CLIMATE CHANGE 2014

SYNTHESIS REPORT

FINAL DRAFT
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This report will be dedicated to the memory of Stephen H. Schneider 1945 - 2010

Contents

Summary for Policy Makers

Introduction

This Synthesis Report is based on the reports of the three Working Groups of the Intergovernmental Panel on Climate Change (IPCC), including relevant Special Reports. It provides an integrated view of climate change as the final part of the IPCC's Fifth Assessment Report (AR5).

This summary follows the structure of this report, which contains the following topics: Observed changes and their causes; Future climate change, risks and impacts; Transformations and changes in systems; Adaptation and mitigation measures. The report also contains a Box on Information relevant to Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC).

In the Synthesis Report, the certainty in key assessment findings is communicated as in the Working Group and Special Reports. It is based on the author teams' evaluations of underlying scientific understanding and is expressed as a qualitative level of confidence (from very low to very high) and, when possible, probabilistically with a quantified likelihood (from exceptionally unlikely to virtually certain)[1]. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers.

1. Observed Changes and their Causes

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. The climate changes that have already occurred have had widespread and consequential impacts on human and natural systems. *{1}*

1.1 Observed changes in the climate system

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen. *{1.2}*

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, where such assessment is possible, the period from 1983 to 2012 was *likely* the warmest 30-year period of the last 1400 years (*medium confidence*). The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06] °C[2] over the period 1880 to 2012, for which several independently produced datasets exist (Figure SPM.1). *{1.2.1, Figure 1.1}*

In addition to robust multi-decadal warming, the globally averaged surface temperature exhibits substantial decadal and interannual variability (Figure SPM.1). Due to this natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over the past 15 years (1998–2012; 0.05 [–0.05 to 0.15] °C per decade), which begins with a strong El Niño, is smaller than the rate calculated since 1951 (1951–2012; 0.12

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[1] Each finding is grounded in an evaluation of underlying evidence and agreement. In many cases, a synthesis of evidence and agreement supports an assignment of confidence. The summary terms for evidence are: limited, medium, or robust. For agreement, they are low, medium, or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high, and very high, and typeset in italics, e.g., medium confidence. 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 % and extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., very likely (see Guidance Note on Uncertainties, 2010, IPCC for more details).

[2] Ranges in square brackets are expected to have a 90% likelihood of including the value that is being estimated, unless otherwise stated.

[0.08 to 0.14] °C per decade). *{1.2.1, Box 1.1}*
Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*). It is *virtually certain* that the upper ocean (0−700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971. *{1.2.2, Figure 1.2}*

Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (*medium confidence* before and *high confidence* after 1951). For other latitudes area-averaged long-term positive or negative trends have *low confidence*. Observations of changes in ocean surface salinity also provide indirect evidence for changes in the global water cycle over the ocean. It is *very likely* that regions of high salinity, where evaporation dominates, have become more saline, while regions of low salinity, where precipitation dominates, have become fresher since the 1950s. *{1.2.1, 1.2.2}*

Oceanic uptake of anthropogenic CO_2 results in gradual acidification of the ocean; the pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era (*high confidence*). *{1.2.2, Figure 1.2}*

Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent (*high confidence*). There is *high confidence* that there are strong regional differences in Antarctic sea ice area, with a *very likely* increase in total area. There is *high confidence* that permafrost temperatures have increased in most regions since the early 1980s in response to increased air temperature and changing snow cover. *{1.2.3, 1.4.2, Figure 1.1}*

Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m. The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*) (Figure SPM.1). *{1.2.4, Figure 1.1}*

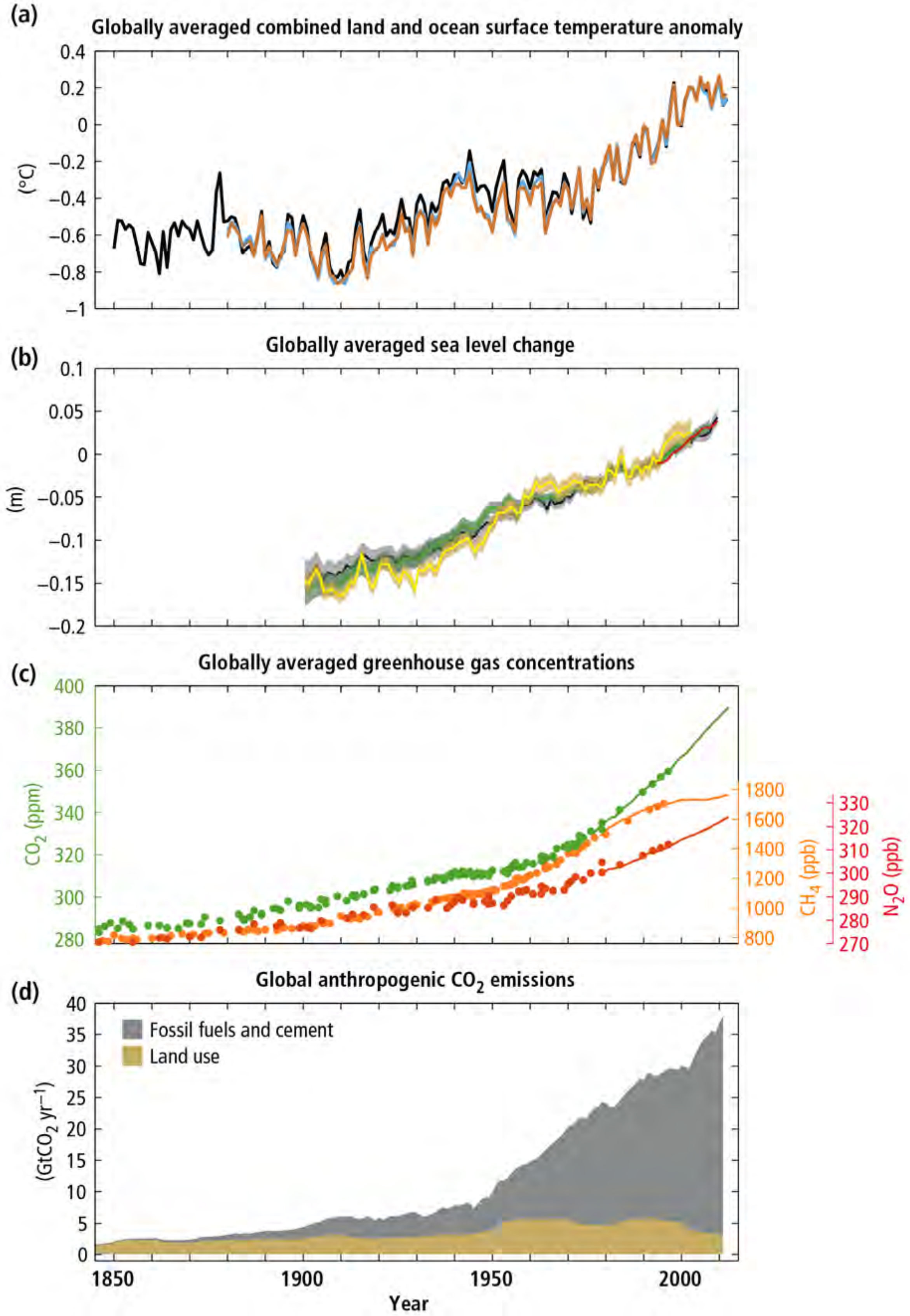


Figure SPM.1: Observed indicators of a changing global climate. (a) Annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1986 to 2005. Colours indicate different data sets. (b) Annually and globally averaged sea level change relative to the average over the period 1986 to 2005 in the longest-running dataset. Colours indicate different data sets. All datasets are aligned to have the same value in 1993, the first year of satellite altimetry data (red). Where assessed, uncertainties are indicated by coloured shading. (c) Atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) determined from ice core data (dots) and from direct atmospheric measurements (lines). (d) Global anthropogenic CO_2

emissions from land use change as well as from burning of fossil fuel and from cement production. *{Figures 1.1, 1.3, 1.5}*

1.2 Causes of Climate Change

Anthropogenic greenhouse gas emissions have increased since the preindustrial era driven largely by economic and population growth. From 2000 to 2010 emissions were the highest in history. Historical emissions have driven atmospheric concentrations of CO_2, CH_4 and N_2O, to levels that are unprecedented in at least the last 800,000 years, leading to an uptake of energy by the climate system. Human influence has been detected in all components of the climate system and is *extremely likely* to have been the dominant cause of the observed warming since the mid-20th century. *{1.3, 1.4.1}*

Anthropogenic greenhouse gas emissions since the preindustrial era have driven large increases in the atmospheric concentrations of CO_2, CH_4 and N_2O (Figure SPM.1). Between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere were 2040 ± 310 $GtCO_2$. About 40% of these emissions have remained in the atmosphere (880 ± 35 $GtCO_2$); the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean. About half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years ***(high confidence)*** (Figure SPM.1). *{1.3.1, 1.3.2}*

Anthropogenic greenhouse gas emissions have continued to increase over 1970 to 2010 with larger absolute increases between 2000 and 2010, despite a growing number of climate change mitigation policies. Emissions in 2010 have reached 49 (±4.5) $GtCO_2yr^{-1}$. Emissions of CO_2 from fossil fuel combustion and industrial processes contributed about 78% of the total greenhouse gas emissions increase from 1970 to 2010, with a similar percentage contribution for the increase during the period 2000–2010 (Figure SPM.2). Globally, economic and population growth remained the most important human drivers of CO_2 emissions from fossil fuel combustion, but the contribution of economic growth has risen sharply between 2000 and 2010. Increased use of coal has reversed the long-standing trend of gradual decarbonization of the world's energy supply *(high confidence). {1.3.2}*

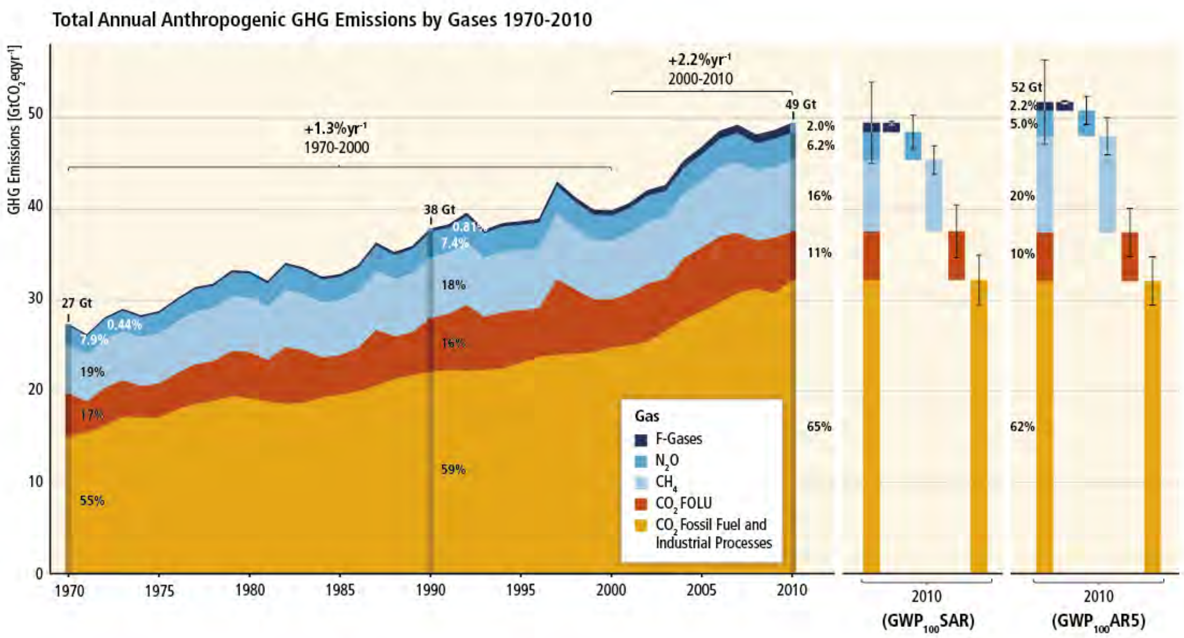


Figure SPM.2: Total annual anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO_2 equivalent per year, $GtCO_2eq/yr$)[3] for the period 1970 to 2010 by gases: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (N_2O); fluorinated gases covered under the Kyoto Protocol (F-gases). Right hand side shows 2010 emissions, using alternatively CO_2 equivalent emission weightings based on AR5 rather than SAR values. CO_2 equivalent emissions include the basket of Kyoto gases (CO_2, CH_4, N_2O as

[3] GHG emissions are quantified as CO_2-equivalent emissions using weightings based on the 100 year Global Warming Potentials, using IPCC SAR values unless otherwise stated *{Box 3.2}*.

well as F-gases) calculated based on 100-year Global Warming Potential (GWP_{100}) values form the Second Assessment Report (SAR), whereas, CO_2 equivalent concentrations are for all anthropogenic radiative forcings, including the cooling effects of aerosols. CO_2-eq is used as shorthand notation in both cases. Using the most recent 100 year Global Warming Potential values would results in higher total annual greenhouse gas emissions (52 $GtCO_2$eq.yr-1) from an increased contribution of methane, but does not change the long-term trend significantly. *{Figure 1.5}.*

The anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings such as aerosols and surface reflectance changes together have *extremely likely* caused more than half of the observed increase in global average surface temperature from 1951 to 2010 (Figure SPM.3). Anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century over every continental region except Antarctica[4]. Anthropogenic influences have *likely* affected the global water cycle since 1960 and contributed to the retreat of glaciers since the 1960s and to the increased surface mass loss of the Greenland ice sheet since 1993. Anthropogenic influences have *very likely* contributed to Arctic sea ice loss since 1979 and have *very likely* made a substantial contribution to increases in global upper ocean heat content (0–700 m) and to global mean sea level rise observed since the 1970s. *{1.4.1}*

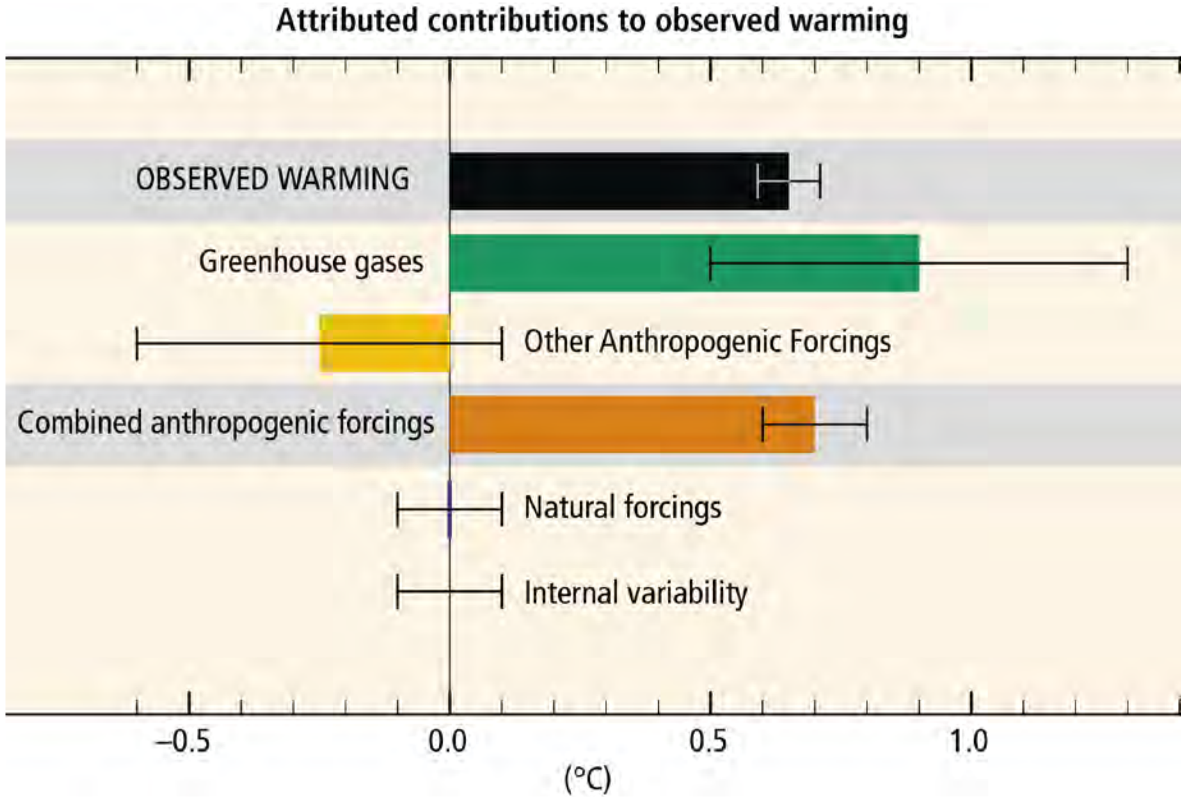


Figure SPM.3: Assessed *likely* ranges (whiskers) and their mid-points (bars) for warming trends over the 1951–2010 period from well-mixed greenhouse gases, other anthropogenic forcings, combined anthropogenic forcings, natural forcings, and internal climate variability (which is the element of climate variability that arises spontaneously within the climate system even in the absence of forcings). The observed warming is shown in black, with the 5–95% uncertainty range due to observational uncertainty. The attributed warming ranges (colours) are based on observations combined with climate model simulations, in order to estimate the contribution of an individual external forcing to the observed warming. The contribution from the combined anthropogenic forcings can be estimated with less uncertainty than the contributions from greenhouse gases and from other anthropogenic forcings separately. This is because these two contributions partially compensate, resulting in a combined signal that is better constrained by observations. *{Figure 1.9}.*

[4] For Antarctica, large observational uncertainties result in *low confidence* that anthropogenic forcings have contributed to the observed warming averaged over available stations.

1.3 Impacts of Climate Change

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate. *{1.4.2}*

Evidence of observed climate-change impacts is strongest and most comprehensive for natural systems. In many regions, changing precipitation or melting snow and ice are altering hydrological systems, which affects water resources in terms of quantity and quality (*medium confidence*). Many terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change (*high confidence*). Some impacts of ocean acidification on marine organisms have been attributed to human influence (*medium confidence*). Some impacts on human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguishable from other influences (Figure SPM.4). Assessment of many studies covering a wide range of regions and crops shows that negative impacts of climate change on crop yields have been more common than positive impacts (*high confidence*).*{1.4.2}*

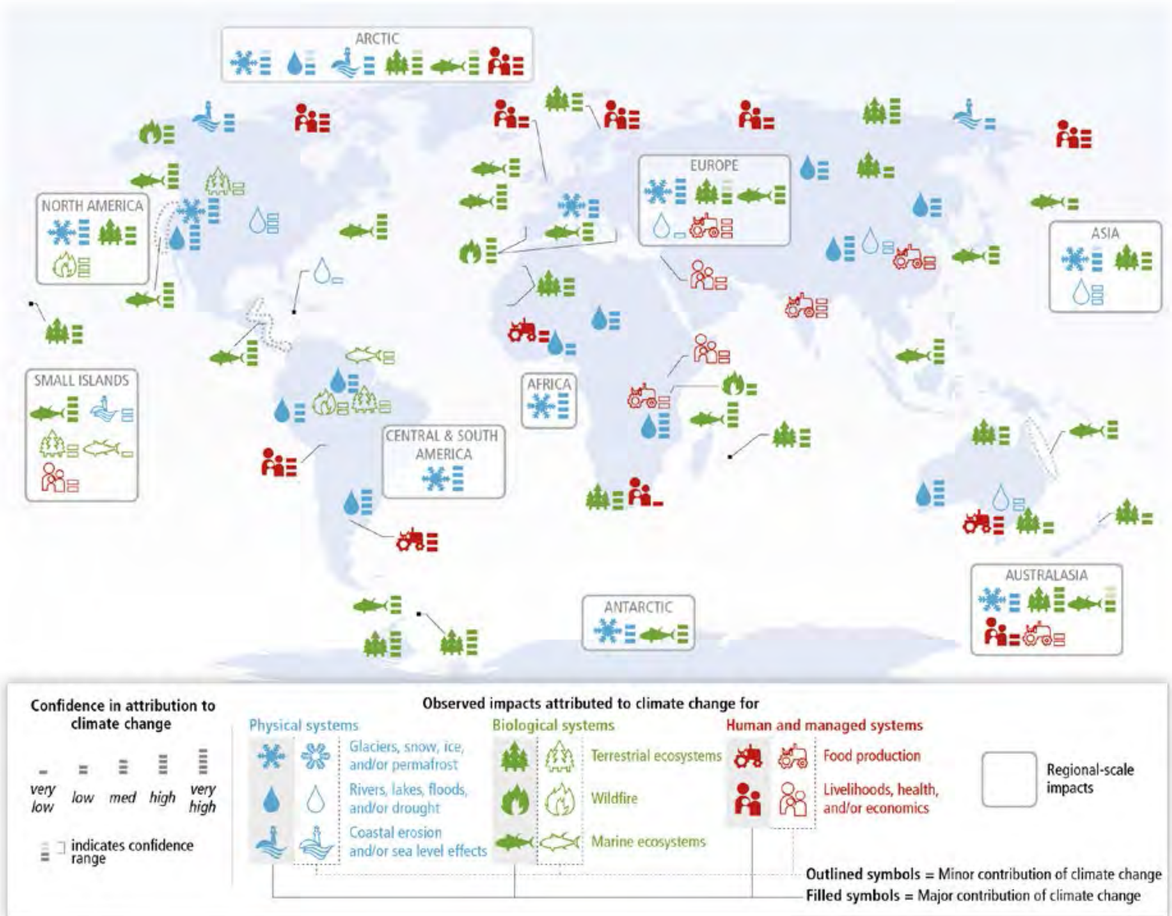


Figure SPM.4: Global patterns of impacts in recent decades attributed to climate change, based on studies since the AR4. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact, and confidence in attribution. *{Figure 1.11}*

1.4. Extremes

Changes in many extreme weather and climate events have been observed since about 1950, including decrease in cold temperature extremes, increase in hot temperature extremes, and increase in extreme high sea levels. Some of these changes have been linked to human influences. *{1.5}*

It is *very likely* that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is *likely* that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. It is *very likely* that human influence has contributed to the observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century. It is *likely* that human influence has more than doubled the probability of occurrence of heat waves in some locations. There is *medium confidence* on increased heat-related human mortality and decreased cold-related human mortality in some regions as a result of warming. *{1.5}*

There are *likely* more land regions where the number of heavy precipitation events has increased than where it has decreased. Recent detection of positive trends in extreme precipitation and discharge in some catchments imply greater risks of flooding at regional scale (*medium confidence*). It is *likely* that extreme sea levels have increased since 1970, being mainly a result of rising mean sea level. *{1.5}*

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability (*very high confidence*). *{1.5}*

2. Future climate changes, risks and impacts

Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. A combination of adaptation and substantial, sustained reductions in greenhouse gas emissions can limit climate change risks. *{2}*

2.1 The basis on which projections are made

Scenarios of future emissions vary over a wide range, depending on socio-economic development and future climate policy. Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21^{st} century and beyond. *{2.1}*

Anthropogenic greenhouse gas emissions are mainly determined by population size, economic activity, lifestyle, energy use, land-use patterns, technology change and climate policy *{2.1, 4.2}*.

The “Representative Concentration Pathways” (RCPs) used for making projections describe the 21st century evolution of atmospheric greenhouse gas emissions and concentrations, air pollutant emissions and land-use change under four different futures. The RCPs include a mitigation scenario leading to a very low forcing level (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6.0), and one scenario with very high greenhouse gas emissions (RCP8.5). Scenarios without additional efforts to constrain emissions (“baseline scenarios”) lead to a range of forcing levels between RCP6.0 and RCP8.5. RCP2.6 is representative of a scenario that aims to keep global warming below 2 °C above pre-industrial temperatures (Figure SPM.5.a). The RCPs are consistent with the wide range of mitigation scenarios as assessed in WGIII, categorized on the basis of 2100 CO_2-eq[5] concentration. *{2.1}*

[5] The CO_2-equivalent (CO_2-eq) concentration includes the forcing of all GHGs including halogenated gases and tropospheric ozone, aerosols and albedo change. The CO2 equivalent concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 - 520 ppm) [WGIII 6.3, Box TS.6, WGI Figure SPM.5, WGI 8.5, WGI 12.3].

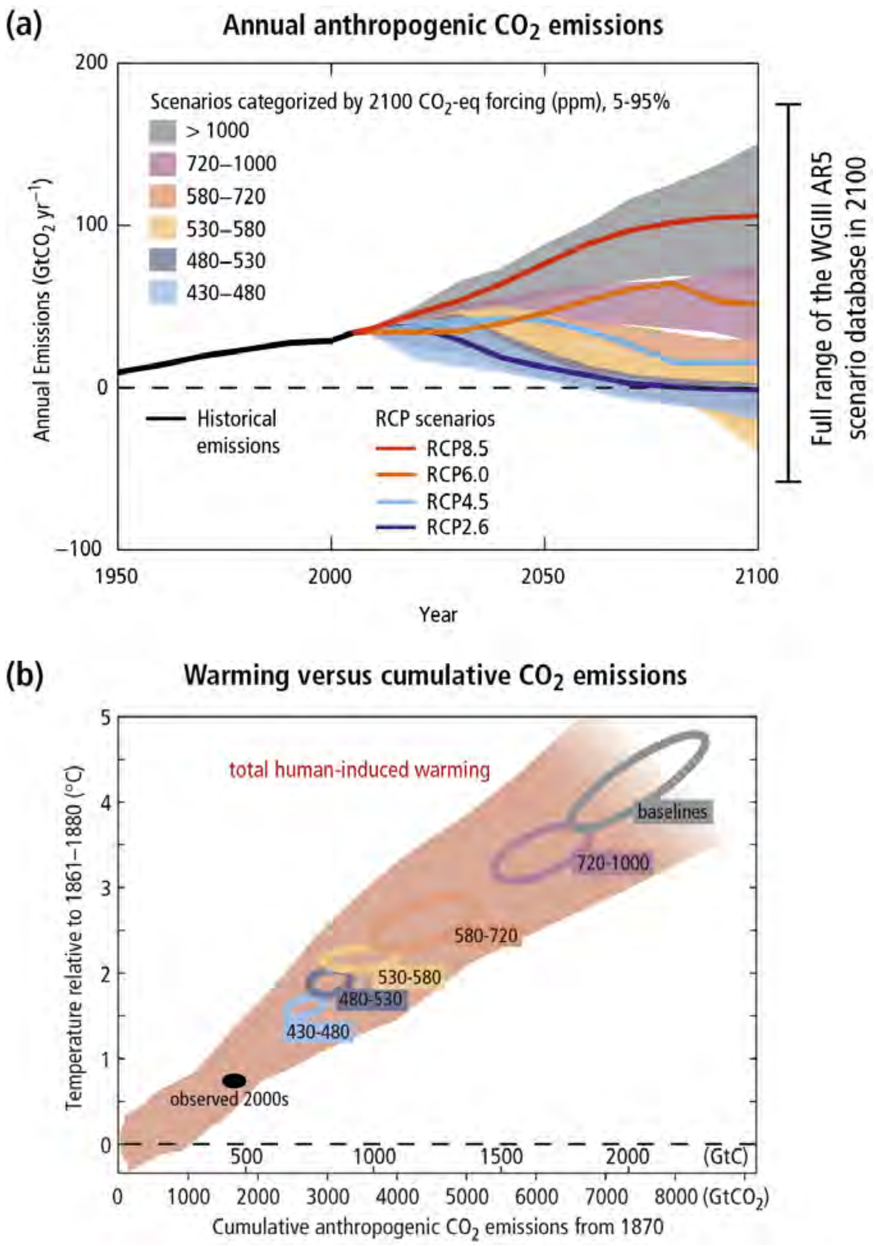


Figure SPM.5 (a): CO_2 emissions in the Representative Concentration Pathways (lines) and the associated scenario categories used in WGIII (coloured areas). The WGIII scenario categories summarize the wide range of emission scenarios published in the scientific literature and are defined on the basis of total greenhouse gas concentration levels (in CO_2-eq) in 2100. The time series of total greenhouse gas emissions are shown in Figure SPM.11. **(b)** Global mean surface temperature increase as a function of cumulative total global CO_2 emissions from various lines of evidence. Coloured plume shows the spread of projections from a hierarchy of climate-carbon cycle models over the four RCPs, and fades with the decreasing number of available models in RCP8.5. Ellipses show total anthropogenic warming versus cumulative CO_2 emissions in a single version of a simple climate model under the scenario categories used in WGIII, showing the impact of different scenarios for non-CO_2 climate drivers. *{Box 2.2, Figure 1, Figure 2.3}*

Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond *{2.4.5}*. There is a strong consistent almost straight-line relationship between cumulative CO_2 emissions and projected 21st century temperature change in both the RCPs and the wider set of mitigation scenarios analysed in WGIII (figure SPM.5.b). Providing a two-in-three chance or higher that total human-induced warming remains less than 2 °C requires total CO_2 emissions since 1870 to be limited to about 2900 $GtCO_2$ (2800-3200 $GtCO_2$), two-thirds of which had already been emitted by 2011. *{Table 2.2}*. Higher CO_2 emissions in early decades require lower or negative emissions in later decades to meet the same temperature goal. *{2.2.5, Box Art. 2}*.

2.2 Projected changes in the climate system

Surface air temperature is projected to rise over the 21st century under all assessed emission scenarios. The ocean will continue to warm, acidify and lose oxygen. Global mean sea level will continue to rise during the 21st century and beyond. *{2.2}*

Estimates of near-term future climate depend on the committed change caused by past anthropogenic forcing, the time evolution of future anthropogenic forcing and natural climate variability. The global mean surface air temperature change for the period 2016-2035 relative to 1986-2005 will *likely* be in the range 0.3˚C-0.7˚C (*medium confidence*) for the four RCP scenarios and assuming no major volcanic eruptions or unexpected changes in total solar irradiance. By mid-21st century, the rate of global warming begins to be strongly dependent on the emissions scenario. *{2.2.1, Table 2.1}*

Relative to 1851-1900, global surface air temperature change for the 2081-2100 period is *likely* to exceed 1.5 °C for all RCP scenarios except RCP2.6 (*high confidence*), *likely* to exceed 2 °C for RCP6.0 and RCP8.5 (*high confidence*), *more likely than not* to exceed 2 °C for RCP4.5 (*medium confidence*), but *unlikely* to exceed 2 °C for RCP2.6 (*medium confidence*). Significant additional warming after 2100 is expected if emissions follow RCP6.0 or RCP8.5. *{2.2.1}*

The remaining projected changes in Section 2.2 are for 2081-2100 relative to 1986-2005, unless otherwise indicated.

The increase of global mean surface temperatures is *likely* to be 0.3 °C–1.7 °C under RCP2.6 and 2.6 °C–4.8 °C under RCP8.5 (Figure SPM.6.a, Figure SPM.7.a)[6]. *{2.2.1, Table 2.1}*

It is *virtually certain* that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal time-scales, as global mean surface temperature increases. It is *very likely* that heat waves will occur with a higher frequency and duration. Occasional cold winter extremes will continue to occur. *{2.2.1}*

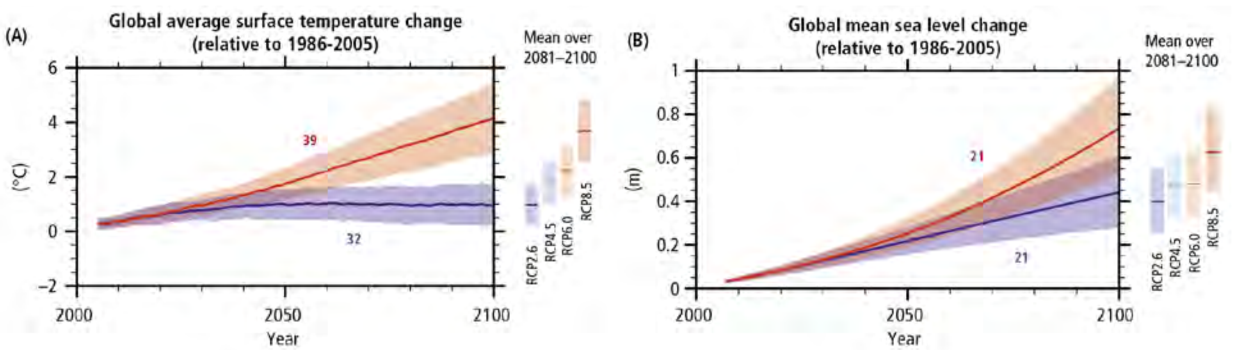


Figure SPM.6: (a) Multi-model simulated time series from 2005 to 2100 for change in global annual mean surface temperature (left) and **(b)** global mean sea level change (right). All changes are relative to 1986–2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). The mean and associated uncertainties averaged over 2081-2100 are given for all RCP scenarios as coloured vertical bars at the right end side of each panel. *{2.2, Figure 2.1}*

[6] The period 1986-2005 is approximately 0.61 [0.55 to 0.67] ˚C warmer than 1850-1900.

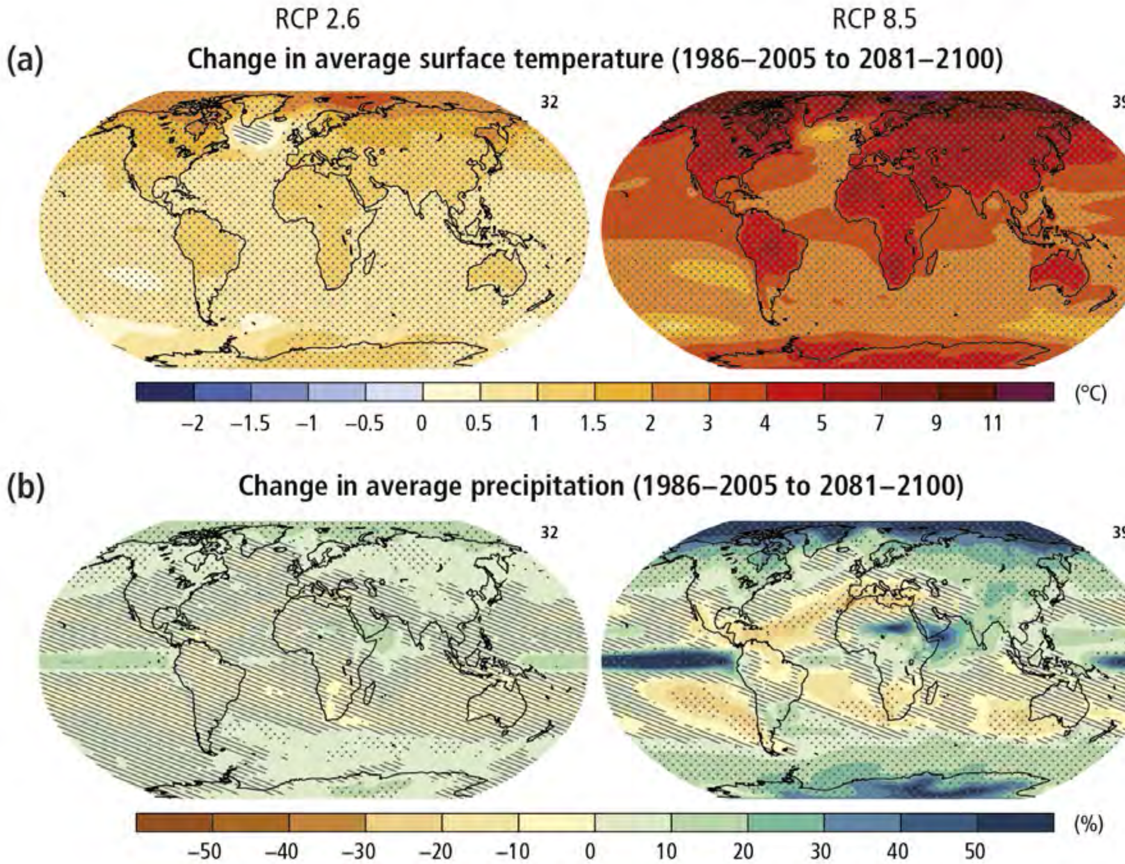


Figure SPM.7: Multi-model mean (i.e. average) projections for 2081– 2100 under the RCP2.6 (left) and RCP8.5 (right) scenarios for **(a)** annual mean surface temperature change and **(b)** percentage change in annual mean precipitation. The number of models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Stippling shows regions where the projected change is large compared to internal variability in 20-yr means, and where at least 90% of models agree on the sign of change. Hatching shows regions where the projected change is less than one standard deviation of the internal variability. *{2.2, Figure 2.2}*

Changes in precipitation will not be uniform. The high-latitudes and the equatorial Pacific are *likely* to experience an increase in annual mean precipitation under the RCP8.5 scenario. In many mid-latitude and subtropical dry regions, mean precipitation will *likely* decrease, while in many mid-latitude wet regions, mean precipitation will *likely* increase under the RCP8.5 scenario (Figure SPM.7.b). *{2.2.2, Figure 2.2}*

Ocean acidification is projected to increase for all RCP scenarios, with a decrease in surface ocean pH below present-day values in the range of 0.06 to 0.07 for RCP2.6, to 0.30 to 0.32 for RCP8.5. {2.2.4, Figure 2.1}

Year-round reductions in Arctic sea ice are projected for all scenarios. A nearly ice-free[7] Arctic Ocean in the summer sea ice minimum in September before mid-century is *likely* for RCP8.5 (*medium confidence*). *{2.2.3}*

It is *virtually certain* that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases with the area of permafrost projected to decrease by between 37% (RCP2.6) to 81% (RCP8.5) (*medium confidence*). *{2.2.3}*

The global glacier volume, excluding glaciers in Antarctica, is projected to decrease by 15 to 55% for RCP2.6, and by 35 to 85% for RCP8.5 (*medium confidence*). *{2.2.3}*

Global mean sea level rise will continue during the 21st century, *very likely* at a faster rate than observed from 1971 to 2010, and will *likely* be in the ranges of 0.26 to 0.55 m for RCP2.6, and of0.45 to 0.82 m for

[7] When sea ice extent is less than one million km^2 for at least five consecutive years.

RCP8.5 (*medium confidence*)[8] (Figure SPM.6.b). Sea level rise will not be uniform. By the end of the 21st century, it is *very likely* that sea level will rise in more than about 95% of the ocean area with about 70% of the coastlines worldwide experiencing a sea level change within ± 20% of the global mean sea level change for RCP4.5 and RCP8.5. *{2.2.3}*

2.3 Future risks and impacts caused by a changing climate

Climate change will create new risks for natural and human systems and amplify existing risks in countries at all levels of development. Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). *{2.3}*

Risks caused by a changing climate depend on the exposure, vulnerability, and ability of the affected system to adapt. Rising magnitudes of warming and other changes in the climate system, paralleled by ocean acidification, increase the risk of severe, pervasive, and in some cases irreversible detrimental impacts. The overall risks of climate change impacts can be reduced by limiting the rate and magnitude of climate change. The precise levels of climate change sufficient to trigger abrupt and irreversible change remain uncertain, but the risk associated with crossing such thresholds increases with rising temperature (*medium confidence*). (Figure SPM.8). *{2.3, 2.4, 3.3, Box 2.3, Box 2.4}*

A large fraction of species faces increased extinction risk due to climate change, especially as climate change interacts with other stressors (*high confidence*). Plants cannot move sufficiently fast to keep up with current and projected rates of climate change in most landscapes; most small mammals and freshwater molluscs will not be able to keep up at the rates projected under RCP4.5 and above in this century (*high confidence*). Future risk is indicated to be high by the observation that natural global climate change at rates lower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years. Marine organisms are at risk from high rates and magnitudes of ocean acidification (*high confidence*), a risk exacerbated by rising ocean temperature extremes (*medium confidence*). Coastal systems are at risk from sea level rise, which will continue for centuries even if the global mean temperature is stabilised (*high confidence*). *{2.3, 2.4, Figure 2.5}*

[8] Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21s century.

