that limit warming to 1.5°C (>50%) with no or limited overshoot are more rapid and pronounced in the near-term than in those that limit warming to 2°C (>67%) (*high confidence*). Such a systemic change is unprecedented in terms of scale, but not necessarily in terms of speed (*medium confidence*). The system transitions make possible the transformative adaptation required for high levels of human health and well-being, economic and social resilience, ecosystem health, and planetary health. {WGII SPM A, WGII Figure SPM.1; WGIII SPM C.3; SR1.5 SPM C.2, SR1.5 SPM C.2.1, SR1.5 SPM C.2, SR1.5 SPM C.5}

Feasible, effective and low-cost options for mitigation and adaptation are already available (*high confidence*) (Figure 4.4). Mitigation options costing USD 100 tCO₂-eq⁻¹ or less could reduce

global GHG emissions by at least half the 2019 level by 2030 (options costing less than USD 20 tCO₂-eq⁻¹ are estimated to make up more than half of this potential) (*high confidence*) (Figure 4.4). The availability, feasibility¹⁵² and potential of mitigation or effectiveness of adaptation options in the near term differ across systems and regions (*very high confidence*). {WGII SPM C.2; WGIII SPM C.12, WGIII SPM E.1.1; SR1.5 SPM B.6}

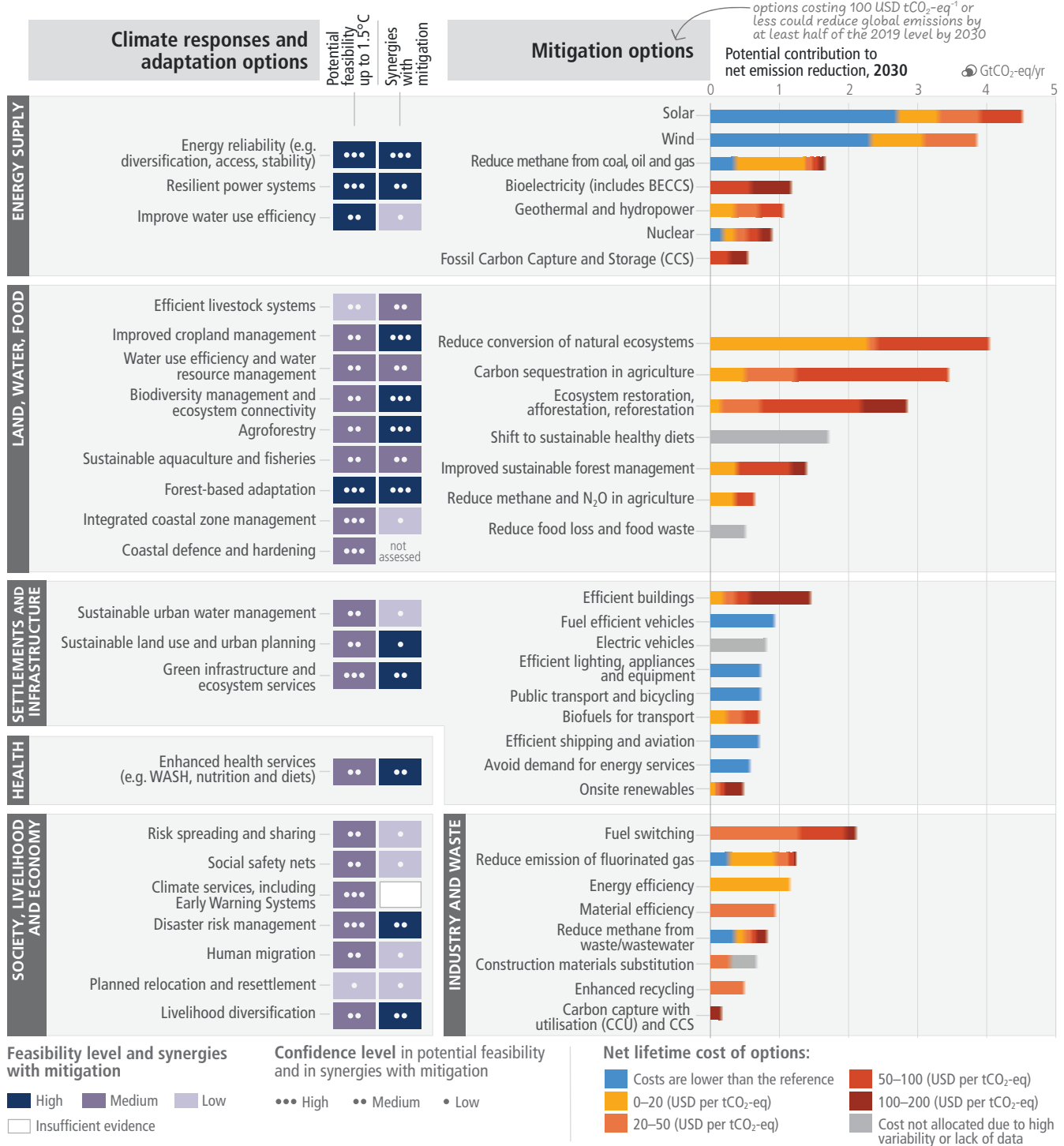
Demand-side measures and new ways of end-use service provision can reduce global GHG emissions in end-use sectors by 40 to 70% by 2050 compared to baseline scenarios, while some regions and socioeconomic groups require additional energy and resources. Demand-side mitigation encompasses changes in infrastructure use, end-use technology adoption, and socio-cultural and behavioural change. (*high confidence*) (Figure 4.4). {WGIII SPM C.10}

¹⁵¹ System transitions involve a wide portfolio of mitigation and adaptation options that enable deep emissions reductions and transformative adaptation in all sectors. This report has a particular focus on the following system transitions: energy; industry; cities, settlements and infrastructure; land, ocean, food and water; health and nutrition; and society, livelihood and economies. {WGII SPM A, WGII Figure SPM.1, WGII Figure SPM.4; SR1.5 SPM C.2}

¹⁵² See Annex I: Glossary.

There are multiple opportunities for scaling up climate action

a) Feasibility of climate responses and adaptation, and potential of mitigation options in the near term



b) Potential of demand-side mitigation options by 2050

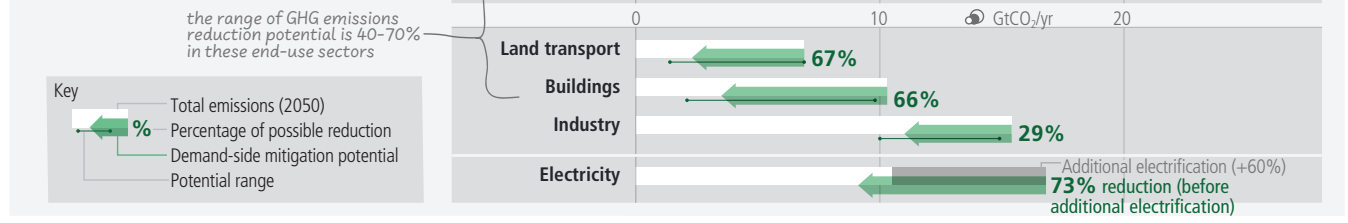


Figure 4.4: Multiple Opportunities for scaling up climate action. Panel (a) presents selected mitigation and adaptation options across different systems. The left hand side of panel (a) shows climate responses and adaptation options assessed for their multidimensional feasibility at global scale, in the near term and up to 1.5°C global warming. As literature above 1.5°C is limited, feasibility at higher levels of warming may change, which is currently not possible to assess robustly. The term response is used here in addition to adaptation because some responses, such as migration, relocation and resettlement may or may not be considered to be adaptation. Migration, when voluntary, safe and orderly, allows reduction of risks to climatic and non-climatic stressors. Forest based adaptation includes sustainable forest management, forest conservation and restoration, reforestation and afforestation. WASH refers to water, sanitation and hygiene. Six feasibility dimensions (economic, technological, institutional, social, environmental and geophysical) were used to calculate the potential feasibility of climate responses and adaptation options, along with their synergies with mitigation. For potential feasibility and feasibility dimensions, the figure shows high, medium, or low feasibility. Synergies with mitigation are identified as high, medium, and low. The right-hand side of panel (a) provides an overview of selected mitigation options and their estimated costs and potentials in 2030. Relative potentials and costs will vary by place, context and time and in the longer term compared to 2030. Costs are net lifetime discounted monetary costs of avoided greenhouse gas emissions calculated relative to a reference technology. The potential (horizontal axis) is the quantity of net GHG emission reduction that can be achieved by a given mitigation option relative to a specified emission baseline. Net GHG emission reductions are the sum of reduced emissions and/or enhanced sinks. The baseline used consists of current policy (around 2019) reference scenarios from the AR6 scenarios database (25–75 percentile values). The mitigation potentials are assessed independently for each option and are not necessarily additive. Health system mitigation options are included mostly in settlement and infrastructure (e.g., efficient healthcare buildings) and cannot be identified separately. Fuel switching in industry refers to switching to electricity, hydrogen, bioenergy and natural gas. The length of the solid bars represents the mitigation potential of an option. Potentials are broken down into cost categories, indicated by different colours (see legend). Only discounted lifetime monetary costs are considered. Where a gradual colour transition is shown, the breakdown of the potential into cost categories is not well known or depends heavily on factors such as geographical location, resource availability, and regional circumstances, and the colours indicate the range of estimates. The uncertainty in the total potential is typically 25–50%. When interpreting this figure, the following should be taken into account: (1) The mitigation potential is uncertain, as it will depend on the reference technology (and emissions) being displaced, the rate of new technology adoption, and several other factors; (2) Different options have different feasibilities beyond the cost aspects, which are not reflected in the figure; and (3) Costs for accommodating the integration of variable renewable energy sources in electricity systems are expected to be modest until 2030, and are not included. Panel (b) displays the indicative potential of demand-side mitigation options for 2050. Potentials are estimated based on approximately 500 bottom-up studies representing all global regions. The baseline (white bar) is provided by the sectoral mean GHG emissions in 2050 of the two scenarios (IEA-STEPS and IP_ModAct) consistent with policies announced by national governments until 2020. The green arrow represents the demand-side emissions reductions potentials. The range in potential is shown by a line connecting dots displaying the highest and the lowest potentials reported in the literature. Food shows demand-side potential of socio-cultural factors and infrastructure use, and changes in land-use patterns enabled by change in food demand. Demand-side measures and new ways of end-use service provision can reduce global GHG emissions in end-use sectors (buildings, land transport, food) by 40–70% by 2050 compared to baseline scenarios, while some regions and socioeconomic groups require additional energy and resources. The last row shows how demand-side mitigation options in other sectors can influence overall electricity demand. The dark grey bar shows the projected increase in electricity demand above the 2050 baseline due to increasing electrification in the other sectors. Based on a bottom-up assessment, this projected increase in electricity demand can be avoided through demand-side mitigation options in the domains of infrastructure use and socio-cultural factors that influence electricity usage in industry, land transport, and buildings (green arrow). {WGII Figure SPM.4, WGII Cross-Chapter Box FEASIB in Chapter 18; WGIII SPM C.10, WGIII 12.2.1, WGIII 12.2.2, WGIII Figure SPM.6, WGIII Figure SPM.7}

4.5.1. Energy Systems

Rapid and deep reductions in GHG emissions require major energy system transitions (*high confidence*). Adaptation options can help reduce climate-related risks to the energy system (*very high confidence*). Net zero CO₂ energy systems entail: a substantial reduction in overall fossil fuel use, minimal use of unabated fossil fuels¹⁵³, and use of Carbon Capture and Storage in the remaining fossil fuel systems; electricity systems that emit no net CO₂; widespread electrification; alternative energy carriers in applications less amenable to electrification; energy conservation and efficiency; and greater integration across the energy system (*high confidence*). Large contributions to emissions reductions can come from options costing less than USD 20 tCO₂-eq⁻¹, including solar and wind energy, energy efficiency improvements, and CH₄ (methane) emissions reductions (from coal mining, oil and gas, and waste) (*medium confidence*).¹⁵⁴ Many of these response options are technically viable and are supported by the public (*high confidence*). Maintaining emission-intensive systems may, in some regions and sectors, be more expensive than transitioning to low emission systems (*high confidence*). {WGII SPM C.2.10; WGIII SPM C.4.1, WGIII SPM C.4.2, WGIII SPM C.12.1, WGIII SPM E.1.1, WGIII TS.5.1}

Climate change and related extreme events will affect future energy systems, including hydropower production, bioenergy yields, thermal power plant efficiencies, and demands for heating and cooling (*high*

confidence). The most feasible energy system adaptation options support infrastructure resilience, reliable power systems and efficient water use for existing and new energy generation systems (*very high confidence*). Adaptations for hydropower and thermo-electric power generation are effective in most regions up to 1.5°C to 2°C, with decreasing effectiveness at higher levels of warming (*medium confidence*). Energy generation diversification (e.g., wind, solar, small-scale hydroelectric) and demand side management (e.g., storage and energy efficiency improvements) can increase energy reliability and reduce vulnerabilities to climate change, especially in rural populations (*high confidence*). Climate responsive energy markets, updated design standards on energy assets according to current and projected climate change, smart-grid technologies, robust transmission systems and improved capacity to respond to supply deficits have high feasibility in the medium- to long-term, with mitigation co-benefits (*very high confidence*). {WGII SPM B.5.3, WGII SPM C.2.10; WGIII TS.5.1}

4.5.2. Industry

There are several options to reduce industrial emissions that differ by type of industry; many industries are disrupted by climate change, especially from extreme events (*high confidence*). Reducing industry emissions will entail coordinated action throughout value chains to promote all mitigation options, including demand management, energy and materials efficiency, circular material flows, as well as abatement technologies and

¹⁵³ In this context, 'unabated fossil fuels' refers to fossil fuels produced and used without interventions that substantially reduce the amount of GHG emitted throughout the life cycle; for example, capturing 90% or more CO₂ from power plants, or 50–80% of fugitive methane emissions from energy supply. {WGIII SPM footnote 54}

¹⁵⁴ The mitigation potentials and mitigation costs of individual technologies in a specific context or region may differ greatly from the provided estimates (*medium confidence*). {WGIII SPM C.12.1}

transformational changes in production processes (*high confidence*). Light industry and manufacturing can be largely decarbonized through available abatement technologies (e.g., material efficiency, circularity), electrification (e.g., electrothermal heating, heat pumps), and switching to low- and zero-GHG emitting fuels (e.g., hydrogen, ammonia, and bio-based and other synthetic fuels) (*high confidence*), while deep reduction of cement process emissions will rely on cementitious material substitution and the availability of Carbon Capture and Storage (CCS) until new chemistries are mastered (*high confidence*). Reducing emissions from the production and use of chemicals would need to rely on a life cycle approach, including increased plastics recycling, fuel and feedstock switching, and carbon sourced through biogenic sources, and, depending on availability, Carbon Capture and Utilisation (CCU), direct air CO₂ capture, as well as CCS (*high confidence*). Action to reduce industry sector emissions may change the location of GHG-intensive industries and the organisation of value chains, with distributional effects on employment and economic structure (*medium confidence*). {WGII TS.B.9.1, WGII 16.5.2; WGIII SPM C.5, WGIII SPM C.5.2, WGIII SPM C.5.3, WGIII TS.5.5}

Many industrial and service sectors are negatively affected by climate change through supply and operational disruptions, especially from extreme events (*high confidence*), and will require adaptation efforts. Water intensive industries (e.g., mining) can undertake measures to reduce water stress, such as water recycling and reuse, using brackish or saline sources, working to improve water use efficiency. However, residual risks will remain, especially at higher levels of warming (*medium confidence*). {WGII TS.B.9.1, WGII 16.5.2, WGII 4.6.3} (Section 3.2)

4.5.3. Cities, Settlements and Infrastructure

Urban systems are critical for achieving deep emissions reductions and advancing climate resilient development, particularly when this involves integrated planning that incorporates physical, natural and social infrastructure (*high confidence*). Deep emissions reductions and integrated adaptation actions are advanced by: integrated, inclusive land use planning and decision-making; compact urban form by co-locating jobs and housing; reducing or changing urban energy and material consumption; electrification in combination with low emissions sources; improved water and waste management infrastructure; and enhancing carbon uptake and storage in the urban environment (e.g. bio-based building materials, permeable surfaces and urban green and blue infrastructure). Cities can achieve net zero emissions if emissions are reduced within and outside of their administrative boundaries through supply chains, creating beneficial cascading effects across other sectors. (*high confidence*) {WGII SPM C.5.6, WGII SPM D.1.3, WGII SPM D.3; WGIII SPM C.6, WGIII SPM C.6.2, WGIII TS 5.4, SR1.5 SPM C.2.4}

Considering climate change impacts and risks (e.g., through climate services) in the design and planning of urban and rural settlements and infrastructure is critical for resilience and enhancing human well-being. Effective mitigation can be advanced at each of the design, construction, retrofit, use and disposal stages for buildings. Mitigation interventions for buildings include: at the construction phase, low-

emission construction materials, highly efficient building envelope and the integration of renewable energy solutions; at the use phase, highly efficient appliances/equipment, the optimisation of the use of buildings and their supply with low-emission energy sources; and at the disposal phase, recycling and re-using construction materials. Sufficiency¹⁵⁵ measures can limit the demand for energy and materials over the lifecycle of buildings and appliances. (*high confidence*) {WGII SPM C.2.5; WGIII SPM C.7.2}

Transport-related GHG emissions can be reduced by demand-side options and low-GHG emissions technologies. Changes in urban form, reallocation of street space for cycling and walking, digitalisation (e.g., teleworking) and programs that encourage changes in consumer behaviour (e.g. transport, pricing) can reduce demand for transport services and support the shift to more energy efficient transport modes (*high confidence*). Electric vehicles powered by low-emissions electricity offer the largest decarbonisation potential for land-based transport, on a life cycle basis (*high confidence*). Costs of electrified vehicles are decreasing and their adoption is accelerating, but they require continued investments in supporting infrastructure to increase scale of deployment (*high confidence*). The environmental footprint of battery production and growing concerns about critical minerals can be addressed by material and supply diversification strategies, energy and material efficiency improvements, and circular material flows (*medium confidence*). Advances in battery technologies could facilitate the electrification of heavy-duty trucks and complement conventional electric rail systems (*medium confidence*). Sustainable biofuels can offer additional mitigation benefits in land-based transport in the short and medium term (*medium confidence*). Sustainable biofuels, low-emissions hydrogen, and derivatives (including synthetic fuels) can support mitigation of CO₂ emissions from shipping, aviation, and heavy-duty land transport but require production process improvements and cost reductions (*medium confidence*). Key infrastructure systems including sanitation, water, health, transport, communications and energy will be increasingly vulnerable if design standards do not account for changing climate conditions (*high confidence*). {WGII SPM B.2.5; WGIII SPM C.6.2, WGIII SPM C.8, WGIII SPM C.8.1, WGIII SPM C.8.2, WGIII SPM C.10.2, WGIII SPM C.10.3, WGIII SPM C.10.4}

Green/natural and blue infrastructure such as urban forestry, green roofs, ponds and lakes, and river restoration can mitigate climate change through carbon uptake and storage, avoided emissions, and reduced energy use while reducing risk from extreme events such as heatwaves, heavy precipitation and droughts, and advancing co-benefits for health, well-being and livelihoods (*medium confidence*). Urban greening can provide local cooling (*very high confidence*). Combining green/natural and grey/physical infrastructure adaptation responses has potential to reduce adaptation costs and contribute to flood control, sanitation, water resources management, landslide prevention and coastal protection (*medium confidence*). Globally, more financing is directed at grey/physical infrastructure than green/natural infrastructure and social infrastructure (*medium confidence*), and there is limited evidence of investment in informal settlements (*medium to high confidence*). The greatest gains in well-being in urban areas can be achieved by prioritising finance to reduce climate risk for low-income

¹⁵⁵ A set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human well-being for all within planetary boundaries. {WGIII Annex I}

and marginalised communities including people living in informal settlements (*high confidence*). {WGII SPM C.2.5, WGII SPM C.2.6, WGII SPM C.2.7, WGII SPM D.3.2, WGII TS.E.1.4, WGII Cross-Chapter Box FEAS; WGIII SPM C.6, WGIII SPM C.6.2, WGIII SPM D.1.3, WGIII SPM D.2.1}

