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IPCC SPECIAL REPORT ON GLOBAL WARMING OF 1.5°C

An IPCC special report on the impacts of global warming of 1.5ºC 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.

Final Draft Summary for Policymakers

(Submitted by the Co-Chairs of Working Groups I, II and III)

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Note:

The Final Draft Summary for Policymakers is submitted to the First Joint Session of Working Groups I, II and III for approval. The approved Summary for Policymakers will be forwarded to the Forty-Eighth Session of the IPCC (Incheon, Republic of Korea, 1 - 5 October 2018) for acceptance.

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WMO UNEP

Summary for Policy Makers

Date of Draft: 30 September 2018

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Introduction

This report responds to the invitation for IPCC '... to provide a Special Report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways' contained in the Decision of the 21st Conference of Parties of the United Nations Framework Convention on Climate Change to adopt the Paris Agreement.[1]

The IPCC accepted the invitation in April 2016, deciding to prepare this 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*.

This Summary for Policy Makers (SPM) presents the key findings of the Special Report, based on the assessment of the available scientific, technical and socio-economic literature[2] relevant to global warming of 1.5°C and for the comparison between global warming of 1.5°C and 2°C. The level of confidence associated with each key finding is reported using the IPCC calibrated language.[3] The underlying scientific basis of each key finding is indicated by references provided to chapter elements.

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[1] COP 21, decision 1, para. 21

[2] The assessment covers literature accepted for publication by 15 May 2018.

[3] 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 a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, more unlikely than likely 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, for example, very likely. See for more details: Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.-K. Plattner, G.W. Yohe and F.W. Zwiers, 2010: Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland, 4 pp.

A. Understanding Global Warming of 1.5°C

A1. Human activities have caused approximately 1.0°C of global warming, with a *likely* range of 0.8° to 1.2°C. Global warming is *likely* to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. (*high confidence*) {1.2, Figure SPM1}

A1.1. Observed global mean surface temperature (GMST) for the decade 2006–2015 was 0.87°C (*likely* between 0.75° and 0.99°C)[4] higher than in 1850–1900 (*very high confidence*). Anthropogenic global warming matches the level of observed warming to within ±20% (*likely* range) and is currently increasing at 0.2°C (*likely* between 0.1°C and 0.3°C) per decade due to ongoing emissions (*high confidence*). {1.2.1, Table 1.1, 1.2.4}

A1.2. Warming greater than the global average is being experienced in many regions and seasons, including two to three times higher in many Arctic regions. Warming is generally higher over land than over the ocean. (*high confidence*) {1.2.1, 1.2.2, Figure 1.1, Figure 1.3, 3.3.1, 3.3.2}

A1.3. Changes in temperature extremes and heavy precipitation have been detected in observations for the 1991–2010 period compared with 1960–1979, a time span over which global warming of approximately 0.5°C occurred, suggesting that further detectable changes in extremes may be associated with every additional 0.5ºC of warming (*medium confidence*). {3.3.1, 3.3.2, 3.3.3}

A2. Past emissions alone are *unlikely* to cause global warming of 1.5°C (*medium confidence*) but will cause further long-term changes in the climate system, such as sea level rise, with associated impacts (*high confidence*). {1.2, 3.3, Figure SPM 1}

A2.1. If all anthropogenic emissions (including greenhouse gases, aerosols and their precursors) were reduced to zero immediately, it is *likely* that further global warming would be less than 0.5°C over the next two to three decades (*high confidence*) and less than 0.5°C on a century time scale (*medium confidence*). {1.2.4, Figure 1.5}

A2.2. Reaching and sustaining net-zero CO_2 emissions and declining non-CO_2 radiative forcing would halt global warming at a level determined by net cumulative CO_2 emissions up to the time of net-zero (*high confidence*) and the average level of non-CO_2 radiative forcing in the decades immediately prior to that time (*medium confidence*) (Figure SPM 1). Net negative CO_2 emissions may still be required to sustain stable temperatures thereafter (*medium confidence*). {Cross-Chapter Box 2 in Chapter 1, 1.2.3, 1.2.4, 2.2.1, 2.2.2}

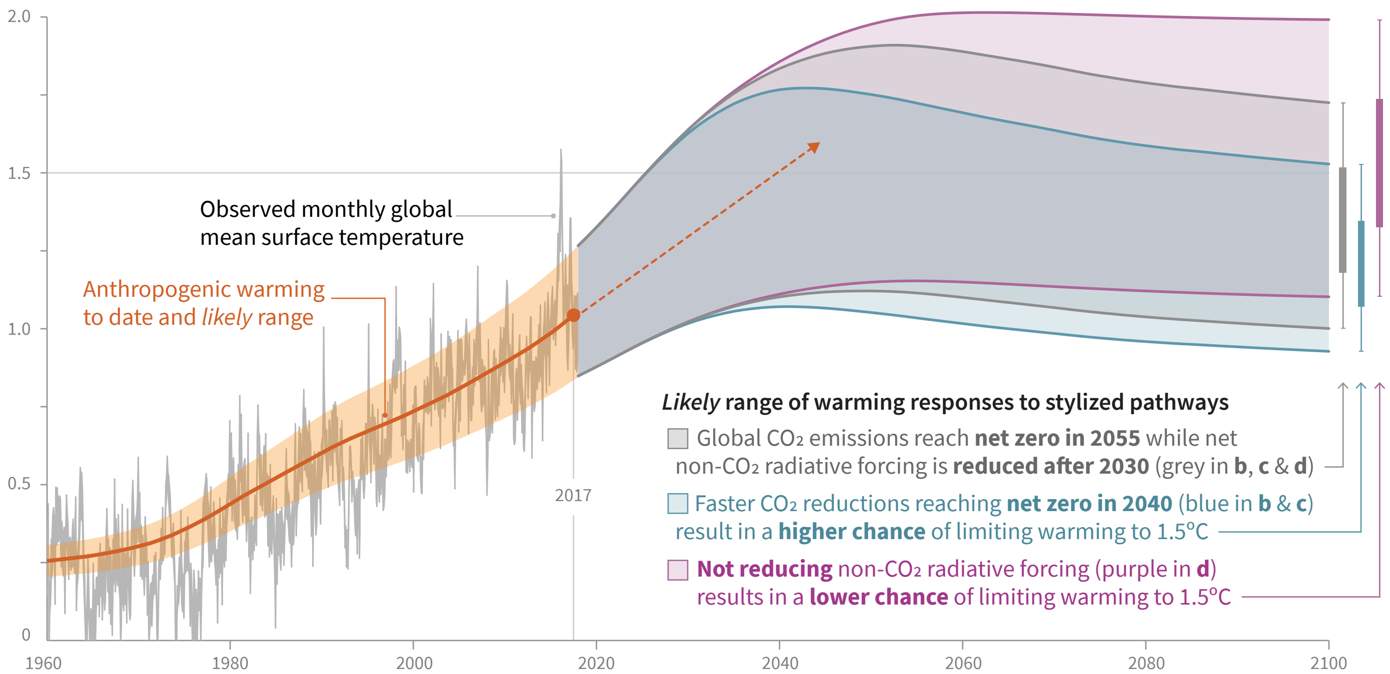
[4] This range spans the four available peer-reviewed estimates of the observed GMST change and also accounts for additional uncertainty due to possible short-term natural variability. {1.2.1, Table 1.1}

Cumulative emissions of CO_2 and future non-CO_2 radiative forcing determine the chance of limiting warming to 1.5°C

This figure uses stylized emissions and forcing pathways to show key factors affecting the prospects of temperatures remaining below 1.5°C.

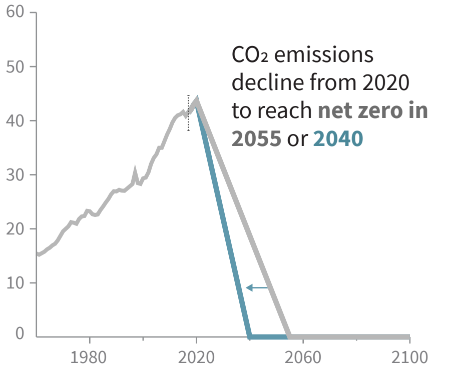
a) Observed global temperature and responses to stylized emission pathways

Global warming relative to 1850-1900 (°C)



b) Stylized global CO_2 emission pathways

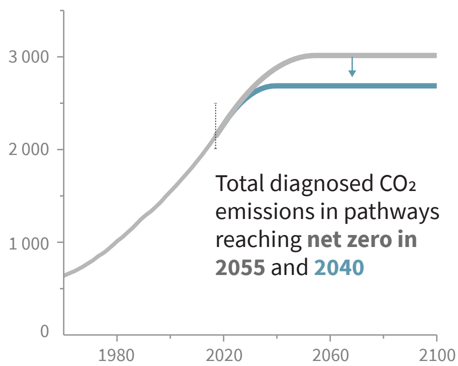
Billion tonnes CO_2 per year (Gt/y)



Faster immediate CO_2 emission reductions reduce total cumulative CO_2 emissions at the time of peak warming.

c) Total cumulative CO_2 emissions

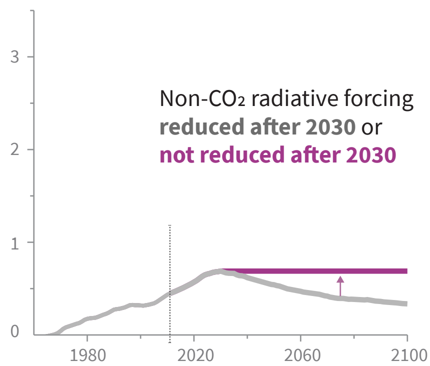
Billion tonnes CO_2 (Gt)



Maximum warming is determined by cumulative CO_2 emissions at the time of peak warming and…

d) Non-CO_2 radiative forcing pathways

Watts per square metre (W/m²)



…maximum warming is also affected by radiative forcing due to methane, nitrous oxide, aerosols and other emissions.