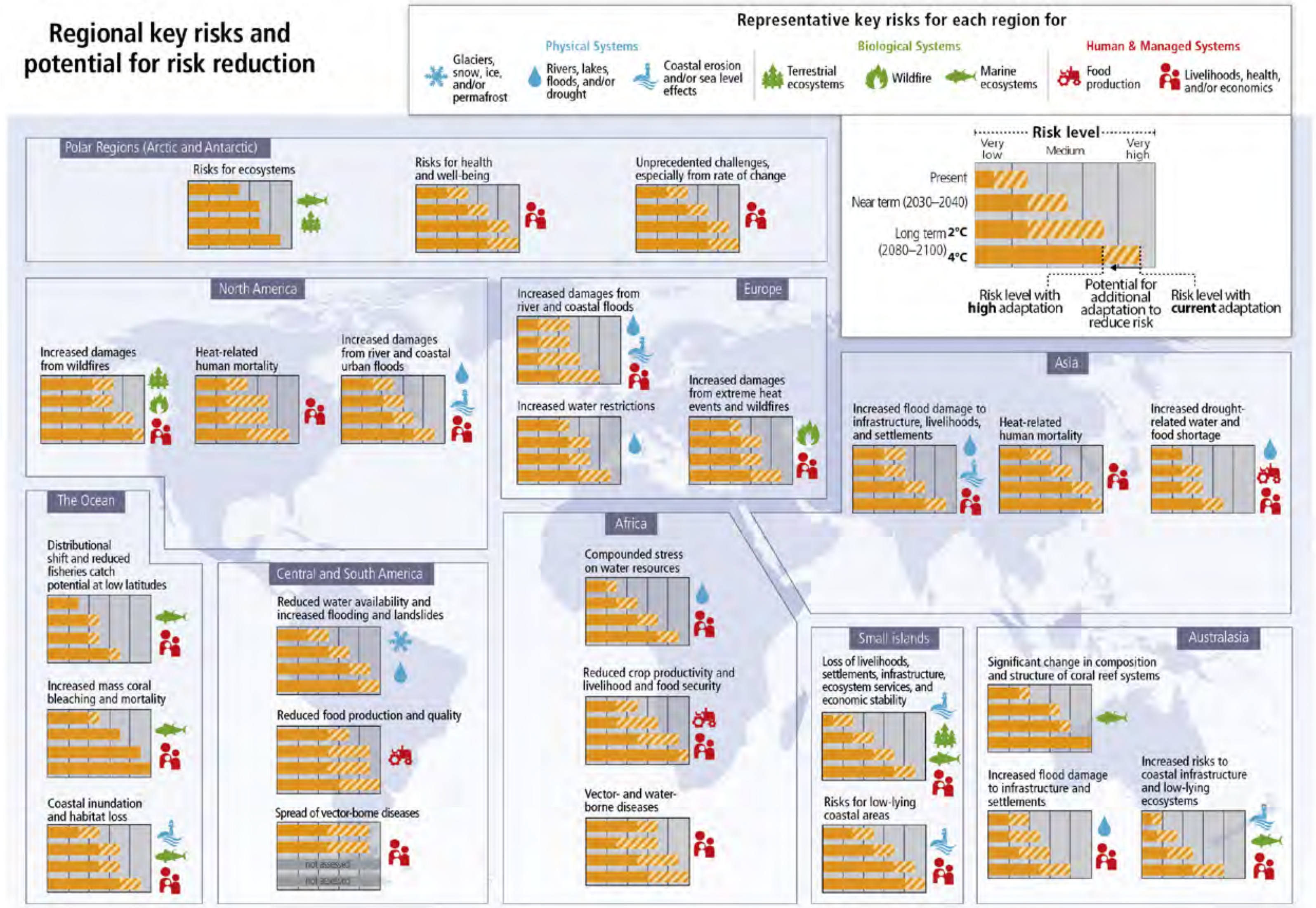


Figure SPM.8: Representative key risks for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation. Each key risk is assessed as very low, low, medium, high, or very high. Risk levels are presented for three time frames: present, near term (here, for 2030-2040), and long term (here, for 2080-2100). In the near term, projected levels of global mean temperature increase do not diverge substantially across different emission scenarios. For the long term, risk levels are presented for two possible futures (2 °C and 4 °C global mean temperature increase above preindustrial levels). For each timeframe, risk levels are indicated for a continuation of current adaptation and for a highly adapted state. *{Figure 2.4}*

Climate change is projected to reduce food security (Figure SPM.9). For wheat, rice, and maize in tropical and temperate regions, climate change without adaptation is projected to negatively impact production for local temperature increases of 2 °C or more above late-20th century levels, although individual locations may benefit (*medium confidence*). Global temperature increases of ~4 °C or more, combined with increasing food demand, would pose large risks to food security globally and regionally (*high confidence*). Species redistribution and biodiversity reduction in the oceans will challenge the sustained provision of fisheries productivity and other ecosystem services (*high confidence*). Climate change is projected to reduce renewable surface and groundwater resources in most dry subtropical regions (*robust evidence*, *high agreement*), intensifying competition for water (*limited evidence*, *medium agreement*). *{2.3.2}*

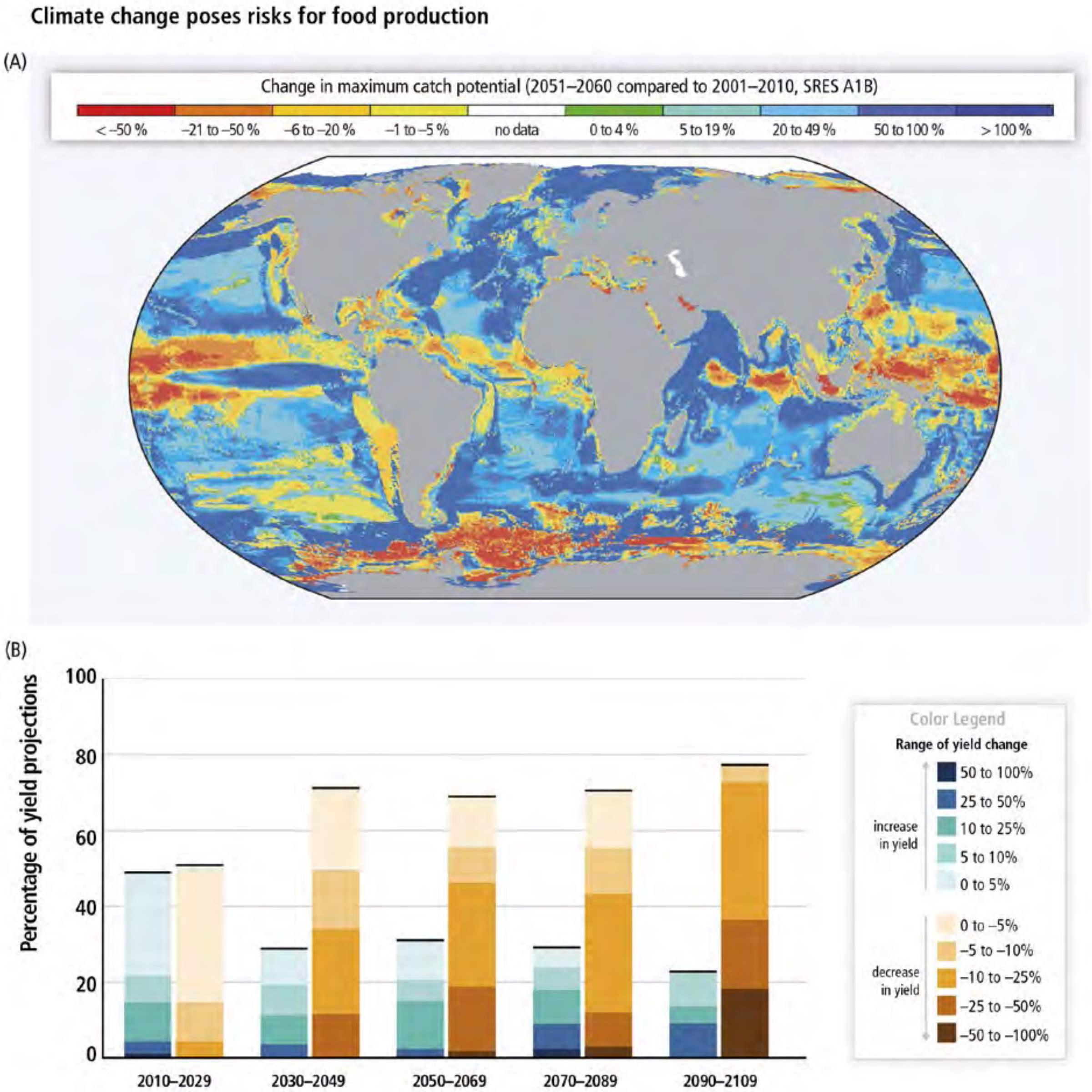


Figure SPM.9: (A) Projected global redistribution of maximum catch potential of ~1000 exploited marine fish and invertebrate species. Projections compare the 10-year averages 2001–2010 and 2051–2060 using SRES A1B (≈RCP6.0), without analysis of potential impacts of overfishing or ocean acidification. **(B)** Summary of projected changes in crop yields, due to climate change over the 21st century. Data for each timeframe sum to 100%, indicating the percentage of projections showing yield increases versus decreases. The figure includes projections for different emission scenarios, for tropical and temperate regions, and for adaptation and no-adaptation cases combined. Changes in crop yields are relative to late-20th-century levels. *{Figure 2.7.a, figure 2.8}*

Climate change is expected to lead to increases in ill-health in many regions, including greater likelihood of death, especially in developing countries with low income (*high confidence*). Up to mid-century, the impact will mainly be through exacerbating health problems that already exist (*very high confidence*). By 2100 for

RCP8.5, the combination of high temperature and humidity in some areas for parts of the year will substantially constrain common human activities (*high confidence*). *{2.3.2, Box Article 2}*

In urban areas, climate change is projected to increase risks for people, economies and ecosystems, including risks from heat stress, storms and extreme precipitation, inland and coastal flooding, water scarcity, sea-level rise, and storm surges (*very high confidence*). These risks are amplified for those lacking essential infrastructure and services or living in exposed areas. Rural areas are expected to experience major impacts on water availability and supply, food security, infrastructure, and agricultural incomes, including shifts in the production areas of food and non-food crops around the world (*high confidence*). *{2.3.2}*

Aggregate economic damages accelerate with increasing temperature (*limited evidence, high agreement*). From a poverty perspective, climate change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food security, and prolong existing and create new poverty traps, the latter particularly in urban areas and emerging hotspots of hunger (*medium confidence*). {2.3.2}

Climate change is projected to increase displacement of people (*medium evidence, high agreement*). Many populations that lack the resources for planned migration experience higher exposure to extreme weather events, particularly in developing countries with low income. Climate change can indirectly increase risks of violent conflicts in the form of civil war and intergroup violence by amplifying well-documented drivers of these conflicts such as poverty and economic shocks (*medium confidence*). *{2.3.2}*

2.4 Climate Change beyond 2100, irreversibility and abrupt changes[9]

Many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases cease. The risk of abrupt and irreversible change increases as the magnitude of the warming increases. *{2.4}*

The anthropogenic contribution to surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. Stabilization of global average surface temperature does not imply stabilization for all aspects of the climate system. Shifting biomes, soil carbon, ice sheets, ocean temperatures and associated sea level rise all have their own intrinsic long timescales which will result in changes lasting hundreds to thousands of years after global surface temperature is stabilized. *{2.1, 2.4}*

There is *high confidence* that ocean acidification will increase for centuries if CO_2 emissions continue, and will strongly affect marine ecosystems. *{2.4}*

It is *virtually certain* that global mean sea level rise will continue for many centuries beyond 2100 from ocean thermal expansion and the loss of mass from ice sheets, with the amount of rise dependent on future emissions. The threshold for loss of the Greenland ice sheet over a millennium or more, and an associated sea level rise of up to 7 m, is greater than 1 °C (*low confidence*) but less than about 4 °C (*medium confidence*) with respect to pre-industrial temperatures. Abrupt and irreversible ice loss from the Antarctic ice sheet is possible, but current evidence and understanding is insufficient to make a quantitative assessment. *{2.4}*

Magnitudes and rates of climate change associated with medium- to high-emission scenarios pose an increased risk of abrupt and irreversible regional-scale change in the composition, structure, and function of terrestrial and freshwater ecosystems, including wetlands (*medium confidence*). A reduction in permafrost extent is *virtually certain* with continued rise in global temperatures. *{2.4}*

[9] 'Abrupt' refers to a rapid change in the rate of change relative to the recent history of the affected components of the climate system. Abrupt change in slow processes may therefore unfold over decades. Not all irreversible changes are abrupt, nor are all abrupt changes irreversible.

3. Transformations and Changes in Systems

Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial near-term emissions reductions can reduce risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation, and contribute to climate-resilient pathways for sustainable development. *{3.2, 3.3, 3.4}*

3.1 Foundations of decision making for climate change

Effective decision making about climate change benefits from a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of ethical dimensions, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty. *{3.1}*

Mitigation and adaptation raise issues of equity, justice, and fairness and have implications for sustainable development and poverty eradication. Many of those most vulnerable to climate change are among the least responsible for GHG emissions. Delaying mitigation shifts burdens from the present to the future. *{3.1}*

Decision makers are sometimes influenced by social, cultural and emotional factors that cause them to misestimate risks, engage in short-term thinking and be biased toward the status quo. For balanced decision making that reflects ethical dimensions, analytic methods of valuation from economics and decision analysis are available. These methods cannot identify a single best balance between mitigation, adaptation, and residual climate impacts, but they can take account of take account of a wide range of possible impacts, including low-probability outcomes with large consequences. *{3.1}*

Climate change has the characteristics of a collective action problem at the global scale. Effective mitigation will not be achieved if individual agents advance their own interests independently, but only through collective response. *{3.1}*.

3.2 Climate change risks reduced by mitigation and adaptation

Without additional mitigation, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread, and irreversible impacts globally *(high confidence)*. Risks from mitigation can be substantial, but they do not involve the same possibility of severe, widespread, and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation action. *{3.2, 3.4}*

Mitigation and adaptation are complementary approaches for reducing risks over different time scales (*high confidence*). Investments in mitigation, in the near-term and through the century, can substantially reduce climate change impacts in the latter decades of the 21st century and beyond. Benefits from adaptation can be realized now in addressing current risks, and over the next few decades in addressing emerging risks. *{3.2, 4.5}*

Five "Reasons for Concern" (RFCs) aggregate climate change risks and illustrate the implications of warming and of adaptation limits for people, economies, and ecosystems across sectors and regions. The Five RFCs are: (1) Unique and threatened systems, (2) Extreme weather events, (3) Distribution of impacts,. (4) Global aggregate impacts, and (5) large-scale singular events. In this report, the RFCs play a role in the information relevant to Article 2 of UNFCCC (Background Box SPM.1).

Background Box SPM.1. Information relevant to Article 2 of UNFCCC

The United Nations Framework Convention on Climate Change states in Article 2 that its ultimate objective is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Determining a level of climate change as dangerous would involve value judgments, which is outside the mandate of the IPCC. The AR5 provides a basis for such a judgment by estimating the magnitude of current and future projected climate change and by assessing associated risks in different contexts and through time. Because climate change is expected to disproportionately affect poor populations, conditions which might characterize dangerous anthropogenic interference could affect some communities and locations well before these are experienced in other parts of the globe. Depending on value judgements and specific circumstances, currently observed impacts might already be considered dangerous for some communities. *{Box Art. 2}*

Without additional mitigation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread, and irreversible impacts globally *(high confidence).* These risks will occur even at the low end of projected warming in baseline scenarios for three of the five RFCs (Figure SPM.10.A). Projected warming in baseline scenarios is *more likely than not* to exceed 4 °C by 2100, surpassing the temperature at which risk becomes high or very high for every Reason For Concern. The risks associated with temperatures at or above 4 °C above pre-industrial levels include substantial species extinction, global and regional food insecurity, consequential constraints on common human activities, and limited potential for adaptation in some cases (*high confidence*). *{2.3, Figure 2.5, 3.2, 3.4,. Box 2.4, Box Art.2}*

The level of warming is largely determined by cumulative emissions of CO_2, which in turn are linked to emissions reductions over the next several decades and beyond (Figure SPM.10.B). Substantial cuts in greenhouse gas emissions over the next few decades can significantly reduce risks of climate change in the second half of the 21st century and beyond, but some risks from residual climate damages are unavoidable (Figure SPM.10.C) (*high confidence*). *{2.2.5, 3.2, 3.4, Box Art.2}*

Stringent mitigation involves its own set of risks. In an iterative risk management framework, inertia in the economic and climate system and the possibility of irreversible impacts from climate change increase the benefits from near-term mitigation efforts (*high confidence*). Delays in additional mitigation or constraints on technological options increase the longer-term mitigation costs and risks to hold climate change risks at a given level (Table SPM.2). *{3.2, 3.4, Box Art.2}*

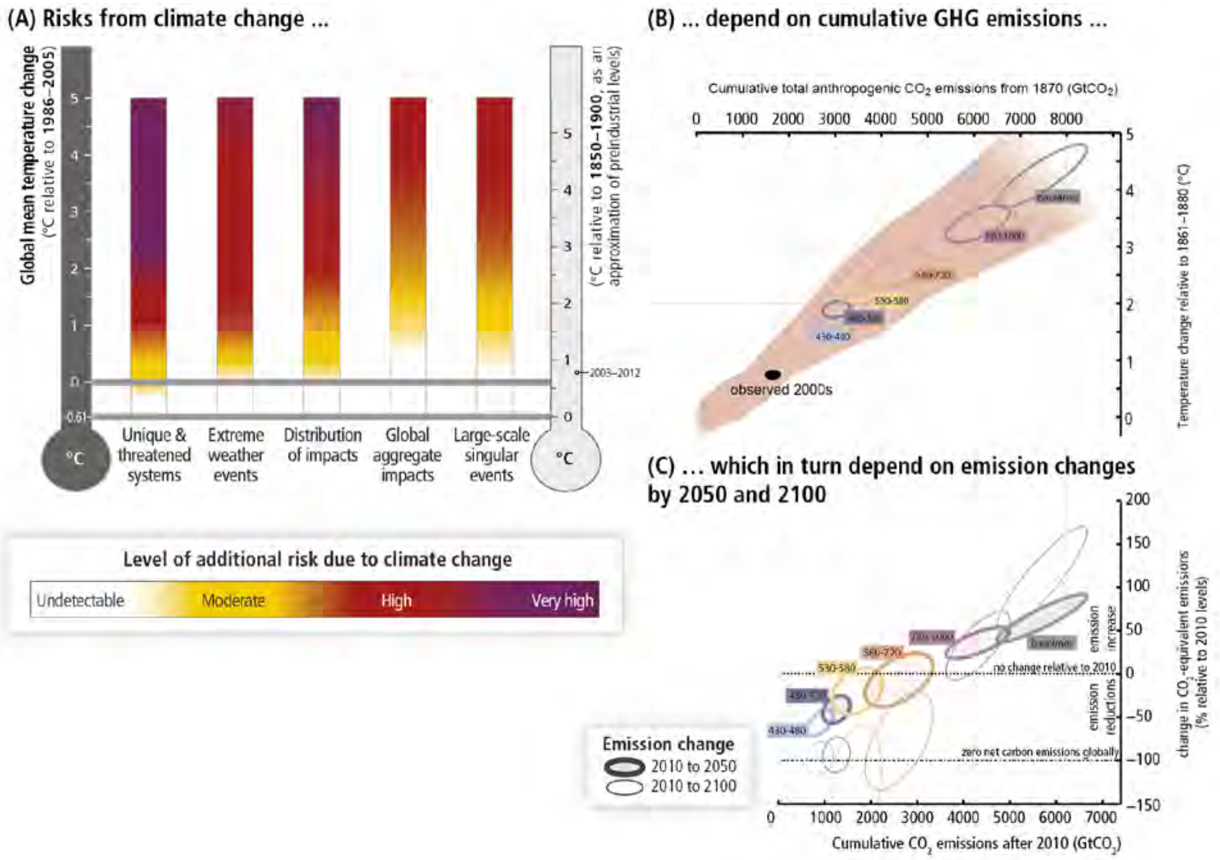


Figure SPM.10: The relationship between Reasons For Concern, temperature, cumulative emissions, and future emissions reductions. **Panel A** reproduces the five Reasons For Concern from WGII *{Box 2,4, Box Article 2}* with temperature changes expressed relative to 1850-1900 (right axis) and 1986-2005 temperatures (left axis). Moderate risk (yellow) indicates that impacts are both detectable and attributable to climate change with at least medium confidence. High risk (red) indicates severe and widespread impacts. Very high risk (purple) indicates that all criteria for "key risk" are met. **Panel B** links these temperature changes to cumulative CO_2 emissions (from 1870), based on CMIP5 and

EMIC simulations (pink plume) and the MAGICC climate model for the baselines and five mitigation scenario categories defined in WGIII Chapter6 (the 6 ellipses) *{Figure 2.2}*. **Panel C** shows the relationship between the cumulative CO_2 emissions of the WGIII scenario categories (X-axis) and their associated change in annual GHG emissions by 2050 and 2100 (Y-axis). The ellipses correspond to the same WGIII scenario categories as in Panel B. Cumulative emissions are shown from 2011 to 2100. The change in annual GHG emissions are shown for 2050 and 2100 relative to 2010 (positive changes refer to cases where emissions in 2050/2100 are larger than 2010). The observed change between the average of the period 1850–1900 and of the AR5 reference period (1986–2005) is about 0.61 °C which is used here as an approximation of the change in global mean surface temperature since preindustrial times *{Figure 3.1}*.

3.3 Characteristics and risks of adaptation pathways

Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, particularly if greenhouse gas emissions are not reduced. A longer-term perspective allows more immediate adaptation actions to be building blocks for future adaptations, increasing future options and preparedness. *{3.3}*

Adaptation can contribute to the wellbeing of populations, the security of assets, and the maintenance of ecosystem services now and in the future. Adaptation is place- and context-specific (*high confidence*). A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability (*high confidence*). *{3.3}*

There are limits to adaptation; greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). Further, poor planning or implementation, overemphasizing short-term outcomes, or failing to sufficiently anticipate consequences, can result in maladaptation, increasing the vulnerability or exposure of the target group in the future or the vulnerability of other people, places, or sectors (*medium evidence, high agreement*). Underestimating the complexity of adaptation as a social process can create unrealistic expectations about achieving intended adaptation outcomes. *{3.3}*

Transformations in economic, social, technological, and political decisions and actions can enhance adaptation and promote sustainable development (*high confidence*). Restricting adaptation responses to incremental changes to existing systems and structures, without considering transformational change, may increase costs and losses, and miss opportunities. Planning and implementation of transformational adaptation may place new and increased demands on governance structures to reconcile different goals and visions for the future and to address possible equity and ethical implications: adaptation pathways are enhanced by iterative learning, deliberative processes, and innovation. *{3.3}*

3.4 Characteristics and risks of mitigation pathways

Measures exist to achieve the substantial emissions reductions over the next few decades necessary to limit *likely* warming to 2 °C. Limiting warming to 2.5 °C or 3 °C involves similar challenges, but less quickly. Implementing such reductions poses substantial technological, economic, social, and institutional challenges, which increase with delays in additional mitigation and technology constraints. *{3.4}*

Without additional efforts to reduce GHG emissions, global emissions growth is expected to persist, driven by population and economic growth. Global mean surface temperature increases in baseline anthropogenic scenarios – those without additional mitigation – are from about 3.7 to 4.8 °C C above the average for 1850-1900 for a median transient climate response, and from 2.5 °C to 7.8 °C when including climate uncertainty. *{3.4}*

CO_2-eq concentrations in 2100 of about 450 ppm or lower are *likely* to maintain temperature change below 2 °C over the century. This will require substantial cuts in anthropogenic GHG emissions by mid-century through large-scale changes in energy systems and possibly land use. Limiting temperature change to higher levels include similar changes, but less quickly (Table SPM.1, Figure SPM.11). Limiting temperature change to lower levels such as 1.5 °C requires these changes on a faster timescale. *(high confidence) {3.4}*

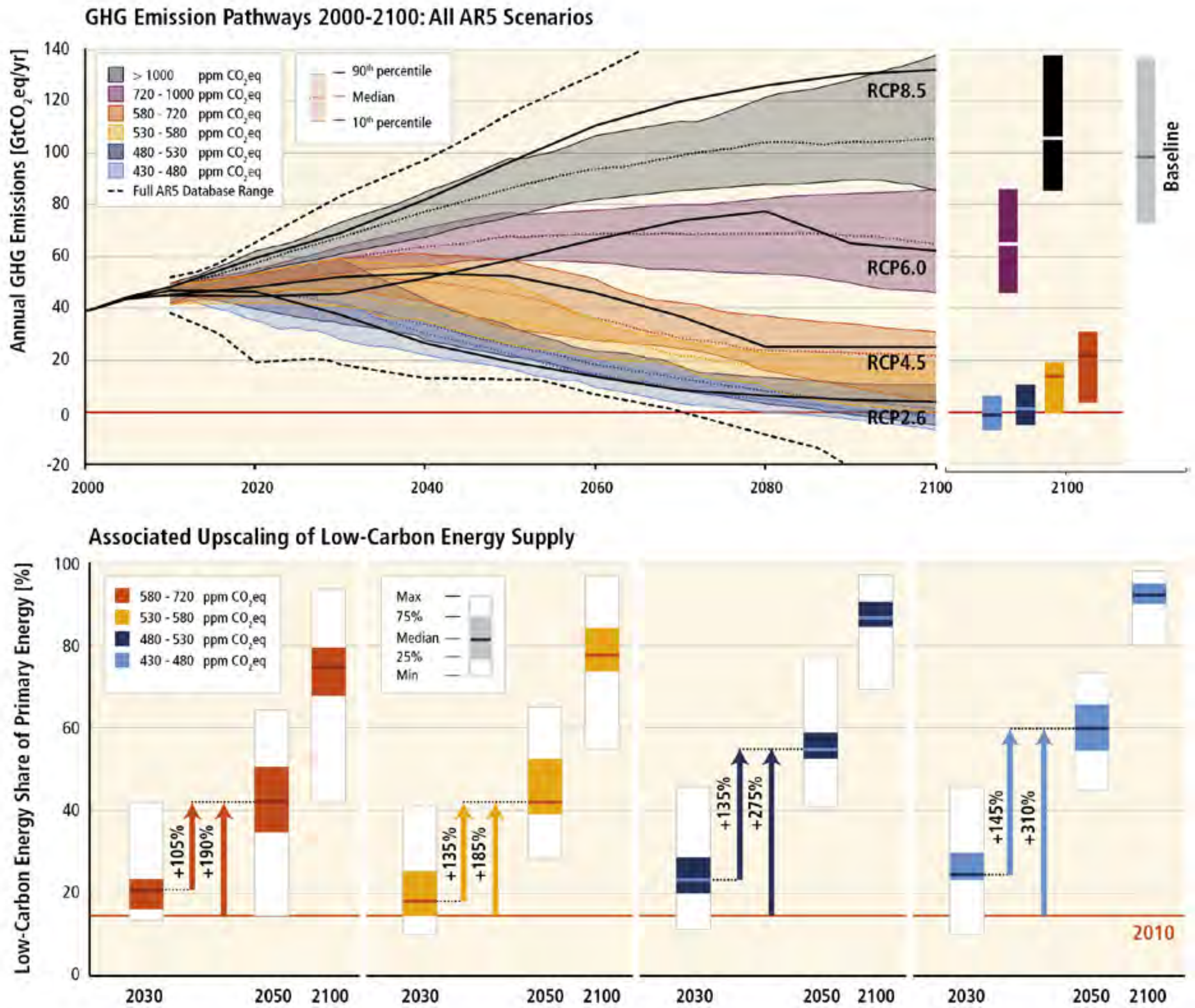


Figure SPM.11: Global GHG emissions ($GtCO_2$eq/yr) in baseline and mitigation scenarios for different long-term concentration levels (upper panel) and associated upscaling requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100 compared to 2010 levels in mitigation scenarios (lower panel). *{Figure 3.2}*

Table SPM.1: Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters, the 10th to 90th percentile of the scenarios is shown[1,2]. *{Table 3.1}*

<table>
<tr><th rowspan="2">CO_2eq Concentrations in 2100 (CO_2eq)[5]

Category label (conc. range)</th><th rowspan="2">Subcategories</th><th rowspan="2">Relative position of the RCPs</th><th colspan="2">Change in CO_2eq emissions compared to 2010 (in %)[3,5]</th><th colspan="4">Likelihood of staying below specific temperature levels (relative to 1850-1900)[5,6,7]</th></tr>
<tr><th>2050</th><th>2100</th><th>Likelihood of staying below 1.5 °C</th><th>Likelihood of staying below 2 °C</th><th>Likelihood of staying below 3 °C</th><th>Likelihood of staying below 4 °C</th></tr>
<tr><td>< 430</td><td colspan="8">Only a limited number of individual model studies have explored levels below 430 ppm CO_2eq</td></tr>
<tr><td>450 (430 – 480)</td><td>Total range[1,4]</td><td>RCP2.6</td><td>-72 to -41</td><td>-118 to -78</td><td>More unlikely than likely</td><td>Likely</td><td rowspan="6">Likely</td><td rowspan="8">Likely</td></tr>
<tr><td rowspan="2">500 (480 – 530)</td><td>No overshoot of 530 ppm CO_2eq</td><td></td><td>-52 to -42</td><td>-107 to -73</td><td rowspan="6">Unlikely</td><td>More likely than not</td></tr>
<tr><td>Overshoot of 530 ppm CO_2eq</td><td></td><td>-55 to -25</td><td>-114 to -90</td><td>About as likely as not</td></tr>
<tr><td rowspan="2">550 (530 – 580)</td><td>No overshoot of 580 ppm CO_2eq</td><td></td><td>-47 to -19</td><td>-81 to -59</td><td rowspan="3">More unlikely than likely[9]</td></tr>
<tr><td>Overshoot of 580 ppm CO_2eq</td><td></td><td>-16 to 7</td><td>-183 to -86</td></tr>
<tr><td>(580 – 650)</td><td>Total range</td><td rowspan="2">RCP4.5</td><td>-38 to 24</td><td>-134 to -50</td></tr>
<tr><td>(650 – 720)</td><td>Total range</td><td>-11 to 17</td><td>-54 to -21</td><td rowspan="2">Unlikely</td><td>More likely than not</td></tr>
<tr><td>(720 – 1000)</td><td>Total range</td><td>RCP6.0</td><td>18 to 54</td><td>-7 to 72</td><td rowspan="2">Unlikely[8]</td><td>More unlikely than likely</td></tr>
<tr><td>>1000</td><td>Total range</td><td>RCP8.5</td><td>52 to 95</td><td>74 to 178</td><td>Unlikely[8]</td><td>Unlikely</td><td>More unlikely than likely</td></tr>
</table>

[1]The 'total range' for the 430 to 480 ppm CO_2-eq concentrations scenarios corresponds to the range of the 10-90th percentile of the subcategory of these scenarios shown in Table 6.3 of the Working Group3 report.

[2] Baseline scenarios fall into the >1000 and 750–1000 ppm CO_2eq categories. The latter category includes also mitigation scenarios. The baseline scenarios in the latter category reach a temperature change of 2.5–5.8 °C above the average for 1850-1900 in 2100. Together with the baseline scenarios in the >1000 ppm CO_2-eq category, this leads to an overall 2100 temperature range of 2.5–7.8 °C (median transient climate response: 3.7–4.8 °C) for baseline scenarios across both concentration categories.

[3] The global 2010 emissions are about 30% above the 1990 emissions (consistent with the historic GHG emission estimates presented in this report). CO_2-eq emissions include the basket of Kyoto gases (CO_2, CH_4, N_2O as well as F-gases).

[4] The assessment here involves a large number of scenarios published in the scientific literature and is thus not limited to the RCPs. To evaluate the GHG concentration and climate implications of these scenarios, the MAGICC model was used in a probabilistic mode For a comparison between MAGICC model results and the outcomes of the models used in WGI, see Section WGI 12.4.1.2 and WGI 12.4.8 and 6.3.2.6

[5] The assessment in this table is based on the probabilities calculated for the full ensemble of scenarios in WGIII using MAGICC and the assessment in WGI of the uncertainty of the temperature projections not covered by climate models. The statements are therefore consistent with the statements in WGI, which are based on the CMIP5 runs of the RCPs and the assessed uncertainties. Hence, the likelihood statements reflect different lines of evidence from both WGs. This WGI method was also applied for scenarios with intermediate concentration levels where no CMIP5 runs are available. The likelihood statements are indicative only and follow broadly the terms used by the WGI SPM for temperature projections: *likely* 66-100%, *more likely than not* >50-100%, *about as likely as not* 33-66%, and *unlikely* 0-33%. In addition the term *more unlikely than likely* 0-<50% is used.

[6] The CO_2-equivalent *concentration* includes the forcing of all GHGs including halogenated gases and tropospheric ozone, aerosols and albedo change (calculated on the basis of the total forcing from a simple carbon cycle/climate model, MAGICC). The CO_2 equivalent concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 – 520 ppm) .This is based on the assessment of total anthropogenic radiative forcing for 2011 relative to 1750 in WGI, i. e. 2.3 $W\ m^{-2}$, uncertainty range 1.1 to 3.3 $W\ m^{-2}$. CO_2 equivalent *emissions* include the basket of Kyoto gases (CO_2, CH_4, N_2O as well as F-gases) calculated based on GWP_{100} values form the Second Assessment Report, whereas, CO_2 equivalent concentrations are for all anthropogenic radiative forcings, including the cooling effects of aerosols. CO_2-eq is used as shorthand notation in both cases.

[7] The vast majority of scenarios in this category overshoot the category boundary of 480 ppm CO_2-eq concentration.

[8] For scenarios in this category, no CMIP5 run or MAGICC realization stays below the respective temperature level. Still, an '*unlikely*' assignment is given to reflect uncertainties that may not be reflected by the current climate models.

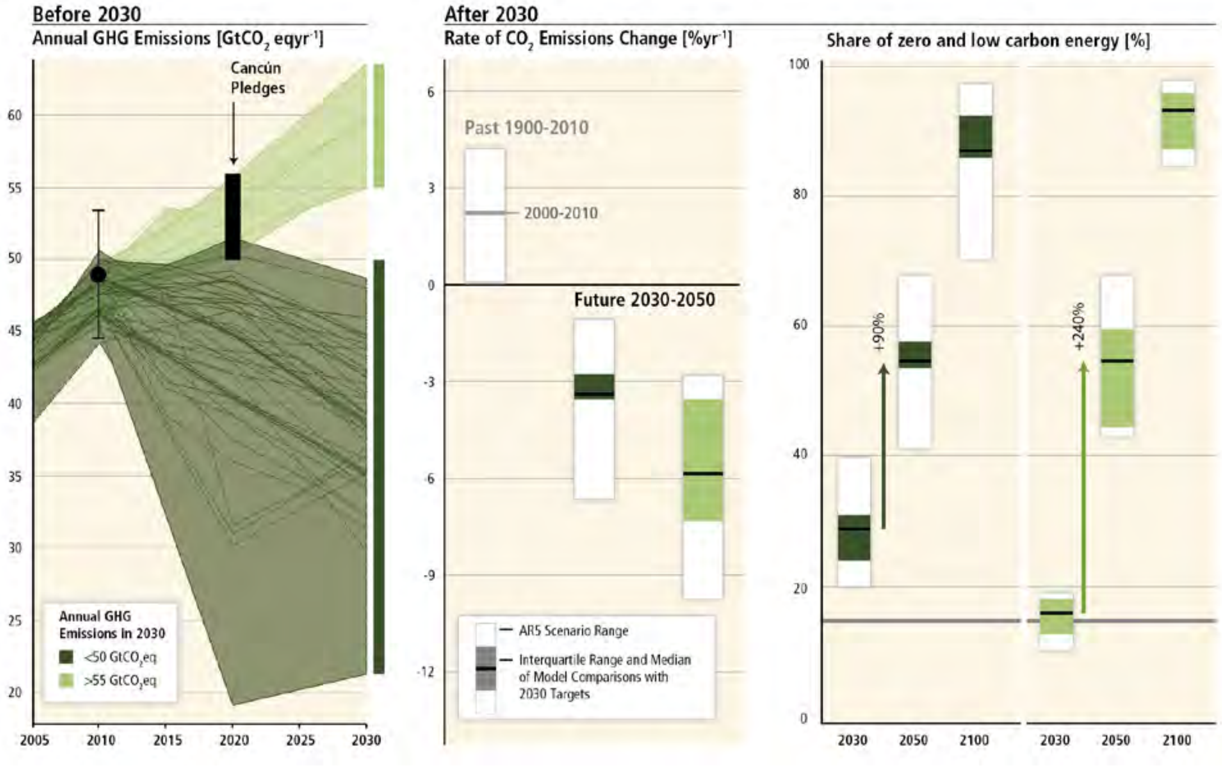
[9] Scenarios in the 580–650 ppm CO_2-eq category include both overshoot scenarios and scenarios that do not exceed the concentration level at the high end of the category (e.g. RCP4.5). The latter type of scenarios, in general, have an assessed probability of *more unlikely than likely* to exceed the 2 °C temperature level, while the former are mostly assessed to have an *unlikely* probability of exceeding this level.

Mitigation scenarios reaching about 450 ppm CO_2-eq in 2100 typically involve temporary overshoot[10] of atmospheric concentrations, as do many scenarios reaching about 500 ppm to about 550 ppm CO_2-eq in 2100 (Table SPM.1). Overshoot scenarios typically rely on the widespread availability and deployment of bioenergy with carbon dioxide capture and storage (BECCS) and afforestation in the second half of the century (Table SPM.1). Such carbon dioxide removal (CDR) technologies play a major role in many ambitious mitigation scenarios. CDR could potentially reduce atmospheric GHG levels but there are biogeochemical, technical and societal limitations that make it difficult to provide quantitative estimates of the potential at large scales. *(high confidence){3.4, Box 3.3}*

Reducing emissions of non-CO_2 agents is an important element of mitigation strategies. Mitigation of certain short-lived climate forcers can reduce the rate of warming in the short-term, but will have a limited effect on long-term warming *(medium confidence)*. Emissions of short-lived forcers are often expressed as CO_2-equivalent emissions, but the choice of metric to calculate these emissions, and the implications for the emphasis and timing of abatement of short-lived climate forcers, depends on application, policy context, and contains implicit value judgments *{3.4, Box 3.2}*.

Delaying additional mitigation to 2030 or beyond will substantially increase the challenges associated with limiting warming to 2 °C. It will require substantially higher rates of emissions reductions in the future; much more rapid scale-up of low-carbon energy over this period; a larger reliance on CDR in the long term; and higher transitional and long-term economic impacts (Figure SPM.12). Estimated global emissions levels in 2020 based on the Cancún Pledges are not consistent with cost-effective trajectories that are at least *about as likely as not* to limit temperature change to 2 °C but they do not preclude the option to meet this goal (Figure SPM.12). *{3.4}*

Solar Radiation Management (SRM) is untested and is not included in any of the mitigation scenarios. SRM entails numerous uncertainties, side-effects, risks, shortcomings and has particular governance and ethical implications. SRM would not reduce ocean acidification. If it were deployed and then terminated, there is *high confidence* that surface temperatures would rise very rapidly impacting ecosystems susceptible to rapid rates of change. *{Box 3.3}*.



[10] In concentration "overshoot" scenarios, concentrations peak during the century and then decline.

Figure SPM.12: The implications of different 2030 GHG emissions levels for the rate of CO_2 emissions reductions from 2030 to 2050 and low-carbon energy upscaling from 2030 to 2050 and 2100 in mitigation scenarios reaching about 450 to 500 (430–530) ppm CO_2eq concentrations by 2100. The scenarios are grouped according to different emissions levels by 2030 (coloured in different shades of green). The left panel shows the pathways of GHG emissions ($GtCO_2$-eq/yr) leading to these 2030 levels. The black bar shows the estimated uncertainty range of GHG emissions implied by the Cancún Pledges. The middle panel denotes the average annual CO_2 emissions reduction rates for the period 2030–2050. It compares the median and interquartile range across scenarios from recent intermodel comparisons with explicit 2030 interim goals to the range of scenarios in the Scenario Database for WGIII AR5. Annual rates of historical emissions change (sustained over a period of 20 years and the average annual CO_2 emission change between 2000 and 2010)) are shown as well. The arrows in the right panel show the magnitude of zero and low-carbon energy supply up-scaling from 2030 to 2050 subject to different 2030 GHG emissions levels. Zero- and low-carbon energy supply includes renewables, nuclear energy, and fossil energy with carbon dioxide capture and storage (CCS), or bioenergy with CCS (BECCS). [Note: Only scenarios that apply the full, unconstrained mitigation technology portfolio of the underlying models (default technology assumption) are shown. Scenarios with large net negative global emissions (>20 $GtCO_2$-eq/yr), scenarios with exogenous carbon price assumptions, and scenarios with 2010 emissions significantly outside the historical range are excluded.] *{Figure 3.4}*

Estimates of the aggregate economic costs of mitigation vary widely depending on methodologies and assumptions, but increase with the stringency of mitigation. Under stylized assumptions about the implementation of climate policies, most studies have estimated that limiting warming to 2 °C through the 21st century would entail losses in global consumption of 1 % to 4% (median: 1.7%) in 2030 and 2% to 6% (median: 3.4%) in 2050, and 3% to 11% (median: 4.8%) in 2100 relative to consumption in baseline scenarios. For context, aggregate consumption in baseline scenarios grows anywhere from 300 % to more than 900 % over the century (Figure SPM.13). *{3.4}*

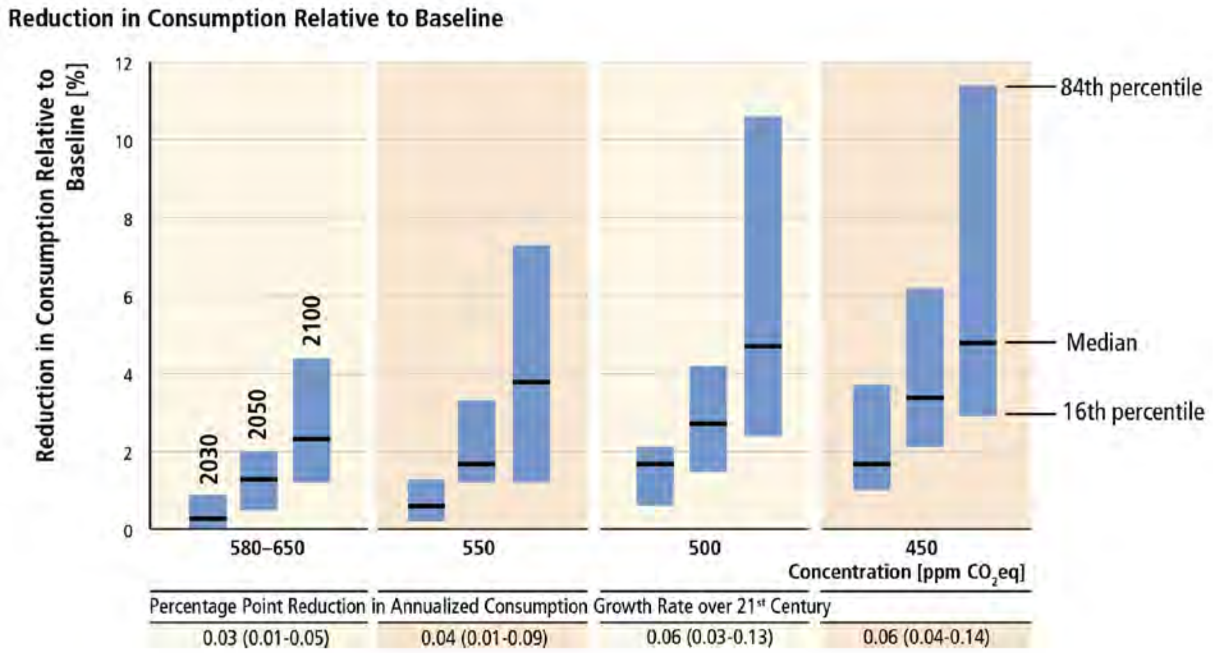


Figure SPM.13: Global mitigation costs in cost-effective scenarios at different atmospheric concentrations levels in 2100. Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions. Consumption losses are shown relative to a baseline development without climate policy. The table at the bottom shows annualized consumption growth reductions relative to consumption growth in the baseline of 1.6% to 3% per year. Cost estimates shown in this table do not consider the benefits of reduced climate change as well as co-benefits and adverse side-effects of mitigation. *{Figure 3.3}*

Under the absence or limited availability of technologies, mitigation costs can increase substantially depending on the technology considered. Delaying additional mitigation further increases mitigation costs in the medium- to long-term. Many models could not reproduce temperature increase below 2 °C with a *likely* chance, if additional mitigation would be considerably delayed, or if availability of key technologies, such as bioenergy, CCS, and their combination (BECCS) would be limited *(high confidence)* (Table SPM.2).