Responses to ongoing sea level rise and land subsidence in low-lying coastal cities and settlements and small islands include protection, accommodation, advance and planned relocation. These responses are more effective if combined and/or sequenced, planned well ahead, aligned with sociocultural values and development priorities, and underpinned by inclusive community engagement processes. (*high confidence*) {WGII SPM C.2.8}

4.5.4. Land, Ocean, Food, and Water

There is substantial mitigation and adaptation potential from options in agriculture, forestry and other land use, and in the oceans, that could be upscaled in the near term across most regions (*high confidence*) (Figure 4.5). Conservation, improved management, and restoration of forests and other ecosystems offer the largest share of economic mitigation potential, with reduced deforestation in tropical regions having the highest total mitigation potential. Ecosystem restoration, reforestation, and afforestation can lead to trade-offs due to competing demands on land. Minimizing trade-offs requires integrated approaches to meet multiple objectives including food security. Demand-side measures (shifting to sustainable healthy diets and reducing food loss/waste) and sustainable agricultural intensification can reduce ecosystem conversion and CH₄ and N₂O emissions, and free up land for reforestation and ecosystem restoration. Sustainably sourced agriculture and forest products, including long-lived wood products, can be used instead of more GHG-intensive products in other sectors. Effective adaptation options include cultivar improvements, agroforestry, community-based adaptation, farm and landscape diversification, and urban agriculture. These AFOLU response options require integration of biophysical, socioeconomic and other enabling factors. The effectiveness of ecosystem-based adaptation and most water-related adaptation options declines with increasing warming (see 3.2). (*high confidence*) {WGII SPM C.2.1, WGII SPM C.2.2, WGII SPM C.2.5; WGIII SPM C.9.1; SRCCL SPM B.1.1, SRCCL SPM B.5.4, SRCCL SPM D.1; SROCC SPM C}

Some options, such as conservation of high-carbon ecosystems (e.g., peatlands, wetlands, rangelands, mangroves and forests), have immediate impacts while others, such as restoration of high-carbon ecosystems, reclamation of degraded soils or afforestation, take decades to deliver measurable results (*high confidence*). Many sustainable land management technologies and practices are financially profitable in three to ten years (*medium confidence*). {SRCCL SPM B.1.2, SRCCL SPM D.2.2}

Maintaining the resilience of biodiversity and ecosystem services at a global scale depends on effective and equitable conservation of approximately 30–50% of Earth's land, freshwater and ocean areas, including currently near-natural ecosystems (*high confidence*). The services and options provided by terrestrial, freshwater, coastal and ocean ecosystems can be supported

by protection, restoration, precautionary ecosystem-based management of renewable resource use, and the reduction of pollution and other stressors (*high confidence*). {WGII SPM C.2.4, WGII SPM D.4; SROCC SPM C.2}

Large-scale land conversion for bioenergy, biochar, or afforestation can increase risks to biodiversity, water and food security. In contrast, restoring natural forests and drained peatlands, and improving sustainability of managed forests enhances the resilience of carbon stocks and sinks and reduces ecosystem vulnerability to climate change. Cooperation, and inclusive decision making, with local communities and Indigenous Peoples, as well as recognition of inherent rights of Indigenous Peoples, is integral to successful adaptation across forests and other ecosystems. (*high confidence*) {WGII SPM B.5.4, WGII SPM C.2.3, WGII SPM C.2.4; WGIII SPM D.2.3; SRCCL B.7.3, SRCCL SPM C.4.3, SRCCL TS.7}

Natural rivers, wetlands and upstream forests reduce flood risk in most circumstances (*high confidence*). Enhancing natural water retention such as by restoring wetlands and rivers, land use planning such as no build zones or upstream forest management, can further reduce flood risk (*medium confidence*). For inland flooding, combinations of non-structural measures like early warning systems and structural measures like levees have reduced loss of lives (*medium confidence*), but hard defences against flooding or sea level rise can also be maladaptive (*high confidence*). {WGII SPM C.2.1, WGII SPM C.4.1, WGII SPM C.4.2, WGII SPM C.2.5}

Protection and restoration of coastal 'blue carbon' ecosystems (e.g., mangroves, tidal marshes and seagrass meadows) could reduce emissions and/or increase carbon uptake and storage (*medium confidence*). Coastal wetlands protect against coastal erosion and flooding (*very high confidence*). Strengthening precautionary approaches, such as rebuilding overexploited or depleted fisheries, and responsiveness of existing fisheries management strategies reduces negative climate change impacts on fisheries, with benefits for regional economies and livelihoods (*medium confidence*). Ecosystem-based management in fisheries and aquaculture supports food security, biodiversity, human health and well-being (*high confidence*). {WGII SPM C.2.2, WGII SPM C.2; SROCC SPM C.2.3, SROCC SPM C.2.4}

4.5.5. Health and Nutrition

Human health will benefit from integrated mitigation and adaptation options that mainstream health into food, infrastructure, social protection, and water policies (*very high confidence*). Balanced and sustainable healthy diets¹⁵⁶ and reduced food loss and waste present important opportunities for adaptation and mitigation while generating significant co-benefits in terms of biodiversity and human health (*high confidence*). Public health policies to improve nutrition, such as increasing the diversity of food sources in public procurement, health insurance, financial incentives, and awareness-raising campaigns, can potentially influence food demand, reduce food waste, reduce healthcare costs, contribute to lower GHG emissions and enhance adaptive capacity (*high confidence*).

¹⁵⁶ Balanced diets refer to diets that feature plant-based foods, such as those based on coarse grains, legumes, fruits and vegetables, nuts and seeds, and animal-sourced food produced in resilient, sustainable and low-GHG emission systems, as described in SRCCL.

Improved access to clean energy sources and technologies, and shifts to active mobility (e.g., walking and cycling) and public transport can deliver socioeconomic, air quality and health benefits, especially for women and children (*high confidence*). {WGII SPM C.2.2, WGII SPM C.2.11, WGII Cross-Chapter Box HEALTH; WGIII SPM C.2.2, WGIII SPM C.4.2, WGIII SPM C.9.1, WGIII SPM C.10.4, WGIII SPM D.1.3, WGIII Figure SPM.6, WGIII Figure SPM.8; SRCCL SPM B.6.2, SRCCL SPM B.6.3, SRCCL B.4.6, SRCCL SPM C.2.4}

Effective adaptation options exist to help protect human health and well-being (*high confidence*). Health Action Plans that include early warning and response systems are effective for extreme heat (*high confidence*). Effective options for water-borne and food-borne diseases include improving access to potable water, reducing exposure of water and sanitation systems to flooding and extreme weather events, and improved early warning systems (*very high confidence*). For vector-borne diseases, effective adaptation options include surveillance, early warning systems, and vaccine development (*very high confidence*). Effective adaptation options for reducing mental health risks under climate change include improving surveillance and access to mental health care, and monitoring of psychosocial impacts from extreme weather events (*high confidence*). A key pathway to climate resilience in the health sector is universal access to healthcare (*high confidence*). {WGII SPM C.2.11, WGII 7.4.6}

4.5.6 Society, Livelihoods, and Economies

Enhancing knowledge on risks and available adaptation options promotes societal responses, and behaviour and lifestyle changes supported by policies, infrastructure and technology can help reduce global GHG emissions (*high confidence*). Climate literacy and information provided through climate services and community approaches, including those that are informed by Indigenous Knowledge and local knowledge, can accelerate behavioural changes and planning (*high confidence*). Educational and information programmes, using the arts, participatory modelling and citizen science can facilitate awareness, heighten risk perception, and influence behaviours (*high confidence*). The way choices are presented can enable adoption of low GHG intensive socio-cultural options, such as shifts to balanced, sustainable healthy diets, reduced food waste, and active mobility (*high confidence*). Judicious labelling, framing, and communication of social norms can increase the effect of mandates, subsidies, or taxes (*medium confidence*). {WGII SPM C.5.3, WGII TS.D.10.1; WGIII SPM C.10, WGIII SPM C.10.2, WGIII SPM C.10.3, WGIII SPM E.2.2, WGIII Figure SPM.6, WGIII TS.6.1, 5.4; SR1.5 SPM D.5.6; SROCC SPM C.4}

A range of adaptation options, such as disaster risk management, early warning systems, climate services and risk spreading and sharing approaches, have broad applicability across sectors and provide greater risk reduction benefits when combined (*high confidence*). Climate services that are demand-driven and inclusive of different users and providers can improve agricultural practices, inform better water use and efficiency, and enable resilient infrastructure planning (*high confidence*). Policy mixes that include weather and health insurance, social protection and adaptive safety nets, contingent finance and reserve funds, and universal access to early warning systems combined with effective contingency plans, can reduce vulnerability and exposure of human systems (*high confidence*).

Integrating climate adaptation into social protection programs, including cash transfers and public works programs, is highly feasible and increases resilience to climate change, especially when supported by basic services and infrastructure (*high confidence*). Social safety nets can build adaptive capacities, reduce socioeconomic vulnerability, and reduce risk linked to hazards (*robust evidence, medium agreement*). {WGII SPM C.2.9, WGII SPM C.2.13, WGII Cross-Chapter Box FEASIB in Chapter 18; SRCCL SPM C.1.4, SRCCL SPM D.1.2}

Reducing future risks of involuntary migration and displacement due to climate change is possible through cooperative, international efforts to enhance institutional adaptive capacity and sustainable development (*high confidence*). Increasing adaptive capacity minimises risk associated with involuntary migration and immobility and improves the degree of choice under which migration decisions are made, while policy interventions can remove barriers and expand the alternatives for safe, orderly and regular migration that allows vulnerable people to adapt to climate change (*high confidence*). {WGII SPM C.2.12, WGII TS.D.8.6, WGII Cross-Chapter Box MIGRATE in Chapter 7}

Accelerating commitment and follow-through by the private sector is promoted for instance by building business cases for adaptation, accountability and transparency mechanisms, and monitoring and evaluation of adaptation progress (*medium confidence*). Integrated pathways for managing climate risks will be most suitable when so-called 'low-regret' anticipatory options are established jointly across sectors in a timely manner and are feasible and effective in their local context, and when path dependencies and maladaptations across sectors are avoided (*high confidence*). Sustained adaptation actions are strengthened by mainstreaming adaptation into institutional budget and policy planning cycles, statutory planning, monitoring and evaluation frameworks and into recovery efforts from disaster events (*high confidence*). Instruments that incorporate adaptation such as policy and legal frameworks, behavioural incentives, and economic instruments that address market failures, such as climate risk disclosure, inclusive and deliberative processes strengthen adaptation actions by public and private actors (*medium confidence*). {WGII SPM C.5.1, WGII SPM C.5.2, WGII TS.D.10.4}

4.6 Co-Benefits of Adaptation and Mitigation for Sustainable Development Goals

Mitigation and adaptation actions have more synergies than trade-offs with Sustainable Development Goals (SDGs). Synergies and trade-offs depend on context and scale of implementation. Potential trade-offs can be compensated or avoided with additional policies, investments and financial partnerships. (*high confidence*)

Many mitigation and adaptation actions have multiple synergies with Sustainable Development Goals (SDGs), but some actions can also have trade-offs. Potential synergies with SDGs exceed potential trade-offs. Synergies and trade-offs are context specific and depend on: means and scale of implementation, intra- and inter-sectoral interactions, cooperation between countries and regions, the sequencing, timing and stringency of actions, governance, and policy design. Eradicating extreme poverty, energy poverty, and providing decent living standards to all, consistent with near-term sustainable development objectives, can be achieved without significant global emissions growth. (*high confidence*) {WGII SPM C.2.3, WGII Figure SPM.4b; WGIII SPM B.3.3, WGIII SPM C.9.2, WGIII SPM D.1.2, WGIII SPM D.1.4, WGIII Figure SPM.8} (Figure 4.5)

Several mitigation and adaptation options can harness near-term synergies and reduce trade-offs to advance sustainable development in energy, urban and land systems (Figure 4.5) (*high confidence*). Clean energy supply systems have multiple co-benefits, including improvements in air quality and health. Heat Health Action Plans that include early warning and response systems, approaches that mainstream health into food, livelihoods, social protection, water and sanitation benefit health and well-being. There are potential synergies between multiple Sustainable Development Goals and sustainable land use and urban planning with more green spaces, reduced air pollution, and demand-side mitigation including shifts to balanced, sustainable healthy diets. Electrification combined with low-GHG energy, and shifts to public transport can enhance health, employment, and can contribute to energy security and deliver equity. Conservation, protection and restoration of terrestrial, freshwater, coastal and ocean ecosystems, together with targeted management to adapt to unavoidable impacts of climate change can generate multiple additional benefits, such as agricultural productivity, food security, and biodiversity conservation. (*high confidence*) {WGII SPM C.1.1, WGII C.2.4, WGII SPM D.1, WGII Figure SPM.4, WGII Cross-Chapter Box HEALTH in Chapter 17, WGII Cross-Chapter Box FEASIB in Chapter 18; WGIII SPM C.4.2, WGIII SPM D.1.3, WGIII SPM D.2, WGIII Figure SPM.8; SRCL SPM B.4.6}

When implementing mitigation and adaptation together, and taking trade-offs into account, multiple co-benefits and synergies for human well-being as well as ecosystem and planetary health can be realised (*high confidence*). There is a strong link between sustainable development, vulnerability and climate risks. Social safety nets that support climate change adaptation have strong co-benefits with development goals such as education, poverty alleviation, gender inclusion and food security. Land restoration contributes to mitigation and adaptation with synergies via enhanced ecosystem services and with economically positive returns and co-benefits for poverty reduction and improved livelihoods. Trade-offs can be evaluated and minimised by giving emphasis to capacity building, finance, technology transfer, investments; governance, development, context specific gender-based

and other social equity considerations with meaningful participation of Indigenous Peoples, local communities and vulnerable populations. (*high confidence*). {WGII SPM C.2.9, WGII SPM C.5.6, WGII SPM D.5.2, WGII Cross-Chapter Box on Gender in Chapter 18; WGIII SPM C.9.2, WGIII SPM D.1.2, WGIII SPM D.1.4, WGIII SPM D.2; SRCL SPM D.2.2, SRCL TS.4}

Context relevant design and implementation requires considering people's needs, biodiversity, and other sustainable development dimensions (*very high confidence*). Countries at all stages of economic development seek to improve the well-being of people, and their development priorities reflect different starting points and contexts. Different contexts include but are not limited to social, economic, environmental, cultural, or political circumstances, resource endowment, capabilities, international environment, and prior development. In regions with high dependency on fossil fuels for, among other things, revenue and employment generation, mitigating risks for sustainable development requires policies that promote economic and energy sector diversification and considerations of just transitions principles, processes and practices (*high confidence*). For individuals and households in low-lying coastal areas, in Small Islands, and smallholder farmers transitioning from incremental to transformational adaptation can help overcome soft adaptation limits (*high confidence*). Effective governance is needed to limit trade-offs of some mitigation options such as large scale afforestation and bioenergy options due to risks from their deployment for food systems, biodiversity, other ecosystem functions and services, and livelihoods (*high confidence*). Effective governance requires adequate institutional capacity at all levels (*high confidence*). {WGII SPM B.5.4, WGII SPM C.3.1, WGII SPM C.3.4; WGIII SPM D.1.3, WGIII SPM E.4.2; SR1.5 SPM C.3.4, SR1.5 SPM C.3.5, SR1.5 SPM Figure SPM.4, SR1.5 SPM D.4.3, SR1.5 SPM D.4.4}

Near-term adaptation and mitigation actions have more synergies than trade-offs with Sustainable Development Goals (SDGs)

Synergies and trade-offs depend on context and scale

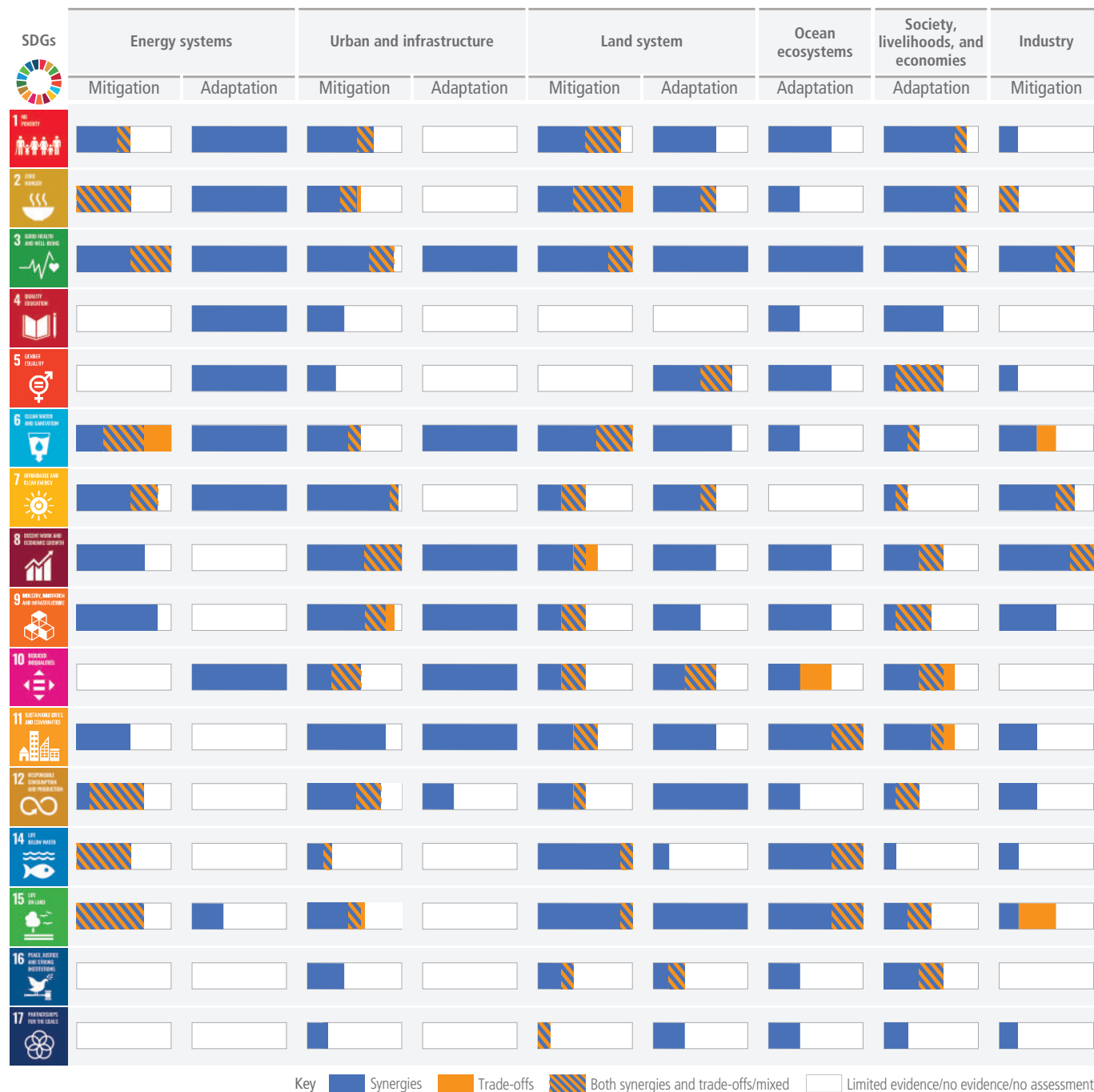


Figure 4.5: Potential synergies and trade-offs between the portfolio of climate change mitigation and adaptation options and the Sustainable Development Goals (SDGs). This figure presents a high-level summary of potential synergies and trade-offs assessed in WGII Figure SPM.4b and WGIII Figure SPM.8, based on the qualitative and quantitative assessment of each individual mitigation or option. The SDGs serve as an analytical framework for the assessment of different sustainable development dimensions, which extend beyond the time frame of 2030 SDG targets. Synergies and trade-offs across all individual options within a sector/system are aggregated into sector/system potentials for the whole mitigation or adaptation portfolio. The length of each bar represents the total number of mitigation or adaptation options under each system/sector. The number of adaptation and mitigation options vary across system/sector, and have been normalised to 100% so that bars are comparable across mitigation, adaptation, system/sector, and SDGs. Positive links shown in WGII Figure SPM.4b and WGIII Figure SPM.8 are counted and aggregated to generate the percentage share of synergies, represented here by the blue proportion within the bars. Negative links shown in WGII Figure SPM.4b and WGIII Figure SPM.8 are counted and aggregated to generate the percentage share of trade-offs and is represented by orange proportion within the bars. 'Both synergies and trade-offs' shown in WGII Figure SPM.4b and WGIII Figure SPM.8 are counted and aggregated to generate the percentage share of 'both synergies and trade-off', represented by the striped proportion within the bars. The 'white' proportion within the bar indicates limited evidence/ no evidence/ not assessed. Energy systems comprise all mitigation options listed in WGIII Figure SPM.8 and WGII Figure SPM.4b for adaptation. Urban and infrastructure comprises all mitigation options listed

in WGIII Figure SPM.8 under Urban systems, under Buildings and under Transport and adaptation options listed in WGII Figure SPM.4b under Urban and infrastructure systems. Land system comprises mitigation options listed in WGIII Figure SPM.8 under AFOLU and adaptation options listed in WGII Figure SPM.4b under Land and ocean systems: forest-based adaptation, agroforestry, biodiversity management and ecosystem connectivity, improved cropland management, efficient livestock management, water use efficiency and water resource management. Ocean ecosystems comprises adaptation options listed in WGII Figure SPM.4b under Land and ocean systems: coastal defence and hardening, integrated coastal zone management and sustainable aquaculture and fisheries. Society, livelihood and economies comprises adaptation options listed in WGII Figure SPM.4b under Cross-sectoral; Industry comprises all those mitigation options listed in WGIII Figure SPM.8 under Industry. SDG 13 (Climate Action) is not listed because mitigation/ adaptation is being considered in terms of interaction with SDGs and not vice versa (SPM SR1.5 Figure SPM.4 caption). The bars denote the strength of the connection and do not consider the strength of the impact on the SDGs. The synergies and trade-offs differ depending on the context and the scale of implementation. Scale of implementation particularly matters when there is competition for scarce resources. For the sake of uniformity, we are not reporting the confidence levels because there is knowledge gap in adaptation option wise relation with SDGs and their confidence level which is evident from WGII fig SPM.4b. {WGII Figure SPM.4b; WGIII Figure SPM.8}