Figure SPM.1: Panel a: Observed monthly global mean surface temperature (GMST, grey line to the left of 2017, from the HadCRUT4, GISTEMP, Cowtan & Way, and NOAA datasets, with varying line thickness indicating the dataset range) and estimated anthropogenic global warming to date (orange line obtained by fitting expected responses to anthropogenic and natural radiative forcing to observed GMST, displaying the anthropogenic component, with orange shading indicating assessed ±20% likely range). Grey plume on right of panel a shows likely range of warming responses to a stylized pathway in which CO2 emissions (grey line in panels b and c) decline in a straight line from 2020 to reach net zero in 2055 while non-CO2 radiative forcing (grey line in panel d) increases to 2030 and then declines, representative of the 1.5°C no or limited overshoot pathways assessed in Chapter 2. Temperature responses are computed with a simple climate carbon cycle model consistent with the assessed likely range in anthropogenic global warming in 2017. Blue plume in panel a shows the response to faster CO2 emissions reductions (blue line in panel b), reaching net-zero in 2040, reducing cumulative CO2 emissions (panel c). Purple plume shows response to CO2 emissions declining to zero in 2055 but non-CO2 forcing remaining constant after 2030. Vertical error bars on right of panel a show likely ranges (thin lines) and central terciles (33rd – 66th percentiles, thick lines) of the estimated distribution of warming in 2100 under these three stylized pathways. Vertical dotted error bars in panels b, c and d show likely ranges of uncertainty in observed annual and cumulative global CO2 emissions in 2017 and in non-CO2 radiative forcing in 2011. Vertical axes in panels c and d are scaled to represent approximately equal effects on GMST. {1.2.1, 1.2.3, 1.2.4, 2.3, Chapter 1 Figure 1.2 & Chapter 1 Technical Annex, Cross Chapter Box 2}

A3. Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C (*high confidence*). These risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options (*high confidence*) (Figure SPM2). {1.3, 3.3, 3.4, 5.6}

A3.1. Impacts on natural and human systems from global warming have already been observed (*high confidence*). Many land and ocean ecosystems and some of the services they provide have already changed due to global warming (*high confidence)*. {1.4, 3.4, 3.5, SPM Figure 2}

A3.2. Future climate-related risks depend on the rate, peak and duration of warming. They are larger if global warming exceeds 1.5°C before returning to that level by 2100 than if global warming gradually stabilizes at 1.5°C, especially if the peak temperature is high (e.g., about 2°C) (*high confidence*). Some risks may be long-lasting or irreversible, such as the loss of ecosystems (*high confidence*). {3.2, 3.4.4, 3.6.3, Cross-Chapter Box 8}

A3.3. Adaptation and mitigation are already occurring (*high confidence*). Future climate-related risks would be reduced by the upscaling and acceleration of far-reaching, multi-level and cross-sectoral climate mitigation and by both incremental and transformational adaptation *(high confidence)* {1.2, 1.3, Table 3.5, 4.2.2, Cross-Chapter Box 9 in Chapter 4, Box 4.2, Box 4.3, Box 4.6, 4.3.1, 4.3.2, 4.3.3, 4.3.4, 4.3.5, 4.4.1, 4.4.4, 4.4.5, 4.5.3}

A4. Limiting global warming to 1.5°C compared to 2°C would make it easier to achieve many aspects of sustainable development, with greater potential to eradicate poverty and reduce inequalities, especially when mitigation actions maximize synergies (high confidence). {1.1, 1.4, 2.5, 5.2, Table 5.1}

A4.1. Climate change impacts and responses are closely linked to sustainable development which balances social well-being, economic prosperity and environmental protection. The United Nations Sustainable Development Goals (SDGs), adopted in 2015, provide an established framework for assessing the links between global warming of 1.5°C or 2°C and development goals that include poverty eradication, reducing inequalities, and climate action (*high confidence*) {Cross-Chapter Box 4 in Chapter 1, 1.4, 5.1}

A4.2. The consideration of ethics and equity can help minimize adverse effects and maximize benefits associated with pathways limiting global warming to 1.5°C, and is central to this report. Additional climate risks at 2°C compared to 1.5°C warming, as well as potential negative consequences of mitigation action, would fall disproportionally on poor and disadvantaged populations, indicating larger challenges associated with poverty eradication and reducing inequalities compared to current conditions *(high confidence).* {1.1.1, 1.1.2, 1.4.3, 2.5.3, 3.4.10, 5.1, 5.2, 5.3. 5.4, Cross-Chapter Box 4 in Chapter 1, Cross-Chapter Boxes 6 and 8 in Chapter 3, and Cross-Chapter Box 12 in Chapter 5}

A5. Mitigation and adaption consistent with global warming of 1.5°C are underpinned by enabling conditions, assessed in this report across the geophysical, environmental-ecological, technological, economic, socio-cultural and institutional dimensions of feasibility. {1.4, Cross-Chapter Box 3 in Chapter 1, 4.4, 4.5, 5.6}

A5.1. Modelling studies identify that pathways limiting global warming to 1.5°C are enabled when considering the combination of effective international cooperation, integrated and stringent policy frameworks, access to finance, and sustainable consumption (*high confidence*) {2.1, 2.3, 2.5}.

A5.2. The availability of finance and technology, integration of institutions, inclusive processes, attention to uneven power and inequality, and reconsideration of values are critical conditions to achieve sustainable development, eradicate poverty and reduce inequalities while limiting global warming to 1.5°C *(high confidence*) {5.6}

A5.3. Strengthened multi-level governance, institutional capacity, policy instruments, technological innovation and transfer and mobilization of finance, and changes in human behaviour and lifestyles are enabling conditions that enhance the feasibility of mitigation and adaptation options for 1.5°C-consistent systems transitions *(high confidence*) {4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5}

B. Projected Climatic Changes, Their Potential Impacts and Associated Risks

B1. Climate models project robust[5] differences in regional climate characteristics between present-day and global warming of 1.5°C,[6] and between 1.5°C and 2°C[6]. These differences include increases in: mean temperature in most land and ocean regions (*high confidence*), hot extremes in most inhabited regions (*high confidence*), heavy precipitation in several regions (*medium confidence*), and the probability of drought in some regions (*medium confidence*). {3.3}

B1.1. Temperature extremes on land are projected to increase more than global warming (*high confidence*): extreme hot days in mid-latitudes by up to about 3°C at global warming of 1.5°C and about 4°C at 2°C, and extreme cold nights in high latitudes by up to about 4.5°C at 1.5°C and about 6°C at 2°C (*high confidence*). The number of hot days is projected to increase in most land regions, with highest increases in the tropics (*high confidence*). {3.3.1, 3.3.2, Cross-Chapter Box 8 in Chapter 3}

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[5] Robust is here used to mean that at least two thirds of climate models show the same sign of changes at the grid point scale, and that differences in large regions are statistically significant.

[6] Projected changes in impacts between different levels of global warming are determined with respect to changes in global surface air temperature.

B1.2. Limiting global warming to 1.5°C compared to 2°C would reduce the probability of increases in heavy precipitation events in several northern hemisphere high-latitude and high-elevation regions (*medium confidence*). Compared to 2°C global warming, less land would be affected by flood hazards (*medium confidence*) and the probability of droughts would be lower in some regions, including the Mediterranean and southern Africa (*medium confidence*). {3.3.3, 3.3.4, 3.3.5}

B2. By 2100, global mean sea level rise would be around 0.1 metre lower with global warming of 1.5°C compared to 2°C (*medium confidence*). Sea level will continue to rise well beyond 2100 (*high confidence*), and the magnitude and rate of this rise is expected to depend on future emission pathways. A slower rate of sea level rise would allow more effective adaptation (including managing and restoring natural coastal ecosystem and infrastructure reinforcement) in small islands, low-lying coastal areas and deltas exposed to increased saltwater intrusion, flooding, and damage to infrastructure (*medium confidence*). {3.3, 3.4, 3.6}

B2.1. Model-based projections of global mean sea level suggest an indicative range of 0.26 to 0.77 m by 2100 for 1.5°C global warming (relative to 1986-2005), 0.1 m (0.04-0.16 m) less than for a global warming of 2°C (*medium confidence*). A reduction of 0.1 m in global sea level rise implies that up to 10 million fewer people would be exposed to related risks, based on population in the year 2010 and assuming no adaptation (*medium confidence*). {3.4.4, 3.4.5, 4.3.2}

B2.2. Sea level rise will continue beyond 2100 even if global warming is limited to 1.5°C in the 21st century (*high confidence*). Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could result in multi-metre rise in sea level over hundreds to thousands of years. There is *medium confidence* that the threshold for such instabilities could lie around 1.5 to 2°C. {3.3.9, 3.4.5, 3.5.2, 3.6.3, Box 3.3, SPM Figure 3.2}

B3. On land, risks of climate-induced impacts on biodiversity and ecosystems, including species loss and extinction, are lower with 1.5°C of global warming than 2°C. Limiting global warming to 1.5°C compared to 2°C has important benefits for terrestrial, freshwater, and coastal ecosystems and for the preservation of their services to humans (*high confidence*). (SPM Figure 2) {3.4, 3.5, Box 3.4, Box 4.2, Cross-Chapter Box 8 in Chapter 3}

B3.1. Of 105,000 species studied, 18% of insects, 16% of plants and 8% of vertebrates are projected to lose over half of their climatically determined geographic range for global warming of 2°C, compared with 6% of insects, 8% of plants and 4% of vertebrates for global warming of 1.5°C (*medium confidence*). Impacts associated with other biodiversity-related risks such as forest fires, and the spread of invasive species, are also reduced at 1.5°C compared to 2°C of global warming (*high confidence*). {3.4.3.3, 3.5.2}

B3.2. Approximately 13% of the global terrestrial land area is projected to undergo a transformation of ecosystems from one type to another at 2ºC of global warming. The area at risk would be approximately halved at 1.5°C (*medium confidence*). {3.4.3.1, 3.4.3.5}

B3.3. High-latitude tundra and boreal forests are particularly at risk of climate change induced degradation and loss, with woody shrubs already encroaching into the tundra (*high confidence*). Limiting global warming to 1.5°C rather than 2°C could also prevent the thawing over centuries of an estimated 2 million km^2 of the existing permafrost area (*medium confidence*) {3.3.2, 3.4.3, 3.5.5}

B4. Limiting global warming to 1.5°C compared to 2ºC is expected to reduce increases in ocean temperature as well as associated increases in ocean acidity and decreases in ocean oxygen levels (*high confidence*). Consequently, limiting global warming to 1.5°C is expected to reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans, as illustrated by recent changes to Arctic sea ice and warm water coral reef ecosystems (*high confidence*). {3.3, 3.4, 3.5, Boxes 3.4, 3.5}

B4.1. There is *high confidence* that the probability of a sea-ice-free Arctic Ocean during summer is substantially higher at global warming of 2°C when compared to 1.5°C. With 2°C global warming, at least one sea ice-free Arctic summer is projected per decade. This likelihood is reduced to one per century with 1.5°C of global warming. Effects of a temperature overshoot are reversible for Arctic sea ice cover on decadal time scales (*high confidence*). {3.3.8, 3.4.4.7}