Table SPM.2: Increase in global mitigation costs due to either limited availability of specific technologies or delays in additional mitigation[1] relative to cost-effective scenarios. [2] The increase in costs is given for the median estimate and the 16th and 84th percentile of the scenarios (in parentheses). In addition, the sample size of each scenario set is provided in square brackets.[3] The colours of the cells indicate the fraction of models from systematic model comparison exercises that could successfully reach the targeted concentration level.[4] *{Table 3.2}*

	Increases in total discounted mitigation costs in scenarios with limited availability of technologies[5]				**Increase in medium- and long-term mitigation costs due to delayed additional mitigation until 2030**	
	[%increase in total discounted[6] mitigation costs (2015-2100) relative to default technology assumptions]				**[% increase in mitigation costs relative to immediate mitigation]**	
2100 concentrations (ppm CO_2eq)	**NoCCS**	**Nuclear phase out**	**Limited Solar/Wind**	**Limited Bioenergy**	**2030-2050**	**2050-2100**
450 (430-480)	138 (29-297) [n=4]	7 (4-18) [n=8]	6 (2-29) [n=8]	64 (44-78) [n=8]	44 (2-78) [n=29]	37 (16-82) [n=29]
500 (480-530)	N/A	N/A	N/A	N/A		
550 (530-580)	39 (18-78) [n=11]	13 (2-23) [n=10]	8 (5-15) [n=10]	18 (4-66) [n=12]	15 (3-32) [n=10]	16 (5-24) [n=10]
580-650	N/A	N/A	N/A	N/A		

[1] Delayed mitigation scenarios are associated with GHG emission of more than 55 $GtCO_2$-eq in 2030, and the increase in mitigation costs is measured relative to cost-effective mitigation scenarios for the same long-term concentration level.

[2] Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions.

[3] The range is determined by the central scenarios encompassing the 16th and 84th percentile of the scenario set. Only scenarios with a time horizon until 2100 are included. Some models that are included in the cost ranges for concentration levels above 530 ppm CO_2-eq in 2100 could not produce associated scenarios for concentration levels below 530 ppm CO_2-eq in 2100 with assumptions about limited availability of technologies and/or delayed additional mitigation.

[4]Green – 100%; yellow – 80-99%; orange – 50-79%; red – <50%; no color – data availability on successful model runs too limited.

[5] No CCS: CCS is not included in these scenarios. Nuclear phase out: No addition of nuclear power plants beyond those under construction, and operation of existing plants until the end of their lifetime. Limited Solar/Wind: a maximum of 20% global electricity generation from solar and wind power in any year of these scenarios. Limited Bioenergy: a maximum of 100 EJ/yr modern bioenergy supply globally (modern bioenergy used for heat, power, combinations, and industry was around 18 EJ/yr in 2008).

[6] Percentage increase of net present value of consumption losses in percent of baseline consumption (for scenarios from general equilibrium models) and abatement costs in percent of baseline GDP (for scenarios from partial equilibrium models) for the period 2015–2100, discounted at 5% per year.

4. Adaptation and Mitigation Measures

Many adaptation and mitigation options can help address the climate challenge, but no single option is sufficient by itself. Effective implementation depends on supporting policies, and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives. *{4}*

4.1 Common enabling factors and constraints for adaptation and mitigation responses

Adaptation and mitigation responses are underpinned by common enabling factors. These include appropriate institutions and governance, innovation and investments in environmentally sound infrastructure, livelihoods, and behavioral and lifestyle choices. *{4.1}*

Inertia in many aspects of the socio-economic system constrains adaptation and mitigation options (*high agreement*, *medium evidence*), whereas investments in technology and infrastructure that reduce GHG emissions and increase resilience to climate change can expand the availability and/or effectiveness of adaptation and mitigation options (*very high confidence*). *{4.1}*

Livelihoods, lifestyles and behaviors have a considerable influence on GHG emissions and vulnerability to climate change (*medium evidence, medium agreement*). Also, the social acceptability and/or effectiveness of climate policies are influenced by the extent to which they incentivise or depend on changes in lifestyles or behaviors. *{4.1}*

For many regions and sectors, enhanced capacities to mitigate and adapt are part of the foundation essential for managing climate change risks (*high confidence*). Constraints associated with mitigation, adaptation, and disaster risk reduction are particularly high in regions with weak institutions and/or poor coordination and cooperation in governance (*very high confidence*). *{4.1}*

4.2 Response options for adaptation

Adaptation options exist in all sectors, but their context for implementation and potential to reduce climate-related risks differs across sectors and regions. Increasing climate change will erode prospects for some adaptation options. *{4.2}*

Adaptation experience is accumulating across regions in the public and private sectors and within communities. Adaptation is becoming embedded in some planning processes, with more limited implementation of responses (*high confidence*). *{1.7, 4.2, 4.4.2.1}*

The needs along with challenges for adaptation are expected to increase with climate change (*very high confidence*). Adaptation options exist in all sectors and regions, with diverse approaches depending on their context in vulnerability reduction, disaster risk management or proactive adaptation planning (Table SPM.3). *{4.2}*

Table SPM.3: Approaches for managing the risks of climate change through adaptation. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Mitigation is considered essential for managing the risks of climate change. It is not addressed in this table as mitigation is addressed elsewhere in this SPM. Examples are presented in no specific order and can be relevant to more than one category. *{Table 4.2}*

Overlapping Approaches	Category	Examples
Vulnerability & Exposure Reduction through development, planning, & practices including many low-regrets measures	Human development	Improved access to education, nutrition, health facilities, energy, safe housing & settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.
	Poverty alleviation	Improved access to & control of local resources; Land tenure; Disaster risk reduction; Social safety nets & social protection; Insurance schemes.
	Livelihood security	Income, asset, & livelihood diversification; Improved infrastructure; Access to technology & decision-making fora; Increased decision-making power; Changed cropping, livestock, & aquaculture practices; Reliance on social networks.
	Disaster risk management	Early warning systems; Hazard & vulnerability mapping; Diversifying water resources; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements.
	Ecosystem management	Maintaining wetlands & urban green spaces; Coastal afforestation; Watershed & reservoir management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Manipulation of disturbance regimes; Community-based natural resource management.
	Spatial or land-use planning	Provisioning of adequate housing, infrastructure, & services; Managing development in flood prone & other high risk areas; Urban planning & upgrading programs; Land zoning laws; Easements; Protected areas.
Adaptation including incremental & transformational adjustments	Structural/physical	***Engineered & built-environment options***: Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.
		Technological options: New crop & animal varieties; Indigenous, traditional, & local knowledge, technologies, & methods; Efficient irrigation; Water-saving technologies; Desalinization; Conservation agriculture; Food storage & preservation facilities; Hazard & vulnerability mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling; Technology development, transfer, & diffusion.
		Ecosystem-based options: Ecological restoration; Soil conservation; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted species migration & dispersal; Ecological corridors; Seed banks, gene banks, & other *ex situ* conservation; Community-based natural resource management.
		Services: Social safety nets & social protection; Food banks & distribution of food surplus; Municipal services including water & sanitation; Vaccination programs; Essential public health services; Enhanced emergency medical services.
	Institutional	***Economic options***: Financial incentives; Insurance; Catastrophe bonds; Payments for ecosystem services; Pricing water to encourage universal provision and careful use; Microfinance; Disaster contingency funds; Cash transfers; Public-private partnerships.
		Laws & regulations: Land zoning laws; Building standards & practices; Easements; Water regulations & agreements; Laws to support disaster risk reduction; Laws to encourage insurance purchasing; Defined property rights & land tenure security; Protected areas; Fishing quotas; Patent pools & technology transfer.
		National & government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Economic diversification; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.
	Social	***Educational options***: Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing indigenous, traditional, & local knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.
		Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development; Integrated assessments.
		Behavioral options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock, & aquaculture practices; Reliance on social networks.
Transformation	Spheres of change	***Practical***: Social & technical innovations, behavioral shifts, or institutional & managerial changes that produce substantial shifts in outcomes.
		Political: Political, social, cultural, & ecological decisions & actions consistent with reducing vulnerability & risk & supporting adaptation, mitigation, & sustainable development.
		Personal: Individual & collective assumptions, beliefs, values, & worldviews influencing climate-change responses.

4.3 Response options for mitigation

Mitigation options exist in every major sector. Cost-effective mitigation is based on an integrated approach that combines measures to reduce energy use and the GHG intensity of end-use sectors, decarbonize energy supply, reduce net emissions and enhance carbon sinks in land-based sectors. *{4.3}*

Well-designed systemic and cross-sectoral mitigation strategies are more cost-effective in cutting emissions than a focus on individual technologies and sectors, with efforts in one sector determining the need for mitigation in others (*medium confidence*). *{4.3}*

Emissions ranges for baseline and mitigation scenarios that stabilize greenhouse gas concentrations at low levels (about 450 ppm CO_2-eq) are shown for different sectors and gases in Figure SPM.14. Key measures to achieve such mitigation goals include decarbonizing (i.e. reducing the carbon intensity of electricity generation *(medium evidence, high agreement)*) as well as efficiency enhancements and behavioral changes, in order to reduce energy demand compared to baseline scenarios without compromising development (*robust evidence, high agreement*). The most cost-effective mitigation options in forestry are afforestation, sustainable forest management and reducing deforestation, with large differences in their relative importance across regions; and in agriculture, cropland management, grazing land management, and restoration of organic soils (*medium evidence, high agreement*). *{4.3, Figures 4.1, 4.2, Table 4.3}*

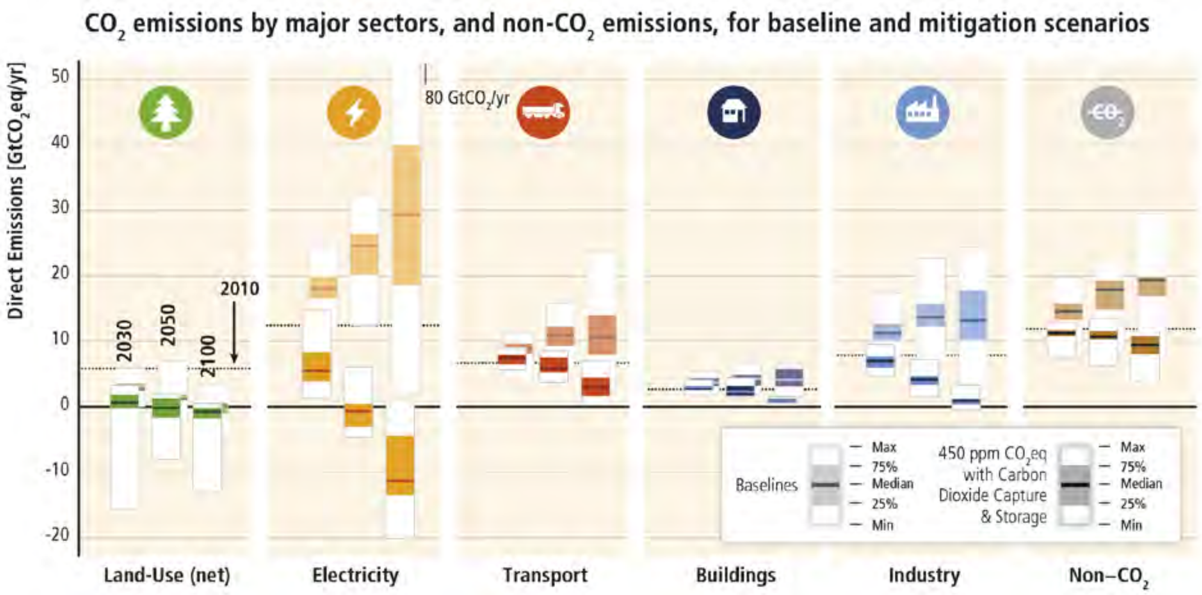


Figure SPM.14: CO_2 emissions by sector and total non-CO_2 GHGs (Kyoto gases) across sectors in baseline (faded bars) and mitigation scenarios (solid color bars) that reach around 450 (430–480) ppm CO_2-eq concentrations in 2100. Mitigation in the end-use sectors leads also to indirect emissions reductions in the upstream energy supply sector. Emissions ranges for mitigation scenarios include Carbon Capture and Storage (CCS); many models cannot reach 450 ppm CO_2-eq concentration by 2100 in the absence of CCS. *{4.3, Figure 4.1}*

Behavior, lifestyle and culture have a considerable influence on energy use and associated emissions, with high mitigation potential in some sectors, in particular when complementing technological and structural change (*medium evidence, medium agreement*). Emissions can be substantially lowered through changes in consumption patterns, adoption of energy savings measures, dietary change and reduction in food wastes. *{4.1, 4.3}*

4.4 Policy approaches at different scales, including technology development/transfer and finance

Effective adaptation and mitigation responses will depend on policies and measures across a range of scales. Support for technology development and transfer, and finance for climate responses, can complement policies that directly promote adaptation and mitigation. *{4.4}*

International cooperation is critical for effective mitigation, even though mitigation can also have local co-benefits. Adaptation focuses primarily on local to national scale outcomes, but its effectiveness can depend on coordination across governance scales, including international cooperation. *{3.1, 4.4.1}*

- The United Nations Framework Convention on Climate Change (UNFCCC) is the main multilateral forum focused on addressing climate change, with nearly universal participation. Other institutions organized at different levels of governance have resulted in diversifying international climate change cooperation. *{4.4.1}*
- The Kyoto Protocol offers lessons towards achieving the ultimate objective of the UNFCCC, particularly with respect to participation, implementation, flexibility mechanisms, and environmental effectiveness (*medium evidence, low agreement*). *{4.4.1}*
- Policy linkages among regional, national, and sub-national climate policies offer potential climate change mitigation benefits *(medium evidence, medium agreement)*. Potential advantages include lower mitigation costs, decreased emission leakage, and increased market liquidity. *{4.4.1}*
- International mechanisms for supporting adaptation planning have received less attention historically than mitigation but are increasing, and have assisted in the creation of adaptation strategies, plans, and actions at the national, sub-national, and local level *(high confidence)*. *{4.4.1}*

There has been a considerable increase in national and sub-national plans and strategies on both adaptation and mitigation since the AR4, with an increased focus on policies designed to integrate multiple objectives and to increase co-benefits *(high confidence)*. *{4.4.2.1, 4.4.2.2}*

- National governments play a key role in adaptation planning and implementation (*high agreement, robust evidence*) through their key roles in coordinating actions and providing of frameworks and support. Subnational governments and the private sector are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households, and civil society and in managing risk information and financing (*medium evidence, high agreement*). Institutional dimensions of adaptation governance play a key role in promoting the transition from planning to implementation of adaptation (*high agreement, robust evidence*). *{4.4.2.1}*
- Various carbon pricing regimes have been implemented with diverse effects. The short-run effects of cap and trade systems have been limited as a result of loose caps or caps that have not proved to be constraining *(limited evidence, medium agreement)*. Tax-based policies specifically aimed at reducing GHG emissions – alongside technology and other policies – have helped to weaken the link between GHG emissions and GDP, and in many countries, fuel taxes have had effects that are akin to sectoral carbon taxes (*robust evidence, medium agreement*). *{4.4.2.2}*
- Regulatory approaches and information measures are widely used and are often environmentally effective *(medium evidence, medium agreement)*. Examples of regulatory approaches include energy efficiency standards; examples of information programmes include labelling programs that can help consumers make better-informed decisions. *{4.4.2.2}*
- Sector-specific mitigation policies have been more widely used than economy-wide policy instruments *(high agreement, medium evidence*). The former may be better suited to address sector-specific barriers or market failures and may be bundled in packages of complementary policies. Interactions between or among mitigation policies may be synergistic or may have no additive effect on reducing emissions. *{4.4.2.2}*

Some mitigation policies raise the prices for some energy services and could hamper the ability of societies to expand access to modern energy services to underserved populations (*low confidence*). These potential adverse side-effects can be avoided with the adoption of complementary policies such as income tax rebates or other benefit transfer mechanisms (*medium confidence*). At the same time, reducing subsidies for GHG-related activities in various sectors can achieve emission reductions, depending on the social and economic context (*high confidence*). *{4.4.2.2}*

Technology policy complements other mitigation policies, and many adaptation efforts critically rely on development and diffusion of technologies and management practices *(high confidence)*. Policies exist to address market failures in R&D, but the effective use of technologies can also depend on capacities to adopt technologies appropriate to local circumstances. *{4.4.3}*

Substantial reductions in emissions would require large changes in investment patterns (*high agreement, robust evidence*). For mitigation scenarios that stabilize concentrations within the range of approximately 430-530 ppm CO_2-eq by 2100, annual investments in low carbon electricity supply and energy efficiency in key sectors are projected to rise by several hundred billion dollars per year before 2030. Within appropriate enabling environments, the private sector, along with the public sector, can play important roles in financing mitigation and adaptation (*medium evidence, high agreement*). *{4.4.4}*

Limited evidence indicates a gap between global adaptation needs and the funds available for adaptation (*medium confidence*). Financial resources have become available more slowly for adaptation than for mitigation in both developed and developing countries. There is a need for better assessment of global adaptation costs, funding and investment. Potential synergies between international finance for disaster risk management and adaptation have not yet been fully realized (*high confidence*). *{4.4.4}*

4.5 Trade-offs, synergies and interactions with sustainable development

Climate change is a threat to sustainable development. Nonetheless, there are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through integrated responses (*high confidence*). Successful implementation relies on relevant tools, appropriate governance structures and enhanced capacity to respond (*medium confidence*). *{3.5, 4.5}*

Climate change exacerbates other threats to social and natural systems, placing additional burdens particularly on the poor. Aligning climate policy with sustainable development requires attention to both adaptation and mitigation. Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, encompassing connections among human health, water, energy, land use, and biodiversity (*medium evidence, high agreement*). *{3.5, 4.5}*

Strategies and actions can be pursued now which will move towards climate-resilient pathways for sustainable development, while at the same time helping to improve livelihoods, social and economic well-being, and responsible environmental management. The effectiveness of integrated responses can be enhanced by relevant tools, appropriate governance structures, and adequate institutional and human capacity (*medium confidence*). Integrated responses are especially relevant to energy planning and implementation, interactions among water, food, energy and carbon sequestration, and urbanization, which provides substantial opportunities for enhanced resilience, reduced emissions and more sustainable development. *{3.5, 4.5}*

Introduction

The Synthesis Report (SYR) of the IPCC Fifth Assessment Report (AR5) provides a high level overview of the state of knowledge concerning the science of climate change, emphasizing new results since the publication of the IPCC Fourth Assessment Report in 2007 (AR4). The SYR synthesizes the main findings of the AR5 (IPCC) based on contributions from Working Group I (The Physical Science Basis), Working Group II (Impacts, Adaptation and Vulnerability), and Working Group III (Mitigation of Climate Change), plus two additional IPCC reports (Special Report on Renewable Energy and Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation).

The AR5 SYR is divided into four topics and a box with information relevant to Article 2 of United Nations Framework Convention on Climate Change (UNFCCC). Topic 1 (Observed changes and their causes) focuses on observational evidence for a changing climate, the impacts caused by this change and the human contributions to it. Topic 2 (Future climate changes, risks, and impacts) assesses projections of future climate change and the resultant projected impacts and risks. Topic 3 (Transformations and changes in systems) considers adaptation and mitigation as complementary strategies for reducing and managing the risks of climate change. Topic 4 (Adaptation and mitigation measures) describes individual adaptation and mitigation options and policy approaches. It also addresses integrated responses that link mitigation and adaptation with other societal objectives.

The challenge of understanding and managing risks and uncertainties are important themes in this report. See Box 1 ('Risk and the management of an uncertain future') and Box 2 ('Sources and treatment of uncertainty').

Box Introduction.1: Risk and the management of an uncertain future

Climate change exposes people, societies, economic sectors and ecosystems to risk. Risk is the potential for consequences when something of human value (including human life itself) is at stake and the outcome is uncertain. *{WGIII 2.1}*

Risks from climate change impacts arise from the interaction between hazard (triggered by an event or trend related to climate change), vulnerability (susceptibility to harm), and exposure (people, assets or ecosystems at risk). Hazards include processes that range from brief events, such as severe storms, to slow trends, such as multi-decade droughts or multi-century sea level rise. Vulnerability and exposure are both sensitive to a wide range of social and economic processes, with possible increases or decreases depending on development pathways. (Section 1.6)

Risks can also be created by policies that aim to mitigate climate change or to adapt to it, as can co-benefits. Risks of adaptation and mitigation materialise when investments are too high, too low, or misallocated. Co-benefits arise when investments in adaptation or mitigation can be managed to yield increased welfare from improved economic growth, public health, or infrastructure. *{WG III 6.3}*

Risk is often represented as the probability of occurrence of hazardous events or trends multiplied by the magnitude of the consequences if these events occur. Therefore, high risk can result not only from high probability outcomes, but also from low probability outcomes with very severe consequences. This makes it important to assess the full range of possible outcomes, from low probability 'tail outcomes to very likely outcomes. For example, it is *unlikely* that global mean sea level will rise by more than one metre in this century, but the consequence of a greater rise could be so severe that this possibility becomes a significant part of risk assessment. Similarly, *low confidence* but high consequence outcomes are also policy relevant; for instance the possibility that the Amazon forest could substantially amplify climate change atmosphere merits consideration despite our currently imperfect ability to project the outcome. (2.4) *{WGI: Table 13.5, WGII: 4.4, Box 4-3}* (Table 2.3) *{WGI Table 13.5, WGII 4.4, Box 4-3, WG III Box 3-9}*

Risk can be understood either qualitatively or quantitatively. It can be reduced and managed using a wide range of formal or informal tools and approaches that are often iterative. *{WGII 1.1.2; 19.3; WGIII 2.5}* Useful approaches for managing risk do not necessarily require that risk levels can be accurately quantified. Approaches recognizing diverse qualitative values, goals, and priorities, based on ethical, psychological, cultural, or social factors, could increase the effectiveness of risk management. *{WGII 2.4, 2.5; WGIII 2.4, 2.5, 3.4}*

Box Introduction.2: Communicating the degree of certainty in assessment findings

An integral feature of IPCC reports is the communication of the strength of and uncertainties in scientific understanding underlying assessment findings. Uncertainty can result from a wide range of sources. Uncertainties in the past and present are the result of limitations of available measurements, especially for rare events, and the challenges of evaluating causation in complex or multi-component processes that can span physical, biological, and human systems. For the future, climate change involves changing likelihoods of diverse outcomes. Many processes and mechanisms are well understood, but others are not. Complex interactions among multiple climatic and non-climatic influences changing over time lead to persistent uncertainties, which in turn, lead to the possibility of surprises. Compared to past IPCC reports, the AR5 assesses a substantially larger knowledge base of scientific, technical, and socio-economic literature. *{WGI: 1.4, WGII: 1.1.2, SPM A-3, WGIII:2.3}*

The IPCC *Guidance Note on Uncertainty* (2010) defines a common approach to evaluating and communicating the degree of certainty in findings of the assessment process. Each finding is grounded in an evaluation of underlying evidence and agreement. In many cases, a synthesis of evidence and agreement supports an assignment of confidence, especially for findings with stronger agreement and multiple independent lines of evidence. The degree of certainty in each key finding of the assessment is based on the type, amount, quality, and consistency of evidence (e.g., data, mechanistic understanding, theory, models, expert judgment) and the degree of agreement. The summary terms for evidence are: *limited*, *medium*, or *robust*. For agreement, they are *low*, *medium*, or *high*. Levels of confidence include five qualifiers: *very low*, *low*, *medium*, *high*, and *very high*. The likelihood, or probability, of some well-defined outcome having occurred or occurring in the future can be described quantitatively through the following terms: *virtually certain,* 99–100% probability; *extremely likely,* 95–100%; *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%; *extremely unlikely,* 0–5%; and *exceptionally unlikely,* 0–1%. Unless otherwise indicated, findings assigned a likelihood term are associated with *high* or *very high confidence*. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers. *{WG II Box SPM.3, WG I SPM B, WG III 2.1}*

Topic 1: Observed Changes and their Causes

Human influence on the climate system is clear, and recent human emissions of greenhouse gases are higher than ever. The climate changes that have already occurred have had widespread and consequential impacts on human and natural systems.

1.1 Introduction

Topic 1 focuses on observational evidence of a changing climate, the impacts caused by this change and the human contributions to it. It discusses observed changes in climate (1.2) and external influences on climate (forcings), differentiating those forcings that are of anthropogenic origin, and their contributions by economic sectors and greenhouse gases (1.3). Section 1.4 attributes causes to observed changes in human and natural systems and determines the degree to which those impacts can be attributed to climate change. The changing probability of extreme events and their causes are discussed in Section 1.5, followed by an account of exposure and vulnerability within a risk context (1.6) and a section on adaptation and mitigation experience (1.7).

1.2 Observed changes in the climate system

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.

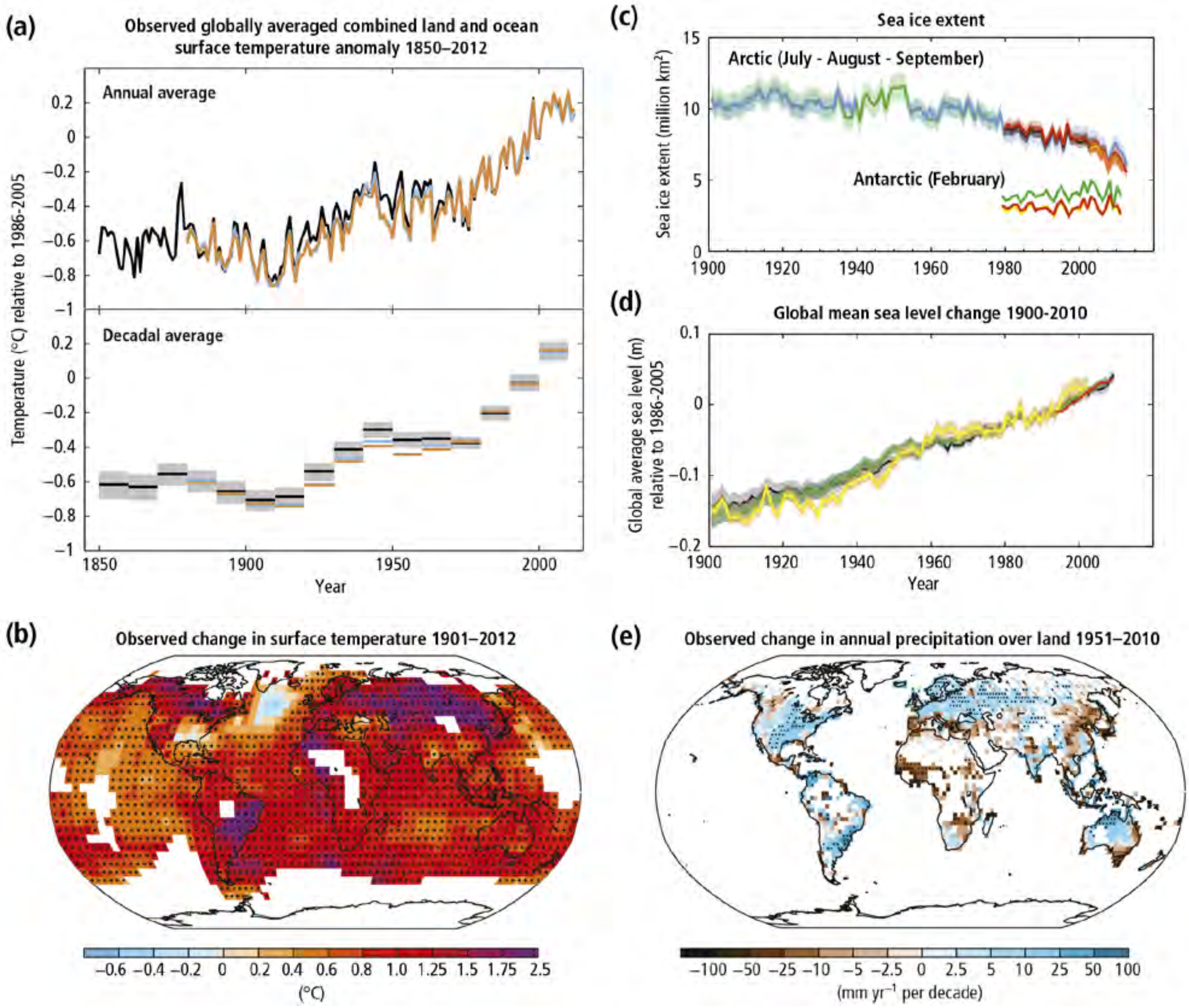


Figure 1.1: Multiple observed indicators of a changing global climate system. (a) Observed globally averaged combined land and ocean surface temperature anomalies (relative to the mean of 1986 to 2005 period, as annual and decadal averages) with an estimate of decadal mean uncertainty included for one data set (grey shading). *{WGI Figure SPM.1; WGI Figure 2.20; a listing of data sets and further technical details are given in the WGI Technical Summary Supplementary Material WGI TS.SM.1.1}* (b) Map of the observed surface temperature change, from 1901 to 2012, derived from temperature trends determined by linear regression from one data set (orange line in Panel a). Trends have been calculated where data availability permitted a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period), other areas are white. Grid boxes where the trend is significant, at the 10% level, are indicated by a + sign. *{WGI Figure SPM.1; WGI Figure 2.21; WGI Figure TS.2; a listing of data sets and further technical details are given in the WGI Technical Summary Supplementary Material WGI TS.SM.1.2}* (c) Arctic (July to September average) and Antarctic (February) sea ice extent. *{WGI Figure SPM.3; WGI Figure 4.3; WGI Figure 4.SM.2; a listing of data sets and further technical details are given in the WGI Technical Summary Supplementary Material WGI TS.SM.3.2}*. (d) Global mean sea level relative to the 1986–2005 mean of the longest running data set, and with all data sets aligned to have the same value in 1993, the first year of satellite altimetry data. All time series (coloured lines indicating different data sets) show annual values, and where assessed, uncertainties are indicated by coloured shading. *{WGI Figure SPM.3; WGI Figure 3.2; a listing of data sets and further technical details are given in the WGI Technical Summary Supplementary Material WGI TS.SM.3.4}*. (e) Map of observed precipitation change, from 1951 to 2010; trends in annual accumulation calculated using the same criteria as in Panel b. *{WGI SPM Figure.2; WGI TS TFE.1, Figure 2; WGI Figure 2.29. A listing of data sets and further technical details are given in the WGI Technical Summary Supplementary Material WGI TS.SM.2.1.*

1.2.1 Atmosphere

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, where such assessment is possible, 1983–2012 was *very likely* the warmest 30-year period of the last 800 years (*high confidence*) and *likely* the warmest 30-year period of the last 1400 years (*medium confidence*). *{WGI 2.4.3, 5.3.5}*

The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06] °C[11],over the period 1880 to 2012, for which multiple independently produced datasets exist. The total increase between the average of the 1850–1900 period and the 2003–2012 period is 0.78 [0.72 to 0.85] °C, based on the single longest dataset available (Figure 1.1). *{WGI SPM B.1, 2.4.3}*

In addition to robust multi-decadal warming, the globally averaged surface temperature exhibits substantial decadal and interannual variability (see Figure 1.1). Due to this natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over the past 15 years (1998–2012; 0.05 [–0.05 to 0.15] °C per decade), which begins with a strong El Niño, is smaller than the rate calculated since 1951 (1951–2012; 0.12 [0.08 to 0.14] °C per decade; see Box 1.1). *{WGI SPM B.1, 2.4.1}*

Based on multiple independent analyses of measurements, it is *virtually certain* that globally the troposphere has warmed and the lower stratosphere has cooled since the mid-20th Century. There is *medium confidence* in the rate of change and its vertical structure in the Northern Hemisphere extratropical troposphere.*{WGI 2.4.4}*

Confidence in precipitation change averaged over global land areas since 1901 is *low* prior to 1951 and *medium* afterwards. Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has *likely* increased since 1901 (*medium confidence* before and *high confidence* after 1951). For other latitudes area-averaged long-term positive or negative trends have *low confidence* (Figure 1.1). *{WGI Figure SPM.2, 2.5.1}*

[11] Ranges in square brackets indicate a 90% uncertainty interval unless otherwise stated. The 90% uncertainty interval is expected to have a 90% likelihood of covering the value that is being estimated. Uncertainty intervals are not necessarily symmetric about the corresponding best estimate. A best estimate of that value is also given where available.

1.2.2 Ocean

Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*) (Figure 1.2). It is *virtually certain* that the upper ocean (0−700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971. It is *likely* that the ocean warmed from 3000 m to the bottom for the period 1992 to 2005. ***{WGI SPM B.2, 3.2, Box 3.1; Figure 1.2}***

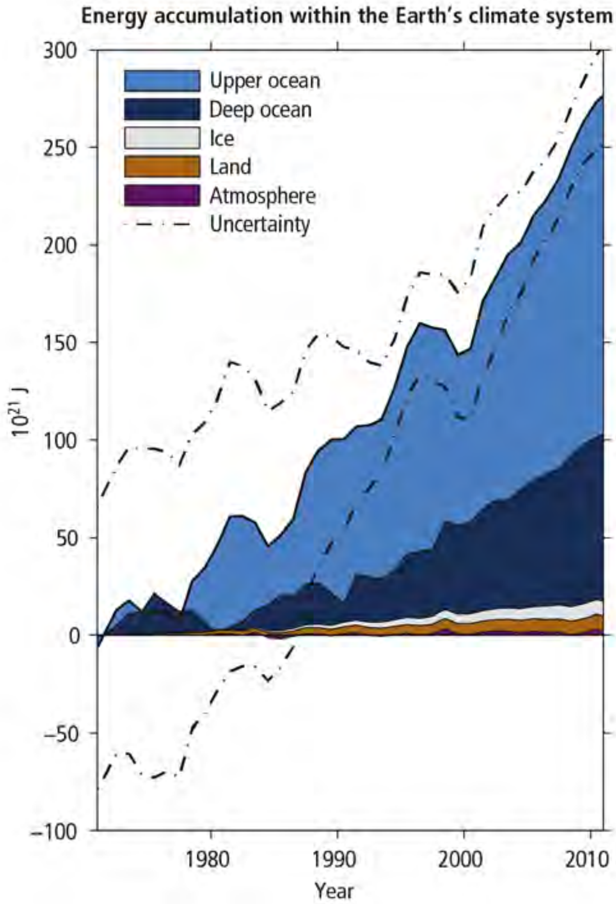


Figure 1.2: Energy accumulation within the Earth's climate system. Estimates are in 10^{21} J and are given relative to 1971 and from 1971 to 2010, unless otherwise indicated. Components included are upper ocean (above 700 m), deep ocean (below 700 m; including below 2000 m estimates starting from 1992), ice melt (for glaciers and ice caps, Greenland and Antarctic ice sheet estimates starting from 1992, and Arctic sea ice estimate from 1979 to 2008), continental (land) warming, and atmospheric warming (estimate starting from 1979). Uncertainty is estimated as error from all five components at 90% confidence intervals. See WGI Chapter 3, Box 3.1, Figure 1 for further details and data sources.