4.7 Governance and Policy for Near-Term Climate Change Action

Effective climate action requires political commitment, well-aligned multi-level governance and institutional frameworks, laws, policies and strategies. It needs clear goals, adequate finance and financing tools, coordination across multiple policy domains, and inclusive governance processes. Many mitigation and adaptation policy instruments have been deployed successfully, and could support deep emissions reductions and climate resilience if scaled up and applied widely, depending on national circumstances. Adaptation and mitigation action benefits from drawing on diverse knowledge. (high confidence)

Effective climate governance enables mitigation and adaptation by providing overall direction based on national circumstances, setting targets and priorities, mainstreaming climate action across policy domains and levels, based on national circumstances and in the context of international cooperation. Effective governance enhances monitoring and evaluation and regulatory certainty, prioritising inclusive, transparent and equitable decision-making, and improves access to finance and technology (high confidence). These functions can be promoted by climate-relevant laws and plans, which are growing in number across sectors and regions, advancing mitigation outcomes and adaptation benefits (high confidence). Climate laws have been growing in number and have helped deliver mitigation and adaptation outcomes (medium confidence). {WGII SPM C.5, WGII SPM C.5.1, WGII SPM C.5.4, WGII SPM C.5.6; WGIII SPM B.5.2, WGIII SPM E.3.1}

Effective municipal, national and sub-national climate institutions, such as expert and co-ordinating bodies, enable co-produced, multi-scale decision-processes, build consensus for action among diverse interests, and inform strategy settings (high confidence). This requires adequate institutional capacity at all levels (high confidence). Vulnerabilities and climate risks are often reduced through carefully designed and implemented laws, policies, participatory processes, and interventions that address context specific inequities such as based on gender, ethnicity, disability, age, location and income (high confidence). Policy support is influenced by Indigenous Peoples, businesses, and actors in civil society, including, youth, labour, media, and local communities, and effectiveness is enhanced by partnerships between many different groups in society (high confidence). Climate-related litigation is growing, with a large number of cases in some developed countries and with a much smaller number in some developing countries, and in some cases has influenced the outcome and ambition of climate governance (medium confidence). {WGII SPM C.2.6, WGII SPM C.5.2, WGII SPM C.5.5, WGII SPM C.5.6, WGII SPM D.3.1; WGIII SPM E.3.2, WGIII SPM E.3.3}

Effective climate governance is enabled by inclusive decision processes, allocation of appropriate resources, and institutional review, monitoring and evaluation (high confidence). Multi-level, hybrid and cross-sector governance facilitates appropriate consideration for co-benefits and trade-offs, particularly in land sectors where decision processes range from farm level to national scale (high confidence). Consideration of climate justice can help to facilitate shifting development pathways towards sustainability. {WGII SPM C.5.5, WGII SPM C.5.6, WGII SPM D.1.1, WGII SPM D.2, WGII SPM D.3.2; SRCL SPM C.3, SRCL TS.1}

Drawing on diverse knowledge and partnerships, including with women, youth, Indigenous Peoples, local communities, and ethnic minorities can facilitate climate resilient development and has allowed locally appropriate and socially acceptable solutions (high confidence). {WGII SPM D.2, D.2.1}

Many regulatory and economic instruments have already been deployed successfully. These instruments could support deep emissions reductions if scaled up and applied more widely. Practical experience has informed instrument design and helped to improve predictability, environmental effectiveness, economic efficiency, and equity. (high confidence) {WGII SPM E.4; WGIII SPM E.4.2}

Scaling up and enhancing the use of regulatory instruments, consistent with national circumstances, can improve mitigation outcomes in sectoral applications (high confidence), and regulatory instruments that include flexibility mechanisms can reduce costs of cutting emissions (medium confidence). {WGII SPM C.5.4; WGIII SPM E.4.1}

Where implemented, carbon pricing instruments have incentivized low-cost emissions reduction measures, but have been less effective, on their own and at prevailing prices during the assessment period, to promote higher-cost measures necessary for further reductions (medium confidence). Revenue from carbon taxes or emissions trading can be used for equity and distributional goals, for example to support low-income households, among other

approaches (*high confidence*). There is no consistent evidence that current emission trading systems have led to significant emissions leakage (*medium confidence*). {WGIII SPM E.4.2, WGIII SPM E.4.6}

Removing fossil fuel subsidies would reduce emissions, improve public revenue and macroeconomic performance, and yield other environmental and sustainable development benefits such as improved public revenue, macroeconomic and sustainability performance; subsidy removal can have adverse distributional impacts especially on the most economically vulnerable groups which, in some cases, can be mitigated by measures such as re-distributing revenue saved, and depend on national circumstances (*high confidence*). Fossil fuel subsidy removal is projected by various studies to reduce global CO₂ emissions by 1–4%, and GHG emissions by up to 10% by 2030, varying across regions (*medium confidence*). {WGIII SPM E.4.2}

National policies to support technology development, and participation in international markets for emission reduction, can bring positive spillover effects for other countries (*medium confidence*), although reduced demand for fossil fuels as a result of climate policy could result in costs to exporting countries (*high confidence*). Economy-wide packages can meet short-term economic goals while reducing emissions and shifting development pathways towards sustainability (*medium confidence*). Examples are public spending commitments; pricing reforms; and investment in education and training, R&D and infrastructure (*high confidence*). Effective policy packages would be comprehensive in coverage, harnessed to a clear vision for change, balanced across objectives, aligned with specific technology and system needs, consistent in terms of design and tailored to national circumstances (*high confidence*). {WGIII SPM E.4.4, WGIII SPM 4.5, WGIII SPM 4.6}

4.8 Strengthening the Response: Finance, International Cooperation and Technology

Finance, international cooperation and technology are critical enablers for accelerated climate action. If climate goals are to be achieved, both adaptation and mitigation financing would have to increase many-fold. There is sufficient global capital to close the global investment gaps but there are barriers to redirect capital to climate action. Barriers include institutional, regulatory and market access barriers, which can be reduced to address the needs and opportunities, economic vulnerability and indebtedness in many developing countries. Enhancing international cooperation is possible through multiple channels. Enhancing technology innovation systems is key to accelerate the widespread adoption of technologies and practices. (*high confidence*)

4.8.1. Finance for Mitigation and Adaptation Actions

Improved availability and access to finance¹⁵⁷ will enable accelerated climate action (*very high confidence*). Addressing needs and gaps and broadening equitable access to domestic and international finance, when combined with other supportive actions, can act as a catalyst for accelerating mitigation and shifting development pathways (*high confidence*). Climate resilient development is enabled by increased international cooperation including improved access to financial resources, particularly for vulnerable regions, sectors and groups, and inclusive governance and coordinated policies (*high confidence*). Accelerated international financial cooperation is a critical enabler of low-GHG and just transitions, and can address inequities in access to finance and the costs of, and vulnerability to, the impacts of climate change (*high confidence*). {WGII SPM C.1.2, WGII SPM C.3.2, WGII SPM C.5, WGII SPM C.5.4, WGII SPM D.2, WGII SPM D.3.2, WGII SPM D.5, WGII SPM D.5.2; WGIII SPM B.4.2, WGIII SPM B.5, WGIII SPM B.5.4, WGIII SPM C.4.2, WGIII SPM C.7.3, WGIII SPM C.8.5, WGIII SPM D.1.2, WGIII SPM D.2.4, WGIII SPM D.3.4, WGIII SPM E.2.3, WGIII SPM E.3.1, WGIII SPM E.5, WGIII SPM E.5.1, WGIII SPM E.5.2, WGIII SPM E.5.3, WGIII SPM E.5.4, WGIII SPM E.6.2}

Both adaptation and mitigation finance need to increase many-fold, to address rising climate risks and to accelerate investments in emissions reduction (*high confidence*). Increased finance would address soft limits to adaptation and rising climate risks while also averting

some related losses and damages, particularly in vulnerable developing countries (*high confidence*). Enhanced mobilisation of and access to finance, together with building capacity, are essential for implementation of adaptation actions and to reduce adaptation gaps given rising risks and costs, especially for the most vulnerable groups, regions and sectors (*high confidence*). Public finance is an important enabler of adaptation and mitigation, and can also leverage private finance (*high confidence*). Adaptation funding predominately comes from public sources, and public mechanisms and finance can leverage private sector finance by addressing real and perceived regulatory, cost and market barriers, for instance via public-private partnerships (*high confidence*). Financial and technological resources enable effective and ongoing implementation of adaptation, especially when supported by institutions with a strong understanding of adaptation needs and capacity (*high confidence*). Average annual modelled mitigation investment requirements for 2020 to 2030 in scenarios that limit warming to 2°C or 1.5°C are a factor of three to six greater than current levels, and total mitigation investments (public, private, domestic and international) would need to increase across all sectors and regions (*medium confidence*). Even if extensive global mitigation efforts are implemented, there will be a large need for financial, technical, and human resources for adaptation (*high confidence*). {WGII SPM C.1.2, WGII SPM C.2.11, WGII SPM C.3, WGII SPM C.3.2, WGII SPM C.3.5, WGII SPM C.5, WGII SPM C.5.4, WGII SPM D.1, WGII SPM D.1.1, WGII SPM D.1.2, WGII SPM C.5.4; WGIII SPM D.2.4, WGIII SPM E.5, WGIII SPM E.5.1, WGIII 15.2} (Section 2.3.2, 2.3.3, 4.4, Figure 4.6)

¹⁵⁷ Finance can originate from diverse sources, singly or in combination: public or private, local, national or international, bilateral or multilateral, and alternative sources (e.g., philanthropic, carbon offsets). It can be in the form of grants, technical assistance, loans (concessional and non-concessional), bonds, equity, risk insurance and financial guarantees (of various types).

There is sufficient global capital and liquidity to close global investment gaps, given the size of the global financial system, but there are barriers to redirect capital to climate action both within and outside the global financial sector and in the context of economic vulnerabilities and indebtedness facing many developing countries (*high confidence*). For shifts in private finance, options include better assessment of climate-related risks and investment opportunities within the financial system, reducing sectoral and regional mismatches between available capital and investment needs, improving the risk-return profiles of climate investments, and developing institutional capacities and local capital markets. Macroeconomic barriers include, amongst others, indebtedness and economic vulnerability of developing regions. (*high confidence*) {WGII SPM C.5.4; WGIII SPM E.4.2, WGIII SPM E.5, WGIII SPM E.5.2, WGIII SPM E.5.3}

Scaling up financial flows requires clear signalling from governments and the international community (*high confidence*). Tracked financial flows fall short of the levels needed for adaptation and to achieve mitigation goals across all sectors and regions (*high confidence*). These gaps create many opportunities and the challenge of closing gaps is largest in developing countries (*high confidence*). This includes a stronger alignment of public finance, lowering real and perceived regulatory, cost and market barriers, and higher levels of public finance to lower the risks associated with low-emission investments. Up-front risks deter economically sound low carbon projects, and developing local capital markets are an option. Investors, financial intermediaries, central banks and financial regulators can shift the systemic underpricing of climate-related risks. A robust labelling of bonds and transparency is needed to attract savers. (*high confidence*) {WGII SPM C.5.4; WGIII SPM B.5.4, WGIII SPM E.4, WGIII SPM E.5.4, WGIII 15.2, WGIII 15.6.1, WGIII 15.6.2, WGIII 15.6.7}

The largest climate finance gaps and opportunities are in developing countries (*high confidence*). Accelerated support from developed countries and multilateral institutions is a critical enabler to enhance mitigation and adaptation action and can address inequities in finance, including its costs, terms and conditions, and economic vulnerability to climate change. Scaled-up public grants for mitigation and adaptation funding for vulnerable regions, e.g., in Sub-Saharan Africa, would be cost-effective and have high social returns in terms of access to basic energy. Options for scaling up mitigation and adaptation in developing regions include: increased levels of public finance and publicly mobilised private finance flows from developed to developing countries in the context of the USD 100 billion-a-year goal of the Paris Agreement; increase the use of public guarantees to reduce risks and leverage private flows at lower cost; local capital markets development; and building greater trust in international cooperation processes. A coordinated effort to make the post-pandemic recovery sustainable over the long term through increased flows of financing over this decade can accelerate climate action, including in developing regions facing high debt costs, debt distress and macroeconomic uncertainty. (*high confidence*) {WGII SPM C.5.2, WGII SPM C.5.4, WGII SPM C.6.5, WGII SPM D.2, WGII TS.D.10.2; WGIII SPM E.5, WGIII SPM E.5.3, WGIII TS.6.4, WGIII Box TS.1, WGIII 15.2, WGIII 15.6}

4.8.2. International Cooperation and Coordination

International cooperation is a critical enabler for achieving ambitious climate change mitigation goals and climate resilient development (*high confidence*). Climate resilient development is enabled by increased international cooperation including mobilising and enhancing access to finance, particularly for developing countries, vulnerable regions, sectors and groups and aligning finance flows for climate action to be consistent with ambition levels and funding needs (*high confidence*). While agreed processes and goals, such as those in the UNFCCC, Kyoto Protocol and Paris Agreement, are helping (Section 2.2.1), international financial, technology and capacity building support to developing countries will enable greater implementation and more ambitious actions (*medium confidence*). By integrating equity and climate justice, national and international policies can help to facilitate shifting development pathways towards sustainability, especially by mobilising and enhancing access to finance for vulnerable regions, sectors and communities (*high confidence*). International cooperation and coordination, including combined policy packages, may be particularly important for sustainability transitions in emissions-intensive and highly traded basic materials industries that are exposed to international competition (*high confidence*). The large majority of emission modelling studies assume significant international cooperation to secure financial flows and address inequality and poverty issues in pathways limiting global warming. There are large variations in the modelled effects of mitigation on GDP across regions, depending notably on economic structure, regional emissions reductions, policy design and level of international cooperation (*high confidence*). Delayed global cooperation increases policy costs across regions (*high confidence*). {WGII SPM D.2, WGII SPM D.3.1, WGII SPM D.5.2; WGIII SPM D.3.4, WGIII SPM C5.4, WGIII SPM C.12.2, WGIII SPM E.6, WGIII SPM E.6.1, WGIII E.5.4, WGIII TS.4.2, WGIII TS.6.2; SR1.5 SPM D.6.3, SR1.5 SPM D.7, SR1.5 SPM D.7.3}

The transboundary nature of many climate change risks (e.g., for supply chains, markets and natural resource flows in food, fisheries, energy and water, and potential for conflict) increases the need for climate-informed transboundary management, cooperation, responses and solutions through multi-national or regional governance processes (*high confidence*). Multilateral governance efforts can help reconcile contested interests, world views and values about how to address climate change. International environment and sectoral agreements, and initiatives in some cases, may help to stimulate low GHG investment and reduce emissions (such as ozone depletion, transboundary air pollution and atmospheric emissions of mercury). Improvements to national and international governance structures would further enable the decarbonisation of shipping and aviation through deployment of low-emissions fuels, for example through stricter efficiency and carbon intensity standards. Transnational partnerships can also stimulate policy development, low-emissions technology diffusion, emission reductions and adaptation, by linking sub-national and other actors, including cities, regions, non-governmental organisations and private sector entities, and by enhancing interactions between state and non-state actors, though uncertainties remain over their costs, feasibility, and effectiveness. International environmental and sectoral agreements, institutions, and initiatives are helping, and in some cases may help, to stimulate low GHG emissions investment and reduce emissions. (*medium confidence*) {WGII SPM B.5.3, WGII SPM C.5.6, WGII TS.E.5.4, WGII TS.E.5.5; WGIII SPM C.8.4, WGIII SPM E.6.3, WGIII SPM E.6.4, WGIII SPM E.6.4, WGIII TS.5.3}

Higher mitigation investment flows required for all sectors and regions to limit global warming

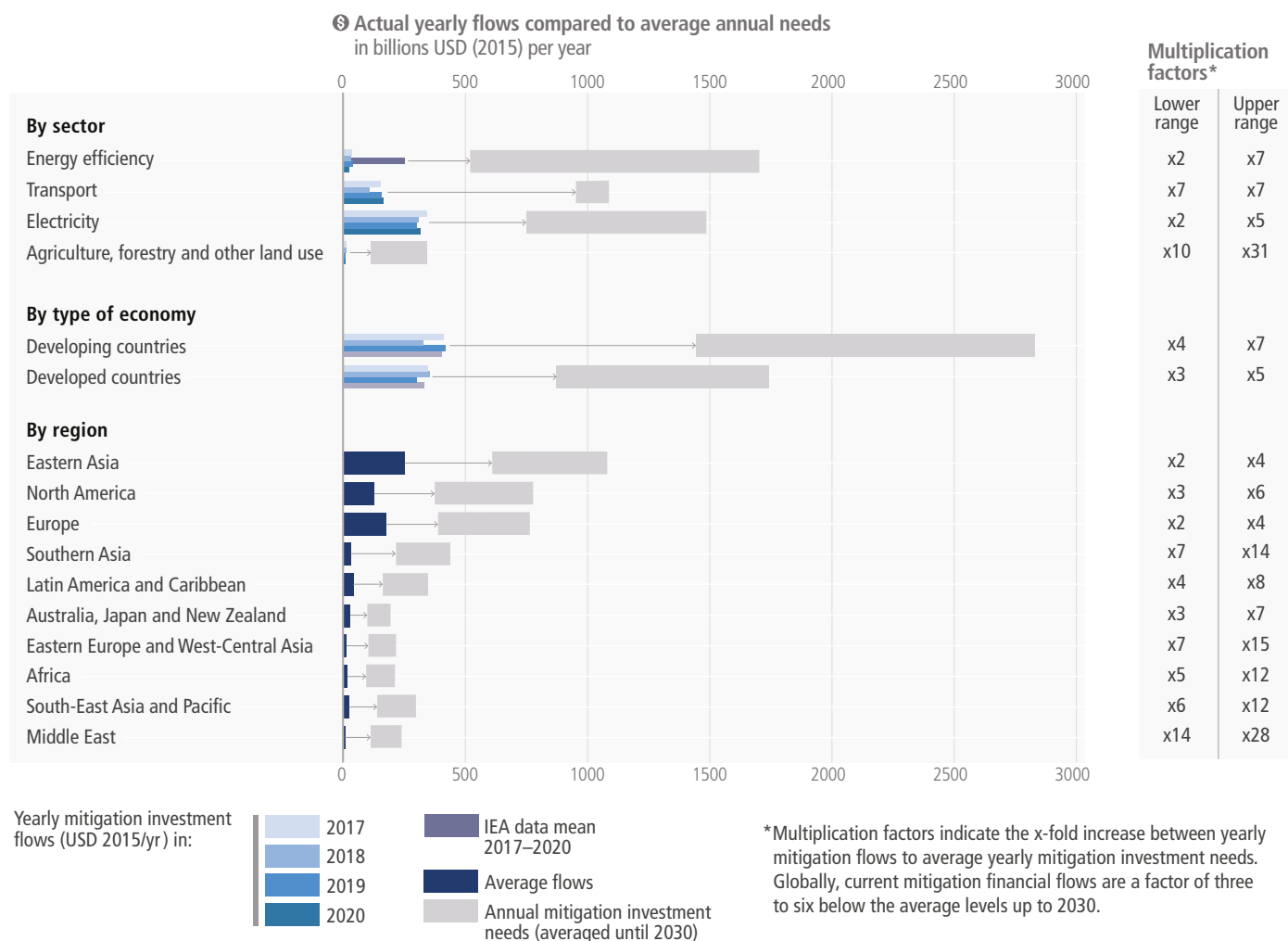


Figure 4.6: Breakdown of average mitigation investment flows and investment needs until 2030 (USD billion). Mitigation investment flows and investment needs by sector (energy efficiency, transport, electricity, and agriculture, forestry and other land use), by type of economy, and by region (see WGIII Annex II Part I Section 1 for the classification schemes for countries and areas). The blue bars display data on mitigation investment flows for four years: 2017, 2018, 2019 and 2020 by sector and by type of economy. For the regional breakdown, the annual average mitigation investment flows for 2017–2019 are shown. The grey bars show the minimum and maximum level of global annual mitigation investment needs in the assessed scenarios. This has been averaged until 2030. The multiplication factors show the ratio of global average early mitigation investment needs (averaged until 2030) and current yearly mitigation flows (averaged for 2017/18–2020). The lower multiplication factor refers to the lower end of the range of investment needs. The upper multiplication factor refers to the upper range of investment needs. Given the multiple sources and lack of harmonised methodologies, the data can be considered only if indicative of the size and pattern of investment needs. {WGIII Figure TS.25, WGIII 15.3, WGIII 15.4, WGIII 15.5, WGIII Table 15.2, WGIII Table 15.3, WGIII Table 15.4}