B4.2. Global warming of 1.5°C is projected to shift species ranges to higher latitudes as well as increase the amount of damage to many ecosystems. It is also expected to drive the loss of coastal resources, and reduce the productivity of fisheries and aquaculture (especially at low latitudes). The risks of climate-induced impacts are projected to be less at 1.5°C than those at global warming of 2°C (*high confidence*). Coral reefs, for example, are projected to decline by a further 70–90% at 1.5°C with larger losses (> 99%) at 2ºC (*very high confidence*). The risk of irreversible loss of many marine and coastal ecosystems increases with global warming, especially at 2°C or more (*high confidence*). {3.4.4, Box 3.4}

B4.3. The level of ocean acidification associated with global warming of 1.5°C is expected to amplify the adverse effects of warming, impacting the survival, calcification, growth, development, and abundance of a broad range of species (i.e. from algae to fish) (*high confidence*). {3.3.10, 3.4.4}

B4.4. Climate change in the ocean is increasing risks to fisheries and aquaculture via impacts on the physiology, survivorship, habitat, reproduction, disease incidence, and risk of invasive species (*medium confidence)* but are projected to be less at 1.5ºC of global warming than at 2ºC. Global fishery models, for example, project a decrease in global annual catch for marine fisheries of more than 3 million tonnes for 2°C of global warming versus a loss of 1.5 million tonnes for 1.5°C of global warming (*medium confidence*). {3.4.4, Box 3.4}

B5. Climate-related risks to health, livelihoods, food and water supply, human security, and economic growth are projected to increase with global warming of 1.5°C and increase further with 2°C. (SPM Figure 2) {3.4, 3.5, 5.2, Box 3.2, Box 3.3, Box 3.5, Box 3.6, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5, 5.2}

B5.1. Populations at disproportionately higher risk of adverse consequences of global warming of 1.5°C and beyond include disadvantaged populations, indigenous peoples, and populations dependent on agriculture or coastal livelihoods. Regions at disproportionately higher risk include Arctic ecosystems, dryland regions, and small-island developing states (*high confidence)*. Poverty and disadvantage are expected to increase in some populations as global warming increases; limiting global warming to 1.5°C, compared with 2°C, could reduce the number of people exposed to climate-related risks and susceptible to poverty by up to several hundred million (*medium confidence*). {3.4.10, 3.4.11, Box 3.5, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5, 5.2.1, 5.2.2, 5.2.3, 5.6.3, Cross-chapter Box 9}

B5.2. Any increase in global warming is expected to affect human health, with primarily negative consequences (*high confidence*). Lower risks are projected at 1.5°C than at 2°C for heat-related morbidity and mortality (*very high confidence*) and for ozone-related mortality if emissions needed for ozone formation remain high (*high confidence)*. Urban heat island effects generally amplify the impacts of heatwaves in cities (*high confidence*). Risks from some vector-borne diseases, such as malaria and dengue fever, are projected to increase with the level of future warming, including potential shifts in their geographic range (*high confidence*). {3.4.7, 3.4.8, 3.5.5.8}

B5.3. Limiting warming to 1.5°C, compared with 2ºC, is projected to result in smaller net reductions in yields of maize, rice, wheat, and potentially other cereal crops, particularly in sub-Saharan Africa, Southeast Asia, and Central and South America; and in the CO_2 dependent, nutritional quality of rice and wheat (*high confidence*). Reductions in projected food availability are larger at 2ºC than at 1.5°C of global warming in the Sahel, southern Africa, the Mediterranean, central Europe, and the Amazon (*medium confidence*). Livestock are projected to be adversely affected with rising temperatures, depending on the extent of changes in feed quality, spread of diseases, and water resource availability (*high confidence*) {3.4.6, 3.5.4, 3.5.5, Box 3.1, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4}

B5.4. Depending on future socioeconomic conditions, limiting global warming to 1.5°C, compared to 2°C, may reduce the proportion of the world population exposed to a climate-change induced increase in water scarcity by up to 50%, although there is considerable variability between regions (*medium confidence*). Many small island developing states would experience substantially less freshwater stress as a result of projected changes in aridity when global warming is limited to 1.5°C, as compared to 2°C (*medium confidence*). {3.3.5, 3.4.2, 3.4.8, 3.5.5, Box 3.2, Box 3.5, Cross-Chapter Box 9 in Chapter 4}

B5.5. Risks to global economic growth posed by climate change-related impacts are projected to be lower at 1.5ºC than at 2ºC of global warming (*medium confidence*). Countries in the tropics and Southern Hemisphere subtropics are most at risk because present-day temperatures in these regions are above the threshold estimated to be optimal for economic production (*medium confidence*). {3.5.2, 3.5.3}

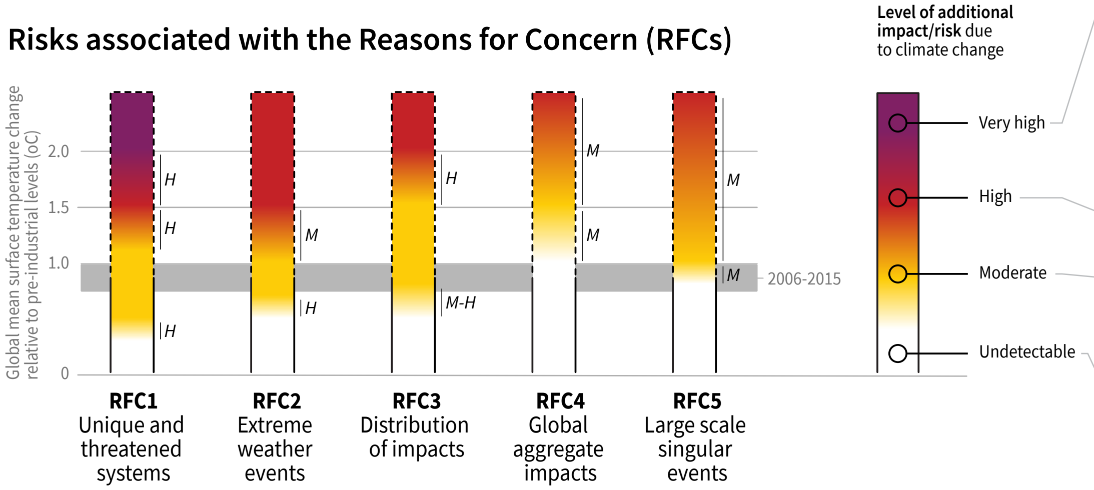
B5.6. Exposure to multiple and compound climate-related risks increases between 1.5°C and 2°C of global warming, with greater proportions of people exposed and susceptible to poverty in Africa and Asia (*high confidence*). Risks across energy, food, and water sectors could overlap spatially and temporally, creating new (and exacerbating current) hazards, exposures, and vulnerabilities that could affect increasing numbers of people and regions with additional global warming (*medium confidence*) {Box 3.5, 3.3.1, 3.4.5.3, 3.4.5.6, 3.4.11, 3.5.4.9}

B5.7. There are multiple lines of evidence that since the AR5 the assessed levels of risk increased for four of the five Reasons for Concern (RFCs) for global warming to 2ºC (*high confidence*). The risk transitions by degrees of global warming are now: from high to very high between 1.5°C and 2°C for RFC1 (Unique and threatened systems) (*high confidence*); from moderate to high risk between 1.0°C and 1.5°C for RFC2 (Extreme weather events) (*high confidence*); from moderate to high risk between 1.5°C and 2°C for RFC3 (Distribution of impacts) (*high confidence*); from moderate to high risk between 1.5°C and 2.5°C for RFC4 (Global aggregate impacts) (*medium confidence*); and from moderate to high risk between 1°C and 2.5°C for RFC5 (Large-scale singular events) (*high confidence*). (SPM Figure 2) {3.4.13; 3.5, 3.5.2}

How the level of global warming affects risks associated with the Reasons for Concern (RFCs) and selected natural, managed and human systems

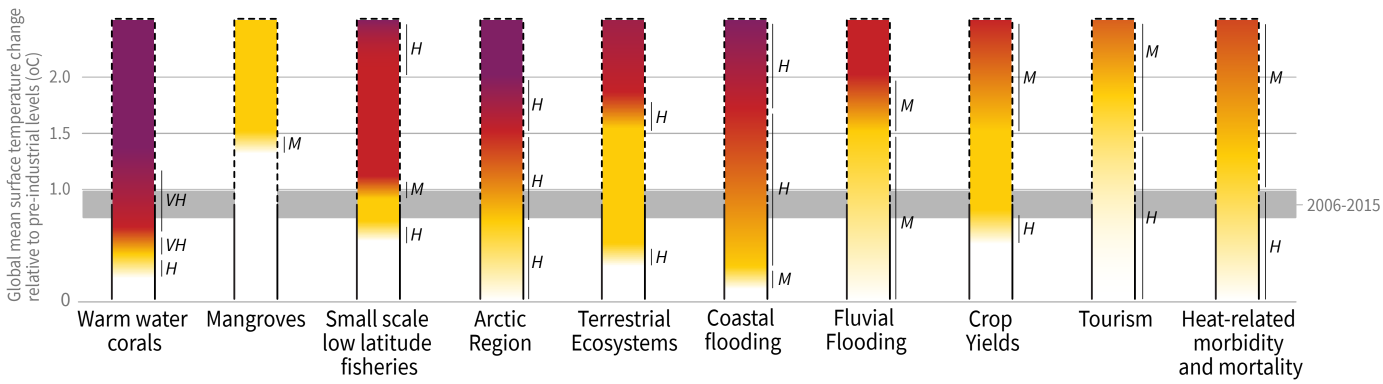
Five Reasons For Concern (RFCs) illustrate the implications of different levels of global warming for people, economies and ecosystems across sectors and regions.

Risks associated with the Reasons for Concern (RFCs)



Purple indicates very high risks of severe impacts/risks 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.
Red indicates severe and widespread impacts/risks.
Yellow indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.
White indicates that no impacts are detectable and attributable to climate change.