It is *very likely* that regions of high surface salinity have become more saline, while regions of low salinity have become fresher since the 1950s. These regional trends in ocean salinity provide indirect evidence for changes in evaporation and precipitation over the oceans and thus for changes in the global water cycle *(medium confidence)*. There is no observational evidence of a long-term trend in the Atlantic Meridional Overturning Circulation (AMOC). *{WGI SPM B.2, 2.5, 3.3, 3.4.3, 3.5, 3.6.3}*

Oceanic uptake of anthropogenic CO_2 has resulted in acidification of the ocean, with a decrease in the pH of surface seawater by 0.1 since the beginning of the industrial era (*high confidence*). There is *medium confidence* that oxygen concentrations have decreased in the open ocean in many ocean regions since the 1960s, with a *likely* expansion of tropical oxygen minimum zones in recent decades. *{WGI SPM B.2, 3.8.1, 3.8.2, 3.8.3, Figure 3.20}*

1.2.3 Cryosphere

Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice (Figure 1.1) and Northern Hemisphere spring snow cover have continued to decrease in extent (*high confidence*). There is *high confidence* that permafrost temperatures have increased in most regions since the early 1980s. There is *high confidence* that there are strong regional differences in Antarctic sea ice area, with a *very likely* increase in total area. *{WGI 4.2–4.7}*

Glaciers have lost mass and contributed to sea level rise throughout the 20th century. The rate of ice mass loss from the Greenland ice sheet has *very likely* substantially increased over the period 1992 to 2011. The rate of ice mass loss from the Antarctic ice sheet, the northern Antarctic Peninsula and the Amundsen Sea sector of West Antarctica, has *likely* increased over the same period. *{WGI 4.3.3, 4.4.2, 4.4.3}*

The average decadal extent of Arctic sea ice has decreased in every season and in every successive decade *(high confidence*) since satellite observations commenced in 1979. For the summer sea ice minimum (perennial sea ice), the decrease was *very likely* in the range of 9.4% to 13.6% per decade (range of 0.73 to 1.07 million km^2 per decade) (Figure 1.1). It is *very likely* that the annual mean Antarctic sea ice extent increased at a rate in the range of 1.2% to 1.8% per decade (range of 0.13 to 0.20 million km^2 per decade) between 1979 and 2012, with strong regional differences *(high confidence). {WGI 4.2.2, 4.2.3}*

There is *very high confidence* that northern hemisphere snow cover has decreased since the mid 20th century. There is *high confidence* that permafrost temperatures have increased in most regions of the Northern Hemisphere since the early 1980s, with reductions in thickness and areal extent in some regions. *{WG1 4.7.2}*

1.2.4 Sea Level

Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (Figure 1.1). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). *{WGI SPM B.4, 3.7.2, 5.6.3, 13.2}*

It is *very likely* that the mean rate of global averaged sea level rise was 1.7 [1.5 to 1.9] mm yr^{-1} between 1901 and 2010 and 3.2 [2.8 to 3.6] mm yr^{-1} between 1993 and 2010. Tide-gauge and satellite altimeter data are consistent regarding the higher rate during the latter period. It is *likely* that similarly high rates occurred between 1920 and 1950. *{WGI SPM B.4, 3.7.4, 13.2}*

Since the early 1970s, glacier mass loss and ocean thermal expansion from warming together explain about 75% of the observed global mean sea level rise (*high confidence*). Over the period 1993–2010, global mean sea level rise is, with *high confidence*, consistent with the sum of the observed contributions from ocean thermal expansion, due to warming, from changes in glaciers, the Greenland ice sheet, the Antarctic ice sheet, and land water storage. *{WGI SPM B.4, 13.3.6}*

Rates of sea level rise over broad regions can be several times larger or smaller than the global mean sea level rise for periods of several decades, due to fluctuations in ocean circulation. Since 1993, the regional rates for the Western Pacific are up to three times larger than the global mean, while those for much of the Eastern Pacific are near zero or negative. *{WGI 3.7.3, FAQ 13.1}*

There is *very high confidence* that maximum global mean sea level during the last interglacial period (129,000 to 116,000 years ago) was, for several thousand years, at least 5 m higher than present and *high confidence* that it did not exceed 10 m above present. During the last interglacial period, the Greenland ice sheet *very likely* contributed between 1.4 and 4.3 m to the higher global mean sea level, implying with *medium confidence* an additional contribution from the Antarctic ice sheet. This change in sea level occurred in the context of different orbital forcing and with high-latitude surface temperature, averaged over several thousand years, at least 2 °C warmer than present (*high confidence). {WGI SPM B.4, 5.3.4, 5.6.2, 13.2.1}*

Box 1.1: Recent temperature trends and their implications

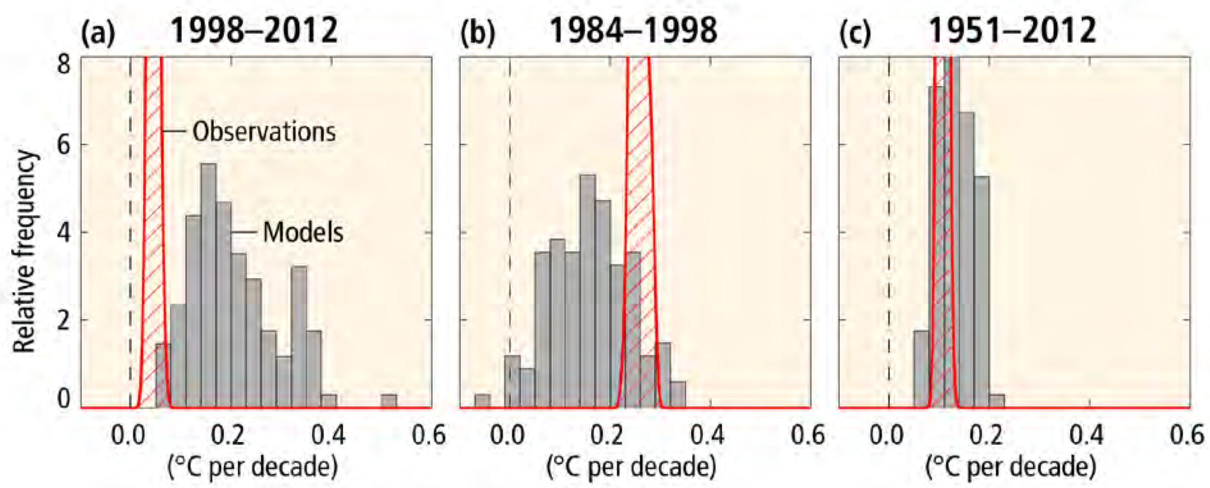
The observed reduction in surface warming trend over the period 1998 to 2012 as compared to the period 1951 to 2012, is due in roughly equal measure to a reduced trend in radiative forcing and a cooling contribution from natural internal variability, which includes a possible redistribution of heat within the ocean (*medium confidence*). The rate of warming of the observed global mean surface temperature over the period from 1998 to 2012 is estimated to be around one-third to one-half of the trend over the period from 1951 to 2012 (Box 1.1, Figures 1a and 1c). Even with this reduction in surface warming trend, the climate system has *very likely* continued to accumulate heat since 1998 (Figure 1.2), and sea level has continued to rise (Figure 1.1). *{WGI SPM D.1, Box 9.2}*

The radiative forcing of the climate system has continued to increase during the 2000s, as has its largest contributor, the atmospheric concentration of CO_2. However, the radiative forcing has been increasing at a lower rate over the period from 1998 to 2011, compared to 1984 to 1998 or 1951 to 2011, due to cooling effects from volcanic eruptions and the cooling phase of the solar cycle over the period from 2000 to 2009. There is, however, *low confidence* in quantifying the role of the forcing trend in causing the reduction in the rate of surface warming. *{WGI 8.5.2, Box 9.2}*

For the period from 1998 to 2012, 111 of the 114 available climate-model simulations show a surface warming trend larger than the observations (Box 1.1, Figure 1a). There is *medium confidence* that this difference between models and observations is to a substantial degree caused by internal climate variability, which sometimes enhances and sometimes counteracts the long-term externally forced warming trend (compare Box 1.1 Figures 1a and 1b; during the period from 1984 to 1998, most model simulations show a smaller warming trend than observed). Internal variability thus diminishes the relevance of short trends for long-term climate change. The difference between models and observations may also contain contributions from inadequacies in the solar, volcanic, and aerosol forcings used by the models and, in some models, from an overestimate of the response to increasing greenhouse gas and other anthropogenic forcing (the latter dominated by the effects of aerosols). *{WGI 2.4.3, 9.4.1; 10.3.1.1, 11.2.3, 11.3.1, 11.3.2, WGI Box 9.2}*

For the longer period from 1951 to 2012, simulated surface warming trends are consistent with the observed trend (Box 1.1, Figure 1c, *very high confidence*). Furthermore, the independent estimates of radiative forcing, of surface warming, and of observed heat storage (the latter available since 1970) combine to give a heat budget for the Earth that is consistent with the assessed *likely* range of equilibrium climate sensitivity (1.5–4.5 ºC)[12]. The record of observed climate change has thus allowed characterisation of the basic properties of the climate system that have implications for future warming, including the equilibrium climate sensitivity and the transient climate response (see SYR topic 2). *{WGI Box 9.2, 10.8.1, 10.8.2, Box 12.2, Box 13.1}*

[12] The connection between the heat budget and equilibrium climate sensitivity, which is the long-term surface warming under an assumed doubling of the atmospheric CO_2 concentration, arises because a warmer surface causes enhanced radiation to space, which counteracts the increase in the Earth's heat content. How much the radiation to space increases for a given increase in surface temperature, depends on the same feedback processes that determine equilibrium climate sensitivity.



Box 1.1, Figure 1: Trends in the global mean surface temperature over the periods from 1998 to 2012 (a), 1984 to 1998 (b), and 1951 to 2012 (c), from observations (red) and the 114 available simulations with current-generation climate models (grey bars). The height of each grey bar indicates how often a trend of a certain magnitude (in °C per decade) occurs among the 114 simulations. The width of the red-hatched area indicates the statistical uncertainty that arises from constructing a global average from individual station data. This observational uncertainty differs from the one quoted in the text of Section 1.2.1; there, an estimate of internal variability is also included. Here, by contrast, the magnitude of internal variability is characterised by the spread of the model ensemble. *{based on WGI Box 9.2, Figure 1}*

1.3 Past and recent drivers of climate change

Natural and anthropogenic substances and processes that alter the Earth's energy budget are physical drivers of climate change. Radiative forcing (RF) quantifies the perturbation of energy into the Earth system caused by these drivers. RFs larger than zero lead to a near-surface warming, and RFs smaller than zero lead to a cooling. RF is estimated based on in-situ and remote observations, properties of greenhouse gases and aerosols, and calculations using numerical models. The RF over the 1750–2011 period is shown in Figure 1.3 in major groupings. The 'Other Anthropogenic' group is principally comprised of cooling effects from aerosol changes, with smaller contributions from ozone changes, land-use reflectance changes and other minor terms. {WGI SPM C, 8.1, 8.5.1}

Anthropogenic greenhouse gas emissions have increased since the preindustrial era driven largely by economic and population growth. From 2000 to 2010 emissions were the highest in history. Historical emissions have driven atmospheric concentrations of CO_2, CH_4 and N_2O, to levels that are unprecedented in at least the last 800,000 years, leading to an uptake of energy by the climate system.

1.3.1 Natural and anthropogenic radiative forcings

Atmospheric concentrations of greenhouse gases are at levels that are unprecedented in at least 800,000 years. Concentrations of CO_2, CH_4 and N_2O have all shown large increases since 1750 (40%, 150% and 20%, respectively) (Figure 1.3). CO_2 concentrations are increasing at the fastest observed decadal rate of change (2.0 ± 10 ppm yr^{-1}). After almost one decade of stable CH_4 concentrations since the late 1990s, atmospheric measurements have shown renewed increases since 2007. N_2O concentrations have steadily increased at a rate of 0.73 ± 0.03 ppb yr^{-1} over the last three decades. *{WGI 2.2.1, 6.1.3, 6.3}*

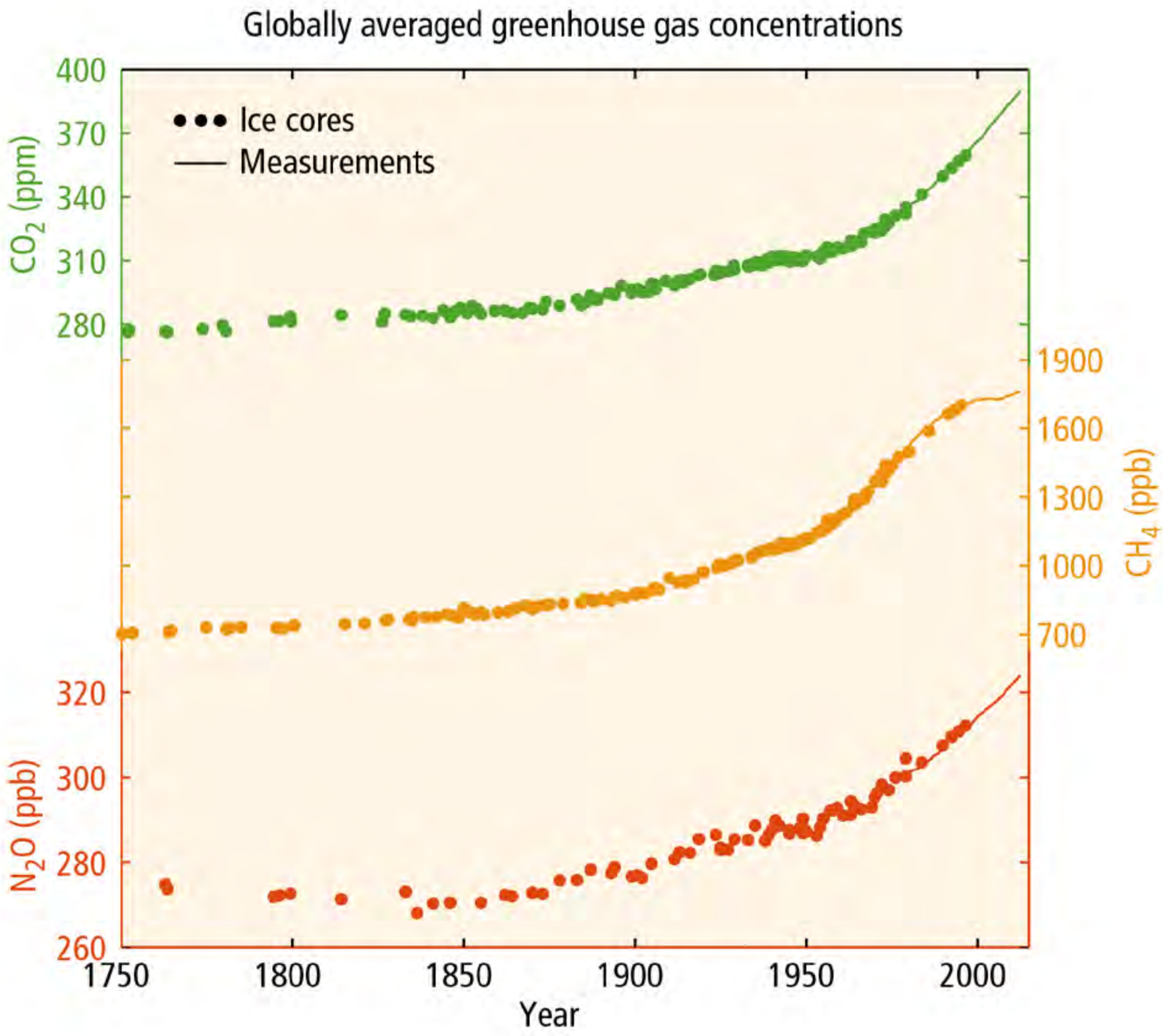


Figure 1.3: Observed changes in atmospheric greenhouse gas concentrations. Atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Data from ice cores (symbols) and direct atmospheric measurements (lines) are overlaid. *{WGI 2.2, 6.2, 6.3, WGI Figure 6.11}*

The total anthropogenic RF over 1750-2011 is calculated to be a warming effect of 2.3 [1.1 to 3.3] W m^{-2} (Figure 1.4), and it has increased more rapidly since 1970 than during prior decades. Carbon dioxide is the largest single contributor to RF over 1750-2011 and its trend since 1970. The total anthropogenic RF estimate for 2011 is substantially higher (43%) than the estimate reported in AR4 for the year 2005. This is caused by a combination of continued growth in most greenhouse gas concentrations and an improved estimate of RF from aerosols. *{WGI SPM C, 8.5.1}*

The RF from aerosols, which includes cloud adjustments, is better understood and indicates a weaker cooling effect than in AR4. The aerosol RF over 1750-2011 is estimated as –0.9 [–1.9 to −0.1] W m^{-2} *(medium confidence)*. RF from aerosols has two competing components: a dominant cooling effect from most aerosols and their cloud adjustments and a partially offsetting warming contribution from black carbon absorption of solar radiation. There is *high confidence* that the global mean total aerosol RF has counteracted a substantial portion of RF from well-mixed greenhouse gases. Aerosols continue to contribute the largest uncertainty to the total RF estimate. *{WGI SPM C, 7.5, 8.3, 8.5.1}*

Changes in solar irradiance and volcanic aerosols cause natural RF (Figure 1.4). The RF from stratospheric volcanic aerosols can have a large cooling effect on the climate system for some years after major volcanic eruptions. Changes in total solar irradiance are calculated to have contributed only around 2% of the total radiative forcing in 2011, relative to 1750. *{WGI 8.4}*

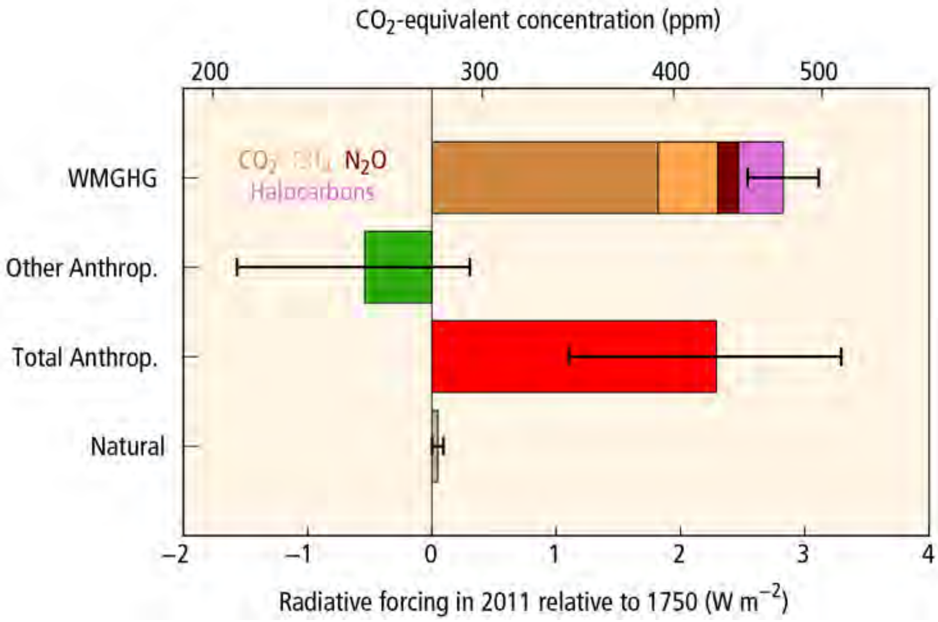


Figure 1.4: Radiative forcing (RF) of climate change during the industrial era (1750–2011). Bars show RF from well-mixed greenhouse gases (WMGHG), other anthropogenic forcings, total anthropogenic forcings and natural forcings. The error bars indicate the 5%-95% uncertainty. Other anthropogenic forcings include aerosol, land-use surface reflectance and ozone changes. Natural forcings include solar and volcanic effects. RF is quoted in terms of CO_2 equivalent concentrations[13] on the top axis for comparison to the mitigation pathways discussed in Topic 3. *{Data from WGI 7.5 and Table 8.6}*

1.3.2 Human activities affecting emission drivers

About half of the cumulative anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years (*high confidence*). Cumulative anthropogenic CO_2 emissions of 2040 ± 310 $GtCO_2$ were added to the atmosphere between 1750 and 2011. Since 1970 cumulative CO_2 emissions from fossil fuel combustion, cement production and flaring have tripled and, cumulative CO_2 emissions from forestry and other land use (FOLU)[14] have increased by about 40% (Figure 1.5)[15]. *{WGI 6.3.1. 6.3.2, WGIII SPM.3}*

[13] CO_2 equivalent concentration is a metric for comparing radiative forcing of a mix of different GHGs and aerosols at a particular time, see Box 3.2 and glossary.
[14] Forestry and other land use (FOLU)—also referred to as LULUCF (land use, land-use change and forestry)—is the subset of agriculture, forestry and other land use (AFOLU) emissions and removals of GHGs related to direct human-induced LULUCF activities, excluding agricultural emissions and removals (see WGIII AR5 Glossary).
[15] Numbers from WGI 6.3 converted into $GtCO_2$ units. Small differences in cumulative emissions from Working Group 3 *{SPM.3, TS.3}* are due to different approaches to rounding, different end years and the use of different data sets for emissions from FOLU. Estimates remain extremely close, given their uncertainties.

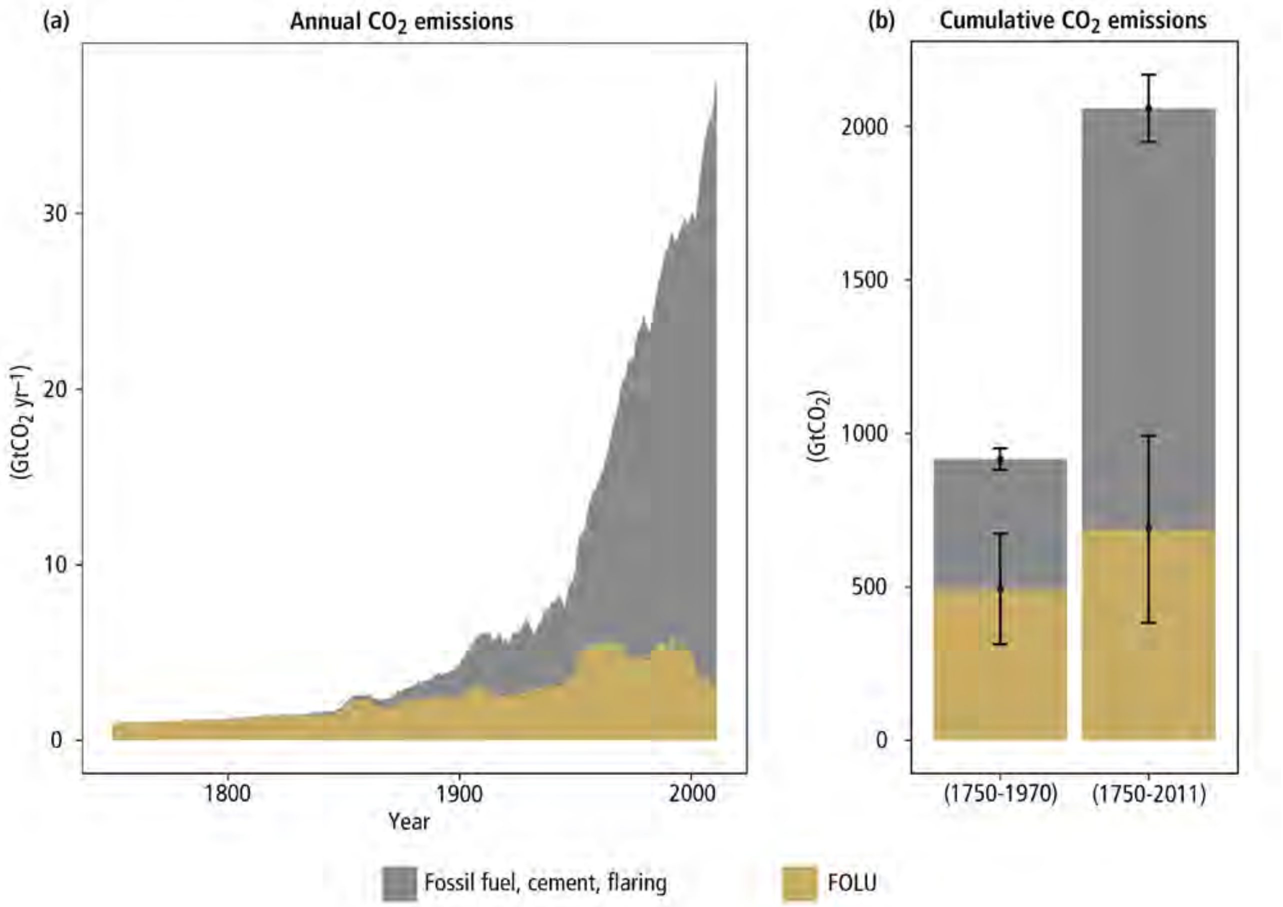


Figure 1.5: Annual anthropogenic CO_2 emissions ($GtCO_2$ yr^{-1}) from fossil fuel combustion, cement production and flaring, and forestry and other land use (FOLU), 1750–2011. Cumulative totals and uncertainties are shown on right hand side. *{modified from WG I Figure TS.4 and WG3 Figure TS.2}*

About 40% of these anthropogenic CO_2 emissions have remained in the atmosphere (880 ± 35 $GtCO_2$) since 1750. The rest was removed from the atmosphere by sinks, and stored in natural carbon cycle reservoirs. Sinks from ocean uptake and vegetation with soils account, in roughly equal measures, for the remainder of the cumulative budget. *{WG1 3.8.1, 6.3.1}*

Total annual anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute decadal increases towards the end of this period (*high confidence*). Despite a growing number of climate change mitigation policies, annual GHG emissions grew on average by 1.0 $GtCO_2$eq (2.2%) per year, from 2000 to 2010, compared to 0.4 $GtCO_2$eq (1.3%) per year, from 1970 to 2000 (Figure 1.6).[16] Total anthropogenic GHG emissions from 2000 to 2010 were the highest in human history and reached 49 (±4.5) $GtCO_2$eq yr^{-1} in 2010. The global economic crisis of 2007/2008 reduced emissions only temporarily. *{WG III SPM.3 1.3, 5.2, 13.3, 15.2.2, Box TS.5, Figure 15.1}*

CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% to the total GHG emission increase between 1970 and 2010, with a contribution of similar percentage over the 2000–2010 period (*high confidence*). Fossil-fuel-related CO_2 emissions reached 32 (±2.7) $GtCO_2$ yr^{-1}, in 2010, and grew further by about 3% between 2010 and 2011, and by about 1% to 2% between 2011 and 2012. CO_2 remains the major anthropogenic greenhouse gas, accounting for 76% of total anthropogenic GHG emissions in 2010. Of the total, 16% comes from methane (CH_4), 6.2% from nitrous oxide (N_2O), and

[16] CO_2 equivalent emission is a common scale for comparing emissions of different GHGs. Throughout the SYR, when historical emissions of GHGs are provided in $GtCO_2$eq, they are weighted by Global Warming Potentials with a 100-year time horizon (GWP_{100}), taken from the IPCC Second Assessment Report (SAR) unless otherwise stated. A unit abbreviation of $GtCO_2$eq is used. {see Box 3.2*}*

2.0% from fluorinated gases (Figure 1.6)[17]. Annually, since 1970, about 25% of anthropogenic GHG emissions have been in the form of non-CO_2 gases.[18] *{WG III SPM.3 1.2, 5.2}*

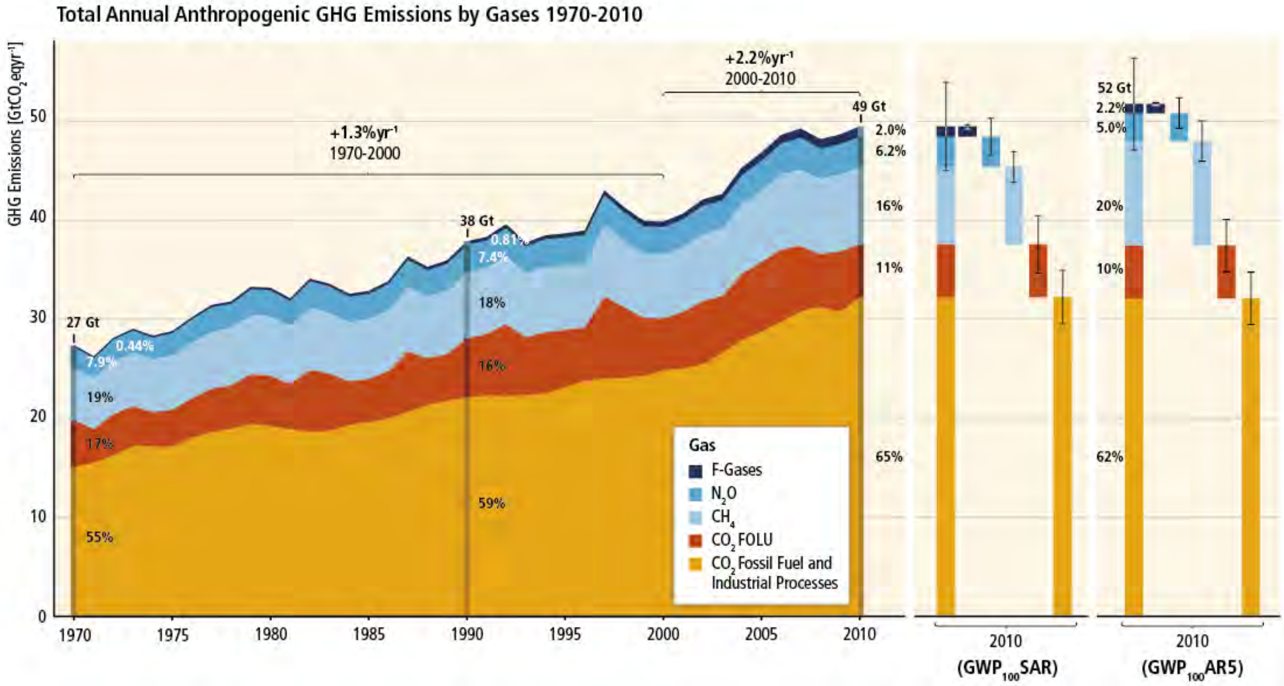


Figure 1.6: Total annual anthropogenic GHG emissions ($GtCO_2eq\ yr^{-1}$), by gas, 1970–2010. CO_2 from fossil fuel combustion and industrial processes; CO_2 from forestry and other land use (FOLU); methane (CH_4); nitrous oxide (N_2O); fluorinated gases covered under the Kyoto Protocol (F-gases). On the right side of the figure, GHG emissions in 2010 are shown again broken down into these components with the associated uncertainties (90% confidence interval) indicated by the error bars. Global CO_2 emissions from fossil fuel combustion are known with an 8% uncertainty margin (90% confidence interval). There are very large uncertainties (of the order of ±50%) attached to the CO_2 emissions from FOLU. Uncertainty about the global emissions of CH_4, N_2O and the F-gases has been estimated at 20%, 60% and 20%, respectively. 2010 was the most recent year for which emission statistics on all gases as well as assessments of uncertainties were essentially complete at the time of data cut off for this report. Emissions are converted into CO_2 equivalents, based on Global Warming Potential with a 100-year time horizon (GWP_{100}), taken from the IPCC Second Assessment Report (right and middle panel) and Fifth Assessment Report (left panel c). Other metric choices would change the contributions of different gases (see Box 3.2). *{WG III Figure SPM.1}* The uncertainty estimates only account for uncertainty in emissions, not in the GWPs (as given in WGI 8.7).

Total annual anthropogenic GHG emissions have increased by about 10 $GtCO_2eq$ between 2000 and 2010. This increase directly came from the energy (47%), industry (30%), transport (11%) and building (3%) sectors (*medium confidence*). Accounting for indirect emissions raises the contributions by the building and industry sectors (*high confidence*). Since 2000, GHG emissions have been growing in all sectors, except in agriculture, forestry and other land use (AFOLU)[14]. In 2010, 35% of GHG emissions were released by the energy sector, 24% (net emissions) from AFOLU, 21% by industry, 14% by transport and 6.4 % by the building sector. When emissions from electricity and heat production are attributed to the sectors that use the final energy (i.e. indirect emissions), the shares of the industry and building sectors in global GHG emissions are increased to 31% and 19%, respectively (Figure 1.7). *{WG III SPM.3 7.3, 8.2, 9.2, 10.3, 11.2} See also Box 3.2 for contributions from various sectors, based on metrics other than GWP_{100}.*

[17] Using the most recent GWP_{100} values from the Fifth Assessment Report *{WG1 8.7}* instead of GWP_{100} values from the Second Assessment Report, global GHG emission totals would be slightly higher (52 $GtCO_2eq$/yr) and non-CO_2 emission shares would be 20% for CH_4, 5% for N_2O and 2.2% for F-gases.
[18] For this report, data on non-CO_2 GHGs, including fluorinated gases, were taken from the EDGAR database *{WG3 Annex II.9}*, which covers substances included in the Kyoto Protocol in its first commitment period.

Greenhouse Gas Emissions by Economic Sectors

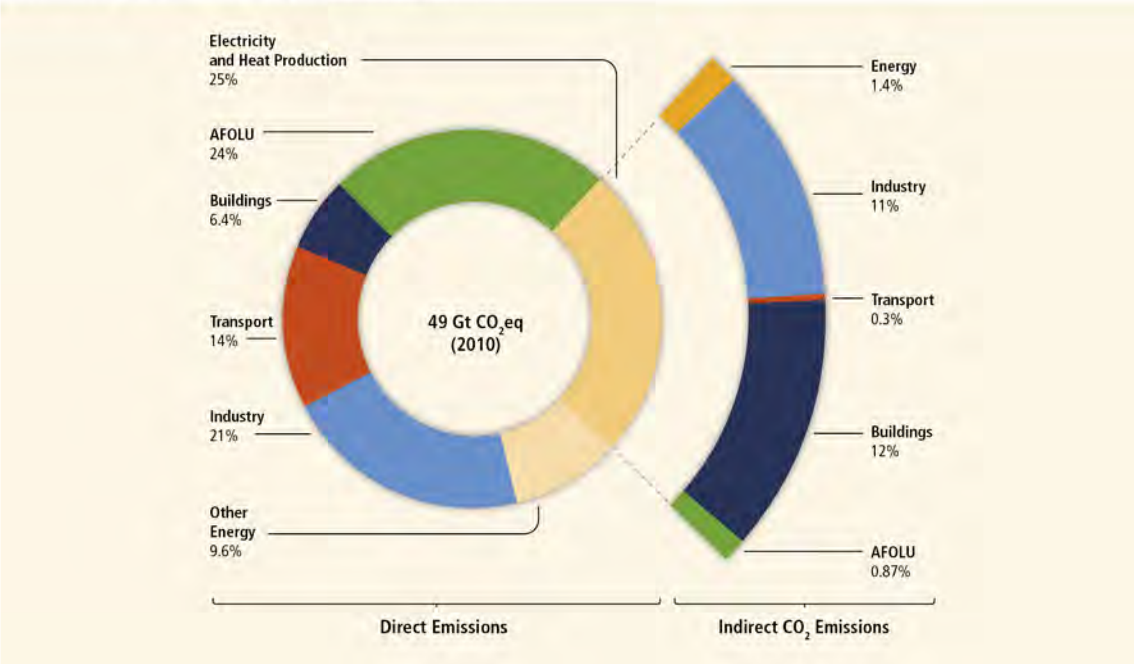


Figure 1.7: Total anthropogenic GHG emissions ($GtCO_2eq\ yr^{-1}$) from economic sectors in 2010. The circle shows the shares of direct GHG emissions (in % of total anthropogenic GHG emissions) from five economic sectors in 2010. The pull-out shows how shares of indirect CO_2 emissions (in % of total anthropogenic GHG emissions) from electricity and heat production are attributed to sectors of final energy use. 'Other Energy' refers to all GHG emission sources in the energy sector as defined in Annex II, other than electricity and heat production *{WGIII Annex II.9.1}*. The emission data on agriculture, forestry and other land use (AFOLU) includes land-based CO_2 emissions from forest fires, peat fires and peat decay that approximate to net CO_2 flux from the sub-sectors of forestry and other land use (FOLU) as described in Chapter 11 of the WGIII report. Emissions are converted into CO_2 equivalents based on $GWP_{100,}$ taken from the IPCC Second Assessment Report.[6] Sector definitions are provided in Annex II.9. *{WGIII Figure SPM.2}*

Globally, economic and population growth continue to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion. The contribution of population growth between 2000 and 2010 remained roughly identical to that of the previous three decades, while the contribution of economic growth rose sharply (*high confidence*). Between 2000 and 2010, both drivers outpaced emission reductions from improvements in energy intensity of GDP (Figure 1.8). Increased use of coal relative to other energy sources has reversed the long-standing trend in gradual decarbonization of the world's energy supply. *{WG III SPM.3 1.3, 5.3, 7.2, 14.3, TS.2.2}*

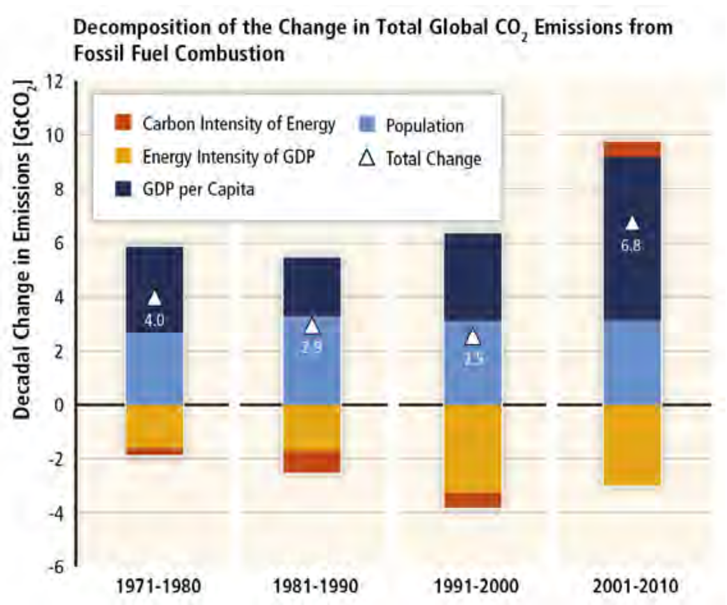


Figure 1.8: Decomposition of the decadal change in total global CO_2 emissions from fossil fuel combustion by four driving factors. Factors are: population, income (GDP) per capita, energy intensity of GDP and carbon intensity of energy. The bar segments show the changes associated with each individual factor, holding the respective other factors constant. Total decadal changes are indicated by a triangle. Changes are measured in $GtCO_2$ emissions per decade; income is converted into common units, using purchasing power parities. *{WG III SPM.3}*

1.4 Attribution of climate changes and impacts

The causes of observed changes in the climate system, as well as in any natural or human system impacted by climate, are established following a consistent set of methods. Detection addresses the question of whether climate or a natural or human system affected by climate has actually changed in a statistical sense, while attribution evaluates the relative contributions of multiple causal factors to an observed change or event with an assignment of statistical confidence[19]. Results from attribution studies support projections of future climate change (see Topic 2); {WGI 10.8}, as well as analyses of the sensitivity of natural or human systems to future climate change, including the risks associated with these sensitivities. Attribution of observed impacts to climate change considers the links between observed changes in natural or human systems and observed climate change, regardless of its cause. In contrast, attribution of climate change to causes quantifies the links between observed climate change and human activity, as well as other natural climate drivers.

Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, and in global mean sea level rise; and it is *extremely likely* to have been the dominant cause of the observed warming since the mid-20th century. In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate.