4.8.3. Technology Innovation, Adoption, Diffusion and Transfer

Enhancing technology innovation systems can provide opportunities to lower emissions growth and create social and environmental co-benefits. Policy packages tailored to national contexts and technological characteristics have been effective in supporting low-emission innovation and technology diffusion. Support for successful low-carbon technological innovation includes public policies such as training and R&D, complemented by regulatory and market-based instruments that create incentives and market opportunities such as appliance performance standards and building codes. (*high confidence*) {WGIII SPM B.4, WGIII SPM B.4.4, WGIII SPM E.4.3, WGIII SPM E.4.4}

International cooperation on innovation systems and technology development and transfer, accompanied by capacity building, knowledge sharing, and technical and financial support can accelerate the global diffusion of mitigation technologies, practices and policies and align these with other development objectives (*high confidence*). Choice architecture can help end-users adopt technology and low-GHG-intensive options (*high confidence*). Adoption of low-emission technologies lags in most developing countries, particularly least developed ones, due in part to weaker enabling conditions, including limited finance, technology development and transfer, and capacity building (*medium confidence*). {WGIII SPM B.4.2, WGIII SPM E.6.2, WGIII SPM C.10.4, WGIII 16.5}

International cooperation on innovation works best when tailored to and beneficial for local value chains, when partners collaborate on an equal footing, and when capacity building is an integral part of the effort (*medium confidence*). {WGIII SPM E.4.4, WGIII SPM E.6.2}

Technological innovation can have trade-offs that include externalities such as new and greater environmental impacts and social inequalities; rebound effects leading to lower net emission reductions or even emission increases; and overdependence on foreign knowledge and providers (*high confidence*). Appropriately designed policies and governance have helped address distributional impacts and rebound effects (*high confidence*). For example, digital technologies can promote large increases in energy efficiency through coordination and an economic shift to services (*high confidence*). However, societal digitalization can induce greater consumption of goods and energy and increased electronic waste as well as negatively

impacting labour markets and worsening inequalities between and within countries (*medium confidence*). Digitalisation requires appropriate governance and policies in order to enhance mitigation potential (*high confidence*). Effective policy packages can help to realise synergies, avoid trade-offs and/or reduce rebound effects: these might include a mix of efficiency targets, performance standards, information provision, carbon pricing, finance and technical assistance (*high confidence*). {WGIII SPM B.4.2, WGIII SPM B.4.3, WGIII SPM E.4.4, WGIII TS 6.5, WGIII Cross-Chapter Box 11 on Digitalization in Chapter 16}

Technology transfer to expand use of digital technologies for land use monitoring, sustainable land management, and improved agricultural productivity supports reduced emissions from deforestation and land use change while also improving GHG accounting and standardisation (*medium confidence*). {SRCCL SPM C.2.1, SRCCL SPM D.1.2, SRCCL SPM D.1.4, SRCCL 7.4.4, SRCCL 7.4.6}

4.9 Integration of Near-Term Actions Across Sectors and Systems

The feasibility, effectiveness and benefits of mitigation and adaptation actions are increased when multi-sectoral solutions are undertaken that cut across systems. When such options are combined with broader sustainable development objectives, they can yield greater benefits for human well-being, social equity and justice, and ecosystem and planetary health. (*high confidence*)

Climate resilient development strategies that treat climate, ecosystems and biodiversity, and human society as parts of an integrated system are the most effective (*high confidence*). Human and ecosystem vulnerability are interdependent (*high confidence*). Climate resilient development is enabled when decision-making processes and actions are integrated across sectors (*very high confidence*). Synergies with and progress towards the Sustainable Development Goals enhance prospects for climate resilient development. Choices and actions that treat humans and ecosystems as an integrated system build on diverse knowledge about climate risk, equitable, just and inclusive approaches, and ecosystem stewardship. {WGII SPM B.2, WGII Figure SPM.5, WGII SPM D.2, WGII SPM D2.1, WGII SPM 2.2, WGII SPM D4, WGII SPM D4.1, WGII SPM D4.2, WGII SPM D5.2, WGII Figure SPM.5}

Approaches that align goals and actions across sectors provide opportunities for multiple and large-scale benefits and avoided damages in the near term. Such measures can also achieve greater benefits through cascading effects across sectors (*medium confidence*). For example, the feasibility of using land for both agriculture and centralised solar production can increase when such options are combined (*high confidence*). Similarly, integrated transport and energy infrastructure planning and operations can together reduce the environmental, social, and economic impacts of decarbonising the transport and energy sectors (*high confidence*). The implementation of packages of multiple city-scale mitigation strategies can have cascading effects across sectors and reduce GHG emissions both within and outside a city's administrative boundaries (*very high confidence*). Integrated design approaches to the construction and retrofit of buildings provide increasing examples of zero energy or zero carbon buildings in several regions. To minimise maladaptation, multi-sectoral, multi-actor and inclusive planning with flexible pathways encourages low-regret and timely actions that keep options

open, ensure benefits in multiple sectors and systems and suggest the available solution space for adapting to long-term climate change (*very high confidence*). Trade-offs in terms of employment, water use, land-use competition and biodiversity, as well as access to, and the affordability of, energy, food, and water can be avoided by well-implemented land-based mitigation options, especially those that do not threaten existing sustainable land uses and land rights, with frameworks for integrated policy implementation (*high confidence*). {WGII SPM C.2, WGII SPM C.4.4; WGIII SPM C.6.3, WGIII SPM C.6, WGIII SPM C.7.2, WGIII SPM C.8.5, WGIII SPM D.1.2, WGIII SPM D.1.5, WGIII SPM E.1.2}

Mitigation and adaptation when implemented together, and combined with broader sustainable development objectives, would yield multiple benefits for human well-being as well as ecosystem and planetary health (*high confidence*). The range of such positive interactions is significant in the landscape of near-term climate policies across regions, sectors and systems. For example, AFOLU mitigation actions in land-use change and forestry, when sustainably implemented, can provide large-scale GHG emission reductions and removals that simultaneously benefit biodiversity, food security, wood supply and other ecosystem services but cannot fully compensate for delayed mitigation action in other sectors. Adaptation measures in land, ocean and ecosystems similarly can have widespread benefits for food security, nutrition, health and well-being, ecosystems and biodiversity. Equally, urban systems are critical, interconnected sites for climate resilient development; urban policies that implement multiple interventions can yield adaptation or mitigation gains with equity and human well-being. Integrated policy packages can improve the ability to integrate considerations of equity, gender equality and justice. Coordinated cross-sectoral policies and planning can maximise synergies and avoid or reduce trade-offs between mitigation

and adaptation. Effective action in all of the above areas will require near-term political commitment and follow-through, social cooperation, finance, and more integrated cross-sectoral policies and support and actions. (*high confidence*). {WGII SPM C.1, WG II SPM C.2, WGII SPM C.2, WGII SPM C.5, WGII SPM D.2, WGII SPM D.3.2, WGII SPM D.3.3, WGII Figure SPM.4; WGIII SPM C.6.3, WGIIISPM C.8.2, WGIII SPM C.9, WGIII SPM C.9.1, WGIII SPM C.9.2, WGIII SPM D.2, WGIII SPM D.2.4, WGIII SPM D.3.2, WGIII SPM E.1, WGIII SPM E.2.4, WGIII Figure SPM.8, WGIII TS.7, WGIII TS Figure TS.29: SRCCL ES 7.4.8, SRCCL SPM B.6} (3.4, 4.4)

Annexes

Annex I

Glossary

Editorial Team

Andy Reisinger (New Zealand), Diego Cammarano (Italy), Andreas Fischlin (Switzerland), Jan S. Fuglestedt (Norway), Gerrit Hansen (Germany), Yonghun Jung (Republic of Korea), Chloé Ludden (Germany/France), Valérie Masson-Delmotte (France), J.B. Robin Matthews (France/United Kingdom), Katja Mintenbeck (Germany), Dan Jezreel Orendain (Philippines/Belgium), Anna Pirani (Italy), Elvira Poloczanska (UK/Australia), José Romero (Switzerland)

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This concise Synthesis Report (SYR) Glossary defines selected key terms used in this report, drawn from the glossaries of the three Working Group contributions to the AR6. A more comprehensive, harmonised set of definitions for terms used in this SYR and the three AR6 Working Group reports is available from the IPCC Online Glossary: <https://apps.ipcc.ch/glossary/>

Readers are requested to refer to this comprehensive online glossary for definitions of terms of a more technical nature, and for scientific references relevant to individual terms. Italicized words indicate that the term is defined in this or/and the online glossary. Subterms appear in italics beneath main terms.

2030 Agenda for Sustainable Development

A UN resolution in September 2015 adopting a plan of action for people, planet and prosperity in a new global development framework anchored in 17 *Sustainable Development Goals*.

Abrupt climate change

A large-scale *abrupt change* in the *climate system* that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades and causes substantial *impacts* in *human and/or natural systems*. **See also:** *Abrupt change, Tipping point*.

Adaptation

In *human systems*, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In *natural systems*, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects. **See also:** *Adaptation options, Adaptive capacity, Maladaptive actions (Maladaptation)*.

Adaptation gap

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.

Adaptation limits

The point at which an actor's objectives (or system needs) cannot be secured from intolerable *risks* through adaptive actions.

- Hard *adaptation* limit - No adaptive actions are possible to avoid intolerable risks.
- Soft *adaptation* limit - Options may exist but are currently not available to avoid intolerable risks through adaptive action.

Transformational adaptation

Adaptation that changes the fundamental attributes of a social-ecological system in anticipation of *climate change* and its *impacts*.

Aerosol

A suspension of airborne solid or liquid particles, with typical particle size in the range of a few nanometres to several tens of micrometres and atmospheric lifetimes of up to several days in the *troposphere* and up to years in the *stratosphere*. The term aerosol, which includes both the particles and the suspending gas, is often used in this report in its plural form to mean 'aerosol particles'. Aerosols may be of either natural or anthropogenic origin in the troposphere; stratospheric aerosols mostly stem from volcanic eruptions. Aerosols can cause an *effective radiative forcing* directly through scattering and absorbing radiation (*aerosol–radiation interaction*), and indirectly by acting as *cloud condensation nuclei* or ice nucleating particles that affect the properties of clouds (*aerosol–cloud interaction*), and upon deposition on snow- or ice-covered surfaces. Atmospheric aerosols may be either emitted as primary particulate matter or formed within the *atmosphere* from gaseous *precursors* (secondary production). Aerosols may be composed of sea salt, organic carbon, *black carbon* (BC), mineral species (mainly desert dust), sulphate, nitrate and ammonium or their mixtures. **See also:** *Particulate matter (PM), Aerosol–radiation interaction, Short-lived climate forcers (SLCFs)*.

Afforestation

Conversion to forest of land that historically has not contained forests. **See also:** *Anthropogenic removals, Carbon dioxide removal (CDR), Deforestation, Reducing Emissions from Deforestation and Forest Degradation (REDD+), Reforestation*.

[Note: For a discussion of the term forest and related terms such as *afforestation, reforestation and deforestation*, see the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and their 2019 Refinement, and information provided by the United Nations Framework Convention on Climate Change]

Agricultural drought

See: *Drought*.

Agriculture, Forestry and Other Land Use (AFOLU)

In the context of national *greenhouse gas (GHG)* inventories under the *United Nations Convention on Climate Change (UNFCCC)*, AFOLU is the sum of the GHG inventory sectors Agriculture and *Land Use, Land-Use Change and Forestry (LULUCF)*; see the 2006 IPCC Guidelines for National GHG Inventories for details. Given the difference in estimating the '*anthropogenic*' *carbon dioxide (CO₂)* removals between countries and the global modelling community, the land-related net GHG emissions from global models included in this report are not necessarily directly comparable with LULUCF estimates in national GHG Inventories. **See also:** *Land use, land-use change and forestry (LULUCF), Land-use change (LUC)*.

Agroforestry

Collective name for *land-use* systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same *land-management* units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components. Agroforestry can also be defined as a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms

and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels.

Anthropogenic

Resulting from or produced by human activities.

Behavioural change

In this report, behavioural change refers to alteration of human decisions and actions in ways that mitigate *climate change* and/or reduce negative consequences of climate change impacts.

Biodiversity

Biodiversity or biological diversity means the variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic *ecosystems*, and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. **See also:** *Ecosystem, Ecosystem services*.

Bioenergy

Energy derived from any form of biomass or its metabolic by-products. **See also:** *Biofuel*.

Bioenergy with carbon dioxide capture and storage (BECCS)

Carbon dioxide capture and storage (CCS) technology applied to a *bioenergy* facility. Note that, depending on the total emissions of the BECCS supply chain, *carbon dioxide (CO₂)* can be removed from the atmosphere. **See also:** *Anthropogenic removals, Carbon dioxide capture and storage (CCS), Carbon dioxide removal (CDR)*.

Blue carbon

Biologically-driven carbon fluxes and storage in marine systems that are amenable to management. Coastal blue carbon focuses on rooted vegetation in the coastal zone, such as tidal marshes, mangroves and seagrasses. These *ecosystems* have high carbon burial rates on a per unit area basis and accumulate carbon in their soils and sediments. They provide many non-climatic benefits and can contribute to *ecosystem-based adaptation*. If degraded or lost, coastal blue carbon ecosystems are likely to release most of their carbon back to the *atmosphere*. There is current debate regarding the application of the blue carbon concept to other coastal and non-coastal processes and ecosystems, including the open *ocean*. **See also:** *Ecosystem services, Sequestration*.

Blue infrastructure

See: *Infrastructure*.

Carbon budget

Refers to two concepts in the literature:

(1) an assessment of carbon cycle *sources* and *sinks* on a global level, through the synthesis of evidence for *fossil fuel* and cement emissions, emissions and removals associated with *land use* and *land-use change*, ocean and natural land sources and sinks of *carbon dioxide (CO₂)*, and the resulting change in atmospheric CO₂ concentration. This is referred to as the Global Carbon Budget; (2) the maximum amount of cumulative net global *anthropogenic* CO₂ emissions that would result in limiting *global warming* to a given level with a given probability, taking

into account the effect of other *anthropogenic* climate *forcers*. This is referred to as the Total Carbon Budget when expressed starting from the *pre-industrial* period, and as the Remaining Carbon Budget when expressed from a recent specified date.

[Note 1: Net anthropogenic CO₂ emissions are *anthropogenic* CO₂ emissions minus *anthropogenic* CO₂ removals. **See also:** *Carbon Dioxide Removal (CDR)*.

Note 2: The maximum amount of cumulative net global *anthropogenic* CO₂ emissions is reached at the time that annual net *anthropogenic* CO₂ emissions reach zero.

Note 3: The degree to which *anthropogenic* climate forcings other than CO₂ affect the total carbon budget and remaining carbon budget depends on human choices about the extent to which these forcings are mitigated and their resulting climate effects.

Note 4: The notions of a total carbon budget and remaining carbon budget are also being applied in parts of the scientific literature and by some entities at regional, national, or sub-national level. The distribution of global budgets across individual different entities and emitters depends strongly on considerations of *equity* and other value judgements.]

Carbon dioxide capture and storage (CCS)

A process in which a relatively pure stream of *carbon dioxide (CO₂)* from industrial and energy-related sources is separated (captured), conditioned, compressed and transported to a storage location for long-term isolation from the *atmosphere*. Sometimes referred to as Carbon Capture and Storage. **See also:** *Anthropogenic removals, Bioenergy with carbon dioxide capture and storage (BECCS), Carbon dioxide capture and utilisation (CCU), Carbon dioxide removal (CDR), Sequestration*.

Carbon dioxide removal (CDR)

Anthropogenic activities removing *carbon dioxide (CO₂)* from the atmosphere and durably storing it in geological, terrestrial, or *ocean* reservoirs, or in products. It includes existing and potential *anthropogenic* enhancement of biological or geochemical CO₂ *sinks* and direct air carbon dioxide capture and storage (DACCS) but excludes natural CO₂ *uptake* not directly caused by human activities. **See also:** *Afforestation, Anthropogenic removals, Biochar, Bioenergy with carbon dioxide capture and storage (BECCS), Carbon dioxide capture and storage (CCS), Enhanced weathering, Ocean alkalization/Ocean alkalinity enhancement, Reforestation, Soil carbon sequestration (SCS)*.

Cascading impacts

Cascading impacts from *extreme weather/climate events occur* when an extreme *hazard* generates a sequence of secondary events in natural and *human systems* that result in physical, natural, social or economic disruption, whereby the resulting impact is significantly larger than the initial impact. Cascading impacts are complex and multi-dimensional, and are associated more with the magnitude of *vulnerability* than with that of the *hazard*.

Climate

In a narrow sense, climate is usually defined as the average weather -or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities- over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World

Meteorological Organization (WMO). The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the *climate system*.

Climate change

A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. **See also:** *Climate variability, Detection and attribution, Global warming, Natural (climate) variability, Ocean acidification (OA)*.

[Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: ‘a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to *natural climate variability* observed over comparable time periods’. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes.]

Climate extreme (extreme weather or climate event)

The occurrence of a value of a weather or *climate* variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of *extreme weather* persists for some time, such as a season, it may be classified as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., high temperature, *drought*, or heavy rainfall over a season). For simplicity, both extreme weather events and extreme climate events are referred to collectively as ‘climate extremes’.

Climate finance

There is no agreed definition of climate finance. The term ‘climate finance’ is applied to the financial resources devoted to addressing *climate change* by all public and private actors from global to local scales, including international financial flows to *developing countries* to assist them in addressing climate change. Climate finance aims to reduce net greenhouse gas emissions and/or to enhance *adaptation* and increase *resilience* to the impacts of current and projected climate change. Finance can come from private and public sources, channelled by various intermediaries, and is delivered by a range of instruments, including grants, concessional and non-concessional debt, and internal budget reallocations.

Climate governance

The structures, processes, and actions through which private and public actors seek to mitigate and adapt to *climate change*.

Climate justice

See: *Justice*.

Climate literacy

Climate literacy encompasses being aware of climate change, its *anthropogenic* causes, and implications.