Risks for selected natural, managed and human systems



Confidence level for transition: *L*=Low, *M*=Medium, *H*=High and *VH*=Very high

Figure SPM.2: Five integrative reasons for concern (RFCs) provide a framework for summarizing key risks across sectors and regions, and were introduced in the IPCC Third Assessment Report. RFCs illustrate the implications of climate change and adaptation limits for people, economies, and ecosystems. Risks for each RFC are based on assessment of the new literature that has appeared. As in the AR5, this literature has been used to make expert judgments to assess the levels of global warming at which levels of risk are undetectable, moderate, high or very high. The selection of risks to natural, managed and human systems in the lower panel is illustrative and is not intended to be fully comprehensive. {3.4, 3.5, 3.5.2.1, 3.5.2.2, 3.5.2.3, 3.5.2.4, 3.5.2.5, 5.4.1 5.5.3, 5.6.1, Box 3.4}

B6. Most adaptation needs will be lower for global warming of 1.5°C compared to 2°C (*high confidence*). There are a wide range of adaptation options that can reduce the risks of climate change (*high confidence*). Limits to adaptation exist with global warming of 1.5°C. The number and availability of adaptation options vary by sector and decline for higher levels of global warming. (*medium confidence*) {Table 3.5, 4.3, 4.5, Cross-Chapter Box 12 in Chapter 5}

B6.1. A wide range of adaptation options are available to reduce the risks to natural and managed ecosystems (e.g., ecosystem restoration, avoided deforestation, biodiversity protection, agricultural irrigation efficiency, sustainable aquaculture), the risks of sea level rise (e.g., coastal infrastructure), and the risks to health, livelihoods, food, water, and economic growth especially in rural landscapes (e.g., social safety nets, disaster risk reduction, insurance, water management and reuse) and urban areas (e.g., green infrastructure, planning) (*medium confidence*). Effective options include community-based adaptation, drawing on local knowledge and indigenous knowledge, and ecosystems-based adaptation (*high confidence*). [(Table SPM.1)] {4.3.1, 4.3.2, 4.3.3, 4.3.5, 4.5.3, 4.5.4, Box 4.2, Box 4.3, Box 4.6, Cross-Chapter Box 9 in Chapter 4}.

B6.2. Adaptation is expected to be more challenging for ecosystems, food and health systems at 2°C of global warming than for 1.5°C (*medium confidence*). Some vulnerable regions, including small islands and Least Developed Countries, are projected to experience high multiple interrelated climate risks even at global warming of 1.5°C (*high confidence*). {3.3.1, 3.4.5, Box 3.5, Table 3.5, Cross-Chapter Box 9 in Chapter 4, 5.6, Cross-Chapter Box 12 in Chapter 5, Box 5.3}

B6.3. Limits to adaptation and associated losses exist at 1.5 of global warming, become more pronounced at higher levels of warming and vary by sector, with site-specific implications for vulnerable regions, ecosystems, and human health (*medium confidence*) {Cross-Chapter Box 12 in Chapter 5, Box 3.5}

C. Emission Pathways and System Transitions Consistent with 1.5°C Global Warming

C1. In pathways with no or limited overshoot of 1.5°C, global CO_2 emissions decline by at least 35% from 2010 levels by 2030, reaching net zero around 2050. For comparison, limiting global warming below 2°C[7] implies CO_2 emissions decline at least 20% by 2030 in most pathways and reach net zero around 2075. Pathways that limit global warming to 1.5°C and those that limit warming to 2°C involve similarly ambitious reductions in non-CO_2 emissions. (*high confidence*) {2.1, 2.3, Figure SPM3a}

C1.1. CO_2 emissions reductions that limit global warming to 1.5°C with no or limited overshoot can involve different portfolios of mitigation measures, striking different balances

[7] References to pathways limiting global warming to 2ºC are based on a 66% probability of staying below 2ºC.

between lowering energy and resource intensity, rate of decarbonization, and the reliance on carbon dioxide removal. Different portfolios face different implementation challenges, and potential synergies and trade-offs with sustainable development. (*high confidence*). {2.3.2, 2.3.4, 2.4, 2.5.3, Figure SPM3b}

C1.2. Pathways that limit global warming to 1.5°C with no or limited overshoot involve deep reductions in emissions of methane and black carbon as well as in most cooling aerosols (35% or more by 2050 relative to 2010). CO_2 mitigation measures can also reduce non-CO_2 emissions, particularly in the energy and transport sectors. Other measures can reduce agricultural nitrous oxide and methane, some sources of black carbon, or hydrofluorocarbons. High bioenergy demand increases emissions of nitrous oxide in some pathways. Improved air quality resulting from reductions in many non-CO2 emissions can provide large, direct, and immediate population health benefits. (*high confidence*). {Figure SPM3a, 2.2.1, 2.3.3, 2.4.4, 2.5.3, 4.3.6, 5.4.2}

C1.3. Revising estimates from AR5, the remaining carbon budget from the beginning of 2018 for a 50% probability of limiting global warming to 1.5°C defined in terms of the increase in global surface air temperature relative to pre-industrial is 580 $GtCO_2$, and 420 $GtCO_2$ for a 66% probability, subject to large uncertainties. If global warming is defined in terms of GMST, which warms slower than global surface air temperature, these remaining carbon budgets would be 770 and 570 $GtCO_2$ respectively[8] (*medium confidence*). {2.2.2, 2.6.1, Table 2.2, Chapter 2 Supplementary Material}

C1.4. From 1876 until the end of 2017 approximately 2200 ± 320 $GtCO_2$ were emitted by human activities. If current anthropogenic CO_2 emissions of 42 ± 3 $GtCO_2$ per year start an immediate and steady decline, staying within the 420-770 $GtCO_2$ remaining carbon budgets quoted above would imply reaching net zero CO_2 emissions in about 20 to 40 years from 2018. (*medium confidence*). {2.2.2, Table 2.2, Figure SPM1, Supplementary Material Chapter 2}

C1.5. The relative importance for remaining carbon budgets of both uncertainties and choices regarding non-CO_2 mitigation increases as global warming thresholds are approached. Uncertainties comprise the possible variation in climate response (±400 $GtCO_2$), the level of historic warming (±250 $GtCO_2$), and the role of future permafrost thawing and potential methane release from wetlands (reducing budgets by up to 100 $GtCO_2$ over the course of this century and more thereafter). Choices regarding non-CO_2 mitigation could alter the remaining carbon budget by 250 $GtCO_2$ in either direction. (*medium confidence*). {2.2.2, 2.6.1, Table 2.2, Supplementary Material Chapter 2}

C1.6. Solar radiation modification (SRM) measures are not included in any of the available assessed pathways. Although some SRM measures may be theoretically effective in reducing an overshoot, they face large uncertainties and knowledge gaps as well as substantial risks, institutional and social constraints to deployment related to governance, ethics, and impacts on sustainable development. They also do not mitigate ocean acidification. (*medium confidence*). {4.3.8, Cross-Chapter Box 10 in Chapter 4}

[8] Irrespective of the definition of global warming used, improved understanding has led to an increase in the estimated remaining carbon budget of about 300 GtCO2 compared to AR5. Roughly two thirds of this increase is due to using an improved estimate of historical warming within the carbon budget assessment, and about one third arises from using non-CO_2 emission pathways consistent with mitigation efforts aiming to limit warming to well below 2°C.

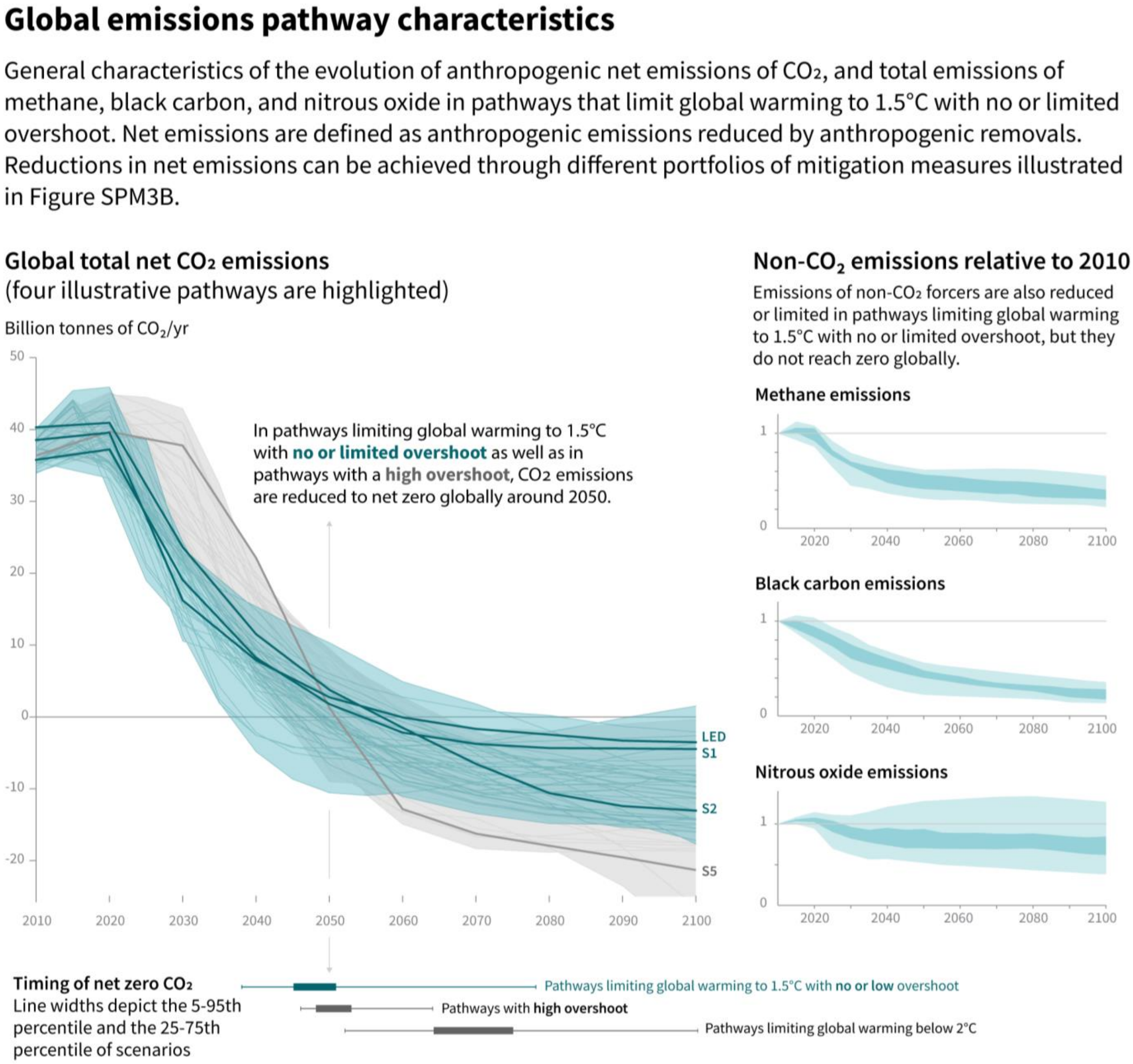
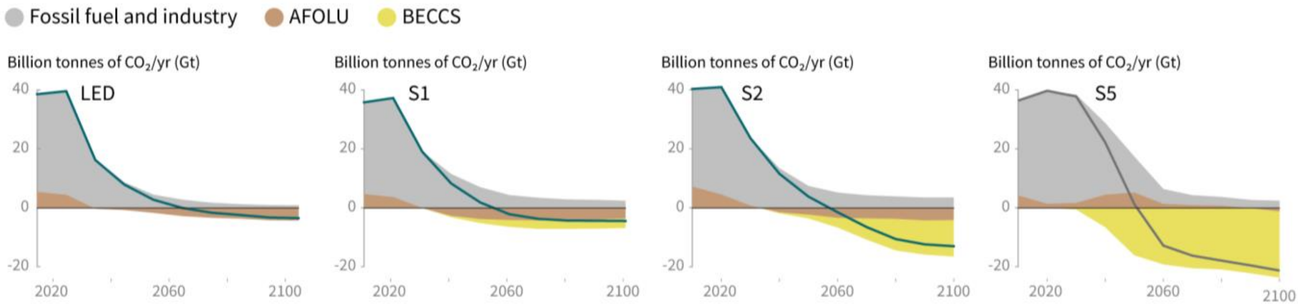