1.4.1 Attribution of climate changes to human and natural influences on the climate system

It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together (Figure 1.9). The best estimate of the human induced contribution to warming is similar to the observed warming over this period. Greenhouse gases contributed a global mean surface warming *likely* to be in the range of 0.5 °C to 1.3 °C over the period 1951 to 2010, with further contributions from other anthropogenic forcings, including the cooling effect of

[19] definitions were taken from the 'Good Practice Guidance Paper on Detection and Attribution, the agreed product of the IPCC Expert Meeting on Detection and Attribution Related to Anthropogenic Climate Change'; see glossary'

aerosols, natural forcings, and from natural internal variability (see Figure 1.9). Together these assessed contributions are consistent with the observed warming of approximately 0.6 °C to 0.7 °C over this period. *{WGI SPM D.3, 10.3.1}*

It is *very likely* that anthropogenic influence, particularly greenhouse gases and stratospheric ozone depletion, has led to a detectable observed pattern of tropospheric warming and a corresponding cooling in the lower stratosphere since 1961. *{WGI SPM D.3, 2.4.4, 9.4.1, 10.3.1}*

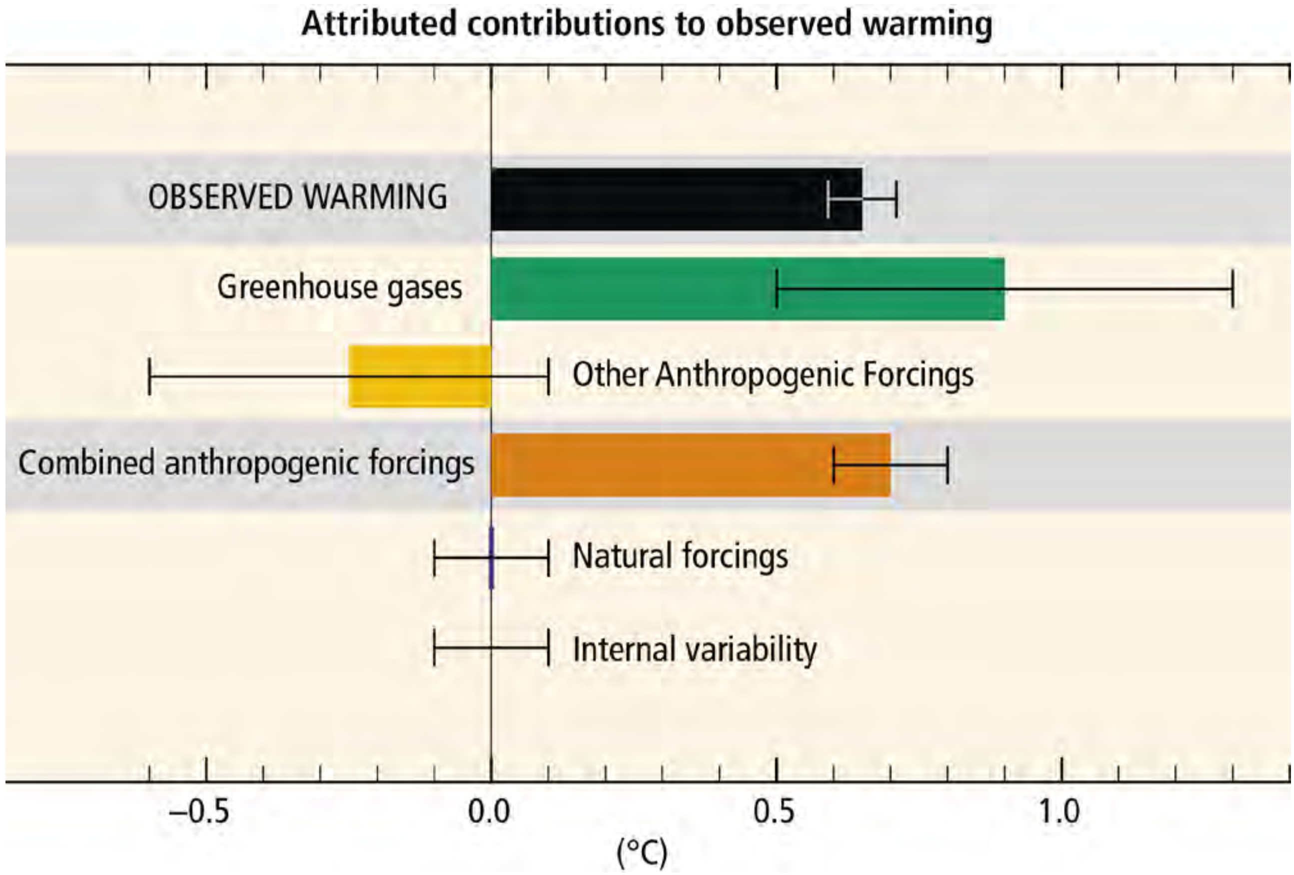


Figure 1.9: Assessed *likely* ranges (whiskers) and their mid-points (bars) for warming trends over the 1951–2010 period from well-mixed greenhouse gases, other anthropogenic forcings, combined anthropogenic forcings, natural forcings, and internal climate variability (which is the element of climate variability that arises spontaneously within the climate system, even in the absence of forcings). The observed warming is shown in black, with the 5%– 95% uncertainty range due to observational uncertainty. The attributed warming ranges (colours) are based on observations combined with climate model simulations, in order to estimate the contribution by an individual external forcing to the observed warming. The contribution from the combined anthropogenic forcings can be estimated with less uncertainty than the separate contributions from greenhouse gases and other anthropogenic forcings. This is because these two contributions are partially compensational, resulting in a signal that is better constrained by observations. *{Based on Figure WGI TS.10}*

Over every continental region except Antarctica, anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century (Figure 1.10). For Antarctica, large observational uncertainties result in *low confidence* that anthropogenic forcings have contributed to the observed warming averaged over available stations. In contrast, it is *likely* that there has been an anthropogenic contribution to the very substantial Arctic warming since the mid-20th century. Human influence has *likely* contributed to temperature increases in many sub-continental regions. *{WGI SPM D.3, 10.3.1, TS 4.8}*

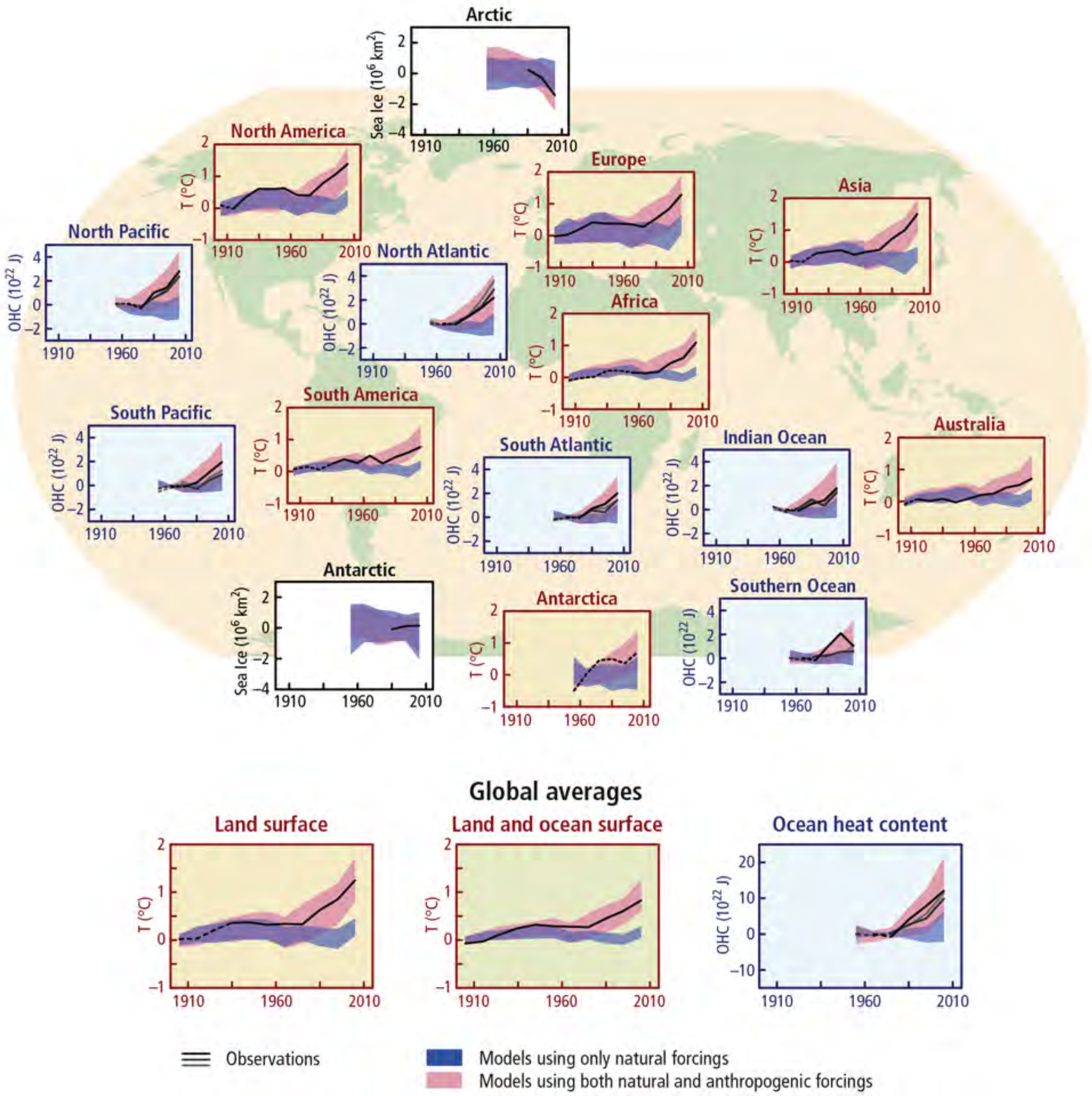


Figure 1.10: Comparison of observed and simulated climate change for change in continental land surface air temperatures (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels). Global average changes are also given. Anomalies are given relative to 1880–1919 for surface temperatures, to 1960–1980 for ocean heat content, and to 1979–1999 for sea ice. All time series are decadal averages, plotted at the centre of the decade. For temperature panels, observations are dashed lines if the spatial coverage of areas being examined is below 50%. For ocean heat content and sea ice panels, the solid lines are where the coverage of data is good and higher in quality, and the dashed lines are where the data coverage is only adequate, and, thus, uncertainty is larger (note that different lines indicate different data sets; for details, see WG1 Figure SPM6). Model results shown are Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble ranges, with shaded bands indicating the 5% to 95% confidence intervals. *{WG1 Figure SPM 6; for detail, see Figure WGI TS.12.}*

Anthropogenic influences have *very likely* contributed to Arctic sea ice loss since 1979 (Figure 1.10). There is *low confidence* in the scientific understanding of the small observed increase in Antarctic sea ice extent due to the incomplete and competing scientific explanations for the causes of change and *low confidence* in estimates of internal variability in that region. *{WGI SPM D.3, 10.5.1, Figure 10.6}*

Anthropogenic influences *likely* contributed to the retreat of glaciers since the 1960s and to the increased surface mass loss of the Greenland ice sheet since 1993. Due to a low level of scientific understanding, however, there is *low confidence* in attributing the causes of the observed loss of mass from the Antarctic ice sheet over the past two decades. It is *likely* that there has been an anthropogenic contribution to observed reductions in Northern Hemisphere spring snow cover since 1970. *{WGI 4.3.3, 10.5.2, 10.5.3}*

It is *likely* that anthropogenic influences have affected the global water cycle since 1960. Anthropogenic influences have contributed to observed increases in atmospheric moisture content (*medium confidence*), to global-scale changes in precipitation patterns over land (*medium confidence)*, to intensification of heavy precipitation over land regions where data are sufficient (*medium confidence; see 1.5*), and to changes in surface and subsurface ocean salinity (*very likely*). *{WG1 SPM D.3; 2.5.1, 2.6.2, 3.3.2, 3.3.3, 7.6.2, 10.3.2, 10.4.2, 10.6.1, 10.6.2}*

It is *very likely* that anthropogenic forcings have made a substantial contribution to increases in global upper ocean heat content (0–700 m) observed since the 1970s (Figure 1.10). There is evidence for human influence in some individual ocean basins**.** It is *very likely* that there is a substantial anthropogenic contribution to the global mean sea level rise since the 1970s. This is based on the *high confidence* in an anthropogenic influence on the two largest contributions to sea level rise: thermal expansion and glacier mass loss. Oceanic uptake of anthropogenic carbon dioxide has resulted in gradual acidification of ocean surface waters (*high confidence*). *{WGI SPM D.3, 3.2.3, 3.8.2, 10.4.1, 10.4.3, 10.4.4, 10.5.2, 13.3, Box 3.2, TS 4.4; WGII 6.1.1.2}*

1.4.2 Observed impacts attributed to climate change

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate. Evidence of climate-change impacts is strongest and most comprehensive for natural systems. Some impacts on human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguishable from other influences (Figure 1.11). Impacts on human systems are often geographically heterogeneous, because they depend not only on changes in climate variables but also on social and economic factors. Hence, the changes are more easily observed at local levels, while attribution can remain difficult. *{WGII SPM A-1, 18.1, 18.3-6}*

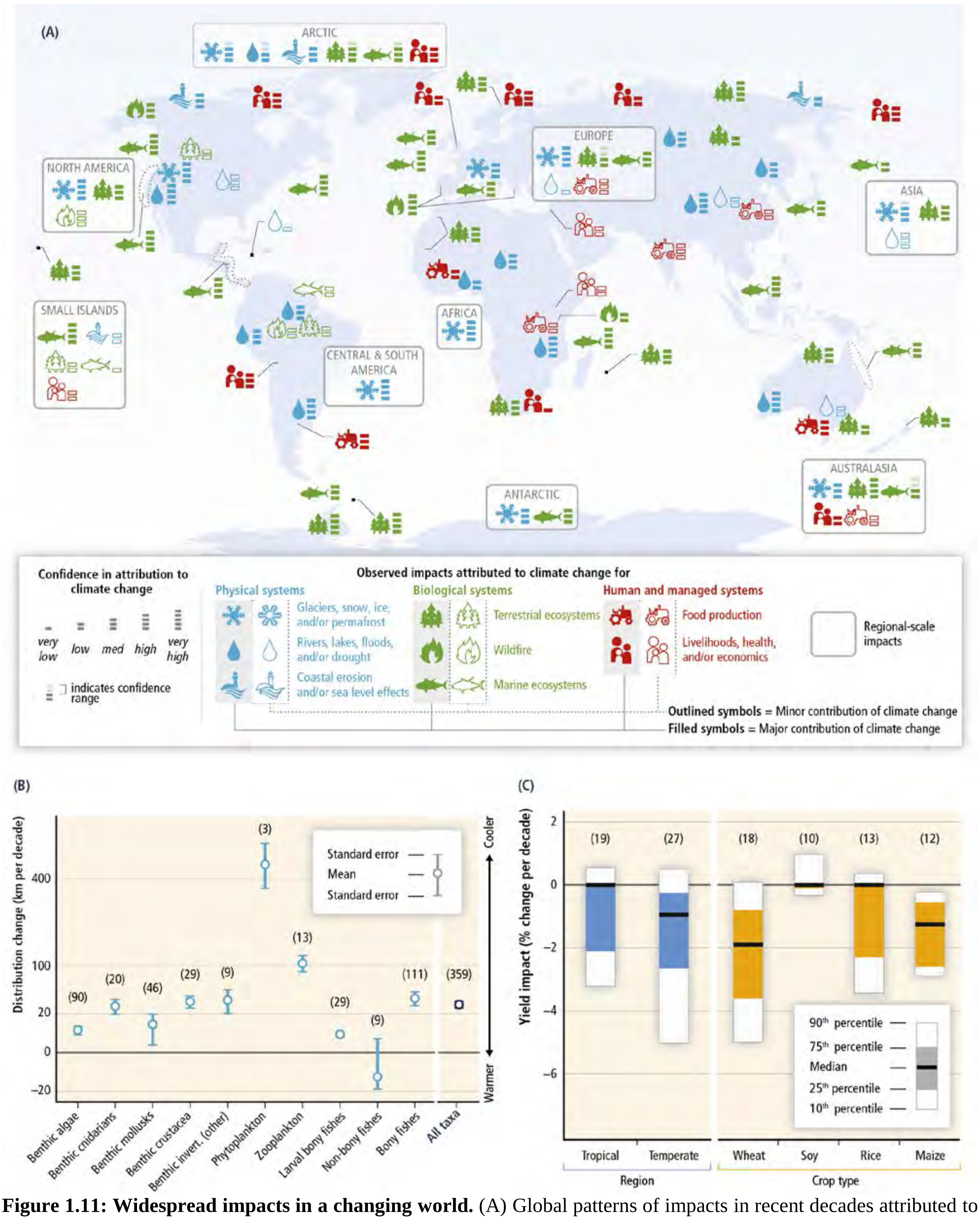


Figure 1.11: Widespread impacts in a changing world. (A) Global patterns of impacts in recent decades attributed to climate change, based on studies since the AR4. Impacts are shown at a range of geographic scales. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact, and confidence in attribution. (B) Average rates of change in distribution (km per decade) for marine taxonomic groups based on observations over 1900-2010. Positive distribution changes are consistent with warming (moving into previously cooler waters, generally poleward). The number of responses analysed is given for each category. (C) Summary of estimated impacts of observed climate changes on yields over 1960-2013 for four major crops in temperate and tropical regions, with the number of data points analysed given within parentheses for each category. *{WG II Figure SPM.2}*

In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (*medium confidence*). Glaciers continue to shrink almost worldwide due to climate change (*high confidence*), affecting runoff and water resources downstream (*medium confidence*). Climate change is causing permafrost warming and thawing in high-latitude regions and in high-elevation regions (*high confidence*). *{WGII SPM A-1}*

Many terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change (*high confidence*). While only a few recent species extinctions have been attributed as yet to climate change (*high confidence*), natural global climate change at rates slower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years (*high confidence*). Increased tree mortality, observed in many places worldwide, has been attributed to climate change in some regions. Increases in the frequency or intensity of ecosystem disturbances such as droughts, wind-storms, fires, and pest outbreaks have been detected in many parts of the world and in some cases are attributed to climate change (*medium confidence*). Numerous observations over the last decades in all ocean basins show changes in abundance, distribution shifts poleward and/or to deeper, cooler waters for marine fishes, invertebrates, and phytoplankton (*very high confidence*), and altered ecosystem composition (*high confidence*), tracking climate trends. Some warm-water corals and their reefs have responded to warming with species replacement, bleaching, and decreased coral cover causing habitat loss. Various observations are consistent with expected impacts of ocean acidification, from the thinning of pteropod and foraminiferan shells (*medium confidence*) to the declining growth rates of corals (*low confidence*). Oxygen minimum zones are progressively expanding in the tropical Pacific, Atlantic, and Indian Oceans, due to reduced ventilation and O_2 solubilities in more stratified oceans at higher temperatures (*high confidence*). *{WGII SPM A-1, Table SPM.A1, 6.3.2.5, 18.3-4, 30.5.1.1, Box CC-OA}*

Based on many studies covering a wide range of regions and crops, negative impacts of climate change on crop yields have been more common than positive impacts (*high confidence*). The smaller number of studies showing positive impacts relate mainly to high-latitude regions, though it is not yet clear whether the balance of impacts has been negative or positive in these regions (*high confidence*). Climate change has negatively affected wheat and maize yields for many regions and in the global aggregate (*medium confidence*). Effects on rice and soybean yield have been smaller in major production regions and globally, with a median change of zero across all available data, which are fewer for soy compared to the other crops. Observed impacts relate mainly to production aspects of food security rather than access or other components of food security. (See Figure 1.11C) Since AR4, several periods of rapid food and cereal price increases following climate extremes in key producing regions indicate a sensitivity of current markets to climate extremes among other factors (*medium confidence*). *{WGII SPM A-1}*

At present the worldwide burden of human ill-health from climate change is relatively small compared with effects of other stressors and is not well quantified. However, there has been increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming (*medium confidence*). Local changes in temperature and rainfall have altered the distribution of some water-borne illnesses and disease vectors (*medium confidence*). *{WGII SPM A-1}*

'Cascading' impacts of climate change can now be attributed along chains of evidence from physical climate through to intermediate systems and then to people. (Figure 1.12) The changes in climate feeding into the cascade, in some cases, are linked to human drivers (e.g., a decreasing amount of water in spring snowpack in Western North America), while, in other cases, assessments of the causes of observed climate change leading into the cascade are not available. In all cases, confidence in detection and attribution to observed climate change decreases for effects further down each impact chain. *{WGII 18.6.3}*

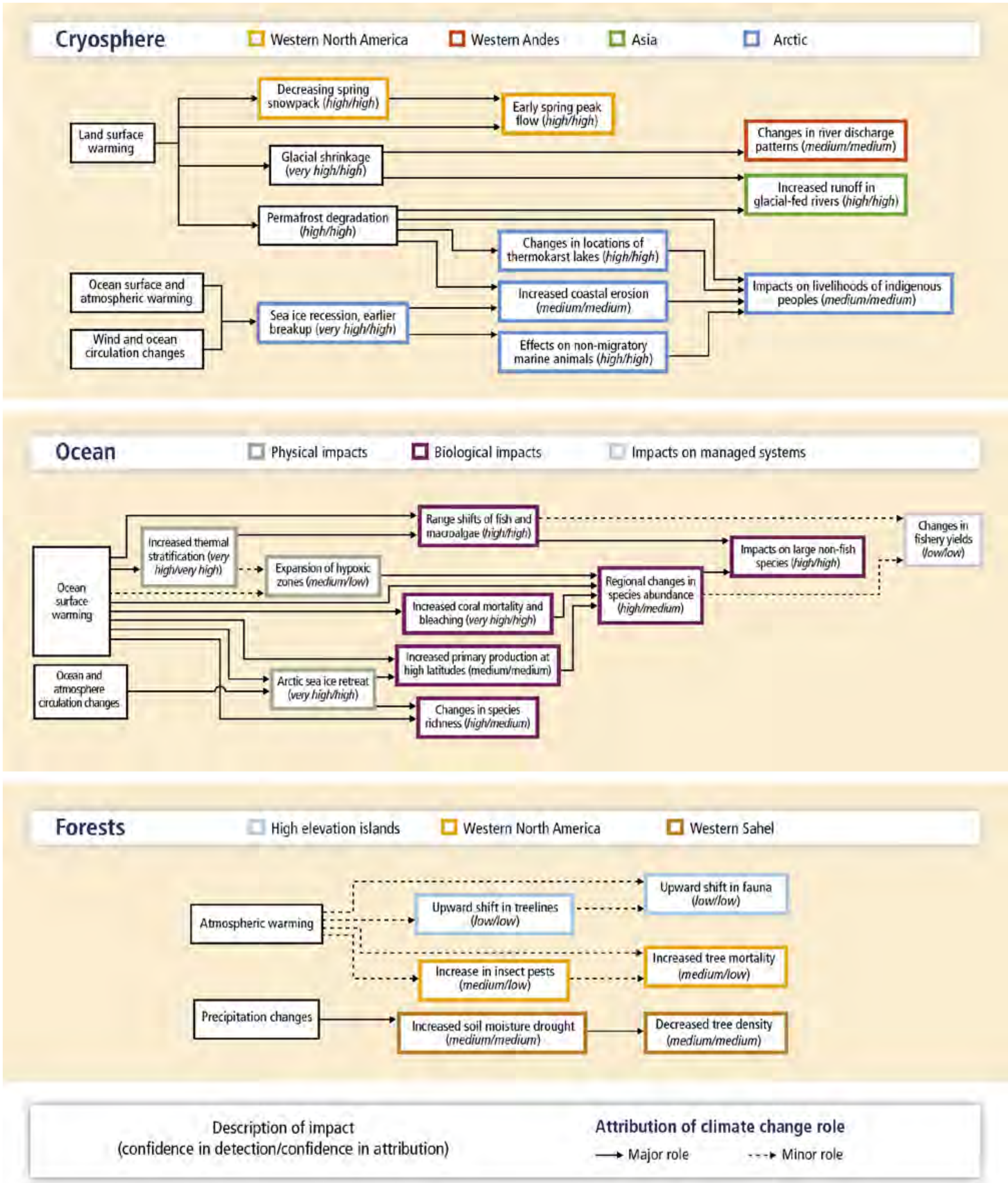


Figure 1.12: Major systems where new evidence indicates interconnected, 'cascading' impacts from recent climate change through several natural and human subsystems. Bracketed text indicates confidence in the detection of a climate change effect and the attribution of observed impacts to climate change. The role of climate change can be major (solid arrow) or minor (dashed arrow). *{WGII Figure 18-4}*

1.5 Extreme events

Changes in many extreme weather and climate events have been observed since about 1950, including decreases in cold temperature extremes, increases in hot temperature extremes, and increase in extreme high sea levels. Some of these changes have been linked to human influences.

It is *very likely* that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is *likely* that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. It is *likely* that human influence has more than doubled the probability of occurrence of heat waves in some locations. *{WGI Table SPM.1, WGI FAQ 2.2, 2.6.1, 10.6.1, 10.6.2}*

There has been increased heat-related human mortality and decreased cold-related human mortality in some regions, as a result of warming (*medium confidence*). *{WGII SPM A-1}* Extreme heat events currently result in increases in mortality and morbidity in North America (*very high confidence*), and in Europe with impacts that vary according to people's age, location and socioeconomic factors (*high confidence*). *{WGII 26.6.1.2}*

There are *likely* more land regions where the number of heavy precipitation events has increased than where it has decreased. The frequency and intensity of heavy precipitation events has *likely* increased in North America and Europe. In other continents, confidence in trends is at most *medium.* It is *very likely* that global near-surface and tropospheric air-specific humidity have increased since the 1970s. In land regions where observational coverage is sufficient for assessment, there is *medium confidence* that anthropogenic forcing has contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century. *{WGI 2.5.1, 2.5.4, 2.5.5, 2.6.2, 10.6.1, 10.6.2, Table SPM.1, FAQ 2.2, SREX Table 3-2}*

There is *low confidence* that anthropogenic climate change has affected the frequency and magnitude of fluvial floods on a global scale. The strength of the evidence is limited mainly by a lack of long-term records from unmanaged catchments. Moreover, floods are strongly influenced by many human activities impacting catchments, making the attribution of detected changes to climate change difficult. However, recent detection of positive trends in extreme precipitation and discharges in some catchments implies greater risks of flooding on a regional scale (*medium confidence*). Costs related to flood damage, worldwide, have been increasing since the 1970s, although this is partly due to the increasing exposure of people and assets. *{WGI 2.6.2; WGII 3.2.7}*

There is *low confidence* in observed global- scale trends in droughts, due to lack of direct observations, dependencies of inferred trends on the choice of the definition for drought, and due to geographical inconsistencies in drought trends. There is also *low confidence* in the attribution of changes in drought over global land areas since the mid 20th century, due to the same observational uncertainties and difficulties in distinguishing decadal scale variability in drought from long-term trends. *{WGI Table SPM1 2.6.2.3, WGII ES Chap 3, WGII 3.2.7 Fig. 2-33d; 10.6}*

There **is *low confidence* that long-term changes in tropical cyclone activity are robust and there is *low confidence* in the attribution of global changes to any particular cause**. However, it is *virtually certain* that intense tropical cyclone activity has increased in the North Atlantic since 1970. *{WGI: Table SPM 1, 2.6.3, 10.6.1, 10.6.2}*

It is *likely* that extreme sea levels have increased since 1970, being mainly the result of mean sea level rise. Due to a shortage of studies and the difficulty to distinguish any such impacts from other modifications to coastal systems, limited evidence is available on the impacts of sea level rise. *{WGI 3.7.4, 3.7.5, 3.7.6., Figure 3.14, WGII 5.3.2.1. 18.3}*

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability (*very high confidence*). Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, human morbidity and mortality, and consequences for mental health and human well-being. For countries at all levels of development, these impacts are consistent with a significant lack of preparedness for current climate variability in some sectors. *{WGII 3.2, 4.2-3, 8.1, 9.3, 10.7, 11.3, 11.7, 13.2, 14.1, 18.6, 22.3, 22.2.3, 23.3.1.2, 24.4.1.3, 25.6-8, 26.6-7, 30.5, WGII Tables 18-3 and 23-1, WGII Figure 26-2, WG II SPM A-1, WGII Boxes 4-3, 4-4, 25-5, 25-6, 25-8, and CC-CR}*

Direct and insured losses from weather-related disasters have increased substantially in recent decades, both globally and regionally. Increasing exposure of people and economic assets has been the major cause of long-term increases in economic losses from weather- and climate-related disasters (*high confidence*). *{SREX 4.5.3.3, WGII 10.7.3, SREX SPM B}*

1.6 Exposure and Vulnerability

The character and severity of impacts from climate change and extreme events emerge from risk that depends not only on climate-related hazards but also on exposure (people and assets at risk) and vulnerability (susceptibility to harm) of human and natural systems.

Exposure and vulnerability are influenced by a wide range of social, economic, and cultural factors and processes that have been incompletely considered to date and that make quantitative assessments of their future trends difficult (*high confidence*). These factors include wealth and its distribution across society, demographics, migration, access to technology and information, employment patterns, the quality of adaptive responses, societal values, governance structures, and institutions to resolve conflict. *{SREX SPM A, WGII SPM, A-3}*

Differences in vulnerability and exposure arise from non-climatic factors and from multidimensional inequalities often produced by uneven development processes (*very high confidence*). These differences shape differential risks from climate change. People who are socially, economically, culturally, politically, institutionally or otherwise marginalized are especially vulnerable to climate change and also to some adaptation and mitigation responses (*medium evidence, high agreement*). This heightened vulnerability is rarely due to a single cause. Rather, it is the product of intersecting social processes that result in inequalities in socioeconomic status and income, as well as in exposure. Such social processes include, for example, discrimination on the basis of gender, class, ethnicity, age, and (dis)ability. *{WGII SPM A-1; Figure SPM.1, WGII 8.1-2, 9.3-4, 10.9, 11.1, 11.3-5, 12.2-5, 13.1-3, 14.1-3, 18.4, 19.6, 23.5, 25.8, 26.6, 26.8, 28.4, WGII Box CC-GC}*

Climate-related hazards exacerbate other stressors, often with negative outcomes for livelihoods, especially for people living in poverty (*high confidence*). Climate-related hazards affect poor people's lives directly through impacts on livelihoods, reductions in crop yields, or the destruction of homes, and indirectly through, for example, increased food prices and food insecurity. Observed positive effects for poor and marginalized people, which are limited and often indirect, include examples such as diversification of social networks and of agricultural practices. *{WGII 8.2-3, 9.3, 11.3, 13.1-3, 22.3, 24.4, 26.8}*

Violent conflict increases vulnerability to climate change (*medium evidence, high agreement*). Large-scale violent conflict harms assets that facilitate adaptation, including infrastructure, institutions, natural resources, social capital, and livelihood opportunities. *{WGII 12.5, 19.2, 19.6}*

1.7 Human responses to climate change: adaptation and mitigation

Throughout history, people and societies have adjusted to and coped with climate, climate variability, and extremes, with varying degrees of success. In today's changing climate, accumulating experience with adaptation and mitigation efforts can provide opportunities for learning and refinement. (See Sections 3 and 4)

Adaptation and mitigation experience is accumulating across regions and scales, even while global anthropogenic GHG emissions have continued to increase.

Adaptation is becoming embedded in some planning processes, with more limited implementation of responses (*high confidence*). Engineered and technological options are commonly implemented adaptive responses, often integrated within existing programmes, such as disaster risk management and water management. There is increasing recognition of the value of social, institutional, and ecosystem-based measures and of the extent of constraints to adaptation (*medium evidence, medium agreement*). *{WGII SPM A-2; WGII SPM A-2, 4.4, 5.5, 6.4, 8.3, 9.4, 11.7, 14.1, 14.3-4, 15.2-5, 17.2-3, 21.3, 21.5, 22.4, 23.7, 25.4, 26.8-9, 30.6, Boxes 25-1, 25-2, 25-9, and CC-EA}*

Governments at various levels have begun to develop adaptation plans and policies and integrate climate-change considerations into broader development plans. Examples of adaptation are now available from all regions of the world (see Topic 4 for details on adaptation options and policies to support their implementation). *{WGII SPM A-2, 22.4, 23.7, 24.4-6, 24.9, 25.4, 25.10, 26.7-9, 27.3, 28.2, 28.4, 29.3, 29.6, 30.6, Tables 25-2 and 29-3, Figure 29-1, Boxes 5-1, 23-3, 25-1, 25-2, 25-9, and CC-TC}*

Global increases in anthropogenic emissions and climate impacts have occurred, even while mitigation activities have taken place in many parts of the world. Though various mitigation initiatives between the sub-national and global scales have been developed or implemented, a full assessment of their impact may be premature. *{WG III SPM.3; SPM.5}*

Topic 2: Future climate changes, risks and impacts

Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. A combination of adaptation and substantial, sustained reductions in greenhouse gas emissions can limit climate change risks.

Topic 2 assesses projections of future climate change and the resulting impacts and risks. Factors that determine future climate change, including scenarios for future GHG emissions, are outlined (Section 2.1). Descriptions of the methods and tools used to make projections of climate, impacts and risks, and their development since AR4, are provided in Boxes 2.1 to 2.3. Details of projected changes in the climate system, including the associated uncertainty and the degree of expert confidence in the projections are provided in Section 2.2. The future impacts of climate change on natural and human systems and associated risks are assessed in Section 2.3. Topic 2 concludes with an assessment of irreversible changes, abrupt changes, and changes beyond 2100, in Section 2.4.

2.1 The basis on which projections are made

Scenarios of future emissions vary over a wide range, depending on socio-economic development and future climate policy. Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond.

Projections are obtained from climate models. Climate models are mathematical representations of processes important in the simulation of the Earth's climate system. Results from a hierarchy of climate models are considered in this report; ranging from simple idealized models, to models of intermediate complexity, to comprehensive General Circulation Models (GCMs), including Earth System Models (ESMs) that also simulate the carbon cycle. The GCMs simulate many climate aspects, including the temperature of the atmosphere and the oceans, precipitation, winds, clouds, ocean currents, and sea-ice extent. The models are extensively tested against historical observations (Box 2.1). *{WGI 1.5.2, 9.1.2, 9.2, 9.8.1}*

Box 2.1: Advancement, confidence and uncertainty in modelling the Earth's climate system

Improvements in climate models since the AR4 are evident in simulations of continental-scale surface temperature, large-scale precipitation, the monsoon, Arctic sea ice, ocean heat content, some extreme events, the carbon cycle, atmospheric chemistry and aerosols, the effects of stratospheric ozone, and the El Niño-Southern Oscillation. Climate models reproduce the observed continental-scale surface temperature patterns and multi-decadal trends, including the more rapid warming since the mid 20th century, and the cooling immediately following large volcanic eruptions (*very high confidence*). The simulation of large-scale patterns of precipitation has improved somewhat since the AR4, although models continue to perform less well for precipitation than for surface temperature. Confidence in the representation of processes involving clouds and aerosols remains low. *{WGI SPM D.1, 7.3.3, 7.6.2, 9.5-9.7, 10.3.1}*

The ability to simulate ocean thermal expansion, glaciers and ice sheets, and thus sea level, has improved since the AR4, but significant challenges remain in representing the dynamics of the Greenland and Antarctic ice sheets. This, together with advances in scientific understanding and capability, has resulted in better sea level projections in this report, compared with the AR4 report. *{*WGI SPM E.6, 9.1.3, 9.2, 9.4.2, 9.6, 9.8, 13.1, 13.4, 13.5*}*

There is overall consistency between the projections from climate models in AR4 and AR5 for large-scale patterns of change, and the magnitude of the uncertainty has not changed significantly, but new experiments and studies have led to a more complete and rigorous characterisation of the uncertainty in long-term projections. *{*WGI 12.4*}*

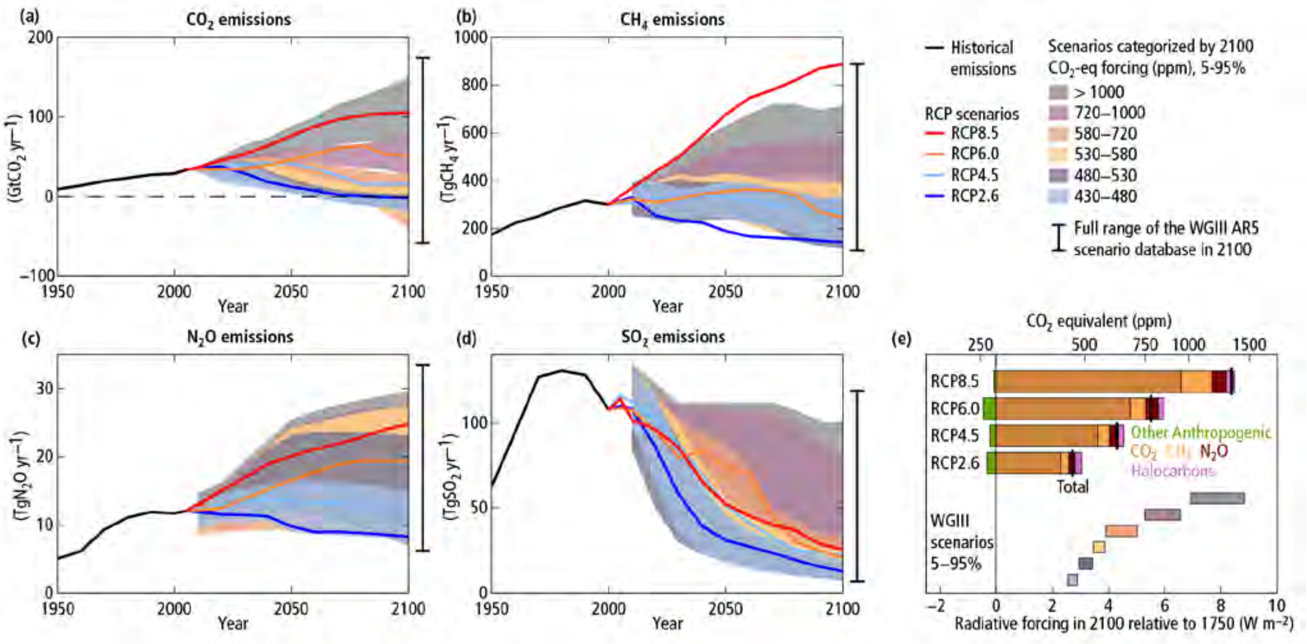
In order to obtain projections, the climate models are forced, using information described in scenarios of greenhouse gas and air pollutant emissions and land-use changes. Scenarios are generated by a range of approaches, from simple idealised experiments to Integrated Assessment Models (IAMs, see Glossary). Key factors determining changes in anthropogenic greenhouse gas emissions are economic and population growth, lifestyle and behavioural changes, associated changes in energy use and land use, technological change, and climate policy. *{WGIII 5, 6; WGI 11.3, 12.4; WGIII 6.1}*

The standard set of scenarios used in the AR5 is called Representative Concentration Pathways (RCPs, Box 2.2). *{WGI Box SPM.1}*

Box 2.2: The 'Representative Concentration Pathways' (RCPs)

The RCPs describe four different evolution patterns for atmospheric greenhouse gas emissions and concentrations, land-use changes, and emissions of air pollutants (e.g. ozone and aerosols). The RCPs have been developed using IAMs as input to a wide range of climate model simulations to project their consequences for the climate system. These climate projections, in turn, are used for impacts and adaptation assessment. The RCPs represent a wider set of scenarios used in mitigation literature to assess the costs associated with emission reductions consistent with these concentration pathways.. The RCPs represent the range of greenhouse gas emissions in the wider literature well (Box 2.2, Figure 1); they include a mitigation scenario leading to a very low forcing level (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6.0), and one scenario with very high greenhouse gas emissions (RCP8.5). Scenarios without additional efforts to constrain emissions ("baseline scenarios") lead to a range of forcing levels between RCP6.0 and RCP8.5. RCP2.6 is representative of a scenario that aims to keep global warming below 2 °C above pre-industrial temperatures. The majority of models indicate that meeting forcing levels similar to RCP2.6 will require substantial net negative emissions[20] by 2100, on average around 2 $GtCO_2$/yr. The land-use scenarios of RCPs, together, show a wide range of possible futures, ranging from a net reforestation to further deforestation, consistent with projections in the full scenario literature. For air pollutants such as SO_2, the RCP scenarios assume a consistent decrease in emissions as a consequence of assumed air pollution control and greenhouse gas mitigation policy (Box 2.2, Figure 1). Importantly, these future scenarios do not account for possible changes in natural forcings (e.g. volcanic eruptions) (see Box 1.1). *{WGI 6.4.3, WGI Box 1.1. 12.3.1, 11-14, WGII 19, 21, WGIII 6.3.2, 6.3.6}.*

The RCPs cover a wider range than the scenarios from the Special Report on Emissions Scenarios (SRES) used in previous assessments, as they also represent scenarios with climate policy. In terms of overall forcing, RCP8.5 is broadly comparable to the SRES A2/A1FI scenario, RCP6.0 to B2 and RCP4.5 to B1. For RCP2.6, there is no equivalent scenario in SRES. As a result, the differences in the magnitude of AR4 and AR5 climate projections are largely due to the inclusion of the wider range of emissions assessed.



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[20] Net negative emissions can be achieved when more greenhouse gases are sequestered than are released into the atmosphere, e.g. by using bio-energy in combination with carbon capture and storage.

Box 2.2, Figure 1: Emission scenarios and the resulting radiative forcing levels for the RCPs (lines) and the associated scenarios categories used in WGIII (coloured areas, see Table 3.1). Panels a to d show the emissions of CO_2, CH_4, N_2O and SO_2. Panel e shows future radiative forcing levels for the RCPs calculated, using the simple carbon cycle/ climate model MAGICC for the RCPs (per forcing agent) and for the WGIII scenario categories (total). *{WGI 8.2.2, 8.5.3, Figure 8.2, WGI Annex II, WGIII Tables SPM.1 and 6.3}*. The WGIII scenario categories summarize the wide range of emission scenarios published in the scientific literature and are defined based on total GHG concentration levels (in CO_2-eq)[21] by 2100 (Table 3.1). The vertical line to the right of the panels (panel a–d) indicate the full range of the WGIII AR5 scenario database.

The methods used to estimate future impacts and risks resulting from climate change are described in Box 2.3. Modelled future impacts assessed in this report are generally based on climate-model projections using the RCPs, and in some cases, the older Special Report on Emissions Scenarios (SRES). *{WGII 1.1, 1.3, 2.2-3, 19.6, 20.2, 21.3, 21.5, 26.2, Box CC-RC; WGI Box SPM.1}*

Risk of climate-related impacts results from the interaction between climate-related hazards (including hazardous events and trends) and the vulnerability and exposure of human and natural systems. Alternative development paths influence risk by changing the likelihood of climatic events and trends, through their effects on greenhouse gases, pollutants and land use, and by altering vulnerability and exposure. *{WGII SPM, WGII 19.2.4, Figure 19-1, Box 19-2}*

Experiments, observations, and models used to estimate future impacts and risks have improved since the AR4, with increasing understanding across sectors and regions. For example, an improved knowledge base has enabled expanded assessment of risks for human security and livelihoods and for the oceans. For some aspects of climate change and climate-change impacts, uncertainty about future outcomes has narrowed. For others, uncertainty will persist. Some of the persistent uncertainties are grounded in the mechanisms that control the magnitude and pace of climate change. Others emerge from potentially complex interactions between the changing climate and the underlying vulnerability and exposure of people, societies, and ecosystems. The combination of persistent uncertainty in key mechanisms plus the prospect of complex interactions motivates a focus on risk in this report. Because risk involves both probability and consequence, it is important to consider the full range of possible outcomes, including low-probability, high-consequence impacts that are difficult to simulate. *{WGII 2.1-4, 3.6, 4.3, 11.3, 12.6, 19.2, 19.6, 21.3-5, 22.4, 25.3-4, 25.11, 26.2}*

Box 2.3: Models and methods for estimating climate change risks, vulnerability and impacts

Future climate-related risks, vulnerabilities and impacts are estimated in the AR5 through experiments, analogies, and models, as in previous assessments. 'Experiments' involve deliberately changing one or more climate-system factors affecting a subject of interest to reflect anticipated future conditions, while holding the other factors affecting the subject constant. 'Analogies' make use of existing variations and are used when controlled experiments are impractical due to ethical constraints, the large area or long time required, or high system complexity. Two types of analogies are used in projections of climate and impacts. Spatial analogies identify another part of the world currently experiencing similar conditions to those anticipated to be experienced in the future. Temporal analogies use changes in the past, sometimes inferred from paleo-ecological data, to make inferences about changes in the future. 'Models' are typically numerical simulations of real-world systems, calibrated and validated using observations from experiments or analogies, and then run using input data representing future climate. Models can also include largely descriptive narratives of possible futures, such as those used in scenario construction. Quantitative and descriptive models are often used together. Impacts are modelled, among other things, for water resources; biodiversity and ecosystem services on land, for inland waters, the oceans and ice bodies, as well as for urban infrastructure, agricultural productivity, health, economic growth and poverty. *{WGII 2.2.1, 2.4.2, 3.4.1, 4.2.2, 5.4.1, 6.5, 7.3.1, 11.3.6, 13.2.2}*

Risks are evaluated based on the interaction of projected changes in the Earth system with the many dimensions of vulnerability in societies and ecosystems. Projection of future exposure and vulnerability of

[21] CO_2 equivalent (CO_2-eq) concentration is a metric of the combined radiative forcing by all GHGs including halogenated gases and tropospheric ozone, aerosols and albedo change at a particular time (see Glossary)

interlinked human and natural systems is challenging due to the number of socioeconomic factors that must be considered, including wealth and its distribution across society, patterns of human aging, access to technology and information, the quality of adaptive responses, societal values, and mechanisms and institutions to resolve conflicts; factors which have been incompletely considered to date. The data are seldom sufficient to allow direct estimation of probabilities of a given outcome; therefore, expert judgment is used to integrate the diverse information sources relating to the severity of consequences and the likelihood of occurrence into a risk evaluation, considering exposure and vulnerability in the context of specific hazards. *{WGII 11.3, 19.2,21.1, 21.3-5, 25.3-4, 25.11, 26.2}*

2.2 Projected changes in the climate system

Surface air temperature is projected to rise over the 21st century under all assessed emission scenarios. The ocean will continue to warm, acidify and lose oxygen. Global mean sea level will continue to rise during the 21st century and beyond. ***{WGI SPM E.1, E.4, E.6, E.7, 6.4.4, 6.4.5 11.3.2, 11.3.3, 12.4.1, 13.4-13.5}***

2.2.1 Air Temperature

Estimates of future near-term surface air temperature depend on past anthropogenic forcing, the time evolution of future natural climate variability and future anthropogenic forcing. The global mean surface air temperature change for the period 2016–2035 relative to 1986–2005 will likely be in the range of 0.3 ˚C to 0.7 ˚C (*medium confidence*)[22]. This range is valid for the four RCP scenarios and assumes no major volcanic eruptions or unexpected changes in total solar irradiance. By the mid 21st century, the rate of global warming begins vary across the emissions scenarios, continuing to diverge through to 2100 and beyond (Table 2.1, Figure 2.1). The ranges provided for particular RCPs, and those given below in Section 2.2, primarily arise from differences in the sensitivity of climate models to the imposed forcing. *{WGI SPM E.1, 11.3.2, 12.4.1}*

Relative to 1851–1900, global surface air temperature change for the end of the 21st century (2081–2100) is *likely* to exceed 1.5 °C for all RCP scenarios except RCP2.6 (*high confidence*). It is *likely* to exceed 2 °C for RCP6.0 and RCP8.5 *(high confidence*), *more likely than not* to exceed 2 °C for RCP4.5 (*high confidence*), but *unlikely* to exceed 2 °C for RCP2.6 (*medium confidence*). *{WGI SPM E.1, 12.4.1, Table 12.3}*

Projected changes described below are for the 2081–2100 period relative to the period 1986-2005, unless otherwise indicated.