Climate resilient development (CRD)

Climate-resilient development refers to the process of implementing *greenhouse gas mitigation* and *adaptation* measures to support *sustainable development* for all.

Climate sensitivity

The change in the surface temperature in response to a change in the atmospheric *carbon dioxide (CO₂)* concentration or other radiative forcing. **See also:** *Climate feedback parameter*.

Equilibrium climate sensitivity (ECS)

The equilibrium (steady state) change in the surface temperature following a doubling of the atmospheric *carbon dioxide (CO₂)* concentration from *pre-industrial* conditions.

Climate services

Climate services involve the provision of climate information in such a way as to assist decision-making. The service includes appropriate engagement from users and providers, is based on scientifically credible information and expertise, has an effective access mechanism, and responds to user needs.

Climate system

The global system consisting of five major components: the *atmosphere*, the *hydrosphere*, the *cryosphere*, the *lithosphere* and the *biosphere*, and the interactions between them. The climate system changes in time under the influence of its own internal dynamics and because of *external forcings* such as volcanic eruptions, solar variations, orbital forcing, and *anthropogenic* forcings such as the changing composition of the *atmosphere* and *land-use change*.

Climatic impact-driver (CID)

Physical *climate system* conditions (e.g., means, events, extremes) that affect an element of society or *ecosystems*. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral or a mixture of each across interacting system elements and *regions*. **See also:** *Hazard, Impacts, Risk*.

CO₂-equivalent emission (CO₂-eq)

The amount of *carbon dioxide (CO₂)* emission that would have an equivalent effect on a specified key measure of *climate change*, over a specified time horizon, as an emitted amount of another *greenhouse gas (GHG)* or a mixture of other GHGs. For a mix of GHGs it is obtained by summing the CO₂-equivalent emissions of each gas. There are various ways and time horizons to compute such equivalent emissions (*see greenhouse gas emission metric*). CO₂-equivalent emissions are commonly used to compare emissions of different GHGs but should not be taken to imply that these emissions have an equivalent effect across all key measures of *climate change*.

[Note: Under the Paris Rulebook [Decision 18/CMA.1, annex, paragraph 37], parties have agreed to use GWP100 values from the IPCC AR5 or GWP100 values from a subsequent IPCC Assessment Report to report

aggregate emissions and removals of GHGs. In addition, parties may use other metrics to report supplemental information on aggregate emissions and removals of GHGs.]

Compound weather/climate events

The terms 'compound events', 'compound extremes' and 'compound extreme events' are used interchangeably in the literature and this report, and refer to the combination of multiple *drivers* and/or *hazards* that contribute to societal and/or environmental *risk*.

Deforestation

Conversion of forest to non-forest. **See also:** *Afforestation*, *Reforestation*, *Reducing Emissions from Deforestation and Forest Degradation (REDD+)*.

[Note: For a discussion of the term forest and related terms such as *afforestation*, *reforestation* and *deforestation*, see the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and their 2019 Refinement, and information provided by the United Nations Framework Convention on Climate Change]

Demand-side measures

Policies and programmes for influencing the *demand* for goods and/ or services. In the energy sector, demand-side *mitigation* measures aim at reducing the amount of *greenhouse gas* emissions emitted per unit of energy service used.

Developed / developing countries (Industrialised / developed / developing countries)

There is a diversity of approaches for categorizing countries on the basis of their level of development, and for defining terms such as industrialised, developed, or developing. Several categorisations are used in this report. (1) In the United Nations (UN) system, there is no established convention for the designation of developed and developing countries or areas. (2) The UN Statistics Division specifies developed and developing regions based on common practice. In addition, specific countries are designated as least developed countries, landlocked developing countries, *Small Island Developing States (SIDS)*, and *transition* economies. Many countries appear in more than one of these categories. (3) The World Bank uses *income* as the main criterion for classifying countries as low, lower middle, upper middle, and high income. (4) The UN Development Programme (UNDP) aggregates indicators for life expectancy, educational attainment, and *income* into a single composite Human Development Index (HDI) to classify countries as low, medium, high, or very high human development.

Development pathways

See: *Pathways*.

Disaster risk management (DRM)

Processes for designing, implementing and evaluating strategies, policies and measures to improve the understanding of current and future *disaster risk*, foster *disaster risk* reduction and transfer, and promote continuous improvement in disaster preparedness, prevention and protection, response and recovery practices, with the explicit purpose of increasing *human security*, *well-being*, quality of life and *sustainable development (SD)*.

Displacement (of humans)

The involuntary movement, individually or collectively, of persons from their country or community, notably for reasons of armed conflict, civil unrest, or natural or human-made disasters.

Drought

An exceptional period of water shortage for existing *ecosystems* and the human population (due to low rainfall, high temperature and/or wind). **See also:** *Plant evaporative stress*.

Agricultural and ecological drought

Depending on the affected *biome*: a period with abnormal *soil moisture* deficit, which results from combined shortage of precipitation and excess *evapotranspiration*, and during the growing season impinges on crop production or ecosystem function in general.

Early warning systems (EWS)

The set of technical and institutional capacities to forecast, predict, and communicate timely and meaningful warning information to enable individuals, communities, managed *ecosystems*, and organisations threatened by a *hazard* to prepare to act promptly and appropriately to reduce the possibility of harm or loss. Depending upon context, EWS may draw upon scientific and/or *Indigenous knowledge*, and other knowledge types. EWS are also considered for ecological applications, e.g., conservation, where the organisation itself is not threatened by *hazard* but the *ecosystem* under conservation is (e.g., *coral bleaching* alerts), in agriculture (e.g., warnings of heavy rainfall, *drought*, ground frost, and hailstorms) and in fisheries (e.g., warnings of storm, *storm surge*, and tsunamis).

Ecological drought

See: *Drought*.

Ecosystem

An ecosystem is a functional unit consisting of living organisms, their nonliving environment and the interactions within and between them. The components included in a given ecosystem and its spatial boundaries depend on the purpose for which the ecosystem is defined: in some cases, they are relatively sharp, while in others they are diffuse. Ecosystem boundaries can change over time. Ecosystems are nested within other ecosystems and their scale can range from very small to the entire *biosphere*. In the current era, most ecosystems either contain people as key organisms, or are influenced by the effects of human activities in their environment. **See also:** *Ecosystem health*, *Ecosystem services*.

Ecosystem-based adaptation (EbA)

The use of *ecosystem* management activities to increase the *resilience* and reduce the *vulnerability* of people and *ecosystems* to *climate change*. **See also:** *Adaptation*, *Nature-based solution (NbS)*.

Ecosystem services

Ecological processes or functions having monetary or non-monetary value to individuals or society at large. These are frequently classified as (1) supporting services such as productivity or *biodiversity* maintenance, (2) provisioning services such as food or fibre, (3) regulating services such as climate regulation or *carbon sequestration*, and (4) cultural

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services such as tourism or spiritual and aesthetic appreciation. **See also:** *Ecosystem*, *Ecosystem health*, *Nature's contributions to people (NCP)*.

Emission scenario

See: *Scenario*.

Emission pathways

See: *Pathways*.

Enabling conditions (for adaptation and mitigation options)

Conditions that enhance the *feasibility* of *adaptation* and *mitigation* options. *Enabling conditions* include finance, technological innovation, strengthening policy instruments, *institutional capacity*, *multi-level governance*, and *changes in human behaviour* and lifestyles.

Equality

A principle that ascribes equal worth to all human beings, including equal opportunities, rights and obligations, irrespective of origins. **See also:** *Equity*, *Fairness*.

Inequality

Uneven opportunities and social positions, and processes of discrimination within a group or society, based on gender, class, ethnicity, age, and (dis)ability, often produced by uneven development. Income inequality refers to gaps between highest and lowest income earners within a country and between countries.

Equilibrium climate sensitivity (ECS)

See: *Climate sensitivity*.

Equity

The principle of being fair and impartial, and a basis for understanding how the *impacts* and responses to climate change, including costs and benefits, are distributed in and by society in more or less equal ways. Often aligned with ideas of *equality*, fairness and *justice* and applied with respect to equity in the responsibility for, and distribution of, climate *impacts* and policies across society, generations, and gender, and in the sense of who participates and controls the processes of decision-making.

Exposure

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. **See also:** *Hazard*, *Exposure*, *Vulnerability*, *Impacts*, *Risk*.

Feasibility

In this report, feasibility refers to the potential for a *mitigation* or *adaptation option* to be implemented. Factors influencing feasibility are context-dependent, temporally dynamic, and may vary between different groups and actors. Feasibility depends on geophysical, environmental-ecological, technological, economic, socio-cultural and institutional factors that enable or constrain the implementation of an option. The feasibility of options may change when different options are combined and increase when *enabling conditions* are strengthened. **See also:** *Enabling conditions (for adaptation and mitigation options)*.

Fire weather

Weather conditions conducive to triggering and sustaining wildfires, usually based on a set of indicators and combinations of indicators including temperature, *soil moisture*, humidity, and wind. Fire weather does not include the presence or absence of fuel load.

Food loss and waste

The decrease in quantity or quality of food. Food waste is part of food loss and refers to discarding or alternative (non-food) use of food that is safe and nutritious for human consumption along the entire food supply chain, from primary production to end household consumer level. Food waste is recognized as a distinct part of food loss because the drivers that generate it and the solutions to it are different from those of food losses.

Food security

A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. The four pillars of food security are availability, access, utilization and stability. The nutritional dimension is integral to the concept of food security.

Global warming

Global warming refers to the increase in global surface temperature relative to a baseline *reference period*, averaging over a period sufficient to remove interannual variations (e.g., 20 or 30 years). A common choice for the baseline is 1850–1900 (the earliest period of reliable observations with sufficient geographic coverage), with more modern baselines used depending upon the application. **See also:** *Climate change*, *Climate variability*, *Natural (climate) variability*.

Global warming potential (GWP)

An index measuring the *radiative forcing* following an emission of a unit mass of a given substance, accumulated over a chosen time horizon, relative to that of the reference substance, carbon dioxide (CO₂). The GWP thus represents the combined effect of the differing times these substances remain in the *atmosphere* and their effectiveness in causing radiative forcing. **See also:** *Lifetime*, *Greenhouse gas emission metric*.

Green infrastructure

See: *Infrastructure*.

Greenhouse gases (GHGs)

Gaseous constituents of the *atmosphere*, both natural and *anthropogenic*, that absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the Earth's surface, by the atmosphere itself, and by clouds. This property causes the *greenhouse effect*. Water vapour (H₂O), carbon dioxide (CO₂), *nitrous oxide* (N₂O), *methane* (CH₄) and *ozone* (O₃) are the primary *GHGs* in the Earth's atmosphere. Human-made *GHGs* include *sulphur hexafluoride* (SF₆), *hydrofluorocarbons* (HFCs), *chlorofluorocarbons* (CFCs) and perfluorocarbons (PFCs); several of these are also O₃-depleting (and are regulated under the *Montreal Protocol*). **See also:** *Well-mixed greenhouse gas*.

Grey infrastructure

See: *Infrastructure*.

Hazard

The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury or other *health* impacts, as well as damage and loss to property, *infrastructure*, *livelihoods*, service provision, *ecosystems* and environmental resources. **See also:** *Exposure*, *Vulnerability*, *Impacts*, *Risk*.

Impacts

The consequences of realised *risks* on natural and *human systems*, where *risks* result from the interactions of climate-related *hazards* (including *extreme weather/climate events*), *exposure*, and *vulnerability*. *Impacts* generally refer to effects on lives, *livelihoods*, *health* and *well-being*, *ecosystems* and species, economic, social and cultural assets, services (including *ecosystem services*), and *infrastructure*. *Impacts* may be referred to as consequences or outcomes and can be adverse or beneficial. **See also:** *Adaptation*, *Hazard*, *Exposure*, *Vulnerability*, *Risk*.

Inequality

See: *Equality*.

Indigenous knowledge (IK)

The understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings. For many *Indigenous Peoples*, IK informs decision-making about fundamental aspects of life, from day-to-day activities to longer term actions. This knowledge is integral to cultural complexes, which also encompass language, systems of classification, resource use practices, social interactions, values, ritual and spirituality. These distinctive ways of knowing are important facets of the world's cultural diversity. **See also:** *Local knowledge (LK)*.

Indigenous Peoples

Indigenous Peoples and nations are those that, having a historical continuity with pre-invasion and pre-colonial societies that developed on their territories, consider themselves distinct from other sectors of the societies now prevailing on those territories, or parts of them. They form at present principally non-dominant sectors of society and are often determined to preserve, develop, and transmit to future generations their ancestral territories, and their ethnic identity, as the basis of their continued existence as peoples, in accordance with their own cultural patterns, social institutions, and common law system.

Informal settlement

A term given to *settlements* or residential areas that by at least one criterion fall outside official rules and regulations. Most informal settlements have poor housing (with widespread use of temporary materials) and are developed on land that is occupied illegally with high levels of overcrowding. In most such settlements, provision for safe water, sanitation, drainage, paved roads, and basic services is inadequate or lacking. The term 'slum' is often used for informal settlements, although it is misleading as many informal settlements develop into good quality residential areas, especially where governments support such development.

Infrastructure

The designed and built set of physical systems and corresponding institutional arrangements that mediate between people, their communities, and the broader environment to provide services that support economic growth, *health*, quality of life, and safety.

Blue infrastructure

Blue infrastructure includes bodies of water, watercourses, ponds, lakes and storm drainage, that provide ecological and hydrological functions including *evaporation*, transpiration, *drainage*, infiltration, and temporary storage of *runoff* and discharge.

Green infrastructure

The strategically planned interconnected set of natural and constructed ecological systems, green spaces and other landscape features that can provide functions and services including air and water purification, temperature management, floodwater management and coastal defence often with *co-benefits* for people and *biodiversity*. Green infrastructure includes planted and remnant native vegetation, soils, *wetlands*, parks and green open spaces, as well as building and street level design interventions that incorporate vegetation.

Grey infrastructure

Engineered physical components and networks of pipes, wires, tracks and roads that underpin energy, transport, communications (including digital), built form, water and sanitation, and solid-waste management systems.

Irreversibility

A perturbed state of a *dynamical system* is defined as irreversible on a given time scale if the recovery from this state due to natural processes takes substantially longer than the time scale of interest. **See also:** *Tipping point*.

Just transition

See: *Transition*.

Justice

Justice is concerned with ensuring that people get what is due to them, setting out the moral or legal principles of *fairness* and *equity* in the way people are treated, often based on the ethics and values of society.

Climate justice

Justice that links development and *human rights* to achieve a human-centred approach to addressing *climate change*, safeguarding the rights of the most vulnerable people and sharing the burdens and benefits of climate change and its *impacts* equitably and fairly.

Social justice

Just or fair relations within society that seek to address the distribution of wealth, access to resources, opportunity, and support according to principles of *justice* and *fairness*.

Key risk

See: *Risk*.

Land use, land-use change and forestry (LULUCF)

In the context of national *greenhouse gas* (GHG) inventories under the United Nations Framework Convention on Climate Change, LULUCF is a GHG inventory sector that covers *anthropogenic emissions* and *removals* of GHG in managed lands, excluding non-CO₂ agricultural emissions. Following the 2006 IPCC Guidelines for National GHG Inventories and

their 2019 Refinement, ‘*anthropogenic*’ land-related GHG fluxes are defined as all those occurring on ‘*managed land*’, i.e., ‘where human interventions and practices have been applied to perform production, ecological or social functions’. Since managed land may include *carbon dioxide* (CO₂) removals not considered as ‘*anthropogenic*’ in some of the scientific literature assessed in this report (e.g., removals associated with CO₂ fertilisation and N deposition), the land-related net *GHG emission* estimates from global models included in this report are not necessarily directly comparable with LULUCF estimates in National GHG Inventories (IPCC 2006, 2019).

Least Developed Countries (LDCs)

A list of countries designated by the Economic and Social Council of the United Nations (ECOSOC) as meeting three criteria: (1) a low *income* criterion below a certain threshold of gross national income per capita of between USD 750 and USD 900, (2) a human resource weakness based on indicators of *health*, education, adult literacy, and (3) an economic vulnerability weakness based on indicators on instability of agricultural production, instability of export of goods and services, economic importance of non-traditional activities, merchandise export concentration, and the handicap of economic smallness. Countries in this category are eligible for a number of programmes focused on assisting countries most in need. These privileges include certain benefits under the articles of the United Nations Framework Convention on Climate Change (UNFCCC).

Livelihood

The resources used and the activities undertaken in order for people to live. *Livelihoods* are usually determined by the entitlements and assets to which people have access. Such assets can be categorised as human, social, natural, physical or financial.

Local knowledge (LK)

The understandings and skills developed by individuals and populations, specific to the places where they live. Local knowledge informs decision-making about fundamental aspects of life, from day-to-day activities to longer term actions. This knowledge is a key element of the social and cultural systems which influence observations of and responses to *climate change*; it also informs *governance* decisions. **See also:** *Indigenous knowledge (IK)*.

Lock-in

A situation in which the future development of a system, including *infrastructure*, technologies, investments, institutions, and behavioural norms, is determined or constrained (‘locked in’) by historic developments. **See also:** *Path dependence*.

Loss and Damage, and losses and damages

Research has taken *Loss and Damage* (capitalised letters) to refer to political debate under the United Nations Framework Convention on Climate Change (UNFCCC) following the establishment of the Warsaw Mechanism on Loss and Damage in 2013, 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 (*losses and damages*) have been taken to refer broadly to harm from (observed) *impacts* and (projected) risks and can be economic or non-economic.

Low-likelihood, high-impact outcomes

Outcomes/events whose probability of occurrence is low or not well known (as in the context of *deep uncertainty*) but whose potential *impacts* on society and *ecosystems* could be high. To better inform *risk assessment* and decision-making, such low-likelihood outcomes are considered if they are associated with very large consequences and may therefore constitute material risks, even though those consequences do not necessarily represent the most likely outcome. **See also:** *Impacts*.

Maladaptive actions (Maladaptation)

Actions that may lead to increased risk of adverse climate-related outcomes, including via increased *greenhouse gas (GHG) emissions*, increased or shifted *vulnerability to climate change*, more inequitable outcomes, or diminished welfare, now or in the future. Most often, maladaptation is an unintended consequence.

Migration (of humans)

Movement of a person or a group of persons, either across an international border, or within a State. It is a population movement, encompassing any kind of movement of people, whatever its length, composition and causes; it includes migration of refugees, displaced persons, economic migrants, and persons moving for other purposes, including family reunification.

Mitigation (of climate change)

A human intervention to reduce emissions or enhance the *sinks of greenhouse gases*.

Mitigation potential

The quantity of net *greenhouse gas* emission reductions that can be achieved by a given *mitigation option* relative to specified emission baselines. **See also:** *Sequestration potential*.

[Note: Net greenhouse gas emission reductions is the sum of reduced emissions and/or enhanced *sinks*]

Natural (climate) variability

Natural variability refers to climatic fluctuations that occur without any human influence, that is *internal variability* combined with the response to external natural factors such as volcanic eruptions, changes in *solar activity* and, on longer time-scales, orbital effects and plate tectonics. **See also:** *Orbital forcing*.

Net zero CO₂ emissions

Condition in which *anthropogenic carbon dioxide (CO₂)* emissions are balanced by *anthropogenic CO₂ removals* over a specified period. **See also:** *Carbon neutrality, Land use, land-use change and forestry (LULUCF), Net zero greenhouse gas emissions*.

[Note: *Carbon neutrality* and net zero CO₂ emissions are overlapping concepts. The concepts can be applied at global or sub-global scales (e.g., regional, national and sub-national). At a global scale, the terms carbon neutrality and net zero CO₂ emissions are equivalent. At sub-global scales, net zero CO₂ emissions is generally applied to emissions and removals under direct control or territorial responsibility of the reporting entity, while carbon neutrality generally includes emissions and removals within and beyond the direct control

or territorial responsibility of the reporting entity. Accounting rules specified by GHG programmes or schemes can have a significant influence on the quantification of relevant CO₂ emissions and removals.]