Figure SPM.3a: Global emissions characteristics of pathways. Four illustrative pathways are highlighted and labelled with LED, S1, S2, and S5 in the main panel. Descriptions and characteristics of these pathways are available in Figure SPM3b. Global net anthropogenic CO2 emissions in pathways limiting global warming to 1.5°C with no or limited overshoot and pathways with higher overshoot. Non-CO2 emissions ranges in the inset show the 5–95% (light shading) and interquartile (dark shading) ranges of pathways limiting global warming to 1.5°C with no or limited overshoot. Box and whiskers in the bottom panel show the timing of pathways reaching global net zero CO_2 emission levels, and a comparison with pathways limiting global warming to 2°C with at least 66% probability. {2.1, 2.2, 2.3, Figure 2.5, Figure 2.10, Figure 2.11}

Characteristics of four illustrative pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limit global warming to 1.5°C with no or limited overshoot. For example, the amount of Carbon Dioxide Removal (CDR) varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for the emissions and several other pathway characteristics.

Breakdown of contributions to global net CO_2 emissions in four illustrative pathways



LED: A scenario in which social, business, and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A down-sized energy system enables rapid decarbonisation of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

S1: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

S2: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

S5: A resource and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

	LED	S1	S2	S5
Estimated overshoot of 1.5°C	No or less than 0.1°C	No or less than 0.1°C	Less than 0.1°C	Larger than 0.2°C
Kyoto-GHG emissions in 2030	24 $GtCO_2eq/yr$	25 $GtCO_2eq/yr$	33 $GtCO_2eq/yr$	47 $GtCO_2eq/yr$
Kyoto-GHG emissions in 2050	9 $GtCO_2eq/yr$	7 $GtCO_2eq/yr$	11 $GtCO_2eq/yr$	10 $GtCO_2eq/yr$
CO_2 emission change in 2030	-58 % rel to 2010	-49 % rel to 2010	-41 % rel to 2010	4 % rel to 2010
Final energy demand in 2030	309 EJ/yr	325 EJ/yr	424 EJ/yr	494 EJ/yr
Final energy demand in 2050	245 EJ/yr	349 EJ/yr	438 EJ/yr	512 EJ/yr
Renewable share of electricity in 2030	60 %	58 %	48 %	25 %
Renewable share of electricity in 2050	77 %	81 %	63 %	70 %
Primary energy from coal in 2030	-78 % rel to 2010	-61 % rel to 2010	-75 % rel to 2010	-59 % rel to 2010
Primary energy from coal in 2050	-97 % rel to 2010	-77 % rel to 2010	-73 % rel to 2010	-97 % rel to 2010
Cumulative BECCS until 2100	0 $GtCO_2$	151 $GtCO_2$	414 $GtCO_2$	1191 $GtCO_2$
Cumulative CCS until 2100	0 $GtCO_2$	348 $GtCO_2$	687 $GtCO_2$	1218 $GtCO_2$
Land-use CO_2 emissions in 2050	-1,7 $GtCO_2/yr$	-3,8 $GtCO_2/yr$	-2,3 $GtCO_2/yr$	5,2 $GtCO_2/yr$
Land footprint of bioenergy crops	22 Mha	93 Mha	283 Mha	724 Mha

Figure SPM.3b: Characteristics of four illustrative pathways in relation to global warming of 1.5°C introduced in Figure SPM3a. A breakdown of the global net anthropogenic CO_2 emissions into the contributions in terms of CO_2 emissions from fossil fuel and industry, agriculture, forestry and other land use (AFOLU), and bioenergy with carbon capture and storage (BECCS) for four illustrative pathways that show a range of potential mitigation approaches. Further characteristics for each of these pathways are listed below each pathway. {2.2, 2.3, 2.4, 2.5.3, Figure 2.5, Figure 2.10, Figure 2.11, Figure SPM3a}

C2. Pathways limiting global warming to 1.5ºC would require rapid and far-reaching transitions in energy, land, urban and infrastructure, and industrial systems. These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed, and imply deep emissions reductions in all sectors and a wide portfolio of mitigation options (*high confidence*). {2.3, 2.4, 2.5, 4.2, 4.3, 4.5}

C2.1. Pathways that limit global warming to 1.5°C with no or limited overshoot are qualitatively similar to those for 2°C, but their system changes are more rapid and pronounced over the next two decades (*high confidence*). These rates of change have been observed in the past within specific sectors, technologies and spatial contexts, but there is no documented historic precedent for their scale (*medium confidence*). {2.3.3, 2.3.4, 2.4, 2.5, 4.2.1, 4.2.2, Cross-Chapter Box 11 in Chapter 4}

C2.2. In energy systems, pathways limiting global warming to 1.5°C with no or limited overshoot generally have lower energy demand, faster electrification of energy end use, a higher share of low-carbon energy sources (including renewables, nuclear and fossil fuel with carbon dioxide capture and storage (CCS)) compared to 2°C pathways, particularly before 2050 (*high confidence*). In 1.5°C pathways, renewables are projected to supply 50–65% (interquartile range) of primary energy and 70–85% of electricity (*high confidence*). The political, economic, social and technical feasibility of solar energy, wind energy and electricity storage technologies increased over the past few years (*high confidence*), [(Table SPM.2)] {2.4.1, 2.4.2, figure 2.1, table 2.6, table 2.7, Cross-Chapter Box 6 in Chapter 3, 4.2.1, 4.3.1, 4.3.3, 4.5.2}

C2.3. CO_2 emissions from industry in pathways limiting global warming to 1.5°C with no or limited overshoot are projected to be about 75-90% lower in 2050 relative to 2010, as compared to 50-80% for global warming of 2ºC. Such reductions can be achieved through combinations of new and existing technologies and practices, including electrification, hydrogen, sustainable bio-based feedstocks, product substitution, and carbon capture, utilization and storage (CCUS). These options are technically proven but their large scale deployment limited by economic and institutional constraints. Emissions reductions by energy and process efficiency by themseleves are insufficient for 1.5°C pathways (*high confidence*). [(Table SPM.2)] {2.4.3, 4.2.1, 4.3.4, Table 4.1, Table 4.3, 4.3.4, 4.5.2}

C2.4. The urban and infrastructure system transition consistent with limiting global warming to 1.5°C with no or limited overshoot would imply changes in land and urban planning practices and deeper emissions reductions in transport and buildings compared to pathways that hold global warming below 2°C. Technical measures and options enabling deep emissions reductions include electrification and energy-efficiency. In pathways limiting global warming to 1.5ºC with no or limited overshoot, the electricity share of demand in buildings would be about 55-75% in 2050 compared to 50-70% in 2050 for 2°C global warming. In the transport sector, the share of low-carbon final energy would rise from less than 5% in 2020 to about 35–65% in 2050 compared to 25–45% for 2°C global warming (*medium confidence*). Socio-cultural, institutional and economic barriers may inhibit these options (*high confidence*). [(Table SPM.2)] {2.3.4, 2.4.3, 4.2.1, Table 4.1, 4.3.3, 4.5.2}.

C2.5. Transitions in global and regional land use are found in all pathways limiting global warming to 1.5ºC with no or limited overshoot, but their scale depends on the pursued mitigation portfolio. 50–800 million hectares of pasture and up to 500 million hectares of agricultural land for food and feed crops are converted into 100–700 million hectares of area for energy crops and forests. The change in forest area by 2050 relative to 2010 ranges from 100 million hectares reduction to 1,000 million hectares increase (*medium confidence*). Such transitions would need to be supported by sustainable management of the various demands on land for human settlements and ecosystem services. Options include sustainable intensification of land use practices, ecosystem restoration and changes towards less resource-intensive diets. Such options are often limited by institutional, environmental and socio-cultural barriers, though careful design and implementation could enhance their acceptability (*medium confidence*). [(Table SPM.2)] {2.4.4, 4.3.2, 4.5.2, Cross-Chapter Box 7 in Chapter 3}

C3. All pathways that limit global warming to 1.5°C with limited or no overshoot use carbon dioxide removal (CDR) on the order of 100–1,000 GtCO_2 over the 21st century to compensate for residual emissions and, in most cases, achieve net negative emissions to return global warming to 1.5°C following a peak (*high confidence*). CDR deployment of several hundreds of GtCO_2 is subject to multiple feasibility and sustainability constraints (*high confidence*). Near-term emissions reductions and measures to lower energy and land demand can limit CDR deployment to a few hundred GtCO_2 without reliance on bioenergy with carbon capture and storage (BECCS) (*high confidence*). {2.3, 2.4, 3.6.2, 4.3, 5.4}

C3.1. Existing and potential CDR measures include afforestation and reforestation, land restoration and soil carbon sequestration, BECCS, direct air carbon capture and storage (DACCS), enhanced weathering and ocean alkalinization. These differ widely in terms of maturity, potentials, costs, risks, co-benefits and trade-offs (*high confidence*). To date, only a few published pathways include CDR measures other than afforestation and BECCS. {2.3.4, 3.6.2, 4.3.2, 4.3.7}