The Arctic region will continue to warm more rapidly than the global mean. Warming globally will be larger over the land than over the ocean *(very high confidence)* (Figure 2.2). *{WGI SPM E.1, 11.3.2, 12.4.3, 14.8.2}*

It is *virtually certain* that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean temperature increases. It is *very likely* that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur. *{WGI SPM E.1, 12.4.3}*

[22] The 1986–2005 period was approximately 0.61 ˚C [0.55 to 0.67] ˚C warmer than the period 1850-1900. *{WGI SPM E, 2.4.3}*

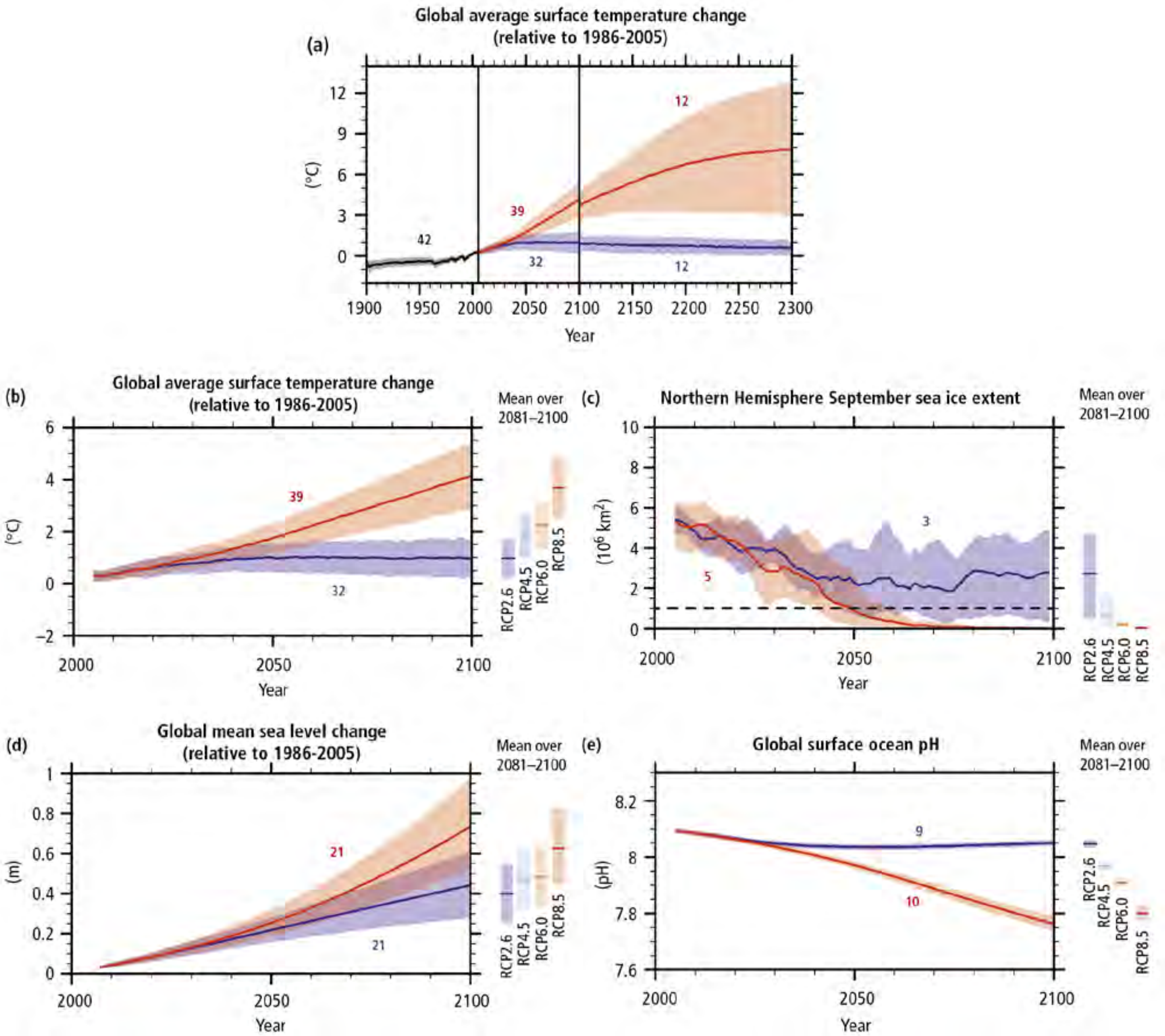


Figure 2.1: (a) Time series of global annual change in mean surface air temperature for the 1900–2300 period (relative to 1986–2005) from Coupled Model Intercomparison Project Phase 5 (CMIP5) concentration-driven experiments. Projections are shown for the multi-model mean (solid lines) and the 5% to 95% range across the distribution of individual models (shading). Grey lines and shading represent the CMIP5 historical simulations. Discontinuities at 2100 are due to different numbers of models performing the extension runs beyond the 21st century and have no physical meaning. (b) Same as (a) but for the 2006–2100 period (relative to 1986–2005). (c) Change in Northern Hemisphere September sea-ice extent (5 year running mean). The dashed line represents nearly ice-free conditions (i.e., when September sea ice extent is less than 10^6 km^2 for at least five consecutive years). (d) Change in global mean sea level. (e) Change in ocean surface pH. All changes are relative to the 1986–2005 period. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). The mean and associated uncertainties averaged over the 2081–2100 period are given for all RCP scenarios as coloured vertical bars on the right hand side of panels (b) to (e). The number of CMIP5 models used to calculate the multi-model mean is indicated. For sea-ice extent (c), the projected mean and uncertainty (minimum–maximum range) is only given for the subset of models that most closely reproduce the climatological mean state and the 1979–2012 trend in the Arctic sea ice. For sea level (d), based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. However, there is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century. *{WGI Figure SPM.7, Figure SPM9, Figure 12.5, 6.4.4 12.4.1, 13.4.4, 13.5.1}*

Table 2.1: Projected change in global mean surface air temperature and global mean sea level rise for the mid and late 21st century, relative to the 1986–2005 period. *{WG1 Table SPM.2, 12.4.1 13.5.1, Table 12.2, Table 13.5}*

		2046–2065		**2081–2100**	
	Scenario	**Mean**	***Likely* range** [c]	**Mean**	***Likely* range** [c]
Global Mean Surface Temperature Change (°C)[a]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	**Mean**	***Likely* range** [d]	**Mean**	***Likely* range** [d]
Global Mean Sea Level Rise[a] **(m)** [b]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Notes:

[a] Based on the CMIP5 ensemble; changes calculated with respect to the 1986–2005 period. Using HadCRUT4 and its uncertainty estimate (5% to 95% confidence interval), the observed warming from 1850–1900 to the reference period 1986–2005 is 0.61 [0.55 to 0.67] °. *Likely* ranges have not been assessed here with respect to earlier reference periods because methods are not generally available in the literature for combining the uncertainties in models and observations. Adding projected and observed changes does not account for potential effects of model biases compared to observations, and for natural internal variability during the observational reference period. *{WGI 2.4.3; 11.2.2, 12.4.1; Tables 12.2 and 12.3}*

[b] Based on 21 CMIP5 models; changes calculated with respect to the 1986–2005 period. Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a metre of sea level rise during the 21st century.

[c] Calculated from projections as 5% to 95% model ranges. These ranges are then assessed to be *likely* ranges after accounting for additional uncertainties or different levels of confidence in models. For projections of global mean surface temperature change in 2046–2065, *confidence* is *medium*, because the relative importance of natural internal variability, and uncertainty in non-greenhouse gas forcing and response, are larger than for the 2081–2100 period. The *likely* ranges for 2046–2065 do not take into account the possible influence of factors that lead to the assessed range for near-term (2016–2035) change in global mean surface temperature that is lower than the 5% to 95% model range, because the influence of these factors on longer term projections has not been quantified due to insufficient scientific understanding. *{WGI 11.3.1}*

[d] Calculated from projections as 5% to 95% model ranges. These ranges are then assessed to be *likely* ranges after accounting for additional uncertainties or different levels of confidence in models. For projections of global mean sea level rise *confidence* is *medium* for both time horizons.

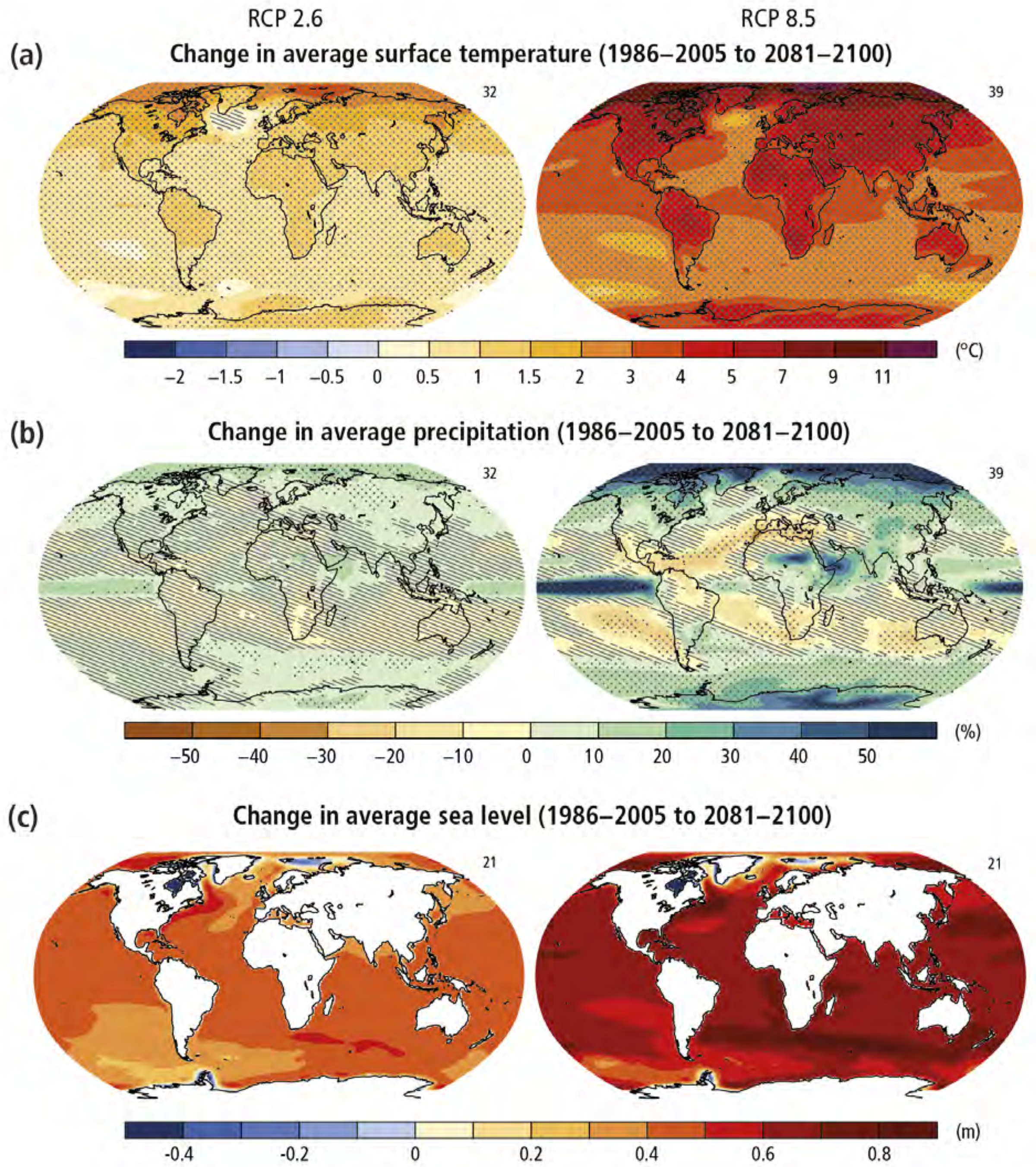


Figure 2.2: CMIP5 multi-model mean projections (i.e. the average of the model projections available) for the 2081–2100 period under the RCP2.6 (left) and RCP8.5 (right) scenarios for (a) change in annual mean surface temperature and (b) change in annual mean precipitation, in percentages, and (c) change in average sea level. Changes are shown relative to the 1986–2005 period. The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Stippling on (a) and (b) indicates regions where the projected change is large compared to internal variability (i.e., greater than two standard deviations of internal variability in 20-year means) and where 90% of the models agree on the sign of change Hatching on (a) and (b) shows regions where the multi-model mean is less than one standard deviation of internal variability in 20-year means. (see WGI, Box 12.1). *{WGI Figure SPM.8, Figure 13.20}*

2.2.2 Water cycle

Changes in precipitation in a warming world will not be uniform. The high latitudes and the equatorial Pacific are *likely* to experience an increase in annual mean precipitation by the end of this century under the RCP8.5 scenario. In many mid-latitude and subtropical dry regions, mean precipitation will *likely* decrease, while in many mid-latitude wet regions, mean precipitation will *likely* increase under the RCP8.5 scenario (Figure 2.2). *{WGI 7.6.2, 12.4.5, 14.3.1, 14.3.5}*

Extreme precipitation events over most mid-latitude land-masses and over wet tropical regions will *very likely* become more intense and more frequent as global mean surface temperature increases. *{WGI SPM, E.2 7.6.2, 12.4.5}*

Globally, in all RCPs, it is *likely* that the area encompassed by monsoon systems will increase and monsoon precipitation is *likely* to intensify and El Niño-Southern Oscillation (ENSO) related precipitation variability on regional scales will *likely* intensify. *{WGI 14.2.5, 14.4.4}*

2.2.3 Ocean, Cryosphere and Sea Level

The global ocean will continue to warm during the 21st century. The strongest ocean warming is projected for the surface in tropical and Northern Hemisphere subtropical regions. At greater depth the warming will be most pronounced in the Southern Ocean (*high confidence*). Warming will *likely* enhance stratification and expansion of water layers with low oxygen contents. *{WGI SPM E.4, WGI 6.4.5, 12.4.7}*

It is *very likely* that the Atlantic Meridional Overturning Circulation (AMOC) will weaken over the 21st century, with best estimates and model ranges for the reduction of 11% (1-24%) for the RCP2.6 scenario, 34% (12-54%) for the RCP8.5. Nevertheless, it is *very unlikely* that the AMOC will undergo an abrupt collapse in the 21st century. *{WGI SPM E.4, WGI SPM, 12.4.7.2}*

Year-round reductions in Arctic sea ice are projected for all RCP scenarios. The subset of models that most closely reproduce the observations[23] project that a nearly ice-free Arctic Ocean[24] in September before mid-century is *likely* for RCP8.5 compared to a third reduction for RCP2.6 (*medium confidence*) (Figure 2.1). In the Antarctic, a decrease in sea ice extent and volume is projected with *low confidence*. *{WGI SPM E.5, WGI 12.4.6.1}*

The area of Northern Hemisphere spring snow cover is *likely* to decrease by 7 ± 4% for RCP2.6 and by 25 ± 8% in RCP8.5 (*medium confidence*). *{WGI SPM E.5, WGI 12.4.6.}*

It is *virtually certain* that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases. The area of permafrost near the surface (upper 3.5 m) is *likely* to decrease by 37 ± 11% (RCP2.6) to 81 ± 12% (RCP8.5) (*medium confidence*). *{WGI SPM E.5, WGI 12.4.6.}*

The global glacier volume, excluding glaciers in Antarctica, is projected to decrease by 15 to 55% for RCP2.6, and by 35 to 85% for RCP8.5 (*medium confidence*). *{WGI SPM E.5, WGI 13.4.2, 13.5.1}*

Global mean sea level will continue to rise during the 21st century and beyond (Table 2.1, Figure 2.1). Under all RCP scenarios, the rate of sea level rise will *very likely* exceed that observed rate of 2.0 [1.7-2.3] mm yr^{-1} during 1971–2010, with the rate of rise for RCP8.5 during 2081-2100 of 8 to 16 mm yr^{-1} (*medium confidence*) (Table 2.1, Figure 2.1). *{WGI SPM E.6, WGI 13.5.3}*

Sea level rise will not be uniform. By the end of the 21st century, it is *very likely* that sea level will rise in more than about 95% of the ocean area. For RCP4.5 and RCP8.5 about 70% of the coastlines worldwide are projected to experience sea level change within ±20% of the global mean sea level change (Figure 2.2). It is *very likely* that there will be a significant increase in the occurrence of future sea level extremes in some regions by 2100. *{WGI SPM E.6, WGI 13.6.5, 13.7.2}*

2.2.4 Carbon cycle and biogeochemistry

Ocean uptake of anthropogenic CO_2 will continue under all four RCPs through to 2100, with higher uptake for higher concentration pathways (*very high confidence*). The future evolution of the land carbon uptake is less certain. A majority of models projects a continued land carbon uptake under all RCPs, but

[23] Climatological mean state and the 1979–2012 trend in Arctic sea-ice extent.
[24] When sea-ice extent is less than 10^6 km^2 for at least 5 consecutive years.

some models simulate a land carbon loss due to the combined effect of climate change and land use change. *{WGI SPM E.7, WGI 6.4.2, 6.4.3}*

Based on Earth System Models, there is high confidence that the feedback between climate change and the carbon cycle will amplify global warming. Climate change will partially offset increases in land and ocean carbon sinks caused by rising atmospheric CO_2. As a result more of the emitted anthropogenic CO_2 will remain in the atmosphere, reinforcing the warming. *{WGI SPM E.7, WGI 6.4.2, 6.4.3}*

Earth System Models project a global increase in ocean acidification for all RCP scenarios, with a decrease in surface ocean pH below present-day values in the range of 0.06 to 0.07 for RCP2.6, to 0.30 to 0.32 for RCP8.5 (Figure 2.1). *{WGI SPM E.7, WGI 6.4.4}*

It is *very likely* that the dissolved oxygen content of the ocean will decrease by a few per cent during the 21st century but there is no consensus on the future development of the volume of hypoxic and suboxic waters in the open ocean because of large uncertainties in potential biogeochemical effects and in the evolution of tropical ocean dynamics. *{WGI 6.4.5}*

2.2.5 Climate system responses

Climate system properties that determine the response to external forcing have been estimated both from climate models and from analysis of past and recent climate change. The equilibrium climate sensitivity (ECS)[25] is *likely* in the range 1.5 °C–4.5 °C, *extremely unlikely* less than 1 °C, and *very unlikely* greater than 6 °C. *{WGI SPM D.2, WGI TS TFE.6, WGI 10.8.1, 10.8.2, WGI 12.5.4, Box 12.2}*

Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. There is a strong and consistent near-linear relationship across all scenarios considered between cumulative CO_2 emissions and projected 21st century temperature change (Figure 2.3). *{WGI SPM E.8, WGI TS TFE.8, WGI 12.5.4}*

The global mean surface temperature change per trillion tonnes of carbon (1000 GtC) emitted as CO_2 is *likely* in the range of 0.8 °C to 2.5 °C. This quantity, called the transient climate response to cumulative carbon emissions (TCRE), is based on multiple lines of evidence and applies to cumulative emissions up to about 2000 GtC. *{WGI SPM D.2, WGI TS TFE.6, WGI 12.5.4, Box 12.2}*

Warming caused by CO_2 emissions is effectively irreversible over multi-century timescales. Ensuring CO_2-induced warming remains *likely* less than 2 °C requires total accumulated CO_2 emissions from all anthropogenic sources to remain below about 3650 $GtCO_2$ (1000 GtC), over half of which were already emitted by 2011. *{WGI SPM E.8, WGI TS TFE.8, WGI 12.5.2, 12.5.3, 12.5.4}*

A two-in-three chance or higher that total human-induced warming remains less than 2 °C requires total CO_2 emissions to be limited to about 2900 $GtCO_2$ if other emissions follow the RCPs, with a range of 2800–3200 $GtCO_2$ across the scenarios considered by WGIII (Table 2.2). Almost 1900 [1630 to 2145] $GtCO_2$ were emitted by 2011, leaving a budget of about 1000 $GtCO_2$ consistent with this temperature goal. Estimated total fossil carbon reserves exceed this remaining budget by a factor of 4 to 7, with resources much larger still. *{WGI SPM E.8, WGI 12.5.4, Figure 12.45; WGI TS TFE.8, Figure 1 and TS Supplementary material, WG III Tables SPM.1, 6.3 and 7.2}*

[25] Defined as the equilibrium global average surface warming following a doubling of CO_2 concentration (relative to pre-industrial).

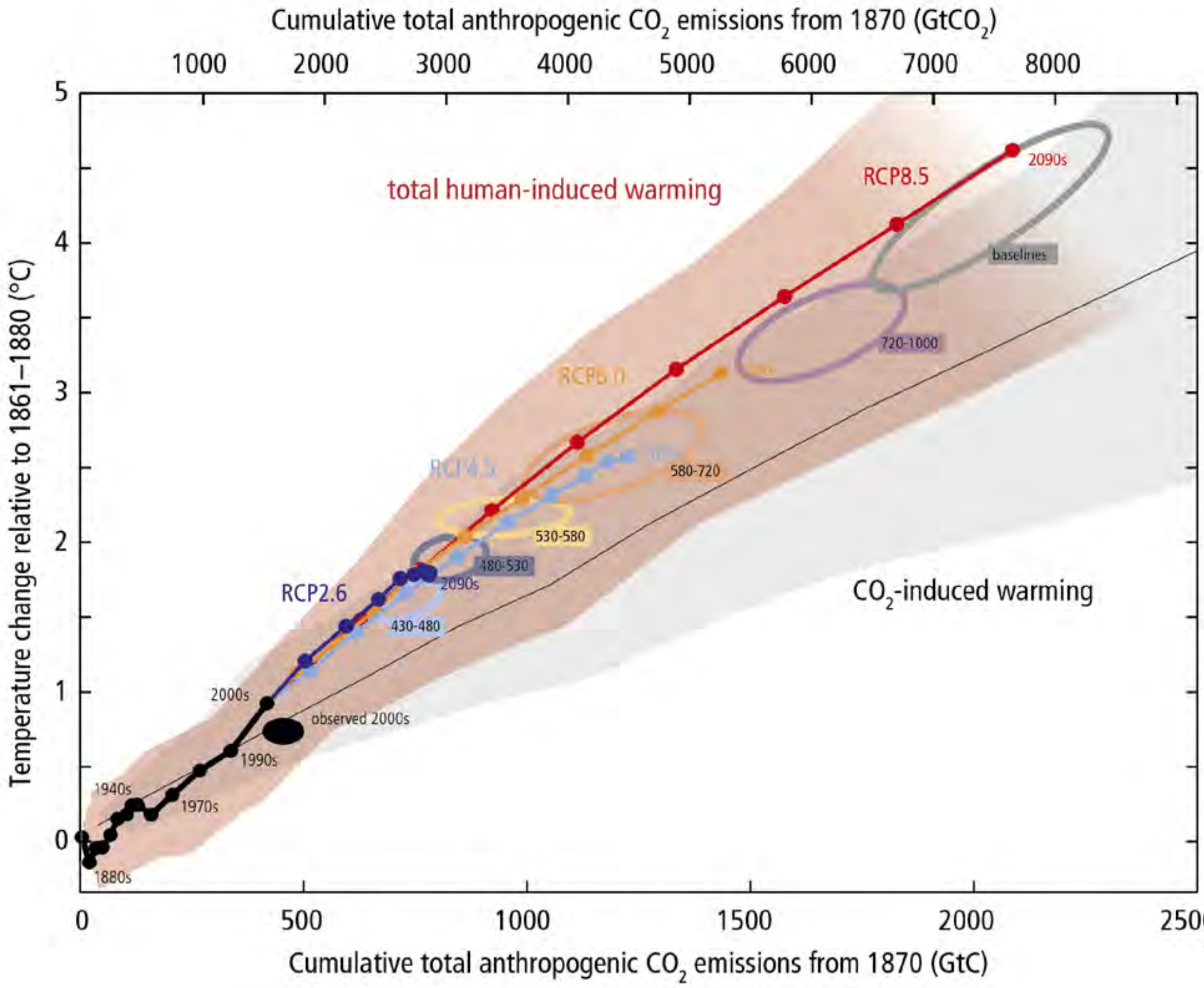


Figure 2.3: Global mean surface temperature increase as a function of cumulative total global CO_2 emissions from various lines of evidence. Multi-model results from a hierarchy of climate carbon-cycle models for each RCP until 2100 are shown (coloured lines). Model results over the historical period (1860 to 2010) are indicated in black. The coloured plume illustrates the multi-model spread over the four RCP scenarios and fades with the decreasing number of available models in RCP8.5. Dots indicate decadal averages, with selected decades labelled. Ellipses show cumulative emissions versus temperature change for the year 2100, for the scenario categories described in Section 3.2. Temperature values are always given relative to the 1861–1880 period, and emissions are cumulative since 1870. *{WGI SPM E.8, WGI 12.5.4, Figure 12.45; WGI TS TFE.8, Figure 1 and TS Supplementary material, WG III Tables SPM.1 and 6.3}*

Table 2.2: Cumulative CO_2 emission budgets consistent with limiting warming to less than stated temperature goals, at different levels of probability, based on different lines of evidence. *{WG1, 12.5.4; WGIII, 6}*

Cumulative CO_2 emissions from 1870 in $GtCO_2$									
Net anthropogenic warming [a]	<1.5 °C			<2 °C			<3 °C		
Fraction of simulations meeting goal	66%	50%	33%	66%	50%	33%	66%	50%	33%
Complex models, RCP scenarios only[b]	2250	2250	2550	2900	3000	3300	4200	4500	4850
Simple model, WGIII scenarios[c]	No data	2300–2350	2400–2950	2550–3150	2900–3200	2950–3800	2850–3850	4150–5750	5250–6000
Cumulative CO_2 emissions from 2011 in $GtCO_2$									

Complex models, RCP scenarios only[b]	400	550	850	1000	1300	1500	2400	2800	3300
Simple model, WGIII scenarios[c]	No data	550–600	600–1150	750–1400	1150–1400	1150–2050	1100–2050	2350–4000	3500–4250
Total fossil carbon available in 2011[d] : 3670–7100 $GtCO_2$ (reserves) & 31300–50050 $GtCO_2$ (resources)									

[a] Warming due to CO_2 and non-CO_2 drivers. Temperature values are given relative to the 1861–1880 base period.
[b] Cumulative CO_2 emissions at the time the temperature threshold is exceeded that are required for 66%, 50% or 33% of the CMIP5 ESM and EMIC simulations, assuming non-CO_2 forcing follows the RCP8.5 scenario. Similar budgets are implied by other RCP scenarios. For most scenario–threshold combinations, emissions and warming continue after the threshold is exceeded. Nevertheless, because of the cumulative nature of CO_2 emissions, these figures provide an indication of the CO_2 emission budgets implied by the CMIP5 model simulations under RCP-like scenarios. Values are rounded to the nearest 50.
[c] Cumulative CO_2 emissions at the time of peak warming from WGIII scenarios for which a fraction of greater than 66% (66-100%), greater than 50% (50-66%) or greater than 33% (33-50%) of climate simulations keep global mean temperature increase to below the stated threshold. Ranges indicate the variation in CO_2 budgets arising from differences in non-CO_2 drivers across the WGIII scenarios. The fraction of climate simulations for each scenario is derived from a 600 member parameter ensemble of a simple carbon-cycle climate model (MAGICC6) in a probabilistic mode. Parameter and scenario uncertainty are explored in this ensemble. Structural uncertainties cannot be explored with a single model set-up. Ranges show the impact of scenario uncertainty, with 80% of scenarios giving budgets within the stated range for the given fraction of simulations. Simple model budgets are constrained by observed changes over the past century, do not account for uncertainty in model structure and may omit some feedback processes: they are hence slightly higher than the ESM/EMIC budgets. Values are rounded to the nearest 50.
[d] Reserves are quantities able to be recovered under existing economic and operating conditions; resources are those where economic extraction is potentially feasible. *{WGIII Table 7.2}*

2.3 Future risks and impacts caused by a changing climate

Climate change will create new risks for natural and human systems and amplify existing risks in countries at all levels of development. Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (high confidence). Increasing magnitudes of warming increase the likelihood of severe, pervasive, and irreversible impacts for people, species and ecosystems. Continued high emissions would lead to mostly negative impacts for biodiversity, ecosystem services, and economic development and amplify risks for livelihoods and for food and human security.

The risks of climate change impacts depend on the magnitude and rate of climate change and on the vulnerability and exposure of affected human and natural systems, including their ability to adapt. Future climate change will amplify existing climate-related risks and create new risks.

Key risks are potentially severe impacts relevant to understanding dangerous anthropogenic interference with the climate system. Risks are considered key due to high hazard or high vulnerability of societies and systems exposed, or both. Their identification is based on large magnitude or high probability of impacts; irreversibility or timing of impacts; persistent vulnerability or exposure; or limited potential to reduce risks. Some key risks come into sharpest focus for individual regions (Figure 2.4), while others are global (Table 2.3). Risk levels often increase with temperature (Box 2.3) and are sometimes more directly linked to other dimensions of climate change, such as the rate of warming, as well as the magnitudes and rates of ocean acidification, and sea level rise (Figure 2.5).

Key risks that span sectors and regions include the following (*high confidence*):

1. Risk of severe ill-health and disrupted livelihoods resulting from storm surges, sea level rise, and coastal flooding; inland flooding in some urban regions; and periods of extreme heat.
2. Systemic risks due to extreme weather events leading to breakdown of infrastructure networks and critical services.
3. Risk of food and water insecurity and loss of rural livelihoods and income, particularly for poorer populations.

4. Risk of loss of ecosystems, biodiversity, and ecosystem goods, functions, and services. *{WGII SPM B-1}*

The overall risks of climate change impacts can be reduced by limiting the rate and magnitude of climate change. Some risks are considerable even at 1 °C global mean temperature increase above preindustrial levels. Many global risks are high to very high for global temperature increases of 4 °C or more (see Box 2.4). These risks include severe and widespread impacts on unique and threatened systems, the extinction of many species, large risks to food security, and compromised normal human activities, including growing food or working outdoors in some areas for parts of the year, due to the combination of high temperature and humidity (*high confidence*). The precise levels of climate change sufficient to trigger tipping points (thresholds for abrupt and irreversible change) remain uncertain, but the risk associated with crossing tipping points in the earth system or in interlinked human and natural systems increases with rising temperatures (*medium confidence*). *{WGII SPM B-1}*

Adaptation can substantially reduce the risks of climate change impacts, but greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). The potential for adaptation, as well as constraints and limits to adaptation, varies among sectors, regions, communities, and ecosystems. The scope for adaptation changes over time, and is closely linked to socioeconomic development pathways and circumstances. See Figure 2.4 and Table 2.3, along with topics 3 and 4. *{WGII SPM and TS Sections B and C}*

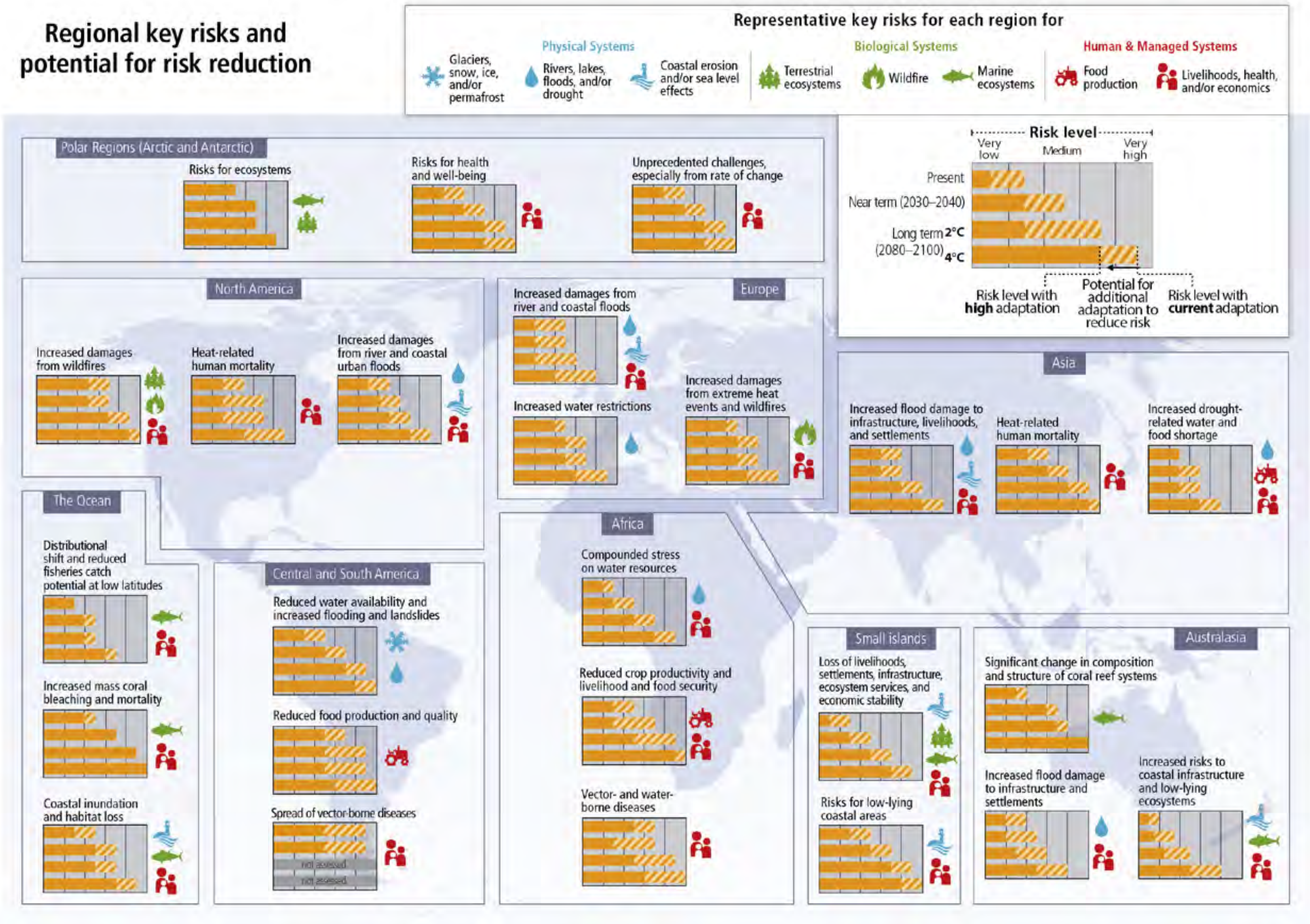


Figure 2.4: Representative key risks for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation. Risk levels are assessed as very low, low, medium, high, or very high for three timeframes: the present, near term (here, for 2030-2040), and long term (here, for 2080–2100). For the near term, projected levels of global mean temperature increase do not diverge substantially across different emission scenarios. For the long term, risk levels are presented for two possible futures (2 °C and 4 °C global mean temperature increase above preindustrial levels). For each time frame, risk levels are indicated for a continuation of current adaptation and for a highly adapted state. *{WGII SPM Assessment Box SPM.2 Table 1}*

2.3.1 Ecosystems and their services in the oceans, along coasts, on land and in fresh water

Risks of harmful impacts on ecosystems and human systems increase with the rates and magnitudes of warming, ocean acidification, sea level rise and other dimensions of climate change (*high confidence*). Future risk is indicated to be high by the observation that natural global climate change at rates lower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years on land and in the oceans (*high confidence*). Many plant and animal species will be unable to adapt locally or move fast enough during the 21st century to track suitable climates under mid- and high-range rates of climate change (RCP4.5, 6.0, and 8.5) (*medium confidence*) (Figure 2.5.A). *{WGII 4.3-4, 5.4, 6.1, 6.3, 6.5, 25.6, 26.4, 29.4, Box CC-RF, Box CC-MB, SPM A-1, SPM B-2}*

A large fraction of terrestrial, freshwater and marine species faces increased extinction risk due to climate change, especially as climate change interacts with other stressors (*high confidence*). Extinction risk is increased relative to pre-industrial and present periods, under all RCP scenarios, as a result of both the magnitude and rate of climate change (*very high confidence*). Extinctions will be driven by several climate-associated drivers (warming, sea ice loss, variations in precipitation, reduced river flows, ocean acidification and hypoxia) and the interactions among these drivers and their interaction with simultaneous habitat modification, over-exploitation of stocks, pollution, eutrophication and invasive species (*high confidence*). *{WGII 4.3-4, 6.1, 6.3, 6.5, 25.6, 26.4, Box CC-RF, Box CC-MB}*

Global marine-species redistribution and marine-biodiversity reduction in sensitive regions, under climate change, will challenge the sustained provision of fisheries productivity and other ecosystem services, especially at low latitudes (*medium confidence*). By the mid-21st century, under 2 °C global warming relative to preindustrial temperatures, spatial shifts of marine species will cause species richness and fisheries catch potential to increase, on average, at mid and high latitudes (*high confidence*) and to decrease at tropical latitudes and in semi-enclosed seas (Figure 2.6A) (*medium confidence*). The progressive expansion of Oxygen Minimum Zones and anoxic 'dead zones' in the oceans will further constrain fish habitats (*medium confidence*). Open-ocean net primary production is projected to redistribute and to decrease globally, by 2100, under all RCP scenarios (*medium confidence*). Climate change adds to the threats of over-fishing and other non-climatic stressors. *{WGII 6.3-5, 7.4, 25.6, 28.3, 29.3, 30.6-7, Boxes CC-MB and CC-PP}*

Marine ecosystems, especially polar ecosystems and coral reefs, are at risk from ocean acidification (*medium* to *high confidence*). The impacts on individual species and the number of species affected in species groups increase from RCP4.5 to 8.5. Highly calcified molluscs, echinoderms, and reef-building corals are more sensitive than crustaceans (*high confidence*) and fishes (*low confidence*) (Figure 2.6B). Ocean acidification acts together with other global changes, (e.g., warming, decreasing oxygen levels) and with local changes (e.g., pollution, eutrophication) (*high confidence*), leading to interactive, complex, and amplified impacts for species and ecosystems (Figure 2.5B). *{WGII 5.4, 6.3, 6.5, 22.3, 25.6, 28.3, 30.5, Figures 6-10, SPM.6B, Boxes CC-CR, CC-OA, and TS.7}*