Net zero GHG emissions

Condition in which metric-weighted *anthropogenic greenhouse gas (GHG) emissions* are balanced by metric-weighted *anthropogenic GHG removals* over a specified period. The quantification of net zero GHG emissions depends on the *GHG emission metric* chosen to compare emissions and removals of different gases, as well as the time horizon chosen for that metric. **See also:** *Greenhouse gas neutrality, Land use, land-use change and forestry (LULUCF), Net zero CO₂ emissions.*

[Note 1: *Greenhouse gas neutrality* and net zero GHG emissions are overlapping concepts. The concept of net zero GHG emissions can be applied at global or sub-global scales (e.g., regional, national and sub-national). At a global scale, the terms GHG neutrality and net zero GHG emissions are equivalent. At sub-global scales, net zero GHG emissions is generally applied to emissions and removals under direct control or territorial responsibility of the reporting entity, while GHG neutrality generally includes anthropogenic emissions and anthropogenic removals within and beyond the direct control or territorial responsibility of the reporting entity. Accounting rules specified by GHG programmes or schemes can have a significant influence on the quantification of relevant emissions and removals.

Note 2: Under the Paris Rulebook (Decision 18/CMA.1, annex, paragraph 37), parties have agreed to use GWP100 values from the IPCC AR5 or GWP100 values from a subsequent IPCC Assessment Report to report aggregate emissions and removals of GHGs. In addition, parties may use other metrics to report supplemental information on aggregate emissions and removals of GHGs.]

New Urban Agenda

The *New Urban Agenda* was adopted at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III) in Quito, Ecuador, on 20 October 2016. It was endorsed by the United Nations General Assembly at its sixty-eighth plenary meeting of the seventy-first session on 23 December 2016.

Overshoot pathways

See: *Pathways.*

Pathways

The temporal evolution of *natural* and/or *human systems* towards a future state. Pathway concepts range from sets of quantitative and qualitative *scenarios* or *narratives* of potential futures to solution-oriented decision-making processes to achieve desirable societal goals. Pathway approaches typically focus on biophysical, techno-economic and/or socio-behavioural trajectories and involve various dynamics, goals and actors across different scales. **See also:** *Scenario, Storyline.*

Development pathways

Development pathways evolve as the result of the countless decisions being made and actions being taken at all levels of societal structure, as well due to the emergent dynamics within and between institutions, cultural norms, technological systems and other drivers of *behavioural change*. **See also:** *Shifting development pathways (SDPs), Shifting development pathways to sustainability (SDPS).*

Emission pathways

Modelled *trajectories* of global *anthropogenic emissions* over the 21st century are termed emission pathways.

Overshoot pathways

Pathways that first exceed a specified concentration, forcing or *global warming* level, and then return to or below that level again before the end of a specified period of time (e.g., before 2100). Sometimes the magnitude and *likelihood* of the *overshoot* are also characterised. The overshoot duration can vary from one *pathway* to the next, but in most overshoot pathways in the literature and referred to as overshoot pathways in the AR6, the overshoot occurs over a period of at least one decade and up to several decades. **See also:** *Temperature overshoot.*

Shared socio-economic pathways (SSPs)

Shared socio-economic pathways (SSPs) have been developed to complement the *Representative Concentration Pathways (RCPs)*. By design, the RCP emission and concentration *pathways* were stripped of their association with a certain socio-economic development. Different levels of emissions and *climate change* along the dimension of the RCPs can hence be explored against the backdrop of different socio-economic development pathways (SSPs) on the other dimension in a matrix. This integrative SSP-RCP framework is now widely used in the climate impact and policy analysis literature (see, e.g., <http://iconics-ssp.org>), where *climate projections* obtained under the RCP *scenarios* are analysed against the backdrop of various SSPs. As several emission updates were due, a new set of *emission scenarios* was developed in conjunction with the SSPs. Hence, the abbreviation SSP is now used for two things: On the one hand SSP1, SSP2, ..., SSP5 is used to denote the five socio-economic *scenario* families. On the other hand, the abbreviations SSP1-1.9, SSP1-2.6, ..., SSP5-8.5 are used to denote the newly developed *emission scenarios* that are the result of an SSP implementation within an *integrated assessment model*. Those SSP *scenarios* are bare of climate policy assumption, but in combination with so-called shared policy assumptions (SPAs), various approximate *radiative forcing* levels of 1.9, 2.6, ..., or 8.5 W m⁻² are reached by the end of the century, respectively. denote trajectories that address social, environmental and economic dimensions of *sustainable development, adaptation and mitigation, and transformation*, in a generic sense or from a particular methodological perspective such as *integrated assessment models* and *scenario* simulations.

Planetary health

A concept based on the understanding that human health and human civilisation depend on *ecosystem* health and the wise stewardship of *ecosystems*.

Reasons for concern (RFCs)

Elements of a classification framework, first developed in the IPCC Third Assessment Report, which aims to facilitate judgements about what level of *climate change* may be dangerous (in the language of Article 2 of the UNFCCC; UNFCCC, 1992) by aggregating *risks* from various sectors, considering *hazards, exposures, vulnerabilities, capacities* to adapt, and the resulting *impacts*.

Reforestation

Conversion to forest of land that has previously contained forests but that has been converted to some other use. **See also:** *Afforestation, Anthropogenic removals, Carbon dioxide removal (CDR), Deforestation, Reducing Emissions from Deforestation and Forest Degradation (REDD+)*.

[Note: For a discussion of the term forest and related terms such as *afforestation, reforestation* and *deforestation*, see the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and their 2019 Refinement, and information provided by the United Nations Framework Convention on Climate Change]

Residual risk

The risk related to *climate change impacts* that remains following *adaptation* and *mitigation* efforts. *Adaptation* actions can redistribute *risk* and *impacts*, with increased *risk* and *impacts* in some areas or populations, and decreased *risk* and *impacts* in others. **See also:** *Loss and Damage, losses and damages*.

Resilience

The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for *adaptation*, learning and/or *transformation*. **See also:** *Hazard, Risk, Vulnerability*.

Restoration

In the environmental context, *restoration* involves human interventions to assist the recovery of an *ecosystem* that has been previously degraded, damaged or destroyed.

Risk

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, risks* can arise from potential *impacts* of *climate change* as well as human responses to *climate change*. Relevant adverse consequences include those on lives, *livelihoods, health* and *well-being*, economic, social and cultural assets and investments, *infrastructure*, services (including *ecosystem services*), *ecosystems* and species.

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 to the *hazards*. *Hazards, exposure* and *vulnerability* may each be subject to *uncertainty* in terms of magnitude and *likelihood* of occurrence, and each may change over time and space due to socio-economic changes and human decision-making.

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* with, or negative side-effects on, other societal objectives, such as the *Sustainable Development Goals (SDGs)*. *Risks* can arise for example from *uncertainty* in the implementation, effectiveness or outcomes of *climate policy*, climate-related investments, technology development or adoption, and system *transitions*.

See also: *Hazard, Exposure, Vulnerability, Impacts, Risk management, Adaptation, Mitigation*.

Key risk

Key risks have potentially severe adverse consequences for humans and social-ecological systems resulting from the interaction of climate related *hazards* with *vulnerabilities* of societies and systems exposed.

Scenario

A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Note that scenarios are neither *predictions* nor *forecasts* but are used to provide a view of the implications of developments and actions. **See also:** *Scenario, Scenario storyline*.

Emission scenario

A plausible representation of the future development of emissions of substances that are radiatively active (e.g., *greenhouse gases* (GHGs) or *aerosols*) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change, energy and *land use*) and their key relationships. Concentration scenarios, derived from *emission scenarios*, are often used as input to a *climate model* to compute climate *projections*.

Sendai Framework for Disaster Risk Reduction

The *Sendai Framework for Disaster Risk Reduction 2015-2030* outlines seven clear targets and four priorities for action to prevent new, and to reduce existing *disaster risks*. The voluntary, non-binding agreement recognises that the State has the primary role to reduce disaster risk, but that responsibility should be shared with other stakeholders including local government, the private sector and other stakeholders, with the aim for the substantial reduction of disaster risk and losses in lives, *livelihoods* and *health* and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries.

Settlements

Places of concentrated human habitation. *Settlements* can range from isolated rural villages to *urban* regions with significant global influence. They can include formally planned and informal or illegal habitation and related *infrastructure*. **See also:** *Cities, Urban, Urbanisation*.

Shared socio-economic pathways (SSPs)

See: *Pathways*

Shifting development pathways (SDPs)

In this report, shifting development pathways describes *transitions* aimed at redirecting existing developmental trends. Societies may put in place *enabling conditions* to influence their future *development pathways*, when they endeavour to achieve certain outcomes. Some outcomes may be common, while others may be context-specific, given different starting points. **See also:** *Development pathways, Shifting development pathways to sustainability*.

Sink

Any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the *atmosphere*. **See also:** *Pool - Carbon and nitrogen, Reservoir, Sequestration, Sequestration potential, Source, Uptake*.

Small Island Developing States (SIDS)

Small Island Developing States (SIDS), as recognised by the United Nations OHRLLS (UN Office of the High Representative for the *Least Developed Countries*, Landlocked Developing Countries and Small Island Developing States), are a distinct group of developing countries facing specific social, economic and environmental vulnerabilities. They were recognised as a special case both for their environment and development at the Rio Earth Summit in Brazil in 1992. Fifty-eight countries and territories are presently classified as SIDS by the UN OHRLLS, with 38 being UN member states and 20 being Non-UN Members or Associate Members of the Regional Commissions.

Social justice

See: *Justice*.

Social protection

In the context of development aid and climate policy, social protection usually describes public and private initiatives that provide *income* or consumption transfers to the poor, protect the vulnerable against *livelihood risks*, and enhance the social status and rights of the marginalized, with the overall objective of reducing the economic and social *vulnerability* of poor, vulnerable, and marginalized groups. In other contexts, social protection may be used synonymously with social policy and can be described as all public and private initiatives that provide access to services, such as *health*, education, or housing, or income and consumption transfers to people. Social protection policies protect the poor and *vulnerable* against livelihood *risks* and enhance the social status and rights of the marginalized, as well as prevent *vulnerable* people from falling into poverty.

Solar radiation modification (SRM)

Refers to a range of radiation modification measures not related to *greenhouse gas (GHG) mitigation* that seek to limit *global warming*. Most methods involve reducing the amount of incoming *solar radiation* reaching the surface, but others also act on the longwave radiation budget by reducing optical thickness and cloud lifetime.

Source

Any process or activity which releases a *greenhouse gas*, an *aerosol* or a precursor of a greenhouse gas into the *atmosphere*. See also: *Pool - carbon and nitrogen*, *Reservoir*, *Sequestration*, *Sequestration potential*, *Sink*, *Uptake*.

Stranded assets

Assets exposed to devaluations or conversion to 'liabilities' because of unanticipated changes in their initially expected revenues due to innovations and/or evolutions of the business context, including changes in public regulations at the domestic and international levels.

Sustainable development (SD)

Development that meets the needs of the present without compromising the ability of future generations to meet their own needs and balances social, economic and environmental concerns. See also: *Development pathways*, *Sustainable Development Goals (SDGs)*.

Sustainable Development Goals (SDGs)

The 17 Global Goals for development for all countries established by the United Nations through a participatory process and elaborated in the *2030 Agenda for Sustainable Development*, including ending poverty and hunger; ensuring health and *well-being*, education, gender equality, clean water and energy, and decent work; building and ensuring resilient and sustainable *infrastructure*, cities and consumption; reducing *inequalities*; protecting land and water *ecosystems*; promoting peace, *justice* and partnerships; and taking urgent action on *climate change*. See also: *Development pathways*, *Sustainable development (SD)*.

Sustainable land management

The stewardship and use of *land* resources, including soils, water, animals and plants, to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions.

Temperature overshoot

Exceedance of a specified *global warming* level, followed by a decline to or below that level during a specified period of time (e.g., before 2100). Sometimes the magnitude and likelihood of the overshoot is also characterized. The overshoot duration can vary from one *pathway* to the next but in most *overshoot pathways* in the literature and referred to as overshoot pathways in the AR6, the overshoot occurs over a period of at least one and up to several decades. See also: *Overshoot Pathways*.

Tipping point

A critical threshold beyond which a system reorganises, often abruptly and/or irreversibly. See also: *Abrupt climate change*, *Irreversibility*, *Tipping element*.

Transformation

A change in the fundamental attributes of *natural* and *human systems*.

Transformational adaptation

See: *Adaptation*.

Transition

The process of changing from one state or condition to another in a given period of time. Transition can be in individuals, firms, *cities*, *regions* and nations, and can be based on incremental or *transformative* change.

Just transitions

A set of principles, processes and practices that aim to ensure that no people, workers, places, sectors, countries or regions are left behind in the *transition* from a high-carbon to a low-carbon economy. It stresses the need for targeted and proactive measures from governments, agencies, and authorities to ensure that any negative social, environmental or economic impacts of economy-wide transitions are minimized, whilst benefits are maximized for those disproportionately affected. Key principles of just transitions include: respect and dignity for vulnerable groups; *fairness* in energy access and use, social dialogue and democratic consultation with relevant stakeholders; the creation of decent jobs; *social protection*; and rights at work. Just transitions could include fairness in energy, *land use* and climate planning and decision-making processes;

economic diversification based on low-carbon investments; realistic training/retraining programs that lead to decent work; gender specific policies that promote equitable outcomes; the fostering of international cooperation and coordinated multilateral actions; and the eradication of poverty. Lastly, just transitions may embody the redressing of past harms and perceived injustices.

Urban

The categorisation of areas as “urban” by government statistical departments is generally based either on population size, population density, economic base, provision of services, or some combination of the above. Urban systems are networks and nodes of intensive interaction and exchange including capital, culture, and material objects. Urban areas exist on a continuum with rural areas and tend to exhibit higher levels of complexity, higher populations and population density, intensity of capital investment, and a preponderance of secondary (processing) and tertiary (service) sector industries. The extent and intensity of these features varies significantly within and between urban areas. Urban places and systems are open, with much movement and exchange between more rural areas as well as other urban regions. Urban areas can be globally interconnected, facilitating rapid flows between them, of capital investment, of ideas and culture, human migration, and disease. **See also:** *Cities, City region, Peri-urban areas, Urban Systems, Urbanisation.*

Urbanisation

Urbanisation is a multi-dimensional process that involves at least three simultaneous changes: 1) *land use change*: transformation of formerly rural *settlements* or natural land into *urban settlements*; 2) demographic change: a shift in the spatial distribution of a population from rural to *urban* areas; and 3) *infrastructure* change: an increase in provision of *infrastructure* services including electricity, sanitation, etc. *Urbanisation* often includes changes in lifestyle, culture, and behaviour, and thus alters the demographic, economic, and social structure of both urban and rural areas. **See also:** *Settlement, Urban, Urban Systems.*

Vector-borne disease

Illnesses caused by parasites, viruses and bacteria that are transmitted by various vectors (e.g. mosquitoes, sandflies, triatomine bugs, blackflies, ticks, tsetse flies, mites, snails and lice).

Vulnerability

The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. **See also:** *Hazard, Exposure, Impacts, Risk.*

Water security

The capacity of a population to safeguard sustainable access to adequate quantities of acceptable-quality water for sustaining *livelihoods*, human *well-being* and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters and for preserving *ecosystems* in a climate of peace and political stability.

Well-being

A state of existence that fulfills various human needs, including material living conditions and quality of life, as well as the ability to pursue one’s goals, to thrive and to feel satisfied with one’s life. Ecosystem well-being refers to the ability of *ecosystems* to maintain their diversity and quality.

Annex II

Acronyms, Chemical Symbols and Scientific Units

Editorial Team

Andreas Fischlin (Switzerland), Yonhung Jung (Republic of Korea), Noémie Leprince-Ringuet (France), Chloé Ludden (Germany/France), Clotilde Péan (France), José Romero (Switzerland)

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Annex II

AFOLU	Agriculture, Forestry and Other Land Use *	Gt	Gigatonnes
AR5	Fifth Assessment Report	GW	Gigawatt
AR6	Sixth Assessment Report	GWL	Global Warming Level
BECCS	Bioenergy with Carbon Dioxide Capture and Storage *	GWP100	Global Warming Potential over a 100 year time horizon *
CCS	Carbon Capture and Storage *	HFCs	Hydrofluorocarbons
CCU	Carbon Capture and Utilization	IEA	International Energy Agency
CDR	Carbon Dioxide Removal *	IEA-STEPS	International Energy Agency Stated Policies Scenario
CH₄	Methane	IMP	Illustrative Mitigation Pathway
CID	Climatic impact-driver *	IMP-LD	Illustrative Mitigation Pathway - Low Demand
CMIP5	Coupled Model Intercomparison Project Phase 5	IMP-NEG	Illustrative Mitigation Pathway - NEGative emissions deployment
CMIP6	Coupled Model Intercomparison Project Phase 6	IMP-SP	Illustrative Mitigation Pathway - Shifting development Pathways
CO₂	Carbon Dioxide	IMP-REN	Illustrative Mitigation Pathway - Heavy reliance on RENewables
CO₂-eq	Carbon Dioxide Equivalent *	IP-ModAct	Illustrative Pathway Moderate Action
CRD	Climate Resilient Development *	IPCC	Intergovernmental Panel on Climate Change
CO₂-FFI	CO ₂ from Fossil Fuel combustion and Industrial processes	kWh	Kilowatt hour
CO₂-LULUCF	CO ₂ from Land Use, Land-Use Change and Forestry	LCOE	Levelized Cost of Energy
CSB	Cross-Section Box	LDC	Least Developed Countries *
DACCS	Direct Air Carbon Capture and Storage	Li-on	Lithium-ion
DRM	Disaster Risk Management *	LK	Local Knowledge *
EbA	Ecosystem-based Adaptation *	LULUCF	Land Use, Land-Use Change and Forestry *
ECS	Equilibrium climate sensitivity *	MAGICC	Model for the Assessment of Greenhouse Gas Induced Climate Change
ES	Executive Summary	MWh	Megawatt hour
EV	Electric Vehicle	N₂O	Nitrous oxide
EWS	Early Warning System *	NDC	Nationally Determined Contribution
FaIR	Finite Amplitude Impulse Response simple climate model	NF₃	Nitrogen trifluoride
FAO	Food and Agriculture Organization of the United Nations	O₃	Ozone
FFI	Fossil-Fuel combustion and Industrial processes	PFCs	Perfluorocarbons
F-gases	Fluorinated gases	ppb	parts per billion
GDP	Gross Domestic Product	PPP	Purchasing Power Parity
GHG	Greenhouse Gas *		

ppm	parts per million	WIM	Warsaw International Mechanism on Loss and Damage under UNFCCC *
PV	Photovoltaic	Wm⁻²	Watts per square meter
R&D	Research and Development		
RCB	Remaining Carbon Budget		
RCPs	Representative Concentration Pathways (e.g. RCP2.6, pathway for which radiative forcing by 2100 is limited to 2.6 Wm ⁻²)		
RFCs	Reasons for Concern *		
SDG	Sustainable Development Goal *		
SDPs	Shifting Development Pathways *		
SF₆	Sulphur Hexafluoride		
SIDS	Small Island Developing States *		
SLCF	Short-Lived Climate Forcer		
SPM	Summary For Policymakers		
SR1.5	Special Report on Global Warming of 1.5°C		
SRCLL	Special Report on Climate Change and Land		
SRM	Solar Radiation Modification *		
SROCC	Special Report on the Ocean and Cryosphere in a Changing Climate		
SSP	Shared Socioeconomic Pathway *		
SYR	Synthesis Report		
tCO₂-eq	Tonne of carbon dioxide equivalent		
tCO₂-FFI	Tonne of carbon dioxide from Fossil Fuel combustion and Industrial processes		
TS	Technical Summary		
UNFCCC	United Framework Convention on Climate Change		
USD	United States Dollar		
WG	Working Group		
WGI	IPCC Working Group I		
WGII	IPCC Working Group II		
WGIII	IPCC Working Group III		
WHO	World Health Organization		

* For a full definition see also Annex I: Glossary

Definitions of additional terms are available in the IPCC Online Glossary: <https://apps.ipcc.ch/glossary/>

Annex III

Contributors

Core Writing Team Members

LEE, Hoesung

IPCC Chair
Korea University
Republic of Korea

CALVIN, Katherine

The National Aeronautics and Space Administration
USA

DASGUPTA, Dipak

The Energy and Resources Institute, India (TERI)
India / USA

KRINNER, Gerhard

The French National Centre for Scientific Research
France / Germany

MUKHERJI, Aditi

International Water Management Institute
India

THORNE, Peter

Maynooth University
Ireland / United Kingdom (of Great Britain and Northern Ireland)

TRISOS, Christopher

University of Cape Town
South Africa

ROMERO, José

IPCC SYR TSU
Switzerland

ALDUNCE, Paulina

University of Chile
Chile

BARRETT, Ko

IPCC Vice-Chair
National Oceanographic and Atmospheric Administration
USA

BLANCO, Gabriel

National University of the Center of the Province of Buenos Aires
Argentina

CHEUNG, William W. L.