C3.2. In pathways limiting global warming to 1.5°C with limited or no overshoot, BECCS deployment ranges from 0-1, 0–8, and 0-16 GtCO_2 yr^{-1} in 2030, 2050, and 2100, respectively, while agriculture, forestry and land-use (AFOLU) related CDR measures remove 0-5, 1 –11, and 1-5 GtCO_2 yr^{-1} in these years (*medium confidence*). The upper end of these deployment ranges by mid-century exceeds the BECCS potential of up to 5 GtCO_2 yr^{-1} and afforestation potential of up to 3.6 GtCO_2 yr^{-1} assessed based on recent literature, indicating that such pathways may be impractical to achieve (*medium confidence*). Some pathways avoid BECCS deployment completely through demand-side measures and greater reliance on AFOLU-related CDR measures (*high confidence*). The use of bioenergy can be as high or even higher when BECCS is excluded compared to when it is included due to its potential for replacing fossil fuels across sectors (*high confidence*) (Figure SPM3) {2.3.3, 2.3.4, 2.4.2, 3.6.2, 4.3.1, 4.2.3, 4.3.2, 4.3.7, 4.4.3, Table 2.4}

C3.3. Pathways that overshoot 1.5°C of global warming rely on CDR exceeding residual CO_2 emissions later in the century to return to below 1.5°C by 2100, with larger overshoots requiring greater amounts of CDR (Figure SPM.3) (*high confidence*). Limitations on the speed, scale, and societal acceptability of CDR deployment hence govern the extent to which global warming can be returned to below 1.5°C following an overshoot. Carbon cycle and climate system understanding is still limited about the effectiveness of CDR to reduce temperatures after they peak (*high confidence*). [(Table SPM.2)] {2.2, 2.3.4, 2.3.5, 2.6, 4.3.7, 4.5.2, Table 4.11}

C3.4. Most current and potential CDR measures could have significant impacts on either land, energy, water, or nutrients if deployed at scale. Afforestation and bioenergy can compete with other land uses and could have significant impacts on agricultural and food systems, biodiversity and other ecosystem services (*high confidence*). Effective governance is needed to limit such trade-offs and ensure permanence of carbon removal in terrestrial, geological and ocean reservoirs (*high confidence*). Feasibility and sustainability of CDR use could be enhanced by a portfolio of options deployed at substantial, but lesser scales, rather than a single option at very large scale (*high confidence*). (Figure SPM3, [Table SPM.2]) {2.3.4, 2.4.4, 2.5.3, 2.6, 3.6.2, 4.3.2, 4.3.7, 4.5.2, 5.4.1, 5.4.2; Cross-Chapter Boxes 7 and 8 in Chapter 3, Table 4.11, Table 5.3, Figure 5.3}

C3.5. Some AFOLU-related CDR measures such as restoration of natural ecosystems and soil carbon sequestration could provide co-benefits such as improved biodiversity, soil quality, and local food security. If deployed at large scale, they would require effective governance to conserve and protect land carbon stocks and other ecosystems services (*medium confidence*). (Figure SPM 4, [Table SPM.2]) {2.3.3, 2.3.4, 2.4.2, 2.4.4, 3.6.2, 5.4.1, Cross-Chapter Boxes 3 in Chapter 1 and 7 in Chapter 3, 4.3.2, 4.3.7, 4.4.1, 4.5.2, Table 2.4}

D. Strengthening the Global Response in the Context of Sustainable Development and Efforts to Eradicate Poverty

D1. The current Nationally Determined Contributions (NDCs) submitted under the Paris Agreement would lead to global greenhouse gas emissions[9] in 2030 of 52–58 $GtCO_2eq\ yr^{-1}$ (*medium confidence)*. This trajectory would not limit global warming to 1.5°C, even if supplemented by very challenging increases in the scale and ambition of emissions reductions after 2030 (*high confidence*). Avoiding overshoot and reliance on future large-scale deployment of carbon dioxide removal (CDR) can only be achieved if global CO_2 emissions start to decline well before 2030 (*high confidence*). {1.2, 2.3, 3.3, 3.4, 4.2, 4.4, Cross-Chapter Box 11 in Chapter 4}

D1.1. Pathways that limit global warming to 1.5°C with no or limited overshoot show clear emission reductions by 2030 (*high confidence*). All but one show a decline in global greenhouse gas emissions to below 35 $GtCO_2eq\ yr^{-1}$ in 2030, and half of available pathways fall within the 25-30 $GtCO_2eq\ yr^{-1}$ range (interquartile range), a 40-50% reduction from 2010 levels. (*high confidence*). The current NDCs are broadly consistent with cost-effective pathways that result in a global warming of about 3°C by 2100, with warming continuing afterwards. (*medium confidence*). {2.3.3, 2.3.5, Cross-Chapter Box 11 in Chapter 4, 5.5.3.2}

D1.2. Overshoot trajectories result in higher impacts and associated challenges compared to pathways that limit global warming to 1.5°C with no or limited overshoot (*high confidence*). Reversing warming after an overshoot of 0.2°C or larger during this century would require upscaling and deployment of CDR at rates and volumes that might not be achievable given considerable implementation challenges (*medium confidence*) {1.3.3, 2.3.4, 2.3.5, 2.5.1, 3.3, 4.3.7, Cross-Chapter Box 8 in Chapter 3, Cross-Chapter Box 11 in Chapter 4}

D1.3. The lower the emissions in 2030, the lower the challenge in limiting global warming to 1.5°C after 2030 with no or limited overshoot (*high confidence*). The challenges from delayed actions to reduce greenhouse gas emissions include the risk of cost escalation, lock-in in carbon-emitting infrastructure, stranded assets, and reduced flexibility in future response options in the medium to long-term (*high confidence*). These may increase uneven distributional impacts between countries at different stages of development (*medium confidence*). {2.3.5, 4.4.5, 5.4.2}

[9] GHG emissions have been aggregated with 100-year GWP values as introduced in the IPCC Second Assessment Report

D2. Adaptation options specific to national contexts, if carefully selected together with enabling conditions, will have benefits for sustainable development and poverty reduction with global warming of 1.5°C (*high confidence*). {1.4, 4.3, 4.5, 5.3}

D2.1. Adaptation options that reduce the vulnerability of agriculture, urban and ecological systems have many synergies with sustainable development, such as ensuring food and water security, reducing disaster risks, improving health, maintaining ecosystem services and reducing poverty and inequality *(high confidence*). Increasing investment in physical and social infrastructure is a key enabling condition to enhance the resilience and the adaptive capacities of societies. These benefits can occur in most regions with adaptation to 1.5°C of global warming *(high confidence).* {1.4.3, 4.2.2, 4.3.1, 4.3.2, 4.3.3, 4.3.5, 4.4.1, 4.4.3, 4.5.3, 5.3.1, 5.3.2}

D2.2. Adaptation to 1.5°C global warming can also result in trade–offs with adverse impacts for sustainable development if poorly designed and implemented. For example, adaptation projects that intensify agriculture or expand urban infrastructure can increase greenhouse gas emissions and water use, increase gender and social inequality, undermine health, and encroach on natural ecosystems *(high confidence)*. These trade-offs can be minimized by adaptation planning that includes attention to poverty and sustainable development implications. (*high confidence*) {4.3.2, 4.3.3, 4.5.4, 5.3.2; Cross-Chapter Boxes 6 and 7 in Chapter 3}

D2.3. A mix of adaptation and mitigation options to limit global warming to 1.5°C, implemented in a participatory and integrated manner, can enable rapid, systemic transitions in urban and rural areas (*high confidence*). These are most effective when aligned with economic and sustainable development, and when local and regional governments are supported by national governments (*medium confidence*) {4.3.2, 4.3.3, 4.4.1, 4.4.2}

D2.4. Adaptation options that also mitigate emissions can provide synergies and cost savings in most sectors and system transitions, such as when land management reduces emissions and disaster risk, or when low carbon buildings are also designed for efficient cooling. Trade-offs between mitigation and adaptation, when limiting global warming to 1.5°C, such as when bioenergy crops or reforestation encroach on land needed for agricultural adaptation, can undermine food security, livelihoods, ecosystem function and other aspects of sustainable development. (*high confidence*) {3.4.3, 4.3.2, 4.3.4, 4.4.1, 4.5.2, 4.5.3, 4.5.4}

D3. Mitigation options consistent with 1.5°C pathways are associated with multiple synergies and trade-offs across the Sustainable Development Goals (SDGs). While the total number of possible synergies exceeds the number of trade-offs, their net effect will depend on the pace and magnitude of changes, the composition of the mitigation portfolio and the management of the transition. *(high confidence*) (SPM Figure 4) {2.5, 4.5, 5.4}

D3.1. 1.5°C pathways have robust synergies particularly for the SDGs 3 (health), 7 (clean energy), 11 (cities and communities), 12 (responsible consumption and production), and 14 (oceans) (*very high confidence*). Some 1.5°C pathways show potential trade-offs with mitigation for SDGs 1 (poverty), 2 (hunger), 6 (water), and 7 (energy access), if not carefully managed (*high confidence*) (Figure SPM4). {5.4.2; Figure 5.4, Cross-Chapter Boxes 7 and 8 in Chapter 3}

D3.2. 1.5°C pathways that include low energy demand (for example the illustrative LED pathway in Figure SPM3a and b), low material consumption, and low GHG-intensive food consumption have the most pronounced synergies and the lowest number of trade-offs with respect to sustainable development and the SDGs (*high confidence*). Such pathways would reduce dependence on carbon dioxide removal (CDR) (*high confidence*). (Figure SPM4, Figure SPM3) {2.4.3, 2.5.1, 2.5.3, Figure 2.4, Figure 2.28, 5.4.1, 5.4.2, Figure 5.4}