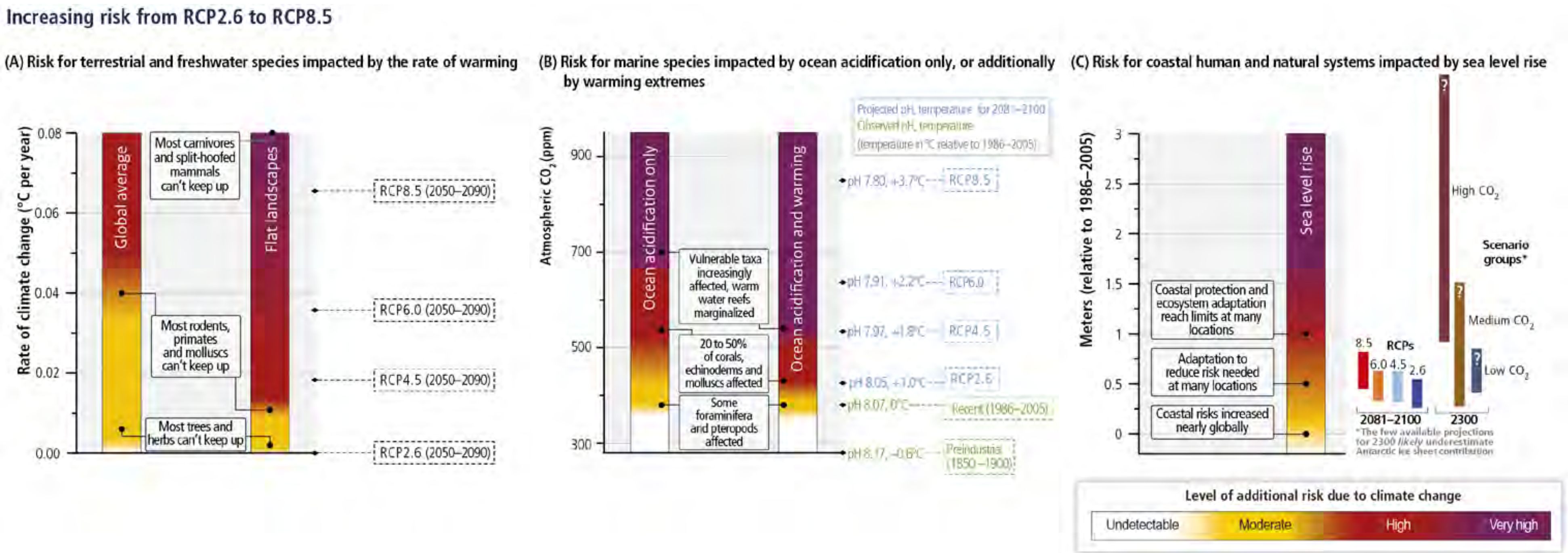


Figure 2.5: The risks of: (A) disruption of the community composition of terrestrial and freshwater ecosystems due to the rate of warming; (B) marine organisms impacted by ocean acidification (OA) or warming extremes combined with OA; and (C) coastal human and natural systems impacted by sea level rise. The risk level criteria are consistent with those used in Box 2.4 and their calibration is illustrated by the annotations to each panel. (A) At high rates of warming, major groups of terrestrial and freshwater species are unable to move fast enough to stay within the spatially shifting climate envelopes to which they are adapted. The median observed or modelled speeds at which species populations move (km/decade) are compared against the speed at which climate envelopes move across the landscape, given the projected climate change rates for each RCP over the 2050–2100 period. The results are presented for the average of all landscapes, globally, as well as for flat landscapes, where the climate envelope moves especially fast. (B) Sensitivity to ocean acidification is high in marine organisms building a calcium carbonate shell. The risks from OA increase with warming because OA lowers the tolerated levels of heat exposure, as seen in corals and crustaceans. (C) The height of a 50-year flood event has already increased in many coastal locations. A 10- to more than 100-fold increase in the frequency of floods in many places would result from a 0.5 m rise in sea level in the absence of adaptation. Local adaptation capacity (and, in particular, protection) reaches its limits for ecosystems and human systems in many places under a 1 m sea level rise. *{WGI, 3.7.5, Figure 13.25, WGII, SPM.5, Figure 4.5, Figure 6.10, CC-OA, 4.4.2.5, 5.2, 5.3-5, 5.4.4, 5.5.6, 6.3.}*

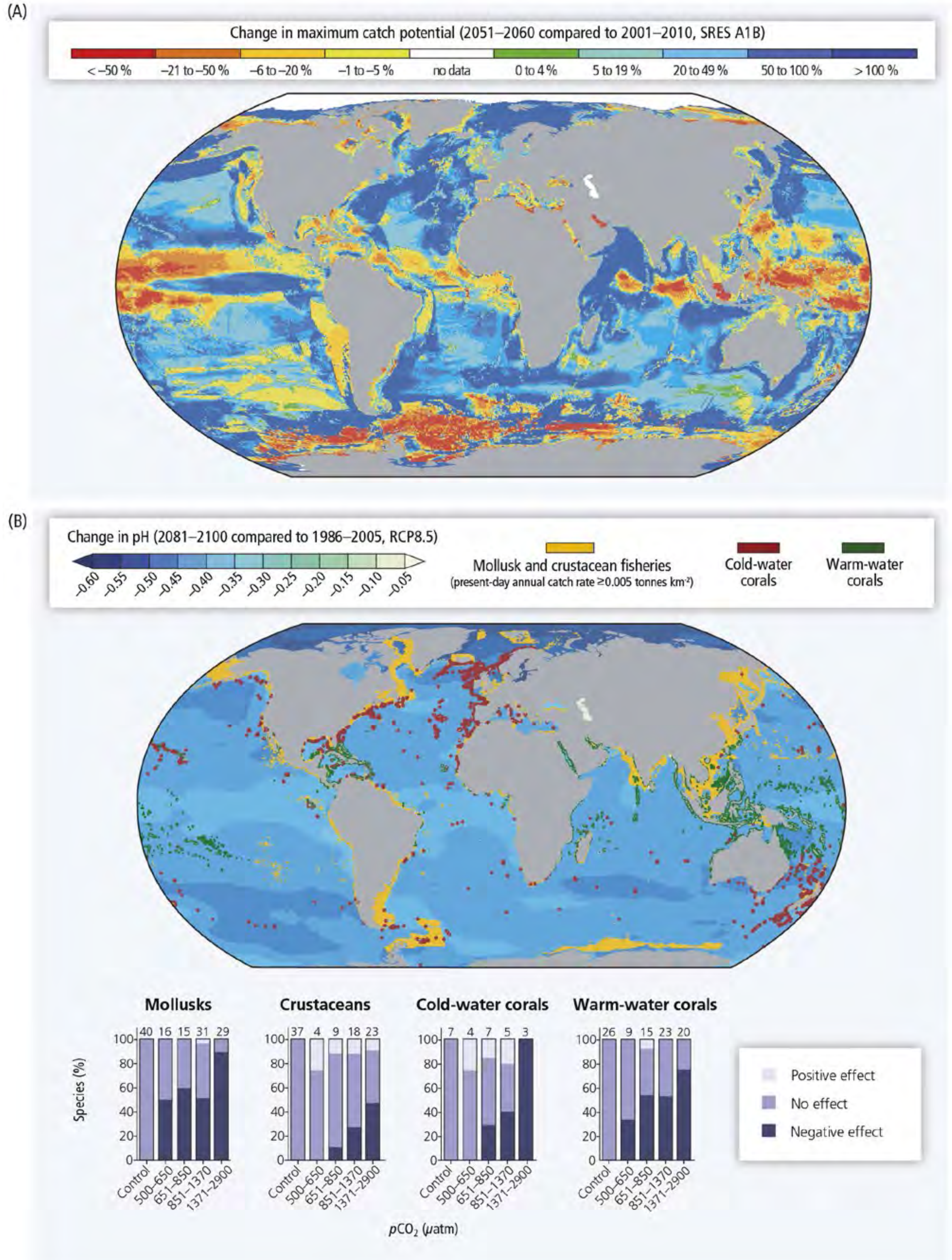


Figure 2.6: Climate change risks for fisheries. (A). Projected global redistribution of maximum catch potential of ~1000 species of exploited fishes and invertebrates, comparing the 10-year averages over 2001–2010 and 2051–2060, under 2 °C warming relative to pre-industrial temperatures, without analysis of potential impacts of overfishing or ocean acidification. (B) Marine mollusc and crustacean fisheries (present-day estimated annual catch rates ≥0.005 tonnes km^{-2}) and known locations of cold- and warm-water corals, depicted on a global map showing the projected distribution of surface ocean acidification in 2100 under RCP8.5.. The bottom panel compares the percentage of species sensitive to ocean acidification for corals, molluscs, and crustaceans, vulnerable animal phyla with socioeconomic relevance (e.g.,

for coastal protection and fisheries). The number of species analysed across studies is given on top of the bars for each category of elevated CO_2. For 2100, RCP scenarios falling within each pCO_2 category are as follows: RCP4.5 for 500–650 μatm, RCP6.0 for 651–850 μatm, and RCP8.5 for 851–1370 μatm. By 2150, RCP8.5 falls within the 1371–2900 µatm category. The control category corresponds to 380 µatm (The unit µatm is approximately equivalent to ppm in the atmosphere). *{WGII 6.1, 6.3, 30.5, Figures 6-10 and 6-14, SPM.6; WGI Figure SPM.8, WGI5 Box SPM.1}*

Carbon stored in the terrestrial biosphere is susceptible to loss to the atmosphere as a result of climate change, deforestation, and ecosystem degradation (*high confidence*). The direct effects of climate change on stored terrestrial carbon include high temperatures, drought and windstorms; indirect effects include increased risk of fires, pest and disease outbreaks**.** Increased tree mortality and associated forest dieback is projected to occur in many regions over the 21st century (*medium confidence*), posing risks for carbon storage, biodiversity, wood production, water quality, amenity, and economic activity. There is a high risk of substantial carbon and methane emissions as a result of permafrost thawing, even under RCP 2.6 in the long term. *{WGII SPM, 4 ES, 4.2-3, Figure 4-8, Boxes 4-2, 4-3, and 4-4}*

Coastal and low-lying areas will increasingly experience submergence, flooding and erosion throughout the 21st century and beyond, due to sea-level rise (*very high confidence*). The population and assets projected to be exposed to coastal risks as well as human pressures on coastal ecosystems will increase significantly in the coming decades due to population growth, economic development, and urbanization (*high confidence*). Climatic and non-climatic drivers affecting coral reefs will erode habitats, increase coastline exposure to waves and storms, and degrade environmental features important to fisheries and tourism (*high confidence*). Some low-lying developing countries and small island states are expected to face very high impacts that could have associated damage and adaptation costs of several percentage points of GDP (Figure 2.5C). *{WGII 5.3-5, 22.3, 24.4, 25.6, 26.3, 26.8, 29.4, Table 26-1, Boxes 25-1 and CC-CR}*

2.3.2 Water, Food and urban systems, human health, security and livelihoods

The fractions of the global population that will experience water scarcity and be affected by major river floods are projected to increase with the level of warming in the 21st century (*robust evidence, high agreement*). *{WGII 3.4-5, 26.3, 29.4, Table 3-2, Box 25-8}*

Climate change over the 21st century is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions (*robust evidence*, *high agreement*), intensifying competition for water among sectors (*limited evidence*, *medium agreement*). In presently dry regions, the frequency of droughts will *likely* increase by the end of the 21st century under RCP8.5 (*medium confidence*). In contrast, water resources are projected to increase at high latitudes (*robust evidence, high agreement*). The interaction of increased temperature; increased sediment, nutrient, and pollutant loadings from heavy rainfall; increased concentrations of pollutants during droughts; and disruption of treatment facilities during floods will reduce raw water quality and pose risks to drinking water quality (*medium evidence, high agreement*). *{WGII 3.2, 3.4-6, 22.3, 23.9, 25.5, 26.3, Table 3-2, 23-3, Boxes 25-2, CC-RF, and CC-WE; WGI AR5 12.4}*

All aspects of food security are potentially affected by climate change, including food production, access, use, and price stability (*high confidence*). For wheat, rice, and maize in tropical and temperate regions, climate change without adaptation is projected to negatively impact production at local temperature increases of 2 °C or more above late 20th century levels, although individual locations may benefit (*medium confidence*). Projected impacts vary across crops and regions and adaptation scenarios, with about 10% of projections for the 2030–2049 period showing yield gains of more than 10%, and about 10% of projections showing yield losses of more than 25%, compared with the late 20th century. Global temperature increases of ~4 °C or more above late 20th century levels, combined with increasing food demand, would pose large risks to food security, both globally and regionally (*high confidence*) (Figure 2.4, 2.7). *{WGII 6.3-5, 7.4-5, 9.3, 22.3, 24.4, 25.7, 26.5, Tables 7-2 and 7-3, Figures 7-1, 7-4, 7-5, 7-6, 7-7, and 7-8, Box 7-1}*

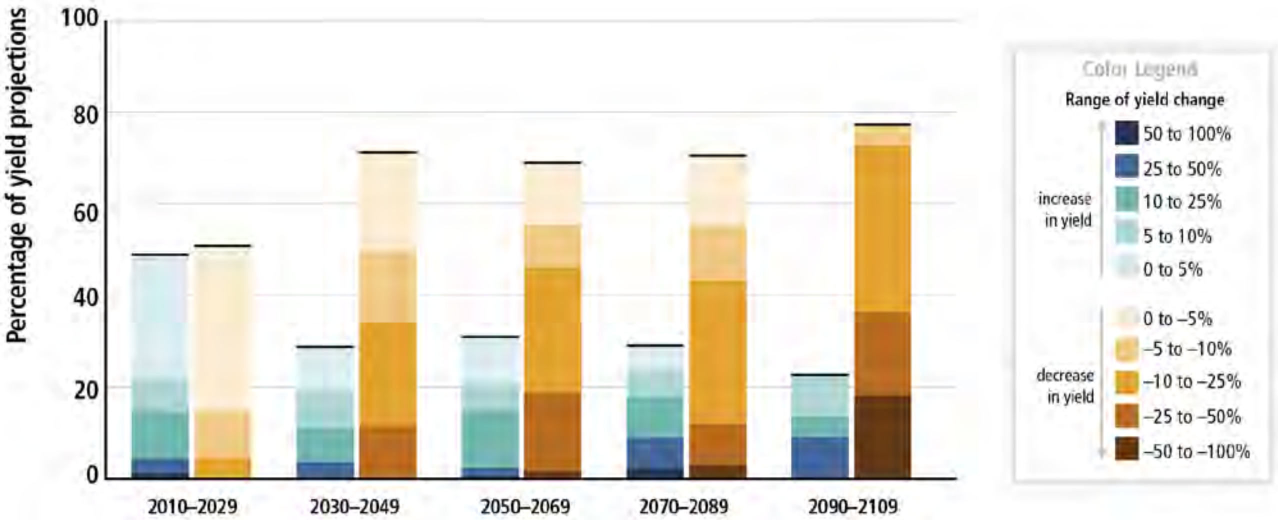


Figure 2.7: Summary of projected changes in crop yields (mostly wheat, maize, rice, and soy) due to climate change over the 21st century. The figure combines 1090 datapoints from crop model projections, covering different emission scenarios, tropical and temperate regions, and adaptation and no-adaptation cases. The projections are sorted into the 20-year periods (horizontal axis) during which their midpoint occurs. Changes in crop yields are relative to late 20th century levels, and data for each time period sum to 100%. Relatively few studies have considered impacts on cropping systems for scenarios where global mean temperatures increase by 4 °C or more. *{WGII, Figure SPM.7}*

Climate change is expected to lead to increases in ill health in many regions, especially in developing countries with low income (*high confidence*). Up to mid century, the impact will mainly exacerbate human health problems that already exist (*very high confidence*). Health impacts include greater likelihood of injury and death due to more intense heatwaves and fires, increased risks from foodborne and waterborne diseases, and loss of work capacity and reduced labour productivity in vulnerable populations (*very high confidence*). Risks of undernutrition in poor regions will increase (*high confidence*). Risks from vector-borne diseases are projected to generally increase with warming, due to the extension of the infection area and season, despite reductions in some areas that become too hot (*medium confidence*). Globally, the magnitude and severity of negative impacts will increasingly outweigh positive impacts (*high confidence*). *{WGII 8.2, 11.3-8, 19.3, 22.3, 25.8, 26.6, Figure 25-5, Box CC-HS}*

In urban areas, climate change is projected to increase risks for people, economies and ecosystems, including risks from heat stress, storms and extreme precipitation, inland and coastal flooding, water scarcity, sea level rise and storm surges (*very high confidence*)**.** These risks will be amplified for those lacking essential infrastructure and services or living in exposed areas. *{WGII 3.5, 8.2-4, 22.3, 24.4-5, 26.8, Table 8-2, Boxes 25-9 and CC-HS}*

Rural areas are expected to experience major impacts on water availability and supply, food security, infrastructure, and agricultural incomes, including shifts in the production areas of food and non-food crops around the world (*high confidence*). These impacts will disproportionately affect the welfare of the poor in rural areas, such as female-headed households and those with limited access to land, modern agricultural inputs, infrastructure, and education. *{WGII 5.4, 9.3, 25.9, 26.8, 28.2, 28.4,Box 25-5}*

Aggregate economic damages accelerate with increasing temperature (*limited evidence, high agreement*). With recognized limitations, the existing incomplete estimates of global annual economic losses for warming of ~2.5 °C above preindustrial levels are 0.2% to 2.0% of income (*medium evidence, medium agreement*). Changes in population, age structure, income, technology, relative prices, lifestyle, regulation, and governance are projected to have relatively larger impacts than climate change, for most economic sectors (*medium evidence, high agreement*). More severe and/or frequent weather hazards are projected to increase disaster-related losses and loss variability, posing challenges for affordable insurance, particularly in developing countries. *{WGII 3.5, 10.2, 10.7, 10.9-10, 17.4-5, 25.7, 26.7-9, Box 25-7}*

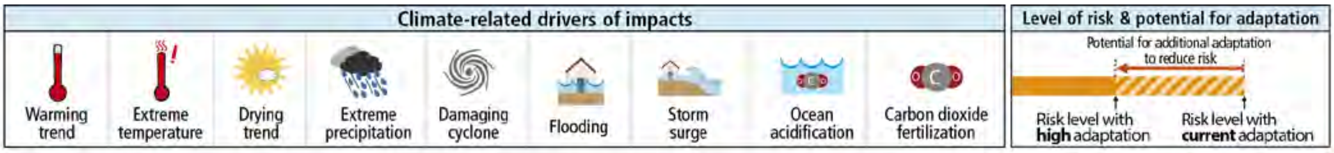
From a poverty perspective, climate change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food security, and prolong existing poverty traps and create new ones, the latter particularly in urban areas and emerging hotspots of hunger (*medium*

***confidence*).** Climate change impacts are expected to exacerbate poverty in most developing countries and create new poverty pockets in countries with increasing inequality, in both developed and developing countries (Figure 2.4). *{WGII 8.1, 8.3-4, 9.3, 10.9, 13.2-4, 22.3, 26.8}*

Climate change is projected to increase displacement of people (*medium evidence, high agreement*). Displacement risk increases when populations that lack the resources for planned migration experience higher exposure to extreme weather events, such as floods and droughts. Expanding opportunities for mobility can reduce vulnerability for such populations. Changes in migration patterns can be responses to both extreme weather events and longer term climate variability and change, and migration can also be an effective adaptation strategy.*{WGII 9.3, 12.4, 19.4, 22.3, 25.9}*

Climate change can indirectly increase risks of violent conflict in the form of civil war and intergroup violence by amplifying well-documented drivers of these conflicts, such as poverty and economic shocks (*medium confidence*). Multiple lines of evidence relate climate variability to these forms of conflict. *{WGII SPM, 12.5, 13.2, 19.4}*

Table 2.3: Examples of global key risks for different sectors, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation. Each key risk is assessed as very low, low, medium, high, or very high. Risk levels are presented for three time frames: present, near term (here, for 2030–2040), and long term (here, for 2080–2100). In the near term, projected levels of global mean temperature increase do not diverge substantially across different emission scenarios. For the long term, risk levels are presented for two possible futures (2 °C and 4 °C global mean temperature increase above preindustrial levels). For each time frame, risk levels are indicated for a continuation of current adaptation and for a highly adapted state. Relevant climate variables are indicated by icons. *{WGII Table TS.4}*



Global Risks

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Reduction in terrestrial carbon sink: Carbon stored in terrestrial ecosystems is vulnerable to loss back into the atmosphere, resulting from increased fire frequency due to climate change and the sensitivity of ecosystem respiration to rising temperatures (*medium confidence*) [4.2, 4.3]	• Adaptation options include managing land use (including deforestation), fire and other disturbances, and non-climatic stressors.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Boreal tipping point: Arctic ecosystems are vulnerable to abrupt change related to the thawing of permafrost, spread of shrubs in tundra, and increase in pests and fires in boreal forests (*medium confidence*) [4.3, Box 4-4]	• There are few adaptation options in the Arctic.		Present Near term (2030–2040) Long-term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Amazon tipping point: Moist Amazon forests could change abruptly to less-carbon-dense, drought- and fire-adapted ecosystems (*low confidence*) [4.3, Box 4-3]	• Policy and market measures can reduce deforestation and fire.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Increased risk of species extinction: A large fraction of the species assessed is vulnerable to extinction due to climate change, often in interaction with other threats. Species with an intrinsically low dispersal rate, especially when occupying flat landscapes where the projected climate velocity is high, and species in isolated habitats such as mountaintops, islands, or small protected areas are especially at risk. Cascading effects through organism interactions, especially those vulnerable to phenological changes, amplify risk (*high confidence*) [4.3, 4.4]	• Adaptation options include reduction of habitat modification and fragmentation, pollution, over-exploitation, and invasive species; protected area expansion; assisted dispersal; and *ex situ* conservation.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Global redistribution and decrease of low-latitude fisheries yields, paralleled by a global trend to catches having smaller fishes (*medium confidence*) [6.3 to 6.5, 30.5, 30.6]	• Increasing coastal poverty at low latitudes as fisheries become smaller – partially compensated by the growth of aquaculture and marine spatial planning, as well as enhanced industrialized fishing efforts		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Reduced growth and survival of commercially valuable shellfish and other calcifiers (e.g., reef building corals, calcareous red algae) due to ocean acidification (*high confidence*) [5.3, 6.1, 6.3, 6.4, 30.3, Box CC-OA]	• Evidence for differential resistance and evolutionary adaptation of some species exists but is *likely* to be limited at higher CO_2 concentrations and temperatures. • Adaptation options include exploiting more resilient species or protecting habitats with low natural CO_2 levels, as well as reducing other stresses, mainly pollution, and limiting pressures from tourism and fishing.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Marine biodiversity loss with high rate of climate change (*medium confidence*) [6.3, 6.4, Table 30-4, Box CC-MB]	• Adaptation options are limited to reducing other stresses, mainly pollution, and limiting pressures from coastal human activities such as tourism and fishing.		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high

Global Risks

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation (Very low – Medium – Very high)
Negative impacts on average crop yields and increases in yield variability due to climate change (*high confidence*) [7.2 to 7.5, Figure 7-5, Box 7-1]	• Projected impacts vary across crops and regions and adaptation scenarios, with about 10% of projections for the period 2030–2049 showing yield gains of more than 10%, and about 10% of projections showing yield losses of more than 25%, compared to the late 20th century. After 2050 the risk of more severe yield impacts increases and depends on the level of warming.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Urban risks associated with water supply systems (*high confidence*) [8.2, 8.3]	• Adaptation options include changes to network infrastructure as well as demand-side management to ensure sufficient water supplies and quality, increased capacities to manage reduced freshwater availability, and flood risk reduction.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Urban risks associated with energy systems (*high confidence*) [8.2, 8.4]	• Most urban centers are energy intensive, with energy-related climate policies focused only on mitigation measures. A few cities have adaptation initiatives underway for critical energy systems. There is potential for non-adapted, centralized energy systems to magnify impacts, leading to national and transboundary consequences from localized extreme events.		Present Near term (2030–2040) Long-term (2080–2100) 2°C / 4°C	
Urban risks associated with housing (*high confidence*) [8.3]	• Poor quality, inappropriately located housing is often most vulnerable to extreme events. Adaptation options include enforcement of building regulations and upgrading. Some city studies show the potential to adapt housing and promote mitigation, adaptation, and development goals simultaneously. Rapidly growing cities, or those rebuilding after a disaster, especially have opportunities to increase resilience, but this is rarely realized. Without adaptation, risks of economic losses from extreme events are substantial in cities with high-value infrastructure and housing assets, with broader economic effects possible.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Displacement associated with extreme events (*high confidence*) [12.4]	• Adaptation to extreme events is well understood, but poorly implemented even under present climate conditions. Displacement and involuntary migration are often temporary. With increasing climate risks, displacement is more likely to involve permanent migration.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Violent conflict arising from deterioration in resource-dependent livelihoods such as agriculture and pastoralism (*high confidence*) [12.5]	Adaptation options: • Buffering rural incomes against climate shocks, for example through livelihood diversification, income transfers, and social safety net provision • Early warning mechanisms to promote effective risk reduction • Well-established strategies for managing violent conflict that are effective but require significant resources, investment, and political will		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Declining work productivity, increasing morbidity (e.g., dehydration, heat stroke, and heat exhaustion), and mortality from exposure to heat waves. Particularly at risk are agricultural and construction workers as well as children, homeless people, the elderly, and women who have to walk long hours to collect water (*high confidence*) [13.2, Box 13-1]	• Adaptation options are limited for people who are dependent on agriculture and cannot afford agricultural machinery. • Adaptation options are limited in the construction sector where many poor people work under insecure arrangements. • Adaptation limits may be exceeded in certain areas in a +4°C world.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	
Reduced access to water for rural and urban poor people due to water scarcity and increasing competition for water (*high confidence*) [13.2, Box 13-1]	• Adaptation through reducing water use is not an option for the many people already lacking adequate access to safe water. Access to water is subject to various forms of discrimination, for instance due to gender and location. Poor and marginalized water users are unable to compete with water extraction by industries, large-scale agriculture, and other powerful users.		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	

Box 2.4: Reasons for concern regarding climate change

Five 'reasons for concern' have provided a framework for summarizing key risks since the Third Assessment Report. They illustrate the implications of warming and of adaptation limits for people, economies, and ecosystems across sectors and regions. They provide one starting point for evaluating dangerous anthropogenic interference with the climate system (Article 2 Box). All warming levels in the text of Box 2.3 are relative to the 1986–2005 period. Adding ~0.6 °C to these warming levels roughly gives warming relative to the 1850–1900 period, used here as a proxy for pre-industrial times (right-hand scale in figure 1). The five reasons for concern are:

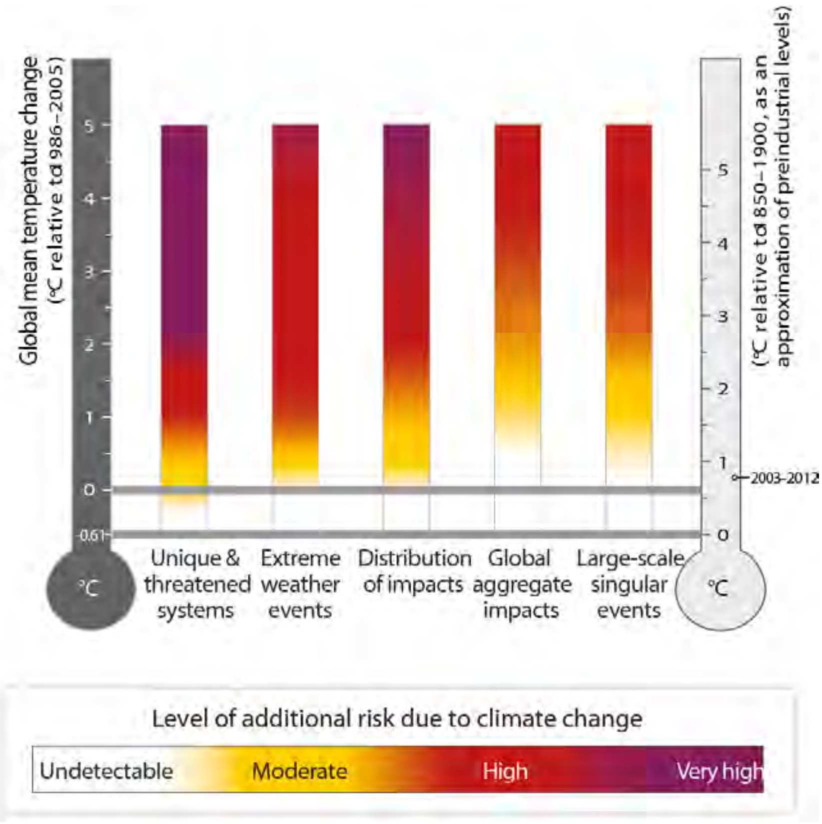
1. **Unique and threatened systems**: Some ecosystems and cultures are already at risk from climate change (*high confidence*). With additional warming of around 1 °C, the number of unique and threatened systems at risk of severe consequences increases. Many systems with limited adaptive capacity, particularly those associated with Arctic sea ice and coral reefs, are subject to very high risks with additional warming of 2 °C. In addition to risks resulting from the *magnitude* of warming, terrestrial species are also sensitive to the *rate* of warming, marine species to the rate and degree of ocean acidification, and coastal systems to sea level rise (Figure 2.5).

2. **Extreme weather events**: Climate-change-related risks from extreme events, such as heatwaves, heavy precipitation and coastal flooding, are already moderate (*high confidence*). With 1 °C additional warming, risks are high (*medium confidence*). Risks associated with some types of extreme events (e.g., extreme heat) increase progressively with further warming (*high confidence*).

3. **Distribution of impacts**: Risks are unevenly distributed between groups of people and between regions; risks are generally greater for disadvantaged people and communities everywhere. Risks are already moderate because of regional differences in observed climate change impacts, particularly for crop production (*medium* to *high confidence*). Based on projected decreases in regional crop yields and water availability, risks of unevenly distributed impacts are high under additional warming of above 2 °C (*medium confidence*).

4. **Global aggregate impacts**: Risks of global aggregate impacts are moderate under additional warming of between 1 and 2 °C, reflecting impacts on both the Earth's biodiversity and the overall global economy (*medium confidence*). Extensive biodiversity loss, with associated loss of ecosystem goods and services, leads to high risks at around 3 °C additional warming (*high confidence*). Aggregate economic damages accelerate with increasing temperature (*limited evidence*, *high agreement*), but few quantitative estimates are available for additional warming of above 3 °C.

5. **Large-scale singular events**: With increasing warming, some physical and ecological systems are at risk of abrupt and/or irreversible changes (see Section 2.4). Risks associated with such tipping points are moderate between 0 and 1 °C additional warming, since there are signs that both warm-water coral reefs and Arctic ecosystems are already experiencing irreversible regime shifts (*medium confidence*). Risks increase at a steepening rate under an additional warming of 1 to 2 °C and become high above 3 °C, due to the potential for large and irreversible sea level rise from ice sheet loss. For sustained warming above some threshold greater than ~0.5 °C additional warming (*low confidence*) but less than ~3.5 °C (*medium confidence*), near-complete loss of the Greenland ice sheet would occur over a millennium or more, eventually contributing up to 7 m to global mean sea level rise.



Box 2.4, Figure 1: Risks associated with reasons for concern at a global scale are shown for increasing levels of climate change. The colour shading indicates the additional risk due to climate change when a temperature level is reached and then sustained or exceeded. White indicates no associated impacts are detectable and attributable to climate change. Yellow indicates that associated impacts are both detectable and attributable to climate change with at least *medium confidence*. Red indicates severe and widespread impacts. Purple, introduced in this assessment, shows that very high risk is indicated by all key risk criteria. *{WGII SPM Box 1, Figure 19-4}*

2.4 Climate Change beyond 2100, irreversibility and abrupt changes[26]

Many aspects of climate change and its impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases cease. The risk of abrupt and irreversible change increases as the magnitude of the warming increases.

Climate change represents a substantial multi-century commitment, effectively irreversible over a period of many human generations. Stabilization of radiative forcing would result in an ongoing global warming for many centuries. Warming would continue beyond 2100 under all RCP scenarios except RCP2.6. (Figure 2.8). *{WGI SPM E.8, 12.5.2}*

The anthropogenic contribution to surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. (See Section 2.2.5 for the relationship between CO_2 emissions and global temperature change.) *{WGI SPM E.8 WGI 12.5.2}*

Stabilization of global average surface temperature does not imply stabilization for all aspects of the climate system. Shifting biomes, re-equilibrating soil carbon, ice sheets, ocean temperatures and associated sea level rise all have their own intrinsic long timescales that will result in ongoing changes for hundreds to

[26] ‘Abrupt’ refers to a rapid change in the rate of change relative to the recent history of the affected components of the climate system. Abrupt change in slow processes may therefore unfold over decades. Not all irreversible changes are abrupt, nor are all abrupt changes irreversible.

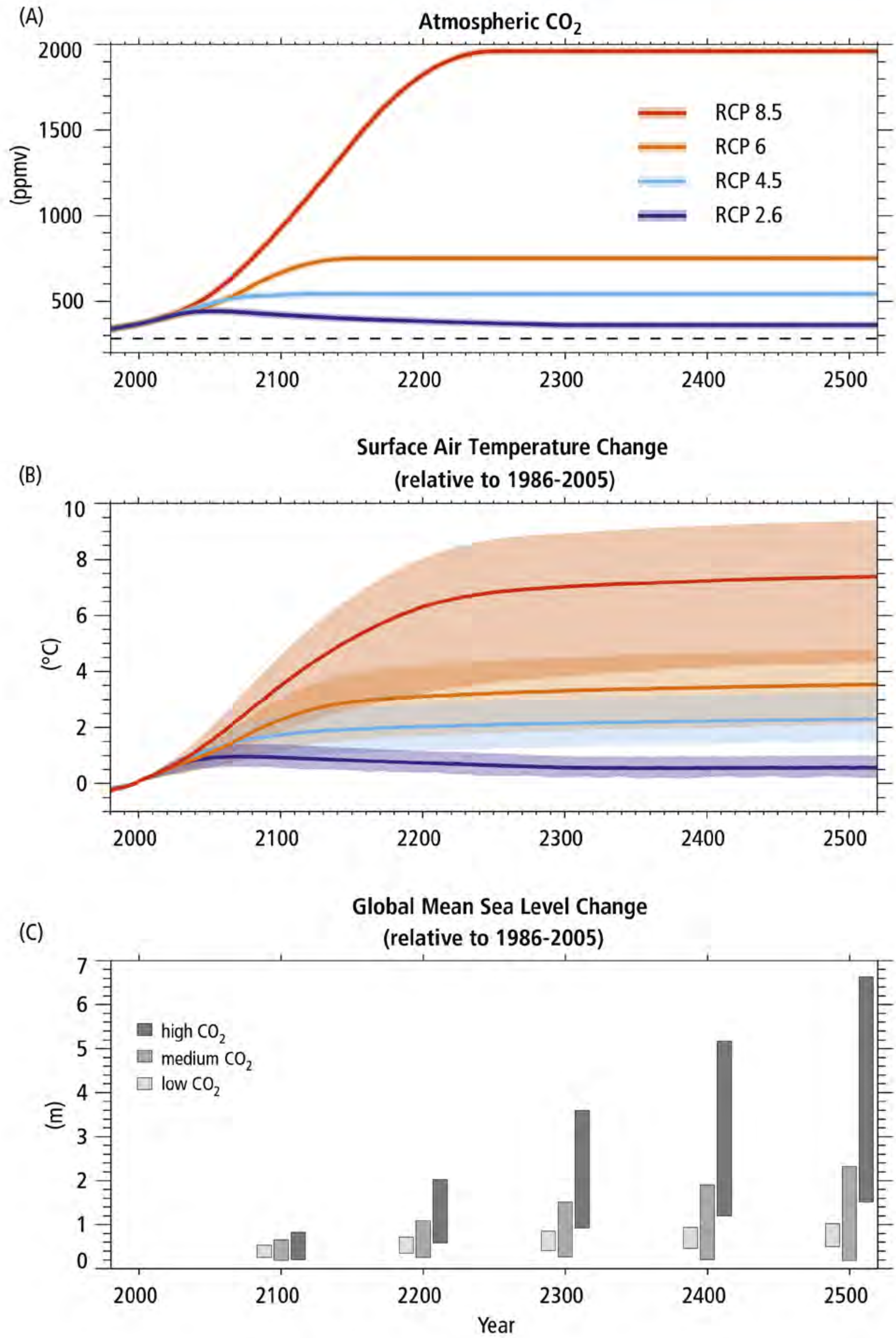
thousands of years after global surface temperature has been stabilized. *{WGI SPM E.8, WGI 12.5.2 to 12.5.4}*

Ocean acidification will increase for centuries if CO_2 emissions continue, will strongly affect marine ecosystems (*high confidence*), and the impact will be exacerbated by rising temperature extremes (Figure 2.5B). Ocean acidification is caused by rising atmospheric CO_2 entering surface waters, and has impacts on physiology, behaviour and population dynamics of organisms (*medium* to *high confidence*). *{WGI 3.8.2, WGI 6.4.4, WGII SPM B2, WGII 6.3.2, WGII 30.3.2, WGII CC-OA}*

Global mean sea level rise, caused by ocean thermal expansion and the loss of mass from ice sheets, will continue for many centuries beyond 2100 *(virtually certain)*. The few available analyses that go beyond 2100 indicate sea level rise to be less than 1 m above the pre-industrial level by 2300 for greenhouse gas concentrations that peak and decline and remain below 500 ppm CO_2-eq, as in scenario RCP2.6. For a radiative forcing that corresponds to a CO_2-eq concentration in 2100 that is above 700 ppm but below 1500 ppm, as in scenario RCP8.5, the projected rise is 1 m to more than 3 m by 2300 (*medium confidence*) (Figure 2.8). There is *low confidence* in the available models' ability to project solid ice discharge from the Antarctic ice sheet. Hence, these models *likely* underestimate the Antarctica ice sheet contribution, resulting in an underestimation of projected sea level rise beyond 2100. *{WGI SPM E.8, WGI 13.4.4, 13.5.4}*

There is little evidence in global climate models of a tipping point or critical threshold in the transition from a perennially ice-covered to a seasonally ice-free Arctic Ocean, beyond which further sea ice loss is unstoppable and irreversible. *{WGI 12.5.5}*

There is *low confidence* in assessing the evolution of the Atlantic Meridional Overturning Circulation beyond the 21st century because of the limited number of analyses and equivocal results. However, a collapse beyond the 21st century for large sustained warming cannot be excluded. *{WGI SPM E.4, 12.4.7, 12.5.5}*



(A)
Atmospheric CO_2
2000
1500
1000
500
(ppmv)
RCP 8.5
RCP 6
RCP 4.5
RCP 2.6
2000
2100
2200
2300
2400
2500
(B)
Surface Air Temperature Change
(relative to 1986-2005)
10
8
6
4
2
0
(°C)
2000
2100
2200
2300
2400
2500
(C)
Global Mean Sea Level Change
(relative to 1986-2005)
7
6
5
4
3
2
1
0
(m)
high CO_2
medium CO_2
low CO_2
2000
2100
2200
2300
2400
2500
Year

Figure 2.8: (a) Atmospheric CO_2 and (b) projected global mean surface temperature change as simulated by Earth System Models of Intermediate Complexity (EMICs) for the 4 RCPs up to 2300 (relative to 1986–2005) followed by a constant (year 2300 level) radiative forcing. A 10-year smoothing was applied. The dashed line on (a) indicates the pre-industrial CO_2 concentration. (c) Sea level change projections grouped into three categories according to the concentration of GHG (in CO_2eq) in 2100 (low: concentrations that peak and decline and remain below 500 ppm, as in scenario RCP2.6; medium: 500–700 ppm, including RCP4.5; high: concentrations that are above 700 ppm but below 1500 ppm, as in scenario RCP6.0 and RCP8.5). The bars in (c) show the maximum possible spread that can be obtained with the few available model results (and should not be interpreted as uncertainty ranges). These models *likely* underestimate the Antarctica ice sheet contribution, resulting in an underestimation of projected sea level rise beyond 2100. *{WGI SPM E.8, WGI Figure 12.43 and 13.13, Table 13.8; WGII SPM B2}*

Sustained mass loss by ice sheets would cause larger sea level rise, and part of the mass loss might be irreversible. There is *high confidence* that sustained global mean warming greater than a threshold would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a sea level rise of up to 7 m. Current estimates indicate that the threshold is greater than 1 °C (*low confidence*) but less than about 4 °C (*medium confidence*) with respect to pre-industrial temperatures. Abrupt and irreversible ice loss from a potential instability of marine-based sectors of the Antarctic ice sheet in response to climate forcing is possible, but current evidence and understanding is insufficient to make a quantitative assessment. *{WGI SPM E.8, WGI 5.6.2, 5.8.1, 13.4.3, 13.5.4}*

Within the 21st century, magnitudes and rates of climate change associated with medium to high emission scenarios (RCP4.5, 6.0, and 8.5) pose a high risk of abrupt and irreversible regional-scale change in the composition, structure, and function of terrestrial, freshwater and marine ecosystems, including wetlands (*medium confidence*) as well as warm water coral reefs (*high confidence*). Examples that could substantially amplify climate change are the boreal-tundra Arctic system (*medium confidence*) and the Amazon forest (*low confidence*). *{WGII 4.3.3.1, Box 4.3, Box 4.4, 5.4.2.4, 6.3.1-4, 6.4.2, 30.5.3-6, WGII CC-CR, CC-MB}*

A reduction in permafrost extent is *virtually certain* with continued rising global temperatures. Current permafrost areas are projected to become a net emitter of carbon (CO_2 and CH_4) with a loss of 180 to 920 $GtCO_2$ (50–250 GtC) by 2100 under RCP8.5 during the 21st century (*low confidence*). *{WGI TFE5, 12.5.5, WGII 4.3.3.4}*

Topic 3: Transformations and Changes in Systems

Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial near-term emissions reductions can reduce risks in the 21st-century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation, and contribute to climate-resilient pathways for sustainable development.

Adaptation and mitigation are two complementary options for responding to climate change. Adaptation is the process of adjustment to actual or expected climate and its effects, in order to either lessen or avoid harm or exploit beneficial opportunities. Mitigation is the process of reducing emissions or enhancing sinks of greenhouse gases, so as to limit future climate change. Both adaptation and mitigation can reduce and manage the risks of climate change impacts. Yet, adaptation and mitigation can also create other risks, as well as benefits. Strategic responses to climate change involve consideration of climate-related risks along with the risks and co-benefits of adaptation and mitigation actions.