The University of British Columbia
Canada

CONNORS, Sarah L.

WGI Technical Support Unit
France / United Kingdom (of Great Britain and Northern Ireland)

DENTON, Fatima

United Nations Economic Commission for Africa
The Gambia

DIONGUE-NIANG, Aïda

National Agency of Civil Aviation and Meteorology
Senegal

DODMAN, David

The Institute for Housing and Urban Development Studies
Jamaica / United Kingdom (of Great Britain and Northern Ireland) /
Netherlands

GARSCHAGEN, Matthias

Ludwig Maximilian University of Munich
Germany

GEDEN, Oliver

German Institute for International and Security Affairs
Germany

HAYWARD, Bronwyn

University of Canterbury
New Zealand

JONES, Christopher

Met Office
United Kingdom (of Great Britain and Northern Ireland)

JOTZO, Frank

The Australian National University
Australia

KRUG, Thelma

IPCC Vice-Chair
INPE, retired
Brazil

LASCO, Rodel

Consultative Group for International Agricultural Research
Philippines

LEE, June-Yi

Pusan National University
Republic of Korea

MASSON-DELMOTTE, Valérie

IPCC WGI Co-Chair
Laboratoire des sciences du climat et de l'environnement
France

MEINSHAUSEN, Malte

University of Melbourne
Australia / Germany

MINTENBECK, Katja

IPCC WGII TSU / Alfred Wegener Institute
Germany

MOKSSIT, Abdalah

IPCC Secretariat
Morocco / WMO

OTTO, Friederike E. L.

Imperial College London
United Kingdom (of Great Britain and Northern Ireland) / Germany

PATHAK, Minal

IPCC WGIII Technical Support Unit
Ahmedabad University
India

PIRANI, Anna

IPCC WGI Technical Support Unit
Italy

POLOCZANSKA, Elvira

IPCC WGII Technical Support Unit
United Kingdom (of Great Britain and Northern Ireland) / Australia Germany

PÖRTNER, Hans-Otto

IPCC WGII Co-Chair
Alfred Wegener Institute
Germany

REVI, Aromar

Indian Institute for Human Settlements
India

ROBERTS, Debra C.

IPCC WGII Co-Chair
eThekweni Municipality
South Africa

ROY, Joyashree

Asian Institute of Technology
India / Thailand

RUANE, Alex C.

The National Aeronautics and Space Administration
USA

SHUKLA, Priyadarshi R.

IPCC WGIII Co-Chair
Ahmedabad University
India

SKEA, Jim

IPCC WGIII Co-Chair
Imperial College London
United Kingdom (of Great Britain and Northern Ireland)

SLADE, Raphael

WG III Technical Support Unit
United Kingdom (of Great Britain and Northern Ireland)

SLANGEN, Aimée

Royal Netherlands Institute for Sea Research
The Netherlands

SOKONA, Youba

IPCC Vice-Chair
African Development Bank
Mali

SÖRENSSON, Anna A.

Universidad de Buenos Aires
Argentina

TIGNOR, Melinda

IPCC WGII Technical Support Unit
USA / Germany

VAN UUREN, Detlef

Netherlands Environmental Assessment Agency
The Netherlands

Annex III

WEI, Yi-Ming

Beijing Institute of Technology
China

WINKLER, Harald

University of Cape Town
South Africa

ZHAI, Panmao

IPCC WGI Co-Chair
Chinese Academy of Meteorological Sciences
China

ZOMMERS, Zinta

United Nations Office for Disaster Risk Reduction
Latvia

Extended Writing Team Members

HOURCADE, Jean-Charles

International Center for Development and Environment
France

JOHNSON, Francis X.

Stockholm Environment Institute
Thailand / Sweden

PACHAURI, Shonali

International Institute for Applied Systems Analysis
Austria / India

SIMPSON, Nicholas P.

University of Cape Town
South Africa / Zimbabwe

SINGH, Chandni

Indian Institute for Human Settlements
India

THOMAS, Adelle

University of The Bahamas
Bahamas

TOTIN, Edmond

Université Nationale d'Agriculture
Benin

Review Editors

ARIAS, Paola

Escuela Ambiental, Universidad de Antioquia
Colombia

BUSTAMANTE, Mercedes

University of Brasília
Brazil

ELGIZOULI, Ismail A.

Sudan

FLATO, Gregory

IPCC WGI Vice-Chair
Environment and Climate Change Canada
Canada

HOWDEN, Mark

IPCC WGII Vice-Chair
The Australian National University
Australia

MÉNDEZ, Carlos

IPCC WGII Vice-Chair
Instituto Venezolano de Investigaciones Científicas
Venezuela

PEREIRA, Joy Jacqueline

IPCC WGII Vice-Chair
Universiti Kebangsaan Malaysia
Malaysia

PICHS-MADRUGA, Ramón

IPCC WGIII Vice-Chair
Centre for World Economy Studies
Cuba

ROSE, Steven K.

Electric Power Research Institute
USA

Saheb, Yamina

OpenExp
Algeria / France

SÁNCHEZ RODRÍGUEZ, Roberto A.

IPCC WGII Vice-Chair
The College of the Northern Border
Mexico

ÜRGE-VORSATZ, Diana

IPCC WGIII Vice-Chair
Central European University
Hungary

XIAO, Cunde

Beijing Normal University
China

YASSAA, Noureddine

IPCC WGI Vice-Chair
Centre de Développement des Energies Renouvelables
Algeria

Contributing authors

ALEGRÍA, Andrés

IPCC WGII TSU
Alfred Wegener Institute
Germany / Honduras

ARMOUR, Kyle

University of Washington
USA

BEDNAR-FRIEDL, Birgit

Universität Graz
Austria

BLOK, Kornelis

Delft University of Technology
The Netherlands

CISSÉ, Guéladio

Swiss Tropical and Public Health Institute and University of Basel
Mauritania / Switzerland / France

DENTENER, Frank

European commission
EU

ERIKSEN, Siri

Norwegian University of Life Sciences
Norway

FISCHER, Erich

ETH Zurich
Switzerland

GARNER, Gregory

Rutgers University
USA

GUIVARCH, Céline

Centre International de Recherche sur l'Environnement et le développement
France

HAASNOOT, Marjolijn

Deltares
The Netherlands

HANSEN, Gerrit

German Institute for International and Security Affairs
Germany

HAUSER, Matthias

ETH Zurich
Switzerland

HAWKINS, Ed

University of Reading
United Kingdom (of Great Britain and Northern Ireland)

HERMANS, Tim

Royal Netherlands Institute for Sea Research
The Netherlands

KOPP, Robert

Rutgers University
USA

LEPRINCE-RINGUET, Noémie

France

LEWIS, Jared

University of Melbourne and Climate Resource
Australia / New Zealand

Annex III

LEY, Debora

Latinoamérica Renovable, UN ECLAC
Mexico / Guatemala

LUDDEN, Chloé

WG III Technical Support Unit
Germany / France

NIAMIR, Leila

International Institute for Applied Systems Analysis
Iran / The Netherlands / Austria

NICHOLLS, Zebedee

University of Melbourne
Australia

SOME, Shreya

IPCC WGIII Technical Support Unit
Asian Institute of Technology
India / Thailand

SZOPA, Sophie

Laboratoire des Sciences du Climat et de l'Environnement
France

TREWIN, Blair

Australian Bureau of Meteorology
Australia

VAN DER WIJST, Kaj-Ivar

Netherlands Environmental Assessment Agency
The Netherlands

WINTER, Gundula

Deltares
The Netherlands / Germany

WITTING, Maximilian

Ludwig Maximilian University of Munich
Germany

Scientific Steering Committee

ABDULLA, Amjad

IPCC WGIII Vice-Chair
IRENA
Maldives

ALDRIAN, Edvin

IPCC WGI Co-Chair
Agency for Assessment and Application of Technology
Indonesia

CALVO, Eduardo

IPCC TFI Co-Chair
National University of San Marcos
Peru

CARRARO, Carlo

IPCC WGIII Vice-Chair
Ca' Foscari University of Venice
Italy

DRIOUECH, Fatima

IPCC WGI Vice-Chair
University Mohammed VI Polytechnic
Morocco

FISCHLIN, Andreas

IPCC WGII Vice-Chair
ETH Zurich
Switzerland

FUGLESTVEDT, Jan

IPCC WGI Vice-Chair
Center for International Climate Research (CICERO)
Norway

DADI, Diriba Korecha

IPCC WGIII Vice-Chair
Ethiopian Meteorological Institute
Ethiopia

MAHMOUD, Nagmeldin G.E.

IPCC WGIII Vice-Chair
Higher Council for Environment and Natural Resources
Sudan

REISINGER, Andy

IPCC WGIII Co-Chair
He Pou A Rangi Climate Change Commission
New Zealand

SEMENOV, Sergey

IPCC WGII Co-Chair

Yu.A. Izrael Institute of Global Climate and Ecology

Russian Federation

TANABE, Kiyoto

IPCC TFI Co-Chair

Institute for Global Environmental Strategies

Japan

TARIQ, Muhammad Irfan

IPCC WGI Co-Chair

Ministry of Climate Change

Pakistan

VERA, Carolina

IPCC WGI Co-Chair

Universidad de Buenos Aires (CONICET)

Argentina

YANDA, Pius

IPCC WGII Co-Chair

University of Dar es Salaam

United Republic of Tanzania

YASSAA, Noureddine

IPCC WGI Co-Chair

Centre de Développement des Energies Renouvelables

Algeria

ZATARI, Taha M.

IPCC WGII Co-Chair

Ministry of Energy, Industry and Mineral Resources

Saudi Arabia

Annex IV
Expert Reviewers AR6 SYR

Annex IV

ABDELFATTAH, Eman

Cairo University
Egypt

ABULEIF, Khalid Mohamed

Ministry of Petroleum and Mineral Resources
Saudi Arabia

ACHAMPONG, Leia

European Network on Debt and Development (Eurodad)
United Kingdom (of Great Britain and Northern Ireland)

AGRAWAL, Mahak

Center on Global Energy Policy
United States of America

AKAMANI, Kofi

Southern Illinois University Carbondale
United States of America

ÅKESSON, Ulrika

Sida
Sweden

ALBIHN, Ann

Swedish University of Agricultural Sciences Uppsala
Sweden

ALCAMO, Joseph

University of Sussex
United Kingdom (of Great Britain and Northern Ireland)

ALSARMI, Said

Oman Civil Aviation Authority
Oman

AMBRÓSIO, Luis Alberto

Instituto de Zootecnia
Brazil

AMONI, Alves Melina

WayCarbon Soluções Ambientais e Projetos de Carbono Ltda
Brazil

ANDRIANASOLO, Rivoniony

Ministère de l'Environnement et du Développement Durable
Madagascar

ANORUO, Chukwuma

University of Nigeria
Nigeria

ANWAR RATEB, Samy Ashraf

Egyptian Meteorological Authority
Egypt

APPADOO, Chandani

University of Mauritius
Mauritius

ARAMENDIA, Emmanuel

University of Leeds
United Kingdom (of Great Britain and Northern Ireland)

ASADNABIZADEH, Majid

UMCS
Poland

ÁVILA ROMERO, Agustín

SEMARNAT
Mexico

BADRUZZAMAN, Ahmed

University of California, Berkeley, CA
United States of America

BALA, Govindasamy

Indian Institute of Science
India

BANDYOPADHYAY, Jayanta

Observer Research Foundation
India

BANERJEE, Manjushree

The Energy and Resources Institute
India

BARAL, Prashant

ICIMOD
Nepal

BAXTER, Tim

Climate Council of Australia
Australia

BELAID, Fateh King Abdullah Petroleum Studies and Research Center Saudi Arabia	BOLLINGER, Dominique HEIG-VD / HES-SO Switzerland
BELEM, Andre Universidade Federal Fluminense Brazil	BONDUELLE, Antoine E&E Consultant sarl France
BENDZ, David Swedish Geotechnical Institute Sweden	BRAGA, Diego Universidade Federal do ABC and WayCarbon Environmental Solutions Brazil
BENKO, Bernadett Ministry of Innovation and Technology Hungary	BRAUCH, Hans Guenter Hans Günter Brauch Foundation on Peace and Ecology in the Anthropocene Germany
BENNETT, Helen Department of Industry, Science, Energy and Resources Australia	BRAVO, Giangiacomo Linnaeus University Sweden
BENTATA, Salah Eddine Algerian Space Agency Algeria	BROCKWAY, Paul University of Leeds United Kingdom (of Great Britain and Northern Ireland)
BERK, Marcel Ministry of Economic Affairs and Climate Policy Netherlands	BRUN, Eric Ministère de la Transition Ecologique et Solidaire France
BERNDT, Alexandre EMBRAPA Brazil	BRUNNER, Cyril Institute of Atmospheric and Climate Science, ETH Zürich Switzerland
BEST, Frank HTWG Konstanz Germany	BUDINIS, Sara International Energy Agency, Imperial College London France
BHATT, Jayavardhan Ramanlal Ministry of Environment, Forests and Climate Change India	BUTO, Olga Wood Plc United Kingdom (of Great Britain and Northern Ireland)
BHATTI, Manpreet Guru Nanak Dev University India	CARDOSO, Manoel Brazilian Institute for Space Research (INPE) Brazil
BIGANO, Andrea Euro-Mediterranean Centre on Climate Change (CMCC) Italy	CASERINI, Stefano Politecnico di Milano Italy

Annex IV

CASTELLANOS, Sebastián
World Resources Institute
United States of America

CATALANO, Franco
ENEA
Italy

CAUBEL, David
Ministry of Ecological Transition
France

CHAKRABARTY, Subrata
World Resources Institute
India

CHAN SIEW HWA, Nanyang
Technological University
Singapore

CHANDRASEKHARAN, Nair Kesavachandran
CSIR-National Institute for Interdisciplinary Science and Technology
India

CHANG, Hoon
Korea Environment Institute
Republic of Korea

CHANG'A Ladislaus
Tanzania Meteorological Authority (TMA)
United Republic of Tanzania

CHERYL, Jeffers
Ministry of Agriculture, Marine Resources, Cooperatives, Environment
and Human Settlements
Saint Kitts and Nevis

CHESTNOY, Sergey
UC RUSAL
Russian Federation

CHOI, Young-jin
Phineo gAG
Germany

CHOMTORANIN, Jainta
Ministry of Agriculture and Cooperatives
Thailand

CHORLEY, Hanna
Ministry for the Environment
New Zealand

CHRISTENSEN, Tina
Danish Meteorological Institute
Denmark

CHRISTOPHERSEN, Øyvind
Norwegian Environment Agency
Norway

CIARLO, James
International Centre for Theoretical Physics
Italy

CINIRO, Costa Jr
CGIAR
Brazil

COOK, Jolene
Department for Business, Energy & Industrial Strategy
United Kingdom (of Great Britain and Northern Ireland)

COOK, Lindsey
FWCC
Germany

COOPER, Jasmin
Imperial College London
United Kingdom (of Great Britain and Northern Ireland)

COPPOLA, Erika
ICTP
Italy

CORNEJO RODRÍGUEZ, Maria del Pilar
Escuela Superior Politécnica del Litoral
Ecuador

CORNELIUS, Stephen
WWF
United Kingdom (of Great Britain and Northern Ireland)

CORTES, Pedro Luiz
University of Sao Paulo
Brazil

COSTA, Inês

Ministry of Environment and Climate Action
Portugal

COVACIU, Andra

Centre of Natural Hazards and Disaster Science
Sweden

COX, Janice

World Federation for Animals
South Africa

CURRIE-ALDER, Bruce

International Development Research Centre
Canada

CZERNICHOWSKI-LAURIOL, Isabelle

BRGM
France

D'IORIO, Marc

Environment and Climate Change Canada
Canada

DAS, Anannya

Centre for Science and Environment
India

DAS, Pallavi

Council on Energy, Environment and Water (CEEW)
India

DE ARO GALERA, Leonardo

Universität Hamburg
Germany

DE MACEDO PONTUAL COELHO, Camila

Rio de Janeiro City Hall
Brazil

DE OLIVEIRA E AGUIAR, Alexandre

Invento Consultoria
Brazil

DEDEOGLU, Cagdas

Yorkville University
Canada

DEKKER, Sabrina

Dekker Dublin City Council
Ireland

DENTON, Peter

Royal Military College of Canada, University of Winnipeg, University of
Manitoba
Canada

DEVKOTA, Thakur Prasad

ITC
Nepal

DICKSON, Neil

ICAO
Canada

DIXON, Tim

IEAGHG
United Kingdom (of Great Britain and Northern Ireland)

DODOO, Ambrose

Linnaeus University
Sweden

DOMÍNGUEZ Sánchez, Ruth

Creara
Spain

DRAGICEVIC, Arnaud

INRAE
France

DREYFUS, Gabrielle

Institute for Governance & Sustainable Development
United States of America

DUMBLE, Paul

Retired Land, Resource and Waste Specialist
United Kingdom (of Great Britain and Northern Ireland)

DUNHAM, Maciel André

Ministry of Foreign Affairs
Brazil

DZIELIŃSKI, Michał

Stockholm University
Sweden

Annex IV

ELLIS, Anna

The Open University
United Kingdom (of Great Britain and Northern Ireland)

EL-NAZER, Mostafa

National Research Centre
Egypt

FARROW, Aidan

Greenpeace Research Laboratories
United Kingdom (of Great Britain and Northern Ireland)

FERNANDES, Alexandre

Belgian Science Policy Office
Belgium

FINLAYSON, Marjahn

Cape Eleuthera Institute
Bahamas

FINNVEDEN, Göran

KTH
Sweden

FISCHER, David

International Energy Agency
France

FLEMING, Sea

University of British Columbia, Oregon State University, and US
Department of Agriculture
United States of America

FORAMITTI, Joël

Universitat Autònoma de Barcelona
Spain

FRA PALEO, Urbano

University of Extremadura
Spain

FRACASSI, Umberto

Istituto Nazionale di Geofisica e Vulcanologia
Italy

FRÖLICHER, Thomas

University of Bern
Switzerland

FUGLESTVEDT, Jan

IPCC WGI Vice-Chair
CICERO
Norway

GARCÍA MORA, Magdalena

ACCIONA ENERGÍA
Spain

GARCÍA PORTILLA, Jason

University of St. Gallen
Switzerland

GARCÍA SOTO, Carlos

Spanish Institute of Oceanography
Spain

GEDEN, Oliver

German Institute for International and Security Affairs
Germany

GEHL, Georges

Ministère du Développement Durable et des Infrastructures
Luxembourg

GIL, Ramón Vladimir

Catholic University of Peru
Peru

GONZÁLEZ, Fernando Antonio Ignacio

IIESS
Argentina

GRANSHAW, Frank D.