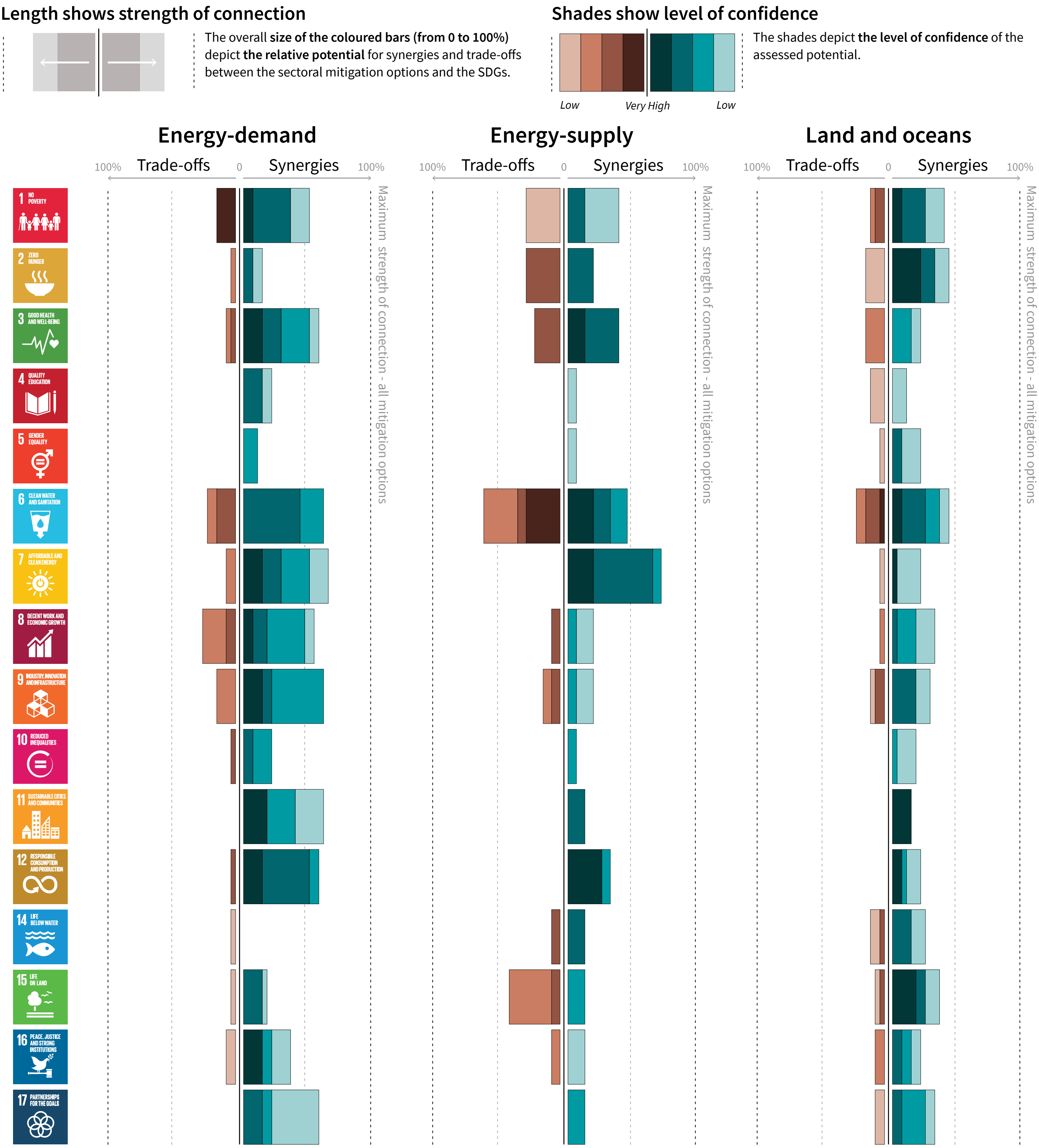
D3.3. The impacts of land-based CDR and other land-intensive mitigation options on SDGs depend on the type of options and the scale of deployment (*high confidence*). If poorly implemented, options such as BECCS, bioenergy and AFOLU would lead to trade-offs. Context-relevant design and implementation requires considering people's needs, biodiversity, and other sustainable development dimensions (*very high confidence*). {4.3.7, 5.4.1.3, Cross-Chapter Box 7 in Chapter 3}

D3.4. Mitigation consistent with 1.5°C pathways creates risks for sustainable development in regions with high dependency on fossil fuels for revenue and employment generation (*high confidence*). Policies that promote diversification of the economy and the energy sector can address the associated challenges (*high confidence*). {5.4.1.2, Box 5.2}

D3.5. Redistributive policies across sectors and populations that shield the poor and vulnerable can resolve trade-offs for a range of SDGs, particularly hunger, poverty and energy access. Investment needs for such complementary policies are only a small fraction of the overall mitigation investments in 1.5°C pathways. (*high confidence*) {2.4.3, 5.4.2, Figure 5.5}

Possible synergies and trade-offs of climate change mitigation with the SDGs

Mitigation options deployed in each sector can be associated with potential synergies or trade-offs with the Sustainable Development Goals (SDGs). The degree to which this potential is realized will depend on the selected portfolio of mitigation options, mitigation policy design, and local circumstances and context. Particularly in the energy-demand sector, the potential for synergies is larger than for trade-offs. The bars group individually assessed options by level of confidence and take into account the relative strength of the assessed mitigation-SDG connections.



[1]**SDG1:** No Poverty, **SDG2:** Zero Hunger, **SDG3:** Good Health and Well-being, **SDG4:** Quality Education, **SDG5:** Gender Equality, **SDG6:** Clean Water and Sanitation, **SDG7:** Affordable and Clean Energy, **SDG8:** Decent Work and Economic Growth, **SDG9:** Industry, Innovation and Infrastructure, **SDG10:** Reduced Inequality, **SDG11:** Sustainable Cities and Communities, **SDG12:** Responsible Consumption and Production, **SDG13:** Climate action is not included because we are considering how mitigation is interacting with SDGs and not vice versa **SDG14:** Life Below Water, **SDG15:** Life on Land, **SDG16:** Peace and Justice Strong Institutions, **SDG17:** Partnerships to achieve the Goal

Data source: Special Report on Global Warming of 1.5°C

Figure SPM.4: Potential synergies and trade-offs between the sectoral portfolio of climate change mitigation options and the Sustainable Development Goals (SDGs). The strength of the sectoral interactions is based on the assessment of individual mitigation options listed in Table 5.2, which assesses for each option the strength and direction of the interaction (synergy or trade-off) as well as the confidence of the underlying literature (shades of green and red). The effect of the individual options is aggregated to represent the total sectoral potential. A potential of 100% depicts a hypothetical case where the interaction of mitigation options in a sector and a specific SDG show maximum strength for all options assessed. The areas above the bars, which indicate no interactions, have *low confidence* due to the uncertainty and limited number of studies exploring indirect effects. The strength of the connection considers only the effect of mitigation and does not include benefits of avoided impacts. SDG 13 (climate action) is not listed because mitigation is being considered in terms of interactions with SDGs and not vice versa. Other approaches assessed in the ocean sector that remove CO_2 from the atmosphere include alkalinization and iron fertilization. {5.4, Table 5.2, Figure 5.2}

D4. Limiting the risks from global warming of 1.5°C in the context of sustainable development and poverty eradication implies system transitions that can be enabled by an increase of adaptation and mitigation investments, policy instruments, the acceleration of technological innovation and behaviour changes (*high confidence*). {2.3, 2.4, 2.5, 3.2, 4.2, 4.4, 4.5, 5.2, 5.5, 5.6}

D4.1. The redirection of world savings towards investment in infrastructure for mitigation and adaptation could provide additional resources. Redirected finance could involve the mobilization of private funds by institutional investors, asset managers and development or investment banks, as well as the application of public funds. Government policies that de-risk low-emission and adaptation investments can facilitate the mobilization of private funds and enhance the effectiveness of other public policies. (*high confidence*) {2.5.2, 4.4.5}

D4.2. Adaptation finance consistent with global warming of 1.5°C is difficult to quantify and compare with 2°C. Knowledge gaps include insufficient data to calculate specific climate resilience-enhancing investments, from the provision of currently underinvested basic infrastructure. Estimates of the costs of adaptation might be lower at global warming of 1.5°C than for 2°C, but would be higher than the USD 22.5 billion (2014) estimates of bilateral and multilateral funding for climate change adaptation (*medium confidence*). Currently, 18–25% of climate finance flows to adaptation in developing countries (*high confidence*) {4.4.5, 4.6}

D4.3. Pathways limiting global warming to 1.5°C with no or limited overshoot involve the redistribution of global investments in infrastructure. Average annual investment in low-carbon energy technologies and energy efficiency roughly doubles while investments in fossil fuel extraction and conversion decrease by about a quarter over the next two decades (*medium confidence*). Additional investment in infrastructure (energy, transportation, buildings, water and sanitation) would be required. Between 2015 and 2035, this investment is estimated to be on average 2.5% of annual economy-wide investment (0.6% of global GDP) (*medium confidence*). {2.5.2, 4.4.5, Box 4.8}

D4.4. Policy packages can help mobilise incremental resources and redirect global world savings through flexible mechanisms that integrate explicit carbon pricing, technology policies, performance standards, reduction of fossil fuel subsidies, de-risking of investments through innovative financial instruments, performance standards, other pricing policies (land, real estates) and compensating transfers to secure the equity of the transition. 1.5°C pathways show an average discounted global cost for the last ton of emissions reductions that is 3-4 times higher than in 2°C pathways across models. (*high confidence*) {1.3.3, 2.3.4, 2.3.5, 2.5.1, Cross-Chapter Box 8 in Chapter 3 and 11 in Chapter 4, 2.5.1, 2.5.2, 4.4.5, 5.5.2}

D4.5. The systems transitions consistent with adapting to and limiting global warming to 1.5°C include the widespread adoption of new and possibly disruptive technologies and practices and enhanced climate-driven innovation. These imply enhanced technological innovation capabilities, including in industry and finance. Both national innovation policies and international cooperation can contribute to the development, commercialization and widespread adoption of mitigation and adaptation technologies. Innovation policies can be more effective when they combine support for research and development with incentives for market uptake in policy mixes. (*high confidence*) {4.4.4, 4.4.5}.

D4.6. Education, information, and community approaches, including those that are informed by Indigenous knowledge and local knowledge, can accelerate the wide scale behaviour changes consistent with adapting to and limiting global warming to 1.5°C. These approaches are more effective when combined with other policies and tailored to the motivations, capabilities, and resources of specific actors and contexts (*high confidence*). Public acceptability can enable or inhibit the implementation of policies and measures to limit global warming to 1.5°C and to adapt to the consequences. Public acceptability depends on the individual's evaluation of expected policy consequences, the perceived fairness of the distribution of these consequences, and perceived fairness of decision procedures (*high confidence*). {1.1, 1.5, 4.3.5, 4.4.1, 4.4.3, Box 4.3, 5.5.3, 5.6.5}

D5. Sustainable development supports, and often enables, the fundamental societal and systems transitions and transformations that help limit global warming to 1.5°C. Such changes facilitate the pursuit of climate-resilient development pathways that achieve ambitious mitigation and adaptation in conjunction with poverty eradication and efforts to reduce inequalities *(high confidence)*. {Box 1.1, 1.4.3, Figure 5.1, 5.5.3, Box 5.3}

D5.1. Social justice and equity are core aspects of climate-resilient development pathways that aim to limit global warming to 1.5°C as they address challenges and inevitable trade-offs, widen opportunities, and ensure that options, visions, and values are deliberated, between and within countries and communities, without making the poor and disadvantaged worse off (*high confidence*). {5.5.2, 5.5.3, Box 5.3, Figure 5.1, Figure 5.6, Cross-chapter Boxes 12 and 13 in Chapter 5}

D5.2. The potential for climate-resilient development pathways differs between and within regions and nations, due to different development contexts and starting points (*very high confidence*). Efforts along such pathways to date have been limited (medium confidence) and would require strengthened contributions from all countries and non-state actors without delay (*high confidence*). {5.5.1, 5.5.3, Figure 5.1}

D5.3. Pathways that are consistent with sustainable development show less mitigation and adaptation challenges and are associated with lower mitigation costs. The large majority of modelling studies could not construct pathways characterized by lack of cooperation, inequality and poverty that were able to limit global warming to 1.5°C. (*high confidence*) {2.3.1, 2.5.3, 5.5.2}

D6. Strengthening the capacities for climate action of national and sub-national authorities, civil society, the private sector, indigenous peoples and local communities can support the implementation of ambitious actions implied by limiting global warming to 1.5°C (*high confidence*). International cooperation can provide an enabling environment for this to be achieved in all countries and for all people, in the context of sustainable development (*high confidence*) {1.4, 2.3, 2.5, 4.2, 4.4, 4.5, 5.3, 5.4, 5.5, 5.6, 5, Box 4.1, Box 4.2, Box 4.7, Box 5.3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 13 in Chapter 5}

D6.1. Partnerships involving non-state public and private actors, institutional investors, the banking system, civil society and scientific institutions would facilitate actions and responses consistent with limiting global warming to 1.5°C (*very high confidence*). {1.4, 4.4.1, 4.2.2, 4.4.3, 4.4.5, 4.5.3, 5.4.1, 5.6.2, Box 5.3}.

D6.2. Cooperation on strengthened multilevel governance, coordinated sectoral and cross-sectoral policies, gender responsive policies, innovative financing and cooperation on technology development and transfer can ensure participation, transparency, capacity building, and learning among different players (*high confidence*). {2.5.2, 4.2.2, 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.5.3, Cross-Chapter Box 9 in Chapter 4, 5.3.1, 4.4.5, 5.5.3, Cross-Chapter Box 13 in Chapter 5, 5.6.1, 5.6.3}

D6.3. International cooperation can support the implementation of 1.5°C-consistent climate responses in developing countries and vulnerable regions, by enabling access to finance and technology and enhancing capacities that can complement domestic resources (*high confidence*). {2.3.1, 4.4.1, 4.4.2, 4.4.4, 4.4.5, 5.4.1 5.5.3, 5.6.1, Box 4.1, Box 4.2, Box 4.7}.

D6.4. Collective efforts in the pursuit of limiting global warming to 1.5ºC can facilitate strengthening the global response to climate change, achieving sustainable development and eradicating poverty *(high confidence).* {1.4.2, 2.3.1, 2.5.2, 4.2.2, 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5, 4.5.3, 5.3.1, 5.4.1, 5.5.3, 5.6.1, 5.6.2, 5.6.3}

Box SPM 1: Core Concepts Central to this Special Report

Global mean surface temperature (GMST): Estimated global average of near-surface air temperatures over land and sea-ice, and sea surface temperatures over ice-free ocean regions, normally expressed as departures from a specified reference period. Projected future changes in GMST are approximated by changes in global surface air temperature.[10] {1.2.1.1}

Pre-industrial: The multi-century period prior to the onset of large-scale industrial activity around 1750. The reference period 1850–1900 is used to approximate pre-industrial GMST. {1.2.1.2}

Global warming: The estimated increase in GMST averaged over a 30-year period, or the 30-year period centered on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current warming trend is assumed to continue. {1.2.1}

Net zero CO_2 emissions: Conditions in which anthropogenic carbon dioxide (CO_2) emissions are approximately balanced globally by anthropogenic CO_2 removals.

Carbon dioxide removal (CDR): Anthropogenic activities removing CO_2 from the atmosphere and transferring it to geological, terrestrial, product or ocean storage. It includes anthropogenic enhancement of biological or geochemical sinks and direct chemical air capture and storage, but excludes natural CO_2 sinks.

Remaining carbon budget: Cumulative net global anthropogenic CO_2 emissions from the start of 2018 to the time that anthropogenic CO_2 emissions reach net zero that would result, at some probability, in limiting global warming to a given level, accounting for the impact of other anthropogenic emissions. The total carbon budget is the sum of historical CO_2 emissions and the remaining carbon budget. {2.2.2}

Temperature overshoot: The temporary exceedance of a specified level of global warming, returning to that level before 2100 through CDR and/or reductions in emissions of other greenhouse gases. {1.2.3, 1.2.3.2}

Pathway: The trajectory of natural and/or human systems towards a future state. Emission pathways are classified by their temperature trajectory over the 21st century: pathways giving at least 50% probability based on current knowledge of limiting global warming to below 1.5°C are classified as 'no overshoot'; those limiting warming to below 1.6°C and returning to 1.5°C by 2100 are classified as '1.5°C limited-overshoot'; while those exceeding 1.6°C but still returning to 1.5°C by 2100 are classified as 'higher-overshoot'.

Impacts: Effects of climate change, such as warming, sea level rise or changes in the frequency and intensity of heat waves or precipitation events, on human and natural systems. Impacts can have beneficial or adverse outcomes for livelihoods, health and well-being, ecosystems and species, services, infrastructure, and economic, social and cultural assets.

Risk: The potential for adverse consequences from a climate-related hazard for human and natural systems, resulting from the interactions between the hazard and the vulnerability and exposure of the affected system. Risk integrates the likelihood of exposure to a hazard and the

[10] Past IPCC reports, reflecting the literature, have used a variety of global mean surface temperature metrics for observed warming, temperature projections, impacts and carbon budgets calculations both within and across Working Group reports.

magnitude of its impact. Risk also can describe the potential for adverse consequences of adaptation or mitigation responses to climate change.

Climate-resilient development pathways (CRDPs): Trajectories that strengthen sustainable development and efforts to eradicate poverty through equitable societal transformations across all scales and economies, while reducing the threat of climate change through ambitious mitigation, adaptation, and climate resilience {1.4.3, Cross-Chapter Box 1 in Chapter 1, 5.1, Figure 5.1, 5.5.3}

[Table SPM.1: Adaptation feasibility table. Feasibility assessment of examples of adaptation options relevant to 1.5°C of global warming with dark shading signifying the absence of barriers in the feasibility dimension, moderate shading that the dimension does not have a positive or negative effect on the feasibility of the option, and light shading the presence of potentially blocking barriers. No shading means that not sufficient literature could be found to make the assessment. {Table 4.12}]

	Adaptation option	**Confidence**	**Economic**	**Technological**	**Institutional**	**Socio-cultural**	**Environmental-ecological**	**Geophysical**	**Context**
Land and Ecosystem Transitions	Conservation agriculture	Medium							Depends on irrigated/rain-fed system, ecosystem characteristics, crop type, other farming practices
	Efficient irrigation	Medium							Depends on agricultural system, technology used, regional institutional and biophysical context
	Efficient livestock systems	Medium							Dependent on livestock breeds, feed practices, and biophysical context (e.g. carrying capacity)
	Community-based adaptation	Medium							Focus on rural areas and combined with ecosystems-based adaptation, does not include urban settings
	Ecosystem restoration & avoided deforestation	High							Mostly focused on existing and evaluated Reducing Emissions from Deforestation and Forest Degradation (REDD+) projects
	Coastal defence & hardening	High							Depends on locations that require it as a first adaptation option
Urban and Infrastructure System Transitions	Sustainable land-use & urban planning	Medium							Depends on nature of planning systems and enforcement mechanisms
	Sustainable water management	High							Balancing sustainable water supply and rising demand especially
	Green infrastructure & ecosystem services	High							Depends on reconciliation of urban development with green infrastructure

[Table SPM.2: Feasibility assessment of examples of mitigation options relevant to 1.5°C global warming and illustrative pathways in Figure SPM3a and b. Dark shading signifies the absence of barriers in the feasibility dimension, moderate shading that on average, the dimension does not have a positive or negative effect on the feasibility of the option, and faint shading the presence of potentially blocking barriers. No shading means that not sufficient literature could be found to make the assessment. Evidence and agreement assessment is undertaken at the option level. The context column on the far right indicates how the assessment might change as a consequence of contextual factors. {Table 4.11}]

	Mitigation Option	**Confidence**	**Economic**	**Technological**	**Institutional**	**Socio-cultural**	**Environmental-ecological**	**Geophysical**	**Context**
Energy System Transitions	Solar PV	High							Cost-effectiveness affected by solar irradiation and incentive regime. Also enhanced by legal framework for independent power producers, which affects uptake.
	Power sector CCS	High							Varies with local CO_2 storage capacity, presence of legal framework, level of development and quality of public engagement
Land and Ecosystem Transitions	Ecosystems restoration	High							Depends on location and institutional factors
Urban and Infrastructure System Transitions	Electric cars and buses	Medium							Varies with degree of government intervention; requires capacity to retrofit ‘fuelling’ stations
	Non-motorized transport	High							Viability rests on linkages with public transport, cultural factors, climate and geography
	Low/zero-energy buildings	High							Depends on size of existing building stock and growth of building stock
Industrial System Transitions	Energy efficiency	High							Potential and adoption depend on existing efficiency, energy prices and interest rates, as well as government incentives.
	Industrial CCUS	High							High concentration of CO_2 in exhaust gas improve economic and technical feasibility of CCUS in industry. CO_2 storage or reuse possibilities.
Carbon Dioxide Removal	BECCS	Medium							Depends on biomass availability, CO_2 storage capacity, legal framework, economic status and social acceptance
	Afforestation & reforestation	High							Depends on location, mode of implementation, and economic and institutional factors