Portland State University
United States of America

GREEN, Fergus

University College London
United Kingdom (of Great Britain and Northern Ireland)

GREENWALT, Julie

Go Green for Climate
Netherlands

GRIFFIN, Emer

Department of Communications, Climate Action and Environment
Ireland

GRIFFITHS, Andy Diageo United Kingdom (of Great Britain and Northern Ireland)	HATZAKI, Maria National and Kapodistrian University of Athens Greece
GUENTHER, Genevieve The New School United States of America	HAUSKER, Karl World Resources Institute United States of America
GUIMARA, Kristel North Country Community College United States of America	HEGDE, Gajanana UNFCCC Germany
GUIOT, Joël CEREGE / CNRS France	HENRIKKA, Säkö Forward Advisory Switzerland
HAIRABEDIAN, Jordan EcoAct France	HIGGINS, Lindsey Pale Blue Dot Sweden
HAMAGUCHI, Ryo UNFCCC Germany	HOFFERBERTH, Elena University of Leeds Switzerland
HAMILTON, Stephen Michigan State University and Cary Institute of Ecosystem Studies United States of America	IGNASZEWSKI, Emma Good Food Institute United States of America
HAN, In-Seong National Institute of Fisheries Science Republic of Korea	IMHOF, Lelia IRNASUS (CONICET-Universidad Católica de Córdoba) Argentina
HANNULA, Ilkka IEA France	JÁCOME POLIT, David Universidad de las Américas Ecuador
HARJO, Rebecca NOAA/National Weather Service United States of America	JADRIJEVIC GIRARDI, Maritza Ministry of Environment Chile
HARNISCH, Jochen KFW Development Bank Germany	JAMDADE, Akshay Anil Central European University Austria
HASANEIN, Amin Islamic Relief Deutschland Germany	JAOUDE, Daniel Studies Center for Public Policy in Human Rights at Federal University of Rio de Janeiro Brazil

Annex IV

JATIB, María Inés

Institute of Science and Technology of the National University of Tres de Febrero (ICyTec-UNTREF)
Argentina

JIE, Jiang

Institute of Atmospheric Physics
China

JÖCKEL, Dennis Michael

Fraunhofer-Einrichtung für Wertstoffkreisläufe und Ressourcenstrategie IWKS
Germany

JOHANNESSEN, Ase

Global Center on Adaptation and Lund University
Sweden

JOHNSON, Francis Xavier

Stockholm Environment Institute
Thailand

JONES, Richard

Met Office Hadley Centre
United Kingdom (of Great Britain and Northern Ireland)

JRAD, Amel

Consultant
Tunisia

JUNGMAN, Laura

Consultant
United Kingdom (of Great Britain and Northern Ireland)

KÄÄB, Andreas

University of Oslo
Norway

KADITI, Eleni

Organization of the Petroleum Exporting Countries
Austria

KAINUMA, Mikiko

Institute for Global Environmental Strategies
Japan

KANAYA, Yugo

Japan Agency for Marine-Earth Science and Technology
Japan

KASKE-KUCK, Clea

WBCSD
Switzerland

KAUROLA, Jussi

Finnish Meteorological Institute
Finland

KEKANA, Maesela

Department of Environmental Affairs
South Africa

KELLNER, Julie

ICES and WHOI
Denmark

KEMPER, Jasmin

IEAGHG United
Kingdom (of Great Britain and Northern Ireland)

KHANNA, Sanjay

McMaster University
Canada

KIENDLER-SCHARR, Astrid

Forschungszentrum Jülich and University Cologne
Austria

KILKIS, Siir

The Scientific and Technological Research Council of Turkey
Turkey

KIM, Hyungjun

Korea Advanced Institute of Science and Technology
Republic of Korea

KIM, Rae Hyun

Central Government
Republic of Korea

KIMANI, Margaret

Kenya Meteorological services
Kenya

KING-CLANCY, Erin

King County Prosecuting Attorney's Office
United States of America

KOFANOV, Oleksii National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" Ukraine	LABINTAN, Adeniyi African Development Bank (AfDB) South Africa
KOFANOVA, Olena National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" Ukraine	LABRIET, Maryse Eneris Consultants Spain
KONDO, Hiroaki National Institute of Advanced Industrial Science and Technology Japan	LAMBERT, Laurent Doha Institute for Graduate Studies (Qatar) and Sciences Po Paris (France) France / Qatar
KOPP, Robert Rutgers University United States of America	LE COZANNET, Gonéri BRGM France
KOREN, Gerbrand Utrecht University Netherlands	LEAVY, Sebastián Instituto Nacional de Tecnología Agropecuaria / Universidad Nacional de Rosario Argentina
KOSONEN, Kaisa Greenpeace Finland	LECLERC, Christine Simon Fraser University Canada
KRUGLIKOVA, Nina University of Oxford United Kingdom (of Great Britain and Northern Ireland)	LEE, Arthur Chevron Services Company United States of America
KUMAR, Anupam National Environment Agency Singapore	LEE, Joyce Global Wind Energy Council Germany
KUNNAS, Jan University of Jyväskylä Finland	LEHOCZKY, Annamaria Fauna and Flora International United Kingdom (of Great Britain and Northern Ireland)
KUSCH-BRANDT, Sigrid University of Southampton and ScEnSers Independent Expertise Germany	LEITER, Timo London School of Economics and Political Science Germany
KVERNDOKK, Snorre Frisc Norway	LENNON, Breffní University College Cork Ireland
LA BRANCHE, Stéphane International Panel On behavioural Change France	LIM, Jinsun International Energy Agency France

Annex IV

LLASAT, Maria Carmen
Universidad de Barcelona
Spain

LOBB, David
University of Manitoba
Canada

LÓPEZ DÍEZ, Abel
University of La Laguna
Spain

LUENING, Sebastian
Institute for Hydrography, Geoecology and Climate Sciences
Germany

LYNN, Jonathan
IPCC
Switzerland

MABORA, Thupana
University of South Africa and Rhodes University
South Africa

MARTINERIE, Patricia
Institut des Géosciences de l'Environnement, CNRS
France

MARTIN-NAGLE, Renée
A Ripple Effect
United States of America

MASSON-DELMOTTE, Valerie
IPCC WGI Co-Chair
IPSL/LSCE, Université Paris Saclay
France

MATHESON, Shirley
WWF EPO
Belgium

MATHISON, Camilla
UK Met Office
United Kingdom (of Great Britain and Northern Ireland)

MATKAR, Ketna
Cipher Environmental Solutions LLP
India

MBATU, Richard
University of South Florida
United States of America

MCCABE, David
Clean Air Task Force
United States of America

MCKINLEY, Ian
McKinley Consulting
Switzerland

MERABET, Hamza
Ministère de l'Enseignement Supérieur et de la Recherche Scientifique
Algeria

LUBANGO, Louis Mitondo
United Nations
Ethiopia

MKUHLANI, Siyabusa
International Institute for Tropical Agriculture
Kenya

MOKIEVSKY, Vadim
IO RAS
Russian Federation

MOLINA, Luisa
Molina Center for Strategic Studies in Energy and the Environment
United States of America

MORENO, Ana Rosa
National Autonomous University of Mexico
Mexico

MUDELSEE, Manfred
Climate Risk Analysis - Manfred Mudelsee e.K.
Germany

MUDHOO, Ackmez
University of Mauritius
Mauritius

MUKHERJI, Aditi
IWMI
India

MULCHAN, Neil Retired from University System of Florida United States of America	NKUBA, Michael University of Botswana Botswana
MÜLLER, Gerrit Utrecht University Netherlands	NOHARA, Daisuke Kajima Technical Research Institute Japan
NAIR, Sukumaran Center for Green Technology & Management India	NOONE, Clare Maynooth University Ireland
NASER, Humood University of Bahrain Bahrain	NORDMARK, Sara The Swedish Civil Contingencies Agency Sweden
NDAO, Séga New Zealand Agricultural Greenhouse Gas Research Centre Senegal	NTAHOMPAGAZE, Pascal Expert Belgium
NDIONE, Jacques André ANSTS Senegal	NYINGURO, Patricia Kenya Meteorological Service Kenya
NEGREIROS, Priscilla Climate Policy Initiative United Kingdom (of Great Britain and Northern Ireland)	NZOTUNGICIMPAYE, Claude-Michel Concordia University Canada
NELSON, Gillian We Mean Business Coalition France	OBBARD, Jeff Cranfield University (UK) and Centre for Climate Research (Singapore) Singapore
NEMITZ, Dirk UNFCCC Germany	O'BRIEN, Jim Irish Climate Science Forum Ireland
NG, Chris Greenpeace Canada	O'CALLAGHAN, Donal Retired from Teagasc Agriculture Development Authority Ireland
NICOLINI, Cecilia Ministry of Environment and Sustainable Development Argentina	OCKO, Ilissa Environmental Defense Fund United States of America
NISHIOKA, Shuzo Institute for Global Environmental Strategies Japan	OH, Yae Won Korea Meteorological Administration Republic of Korea

Annex IV

O'HARA, Ryan

Harvey Mudd College
United States of America

OHNEISER, Christian

University of Otago
New Zealand

OKPALA, Denise

ECOWAS Commission
Nigeria

OMAR, Samira

Kuwait Institute for Scientific Research
Kuwait

ORLOV, Alexander

Ukraine

ORTIZ, Mark

The University of North Carolina at Chapel Hill
United States of America

OSCHLIES, Andreas

GEOMAR
Germany

OTAKA, Junichiro

Ministry of Foreign Affairs
Japan

PACAÑOT, Vince Davidson

University of the Philippines Diliman
Philippines

PALMER, Tamzin

Met Office
United Kingdom (of Great Britain and Northern Ireland)

PARRIQUE, Timothée

Université Clermont Auvergne
France

PATTNAYAK, Kanhu Charan

Ministry of Sustainability and Environment
Singapore

PEIMANI, Hooman

International Institute for Asian Studies and Leiden University (The Netherlands)
Canada

PELEJERO, Carles

ICREA and Institut de Ciències del Mar, CSIC
Spain

PERUGINI, Lucia

Euro-Mediterranean Center on Climate Change
Italy

PETERS, Aribert

Bund der Energieverbraucher e.V.
Germany

PETERSON, Bela

coneva GmbH
Germany

PETERSSON, Eva

Royal Swedish Academy of Agriculture and Forestry
Sweden

PINO MAESO, Alfonso

Ministerio de la Transición Ecológica
Spain

PLAISANCE, Guillaume

Bordeaux University
France

PLANTON, Serge

Association Météo et Climat
France

PLENCOVICH, María Cristina

Universidad de Buenos Aires
Argentina

PLESNIK, Jan

Nature Conservation Agency of the Czech Republic
Czech Republic

POLONSKY, Alexander

Institute of Natural Technical Systems
Russian Federation

POPE, James
Met Office
United Kingdom (of Great Britain and Northern Ireland)

PÖRTNER, Hans-Otto
IPCC WGII Co-Chair
Alfred-Wegener-Institute for Polar and Marine Research
Germany

PRENKERT, Frans
Örebro University
Sweden

PRICE, Joseph
UNEP
United Kingdom (of Great Britain and Northern Ireland)

QUENTA, Estefania
Universidad Mayor de San Andrés
Bolivia

RADUNSKY, Klaus
Austrian Standard International
Austria

RAHAL, Farid
University of Sciences and Technology of Oran - Mohamed Boudiaf
Algeria

RAHMAN, Syed Masiur
King Fahd University of Petroleum & Minerals
Saudi Arabia

RAHMAN, Mohammad Mahbubur
Lancaster University
United Kingdom (of Great Britain and Northern Ireland)

RAYNAUD, Dominique
CNRS
France

REALE, Marco
National Institute of Oceanography and Applied Geophysics
Italy

RECALDE, Marina
FUNDACION BARILOCHE / CONICET
Argentina

REISINGER, Andy
IPCC WGIII Vice-Chair
Climate Change Commission
New Zealand

RÉMY, Eric
Université Toulouse III Paul Sabatier
France

REYNOLDS, Jesse
Consultant
Netherlands

RIZZO, Lucca
Mattos Filho
Brazil

RÓBERT, Blaško
Slovak Environment Agency
Slovakia

ROBOCK, Alan
Rutgers University
United States of America

RODRIGUES, Mónica A.
University of Coimbra
Portugal

ROELKE, Luisa
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
Germany

ROGERS, Cassandra
Australian Bureau of Meteorology
Australia

ROMERI, Mario Valentino
Consultant
Italy

ROMERO, Javier
University of Salamanca
Spain

ROMERO, Mauricio
National Unit for Disaster Risk Management
Colombia

Annex IV

RUIZ-LUNA, Arturo

Centro de Investigación en Alimentación y Desarrollo, A.C. - Unidad Mazatlán
Mexico

RUMMUKAINEN, Markku

Swedish Meteorological and Hydrological Institute
Sweden

SAAD-HUSSEIN, Amal

Environment & Climate Change Research Institute, National Research Centre
Egypt

SALA, Hernan E.

Argentine Antarctic Institute - National Antarctic Directorate
Argentina

SALADIN, Claire

IUCN / WIDECAST
France

SALAS Y MELIA, David

Météo-France
France

SANGHA, Kamaljit K.

Charles Darwin University
Australia

SANTILLO, David

Greenpeace Research Laboratories (University of Exeter)
United Kingdom (of Great Britain and Northern Ireland)

SCHACK, Michael

ENGIE, Consultant
France

SCHNEIDER, Linda

Heinrich Boell Foundation
Germany

SEMENOV, Sergey

IPCC WGII Vice-Chair
Institute of Global Climate and Ecology
Russian Federation

SENSOY, Serhat

Turkish State Meteorological Service
Turkey

SHAH, Parita

University of Nairobi
Kenya

SILVA, Vintura

UNFCCC
Grenada

SINGH, Bhawan

University of Montreal
Canada

SMITH, Sharon

Geological Survey of Canada, Natural Resources Canada
Canada

SMITH, Inga Jane

University of Otago
New Zealand

SOLMAN, Silvina Alicia

CIMA (CONICET/UBA)-DCAO (FCEN/UBA)
Argentina

SOOD, Rashmi

Concentrix
India

SPRINZ, Detlef

PIK
Germany

STARK, Wendelin

ETH Zurich,
Switzerland

STRIDBÆK, Ulrik

Ørsted A/S
Denmark

SUGIYAMA, Masahiro

University of Tokyo
Japan

SUN, Tianyi

Environmental Defense Fund
United States of America

SUTTON, Adrienne
NOAA
United States of America

SYDNOR, Marc
Apex Clean Energy
United States of America

SZOPA, Sophie
Commissariat à l'Énergie Atomique et aux Énergies Alternatives
France

TADDEI, Renzo
Federal University of Sao Paulo
Brazil

TAIMAR, Ala
Estonian Meteorological & Hydrological Institute
Estonia

TAJBAKSHI, Mosalman Sahar
Islamic Republic of Iran Meteorological Organization
Iran

TALLEY, Trigg
U.S. Department of State
United States of America

TANCREDI, Elda
National University of Lujan
Argentina

TARTARI, Gianni
Water Research Institute - National Research Council of Italy
Italy

TAYLOR, Luke
Otago Innovation Ltd (University of Otago)
New Zealand

THOMPSON, Simon
Chartered Banker Institute
United Kingdom (of Great Britain and Northern Ireland)

TIRADO, Reyes
Greenpeace International and University of Exeter
Spain

TREGUIER, Anne Marie
CNRS
France

TULKENS, Philippe
European Union
Belgium

TURTON, Hal
International Atomic Energy Agency
Austria

TUY, Héctor
Organismo Indígena Naleb'
Guatemala

TYRRELL, Tristan
Ireland

URGE-VORSATZ, Diana
IPCC WGIII Vice-Chair
Central European University
Hungary

VACCARO, James
Climate Safe Lending Network
United Kingdom (of Great Britain and Northern Ireland)

VAN YPERSELE, Jean-Pascal
Université Catholique de Louvain
Belgium

VASS, Tiffany
IEA
France

VERCHOT, Louis
Alliance Bioversity Ciat
Colombia

VICENTE-VICENTE, Jose Luis
Leibniz Centre for Agricultural Landscape Research
Germany

VILLAMIZAR, Alicia
Universidad Simón Bolívar
Venezuela

Annex IV

VOGEL, Jefim

University of Leeds

United Kingdom (of Great Britain and Northern Ireland)

VON SCHUCKMANN, Karina

Mercator Ocean International

France

VORA, Nemi

Amazon Worldwide Sustainability and IIASA

United States of America

WALZ, Josefine

Federal Agency for Nature Conservation

Germany

WEI, Taoyuan

CICERO

Norway

WEIJIE, Zhang

Ministry of Environment and Natural Resources

Singapore

WESSELS, Josepha

Malmö University

Sweden

WITTENBRINK, Heinrich

FH Joanneum

Austria

WITTMANN, Veronika

Johannes Kepler University Linz

Austria

WONG, Li Wah

CEARCH

Germany

WONG, Poh Poh

University of Adelaide

Australia / Singapore

WYROWSKI, Lukasz

UNECE

Switzerland

YAHYA, Mohammed

IUCN

Kenya

YANG, Liang Emlyn

LMU Munich

Germany

YOMMEE, Suriyakit

Thammasat University

Thailand

YU, Jianjun

National Environment Agency

Singapore

YULIZAR, Yulizar

Universitas Pertamina

Indonesia

ZAELKE, Durwood

Institute for Governance & Sustainable Development

United States of America

ZAJAC, Joseph

Technical Reviewer

United States of America

ZANGARI DEL BALZO, Gianluigi

Sapienza University of Rome

Italy

ZDRULI, Pandi

CIHEAM

Italy

ZHUANG, Guotai

China Meteorological Administration

China

ZOMMERS, Zinta

Latvia

ZOPATTI, Alvaro

University of Buenos Aires

Argentina

Annex V
List of Publications of the
Intergovernmental Panel
on Climate Change

Assessment Reports

Sixth Assessment Report

Climate Change 2021: The Physical Science Basis

Contribution of Working Group I to the Sixth Assessment Report

Climate Change 2022: Impacts, Adaptation, and Vulnerability

Contribution of Working Group II to the Sixth Assessment Report

Climate Change 2022: Mitigation of Climate Change

Contribution of Working Group III to the Sixth Assessment Report

Climate Change 2023: Synthesis Report

A Report of the Intergovernmental Panel on Climate Change

Fifth Assessment Report

Climate Change 2013: The Physical Science Basis

Contribution of Working Group I to the Fifth Assessment Report

Climate Change 2014: Impacts, Adaptation, and Vulnerability

Contribution of Working Group II to the Fifth Assessment Report

Climate Change 2014: Mitigation of Climate Change

Contribution of Working Group III to the Fifth Assessment Report

Climate Change 2014: Synthesis Report

A Report of the Intergovernmental Panel on Climate Change

Fourth Assessment Report

Climate Change 2007: The Physical Science Basis

Contribution of Working Group I to the Fourth Assessment Report

Climate Change 2007: Impacts, Adaptation and Vulnerability

Contribution of Working Group II to the Fourth Assessment Report

Climate Change 2007: Mitigation of Climate Change

Contribution of Working Group III to the Fourth Assessment Report

Climate Change 2007: Synthesis Report

A Report of the Intergovernmental Panel on Climate Change

Third Assessment Report

Climate Change 2001: The Scientific Basis

Contribution of Working Group I to the Third Assessment Report

Climate Change 2001: Impacts, Adaptation, and Vulnerability

Contribution of Working Group II to the Third Assessment Report

Climate Change 2001: Mitigation

Contribution of Working Group III to the Third Assessment Report

Climate Change 2001: Synthesis Report

Contribution of Working Groups I, II and III to the Third Assessment Report

Second Assessment Report

Climate Change 1995: Science of Climate Change

Contribution of Working Group I to the Second Assessment Report

Climate Change 1995: Scientific-Technical Analyses of Impacts, Adaptations and Mitigation of Climate Change

Contribution of Working Group II to the Second Assessment Report

Climate Change 1995: Economic and Social Dimensions of Climate Change

Contribution of Working Group III to the Second Assessment Report

Climate Change 1995: Synthesis of Scientific-Technical Information Relevant to Interpreting Article 2 of the UN Framework Convention on Climate Change

A Report of the Intergovernmental Panel on Climate Change

Supplementary Reports to the First Assessment Report

Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment

Supplementary report of the IPCC Scientific Assessment Working Group I

Climate Change 1992: The Supplementary Report to the IPCC Impacts Assessment

Supplementary report of the IPCC Impacts Assessment Working Group II

Climate Change: The IPCC 1990 and 1992 Assessments

IPCC First Assessment Report Overview and Policymaker Summaries and 1992 IPCC Supplement

First Assessment Report

Climate Change: The Scientific Assessment

Report of the IPCC Scientific Assessment Working Group I, 1990

Climate Change: The IPCC Impacts Assessment

Report of the IPCC Impacts Assessment Working Group II, 1990

Climate Change: The IPCC Response Strategies

Report of the IPCC Response Strategies Working Group III, 1990

Special Reports

The Ocean and Cryosphere in a Changing Climate 2019

Climate Change and Land

An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems 2019

Global Warming of 1.5 °C

An IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. 2018

Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation 2012

Renewable Energy Sources and Climate Change Mitigation 2011

Carbon Dioxide Capture and Storage 2005

Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons (IPCC/TEAP joint report) 2005

Land Use, Land-Use Change, and Forestry 2000

Emissions Scenarios 2000

Methodological and Technological Issues in Technology Transfer 2000

Aviation and the Global Atmosphere 1999

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