Mitigation, adaptation, and climate impacts can all result in transformations to and changes in systems. Depending on the rate and magnitude of change and the vulnerability and exposure of human and natural systems, climate change will alter ecosystems, food systems, infrastructure, coastal, urban and rural areas, human health and livelihoods. Adaptive responses to a changing climate require actions that range from incremental changes to more fundamental, transformational changes.[27] Mitigation involves fundamental changes in the way that human societies produce and use energy services and land.

Topic 3 of this report examines the factors that influence the assessment of mitigation and adaptation strategies. It considers the benefits, risks, incremental changes, and potential transformations from different combinations of mitigation, adaptation, and residual climate-related impacts. It considers how responses in the coming decades will influence options for limiting long-term climate change and opportunities for adapting to it. Finally, it considers factors – including uncertainty, ethical considerations, and links to other societal goals – that may influence choices about mitigation and adaptation. Topic 4 then assesses the prospects for mitigation and adaptation on the basis of current knowledge of tools, options and policies.

3.1 The Foundations of Decision-Making for Climate Change

Effective decision making about climate change benefits from a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of ethical dimensions, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty.

Mitigation and adaptation raise issues of equity, justice, and fairness, and have implications for sustainable development and poverty eradication. Many of those most vulnerable to climate change are the poor and least responsible for GHG emissions. Delaying mitigation shifts burdens from present-day people towards those who live in the future. Both adaptation and mitigation can have distributional effects on locally, nationally and internationally, depending on who pays and who benefits. The process of decision-making about climate change, and the degree to which it respects the rights and views of all those affected, is also a concern of justice. Cooperation and effective governance can be facilitated by *agreements* that are seen as fair (SYR 3.5). *{WG II 2.2, 2.3, 13.3, 13.4, 17.3, 20.2, 20.5; WG III 3.3, 3.10, 4.1.2, 4.2, 4.3, 4.5, 4.6, 4.8}*

Effective mitigation will not be achieved if individual agents advance their own interests independently. Climate change has the characteristics of a collective action problem at the global scale, because most greenhouse gases (GHGs) accumulate over time and mix globally, and emissions by any agent (e.g., individual, community, company, country) affect other agents. Decision-making by and

[27] Transformation is used in this report to refer to a change in the fundamental attributes of a system (see Glossary). Transformations can occur at multiple levels; at the national level, transformation is considered most effective when it reflects a country's own visions and approaches to achieving sustainable development in accordance with their national circumstances and priorities. *{WG II SPM .C-2, Chapters 2–13, 20.5; WG III SPM, Chapters 6–12}*

coordination between governments and other collective agents is therefore involved in responding to climate change. *{WG II 20.3.1; WG III 1.2, 2.6, 3.2, 4.2, 13.2, 13.3}*

Decision-making about climate change involves valuation and mediation among diverse values, and may be aided by the analytic methods of several normative disciplines. Ethics analyses the different values involved and the relations between them. Recent political philosophy has investigated the question of responsibility for the effects of emissions. Economics and decision analysis provide quantitative methods of valuation, which can be used for estimating the social cost of carbon, in cost–benefit and cost-effectiveness analyses, in Integrated Assessment Models, and elsewhere. Economic methods can reflect ethical principles, and take account of non-marketed goods, equity, behavioural biases, ancillary benefits and costs and the differing values of money to different people. They are, however, subject to well-documented limitations. *{WG II 2.2, 2.3; WG III 2.5, 2.6, 3.2-6, 3.9, 3.9.4, Box TS.2, SPM.2}*

Analytic methods are not able to identify a single target for climate policy or a single best balance between mitigation, adaptation, and residual climate impacts. Important reasons for this are that climate change involves extremely complex natural and social processes, there is extensive disagreement about the values concerned, and climate change impacts and mitigation approaches have important distributional impacts. Nevertheless, information on the consequences of emissions pathways to alternative climate goals and risk levels can be a useful input into decision-making processes. Evaluating responses to climate change involves assessment of the widest possible range of impacts, including low-probability outcomes with large consequences. *{WG II 1.1.4, 2.3, 2.4, 17.3, 19.6, 19.7; WG III 2.5, 2.6, 3.4, 3.7, Box 3-9}*

Effective decision-making and risk management in the complex environment of climate change is *likely* to be iterative: strategies can often be adjusted as new information and understanding develops during implementation. However, adaptation and mitigation choices in the near term will affect the risks of climate change throughout the 21st century and beyond, and prospects for climate-resilient pathways for sustainable development depend on what is achieved through mitigation. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if mitigation is delayed too long. Effective risk management strategies are *likely* to take into account how relevant stakeholders perceive and respond to risk and uncertainty. Decision processes about climate change often include both intuitive and deliberative thinking. Laypersons are sometimes influenced by emotional, social and cultural factors that cause them to overestimate or underestimate risks and be biased towards the status quo. Formalized analytical methods for decision-making under uncertainty can focus attention on both short- and long-term consequences. *{WG II 2.1-4, 3.6, 5.5 14.1-3, 15.2-4, 17.1-3, 17.5, 20.6; WG III 2.4, 2.5, 2.6, 5.5, 16.4, 20.2, SPM.2}*

3.2 Climate Change Risks Reduced by Mitigation and Adaptation

Without additional mitigation, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread, and irreversible impacts globally *(high confidence)*. Risks from mitigation can be substantial, but they do not involve the same possibility of severe, widespread, and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation action.

The risks and benefits of climate change, adaptation, and mitigation differ in nature, timescale, magnitude, and persistence *(high confidence)*. Risks from adaptation include maladaptation and negative ancillary impacts. Risks from mitigation include possible adverse side effects of large-scale deployment of low-carbon technology options and economic costs. Climate change risks may persist for millennia and can involve very high risk of severe impacts and the presence of significant irreversibilities combined with limited adaptive capacity. In contrast, the stringency of climate policies can be adjusted much more quickly in response to observed consequences and costs and create lower irreversibility risks. *{WGI SPM E.8, 12.4, 12.5.2,, 13.5; WG II 4.2, 17.2, 19.6; SYR 3.3, 3.4, 4.3; WG III 2.5}*

Mitigation and adaptation interact with one another and reduce risks, over different timescales *(high confidence)*. Adaptation has the potential to reduce climate change impacts over the next few decades, while mitigation has relatively little influence on climate outcomes over this timescale. Near-term and longer-term mitigation and adaptation, as well as development pathways, will determine the risks of climate change beyond mid-century. The level of mitigation will influence the rate and magnitude of climate change, and greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). The potential for adaptation differs across sectors and will be limited by institutional and capacity constraints, increasing the long-term benefits of mitigation *(high confidence). {WGI 11.3, 12.4, WGII 1.1.4.4., 2.5, 16.3-6, 17.3, 19.2, 20.2.3, 20.3, 20.6, SPM.B.2, C.2, SYR 3.3}*

Without additional mitigation, climate change risks are *likely* to be high to very high by the end of the 21st century, for all Reasons for Concern, and the potential of adaptation to reduce some of these risks will be limited *(medium confidence)*. (Topic 2 and Figure 3.1 panel A). Estimates of temperature change in 2100 without climate mitigation are from 3.7 °C to 4.8 °C (median estimates; the range is 2.5 °C to 7.8 °C when including climate uncertainty) (Figure 3.1; figure 3.4; WGIII SPM.3). The potential risks associated with temperatures at or above 4 °C include severe and widespread impacts on unique and threatened systems, substantial species extinction, large risks to global and regional food security, impacts on normal human activities, increased likelihood of triggering tipping points (critical thresholds), and the likelihood of exceeding adaptation limits (*high confidence*) (see SYR Box 3.3). *{WG II SPM.B1; WG II SPM.C2}*

Mitigation over the next few decades can substantially reduce risks of climate change in the second half of the 21st century and beyond *(high confidence)*. The level of risk as measured in the five Reasons for Concern is related to the level of global average warming (Panel A). Warming is linked to cumulative emissions (Figure 3.1, Panel B), which are, in turn, linked to emission reductions over different timescales (Figure 3.1, Panel C). Reducing risks of climate change through mitigation can involve substantial cuts in anthropogenic GHG emissions over the coming decades (Figure 3.1, Panel C; figure 3.4). Maintaining climate change risks below a threshold (Panel A) requires keeping cumulative emissions below a certain level (Panel B), which means that global net emissions eventually must decrease to zero (Panel C). Under all assessed scenarios for mitigation and adaptation, some risk from residual damages is unavoidable (very high confidence). A subset of relevant climate change risks has been estimated using aggregate economic indicators. Such economic estimates are attended by important limitations and are therefore a useful but insufficient basis for decision-making regarding decisions on long-term mitigation targets (see Box 3.1). *{WG II 19.7.1; WG III SPM.3, Figure 3.1, Panel A}*

Stringent mitigation involves its own set of risks *(high confidence)*. Scenarios that are *likely* to limit warming to below 2 °C or even 3 °C involve large-scale changes in energy systems and potentially land-use over the coming decades (3.4). Associated risks include those associated with large-scale deployment of technology options for producing low-carbon energy, the potential for high aggregate economic costs, and impacts on vulnerable countries and industries. Other risks are associated with human health, food security, energy security, poverty reduction, biodiversity conservation, water availability, income distribution, efficiency of taxation systems, labour supply and employment, urban sprawl, and the economic growth of developing countries (Table 4.5). *{WG III SPM.4.1}*

In an iterative risk management framework, inertia in the economic and climate systems and the possibility of irreversible impacts from climate change increase the benefits of near-term mitigation efforts *(high confidence)*. The actions taken today affect the options available in the future to reduce emissions, limit temperature change, and adapt to climate change. Near-term choices can create, amplify or limit significant elements of lock-in that are important for decision-making. Lock-ins and irreversibilities occur in the climate system due to large inertia in some of its components such as heat transfer from the ocean surface to depth leading to continued ocean warming for centuries regardless of emission scenario and the irreversibility of a large fraction of anthropogenic climate change resulting from CO_2 emissions on a multi-century to millennial time scale unless CO_2 were to be removed from the atmosphere through large scale human interventions over a sustained period (see also Box 3.3). *{WG I SPM.E.8}* Irreversibilities in socio-economic and biological systems also result from infrastructure development and long-lived products *{WG III SPM.4.2.1}* and from climate change impacts, such as species extinction. The larger potential for irreversibility and pervasive impacts from climate change risks than from mitigation risks increases the benefit of short-term mitigation efforts. Delays in additional mitigation limit the mitigation options and increase the mitigation costs and risks that would be incurred in the medium to long term to maintain climate change risks at a given level (Table WG III.SPM.2, blue segment). *{WG II 2.5, 19.7, 20.3, Box 20-4, SPM.B.2; WG III 3.6, 3.7, 6.9}*

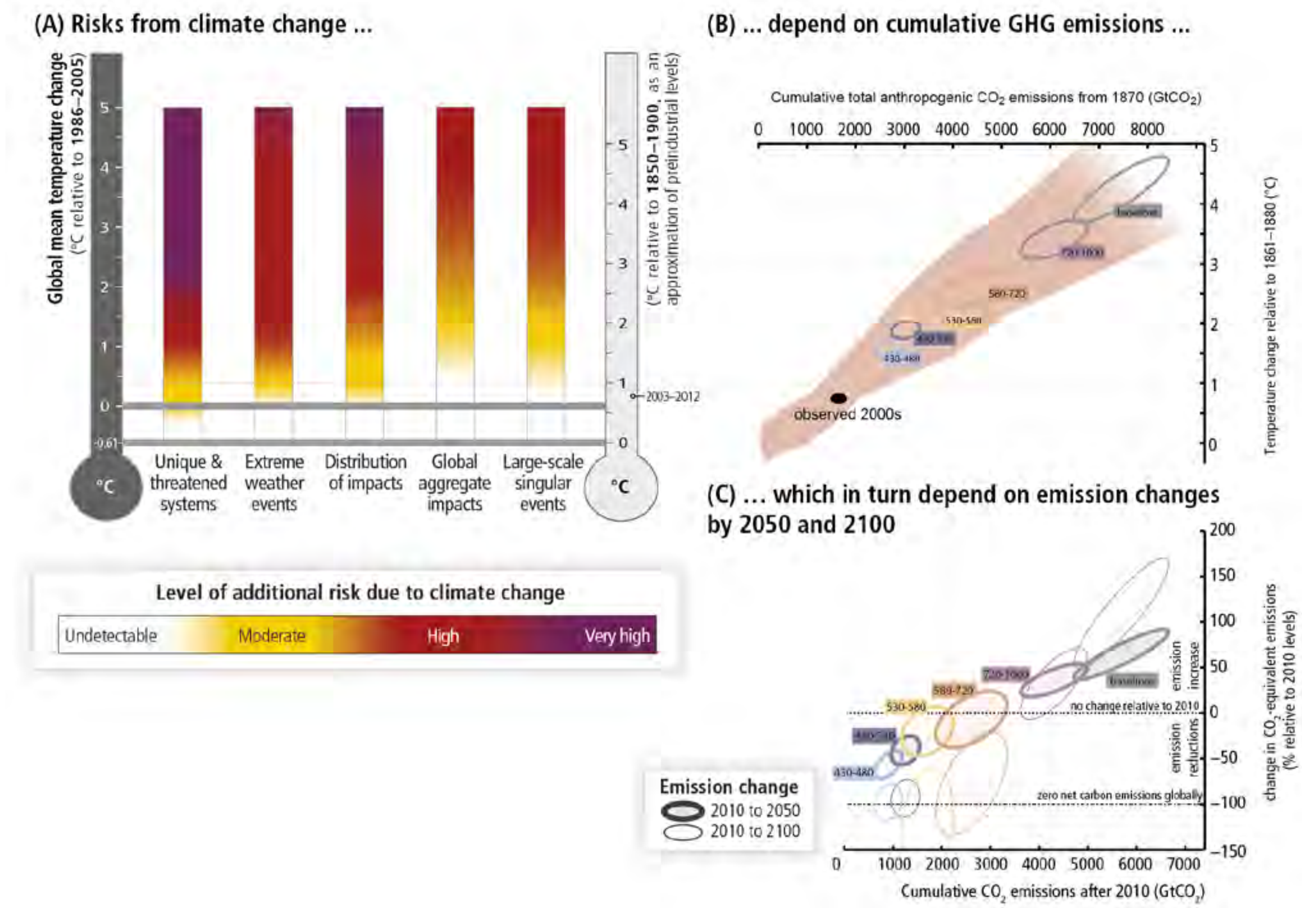


Figure 3.1: The relationship between Reasons for Concern, temperature, cumulative emissions, and future emissions reductions. **Panel A** reproduces the five Reasons for Concern from WGII (Topic 2 and Article 2 box) with temperature changes expressed relative to 1850-1900 (right axis) and 1986-2005 temperatures (left axis). Moderate risk (yellow) indicates that impacts are both detectable and attributable to climate change with at least medium confidence. High risk (red) indicates severe and widespread impacts. Very high risk (purple) indicates that all criteria for "key risk" are met (WG II19). **Panel B** links these temperature changes to cumulative CO_2 emissions (from 1870), based on CMIP5 and EMIC simulations (pink plume) and the MAGICC climate model for the baselines and five mitigation scenario categories defined in Chapter WGIII.6 (the 6 ellipses); see Figure 2.2 for details. **Panel C** shows the relationship between the cumulative CO_2 emissions of the WG III scenario categories (X-axis) and their associated change in annual GHG emissions by 2050 and 2100 (Y-axis). The ellipses correspond to the same WGIII scenario categories as in Panel B. Cumulative emissions are shown from 2011 to 2100. The change in annual GHG emissions are shown for 2050 and 2100 relative to 2010 (positive changes refer to cases where emissions in 2050/2100 are larger than 2010). *{Table WG III.SPM.1}*

Box 3.1: The limits of the economic assessment of climate change risks

A subset of climate change risks and impacts are often measured using aggregate economic indicators, such as GDP or aggregate income. Estimates, however, are partial and affected by important conceptual and empirical limitations. These incomplete estimates of global annual economic losses for additional temperature increases of ~2 °C are between 0.2 and 2.0% of income) (medium evidence, medium *agreement*). Losses are *more likely than not* to be greater, rather than smaller, than this range (limited evidence, high *agreement*). Estimates of the incremental aggregate economic impact of emitting one more tonne of carbon dioxide (the social cost of carbon) are derived from these studies and lie between a few dollars and several hundreds of dollars per tonne of carbon in 2000 to 2015 (robust evidence, medium *agreement*). These impact estimates are incomplete and depend on a large number of assumptions, many of which are disputable. Many estimates do not account for the possibility of large-scale singular events and irreversibility, tipping points, and other important factors, especially those that are difficult to monetize, such as loss of biodiversity. Estimates of aggregate costs mask significant differences in impacts across sectors, regions, countries and populations, and they therefore depend on ethical considerations, especially on distribution of losses across and within countries *(high confidence).* Estimates of global aggregate economic losses exist only for limited warming that occurs in scenarios with additional mitigation action and associated costs. As a result, mitigation cost and climate damage estimates at any given temperature level cannot be compared to evaluate the costs and benefits of mitigation. Very little is known about the economic cost of warming above 3 °C relative to the current temperature level. Accurately estimating climate change risks (and thus the benefits of mitigation) takes into account the full range of possible impacts of climate change, including those with high consequences but a low probability of occurrence. The benefits of mitigation may otherwise be underestimated (*high confidence*). Some limitations of current estimates may be unavoidable, even with more knowledge, such as issues with aggregating impacts over time and across individuals when values are heterogeneous. In view of these limitations, it is outside the scope of science to identify a single climate change target and an optimal climate policy (3.1, 3.4). *{WG II 10.9.2, 10.9.4, 13.2, 17.2-3, 18.4,19.6, 19.6; WG III 3.6}*

3.3 Characteristics and risks of adaptation pathways

Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, particularly if greenhouse gas emissions are not reduced. A longer-term perspective allows more immediate adaptation actions to be building blocks for future adaptations, increasing future options and preparedness.

Adaptation can contribute to the well-being of current and future populations, the security of assets and the maintenance of ecosystem services now and in the future. Adaptation is place- and context-specific, with no single approach for reducing risks appropriate across all settings *(high confidence)*. Effective risk reduction and adaptation strategies consider vulnerability and exposure and their linkages with socioeconomic processes, sustainable development, and climate change. Adaptation research since the AR4 has evolved from a dominant consideration of engineering and technological adaptation pathways to include more ecosystem-based, institutional, and social measures. A previous focus on cost–benefit analysis, optimization, and efficiency approaches has broadened with the development of multi-metric evaluations that include risk and uncertainty dimensions integrated within wider policy and ethical frameworks to assess trade-offs and constraints. The range of specific adaptation measures has also expanded (see SYR 4.2 and 4.4.2.1), as have the links to sustainable development (see SYR 3.5). There are many studies on local and sectoral adaptation costs and benefits, but few global analyses and *very low confidence* in their results. *{WG II 14.1, 14.3, 15.2, 15.5, 17.2, 17.3, SPM.C-1, Table SPM.1}*

Adaptation planning and implementation at all levels of governance are contingent on societal values, objectives, and risk perceptions *(high confidence)*. Recognition of diverse interests, circumstances, social-cultural contexts, and expectations can benefit decision-making processes. Indigenous, local, and traditional knowledge systems and practices are a major resource for adapting to climate change, but these have not been used consistently in existing adaptation efforts. Integrating such forms of knowledge into practices increases the effectiveness of adaptation as do effective decision support, engagement and policy processes (see SYR 4.4.2). *{WG II SPM.C-1}*

A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability *(high confidence)*, but some near-term responses to climate change may also limit future choices. Integration of adaptation into planning and decision making can promote synergies with development and disaster risk reduction. However, overemphasizing short-term outcomes, or failing to sufficiently anticipate consequences, can increase the vulnerability or exposure of the target group in the future, or the vulnerability of other people, places, or sectors (*medium evidence*, *high agreement*). For example, enhanced protection of exposed assets can lock in dependence on further protection measures. Appropriate adaptation options can be better assessed by including co-benefits and mitigation implications (see Sections 3.5 and 4.2). *{WG II SPM.C-1}*

Numerous interacting constraints can impede adaptation planning and implementation *(high confidence)*. Common constraints on implementation arise from the following: limited financial and human resources; limited integration or coordination of governance; uncertainties about projected impacts; different perceptions of risks; competing values; absence of key adaptation leaders and advocates; and limited tools to monitor adaptation effectiveness. Other constraints include insufficient research, monitoring, and observation and the resources to maintain them. Underestimating the complexity of adaptation as a social process can create unrealistic expectations about achieving intended adaptation outcomes (see Sections 4.1 and 4.2 for details in relation to implementation). *{WG II SPM.C-1}*

There are limits to adaptation; greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits *(high confidence)*. Limits to adaptation occur when adaptive actions to avoid intolerable risks for an actor's objectives or for the needs of a system are not possible or are not currently available. Value-based judgments of what constitutes an intolerable risk may differ. Limits to adaptation emerge from the interaction among climate change and biophysical and/or socioeconomic constraints. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if limits to adaptation are exceeded. In some parts of the world, insufficient responses to emerging impacts are already eroding the basis for sustainable development. For most regions and sectors, empirical evidence is not sufficient to quantify magnitudes of climate change that would constitute a future adaptation limit. Furthermore, economic development, technology, and cultural norms and values can change over time to enhance or reduce the capacity of systems to avoid limits. As a consequence, some limits are 'soft' in that they may be alleviated over time. Other limits are 'hard' in that there are no reasonable prospects for avoiding intolerable risks. *{WG II SPM.C-2; WG II TS}*

Transformations in economic, social, technological, and political decisions and actions can enable climate-resilient pathways *(high confidence)*. Restricting adaptation responses to incremental changes to existing systems and structures without considering transformational change, may increase costs and losses, and miss opportunities. For example, enhancing infrastructure to protect other built assets can be expensive and ultimately not defray increasing costs and risks, whereas options such as relocation or using ecosystem services to adapt may provide a range of benefits now and in the future. Transformational adaptation can include introduction of new technologies or practices, formation of new financial structures or systems of governance, adaptation at greater scales or magnitudes, and shifts in the location of activities. Planning and implementation of transformational adaptation may place new and increased demands on governance structures to reconcile different goals and visions for the future and to address possible equity and ethical implications: Transformations to sustainability are considered to benefit from iterative learning, deliberative processes, and innovation. *{WG II 1.1, 2.5, 5.5, 8.4, 14.1, 14.3, Table 14.4, 15.5, 16.2-7, Table 16-3, Box 16.1, Box 16.4, 20.3.3, 20.5, 25.10, Box 25.1, 26.8, SPM C-2}*

Building adaptive capacity is crucial for effective selection and implementation of adaptation options (*high agreement, robust evidence*). Successful adaptation requires not only identifying adaptation options and assessing their costs and benefits, but also increasing the adaptive capacity of human and natural systems (*see SYR 4.2*) (*high agreement, medium evidence*). This can involve complex governance challenges and new institutions and institutional arrangements. *{WG II 5.5, 12.3, 14.1-3, 16.2, 16.3, 16.5, 16.8, SYR 4.2}*

3.4 Characteristics and risks of mitigation pathways

Measures exist to achieve the substantial emissions reductions over the next few decades necessary to limit *likely* warming to 2 °C. Limiting warming to 2.5 °C or 3 °C involves similar reductions, but less quickly. Implementing such reductions poses substantial technological, economic, social, and institutional challenges, which increase with delays in additional mitigation and technology constraints.

Without additional efforts to reduce GHG emissions, global emission growth is expected to persist driven by population and economic growth (Figure 3.1) (*high confidence*). Global emissions under most scenarios without additional mitigation (baseline scenarios) are between about 75 $GtCO_2eq$/yr and almost 140 $GtCO_2eq$/yr in 2100, which is approximately between the 2100 emissions in the RCP 6.0 and RCP 8.5 pathways (Figure 3.2)[28]. Concentrations under baseline scenarios exceed 450 parts per million (ppm) CO_2eq by 2030 and reach CO_2eq levels between about 750 and more than 1300 ppm CO_2eq by 2100. Global mean surface temperature increases by 2100 are from about 3.7 to 4.8 °C (range based on median climate response;

[28] For a discussion on CO_2 equivalent (CO_2eq) emissions and concentrations, see Box 3.2 on greenhouse gas metrics and mitigation pathways and the Glossary.

the range is from 2.5 °C to 7.8 °C when including climate uncertainty). The future scenarios do not account for possible changes in natural forcings in the climate system (see Box 1.1). *{WG III 6.3, Box TS.6}*

Many different combinations of technological, behavioural, and policy options can be used to reduce emissions and limit temperature change *(high confidence)*. To evaluate possible pathways to long-term climate goals, about 900 mitigation scenarios were collected for this assessment, each of which describes different technological, socioeconomic, and institutional transformations. Emission reductions under these scenarios lead to concentrations by 2100 from roughly 430 ppm CO_2eq to below 1000 ppm CO_2eq, which is comparable to the 2100 concentration levels between RCP 2.6 and RCP 6.0. Scenarios with concentration levels by 2100 of below 430 ppm CO_2eq were also assessed. *{WG III SPM.4.1, WG III Chapter 6, Annex II}*

Scenarios leading to concentration levels by 2100 of about 450 ppm CO_2eq are *likely* to maintain temperature change at below 2 °C over the century (*high confidence*). Scenarios reaching concentration levels of about 500 ppm CO_2eq by 2100 are *more likely than not* to limit temperature change to less than 2 °C, unless concentration levels temporarily exceed roughly 530 ppm CO_2eq before 2100. In this case, temperature is *about as likely as not* to remain below 2 °C. Scenarios that exceed about 650 ppm CO_2eq by 2100 are *unlikely* to limit temperature change to below 2 °C. Mitigation scenarios in which temperature increase is *more likely than not* to be less than 1.5 °C by 2100 are characterized by concentration levels by 2100 of below 430 ppm CO_2eq. In these scenarios, temperature will peak during the century and subsequently decline. *{WG III 6.3, Box TS.6, Table SPM.1}*

Scenarios reaching about 450 ppm CO_2eq by 2100 typically involve temporary overshoot of atmospheric concentrations, as do many scenarios reaching about 500 ppm to about 550 ppm CO_2eq by 2100.[29] Overshoot scenarios typically rely on the widespread deployment of bioenergy with carbon dioxide capture and storage (BECCS) and afforestation in the second half of the century (*high confidence*). The magnitude of this deployment depends on the degree of overshoot. The availability and scale of BECCS, afforestation, and other Carbon Dioxide Removal (CDR) technologies and methods are uncertain, and CDR technologies and methods are, to varying degrees, associated with challenges and risks (see Box 3.3)**.** CDR is also present in many scenarios without overshoot. *{WG III 2.6, 6.3, 6.9.1, Figure 6.7, 7.11, 11.13, Table SPM.1}*

Limiting *likely* temperature change to 2 °C will require substantial cuts in anthropogenic GHG emissions by mid-century through large-scale changes in energy systems and possibly land use. Limiting temperature change to higher levels involves these same reductions but less quickly (*high confidence*). Scenarios reaching 450 ppm by 2100 (these scenarios are *likely* to maintain temperature change at below 2 °C) involve a 40% to 70% reduction in GHG emissions by 2050, relative to 2010 levels[30], and emissions near zero $GtCO_2$eq or below in 2100 (Figure 3.2, Table 3.1). These scenarios include more rapid improvements in energy efficiency and a tripling to nearly a quadrupling of the share of zero- and low-carbon energy supply from renewable energy, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS), or bioenergy with CCS (BECCS) by the year 2050 (Figure 3.2, lower panel). The scenarios describe a wide range of changes in land use, reflecting different assumptions about the scale of bioenergy production, afforestation, and reduced deforestation. *{WG III, 6.3, 7.11}*

[29] In concentration 'overshoot' scenarios, concentrations peak during the century and then decline.

[30] This range differs from the range provided for a similar concentration category in AR4 (50 % to 85 % lower than in 2000, for CO_2 only). Reasons for this difference include that this report has assessed a substantially larger number of scenarios than in AR4 and looks at all GHGs. In addition, a large proportion of the new scenarios include CDR technologies. Other factors include the use of 2100 concentration levels instead of stabilization levels and the shift in reference year from 2000 to 2010. Scenarios with higher emission levels by 2050 are characterized by a greater reliance on CDR technologies beyond mid-century.

Table 3.1: Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters, the 10th to 90th percentile of the scenarios is shown[1,2]. *{WG III SPM Table SPM1, Table 6.3}*

<table>
<tr><th rowspan="2">CO_2eq Concentrations in 2100 (CO_2eq)[5]
Category label (conc. range)</th><th rowspan="2">Subcategories</th><th rowspan="2">Relative position of the RCPs</th><th colspan="2">Change in CO_2eq emissions compared to 2010 (in %)[3,5]</th><th colspan="4">Likelihood of staying below specific temperature levels (relative to 1850–1900)[5,6,7]</th></tr>
<tr><th>2050</th><th>2100</th><th>Likelihood of staying below 1.5 °C</th><th>Likelihood of staying below 2 °C</th><th>Likelihood of staying below 3 °C</th><th>Likelihood of staying below 4 °C</th></tr>
<tr><td>< 430</td><td colspan="8">Only a limited number of individual model studies have explored levels below 430 ppm CO_2eq</td></tr>
<tr><td>450
(430 – 480)</td><td>Total range[1,4]</td><td>RCP2.6</td><td>-72 to -41</td><td>-118 to -78</td><td>More unlikely than likely</td><td>Likely</td><td rowspan="6">Likely</td><td rowspan="7">Likely</td></tr>
<tr><td rowspan="2">500
(480 – 530)</td><td>No overshoot of 530 ppm CO_2eq</td><td></td><td>-52 to -42</td><td>-107 to -73</td><td rowspan="6">Unlikely</td><td>More likely than not</td></tr>
<tr><td>Overshoot of 530 ppm CO_2eq</td><td></td><td>-55 to -25</td><td>-114 to -90</td><td>About as likely as not</td></tr>
<tr><td rowspan="2">550
(530 – 580)</td><td>No overshoot of 580 ppm CO_2eq</td><td></td><td>-47 to -19</td><td>-81 to -59</td><td rowspan="3">More unlikely than likely[9]</td></tr>
<tr><td>Overshoot of 580 ppm CO_2eq</td><td></td><td>-16 to 7</td><td>-183 to -86</td></tr>
<tr><td>(580 – 650)</td><td>Total range</td><td rowspan="2">RCP4.5</td><td>-38 to 24</td><td>-134 to -50</td></tr>
<tr><td>(650 – 720)</td><td>Total range</td><td>-11 to 17</td><td>-54 to -21</td><td rowspan="2">Unlikely</td><td>More likely than not</td></tr>
<tr><td>(720 – 1000)</td><td>Total range</td><td>RCP6.0</td><td>18 to 54</td><td>-7 to 72</td><td rowspan="2">Unlikely[8]</td><td>More unlikely than likely</td></tr>
<tr><td>>1000</td><td>Total range</td><td>RCP8.5</td><td>52 to 95</td><td>74 to 178</td><td>Unlikely[8]</td><td>Unlikely</td><td>More unlikely than likely</td></tr>
</table>

[1]The 'total range' for the 430 to 480 ppm CO_2eq concentration scenarios corresponds to the range of the 10th to 90th percentile of the subcategory of these scenarios shown in Table 6.3.

[2] Baseline scenarios (see SPM.3) are categorized in the >1000 and 750–1000 ppm CO_2eq categories. The latter category includes also mitigation scenarios. The baseline scenarios in the latter category reach a temperature change of between 2.5 and 5.8 °C above 1850-1900 levels, by 2100. Together with the baseline scenarios in the >1000 ppm CO_2eq category, this leads to an overall 2100 temperature range of between 2.5 and 7.8 °C (median transient climate response: 3.7–4.8 °C) for baseline scenarios across both concentration categories.

[3] Global 2010 emission levels are 31% above 1990 emission levels (consistent with the historical GHG emission estimates presented in this report). CO_2eq emissions include the basket of Kyoto gases (CO_2, CH4, N2O as well as F-gases). CO_2 equivalent *emissions* include the basket of Kyoto gases (CO_2, CH_4, N_2O as well as F-gases) calculated based on GWP_{100} values form the Second Assessment Report, whereas, CO_2 equivalent *concentrations* are for all anthropogenic radiative forcings, including the cooling effects of aerosols. CO_2eq is used as shorthand notation in both cases. CO_2equivalent emissions in 2010 are 49 (±4.5) $GtCO_2eq\ yr^{-1}$ (based on GWP_{100} values from IPCC Second Assessment Report) and 52 (± 4.7) $GtCO_2eq\ yr^{-1}$ (based on GWP_{100} values from AR5). (See Box 3.2 and the Glossary).

[4] The assessment here involves a large number of scenarios published in the scientific literature and is thus not limited to the RCPs. To evaluate the GHG concentration and climate implications of these scenarios, the MAGICC model was used in a probabilistic mode (see Annex II). For a comparison between MAGICC model results and the outcomes of the models used in WGI, see Section WGI 12.4.1.2 and WGI 12.4.8 and 6.3.2.6 (see also Table WG3, SPM1).

[5] The assessment in this table is based on the probabilities calculated for the full ensemble of scenarios in WGIII using MAGICC and the assessment in WGI of the uncertainty of the temperature projections not covered by climate models. The statements are therefore consistent with the statements in WGI, which are based on the CMIP5 runs of the RCPs and the assessed uncertainties. Hence, the likelihood statements reflect different lines of evidence from both WGs. This WGI method was also applied for scenarios with intermediate concentration levels where no CMIP5 runs are available. The likelihood statements are indicative only (6.3), and broadly follow the terms used by the WGI SPM for temperature projections: *likely* 66-100%, *more likely than not* >50-100%, *about as likely as not* 33-66%, and *unlikely* 0-33%. .

[6] The CO_2 equivalent *concentration* includes the forcing of all GHGs including halogenated gases and tropospheric ozone, aerosols and albedo change (calculated on the basis of the total forcing from a simple carbon cycle / climate model MAGICC). The CO_2 equivalent concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 – 520 ppm) [WGIII 6.3, Box TS.6; WGI Figure SPM.5, WGI 8.5.1, WGI 12.3]. This is based on the assessment of total anthropogenic radiative forcing for 2011 relative to 1750 in WGI, i. e. 2.3 $W\ m^{-2}$, uncertainty range 1.1 to 3.3 $W\ m^{-2}$. *{WGI Figure SPM.5, 8.5.1, 12.3}*

[7] The vast majority of scenarios in this category overshoot the category boundary of 480 ppm CO_2eq concentration.

[8] For scenarios in this category, no CMIP5 run or MAGICC realization (6.3) stays below the respective temperature level. Still, an *'unlikely'* assignment is given to reflect uncertainties that might not be reflected by the current climate models. *{WGI 12, Table 12.3}*

[9] Scenarios in the 580–650 ppm CO_2eq category include both overshoot scenarios and scenarios that do not exceed the concentration level at the high end of the category (e.g. RCP4.5). The latter type of scenarios, in general, have an

assessed probability of more unlikely than likely to exceed the 2 °C temperature level, while the former are mostly assessed to have an unlikely probability of exceeding this level.

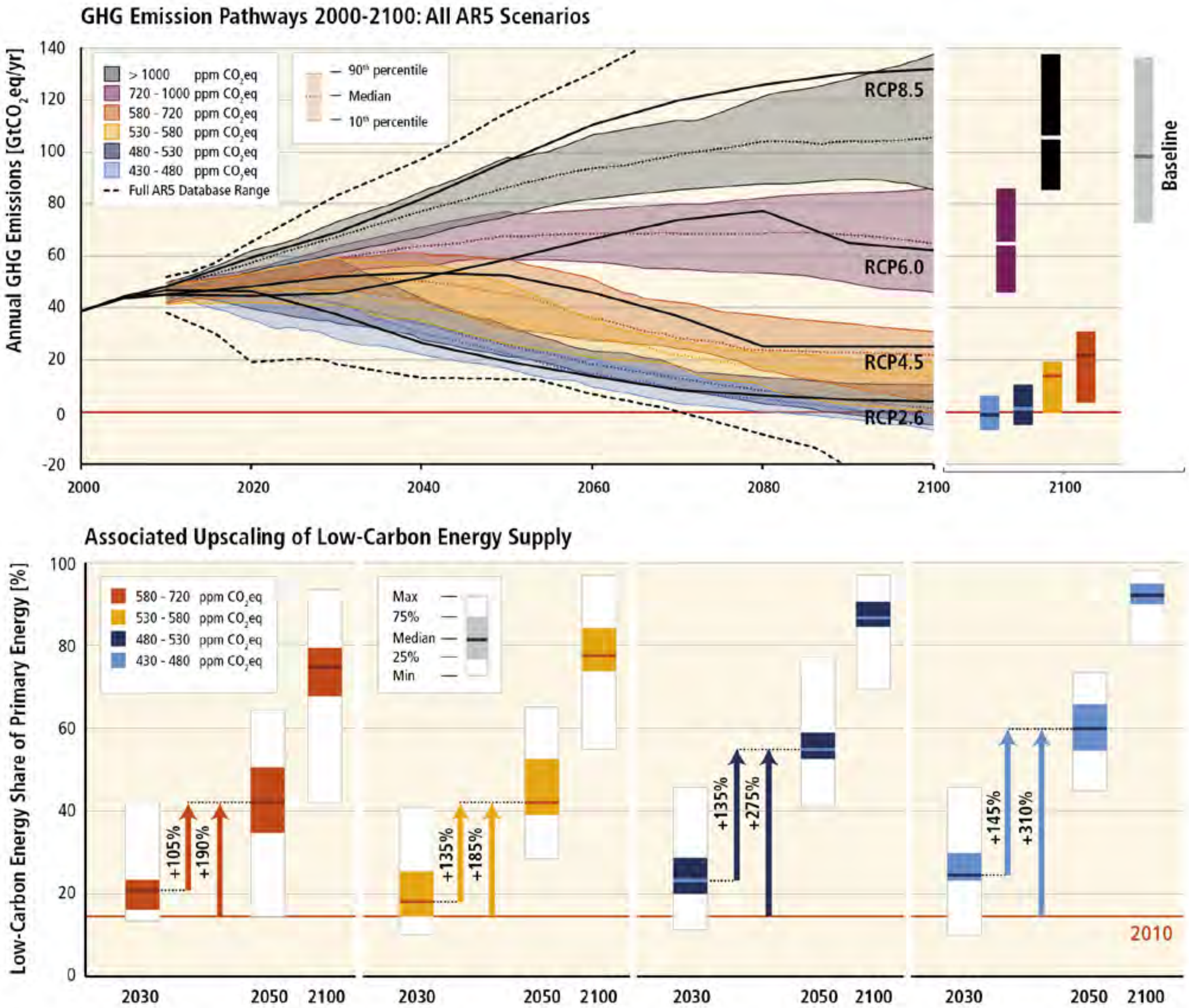


Figure 3.2: Global GHG emissions ($GtCO_2eq/yr$) in baseline and mitigation scenarios for different long-term concentration levels (upper panel) and associated scale-up requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100, compared to 2010 levels, in mitigation scenarios (lower panel). *{WG III Figure 6.7, Figure 7.16}* [Note: CO_2eq emissions include the basket of Kyoto gases (CO_2, CH_4, N_2O as well as F-gases) calculated based on GWP_{100} values from the Second Assessment Report].

Estimates of the aggregate economic costs of mitigation vary widely depending on methodologies and assumptions, but increase with the stringency of mitigation (*high confidence*). As a benchmark, global macroeconomic costs have frequently been estimated in modelling studies on the assumption that all countries of the world begin mitigation immediately, with a single global carbon price, and with all key technologies being available (Table 3.2). Under these assumptions, mitigation scenarios that reach atmospheric concentration levels of about 450 ppm CO_2eq by 2100 (these scenarios limit *likely* warming this century to 2 °C) entail losses in global consumption of 1% to 4% (median: 1.7%) by 2030, 2% to 6% (median: 3.4%) by 2050, and 3% to 11% (median: 4.8%) by 2100, relative to consumption under the baseline scenarios. These numbers correspond to an annualized reduction of consumption growth by 0.04 to 0.14 (median: 0.06) percentage points over the century (Table 3.2) relative to annualized consumption growth in the baseline that is between 1.6% and 3% per year. Mitigation costs can increase substantially if key technologies are not available (Table 3.2). Delaying additional mitigation reduces near-term costs, but increases medium and long-term costs (Table 3.2). Many models could not reproduce temperature increase below 2 °C with a *likely* chance, if additional mitigation would be considerably delayed, or if availability of key technologies, such as bioenergy, CCS, and their combination (BECCS) would be limited (Table 3.2).

Mitigation measures intersect with other societal goals creating the possibility of co-benefits or adverse side effects, which are not included in these cost estimates (SYR 3.5, 4.3). *{WG III 6.3, 6.6}*

Mitigation efforts and associated cost are expected to vary across countries. The distribution of costs can differ from the distribution of the actions themselves *(high confidence)*. Globally, mitigation is most cost-effective if the majority of mitigation efforts takes place in countries that would otherwise have the highest emission levels. Some studies exploring particular effort-sharing frameworks, under the assumption of a global carbon market, have estimated substantial global financial flows associated with mitigation leading to 2100 concentration levels of about 450 to about 550 ppm CO_2eq (these scenarios are *likely* to *more unlikely than* to limit temperature change to less than 2 °C this century). *{WG III 6.3, 13.2.2}*

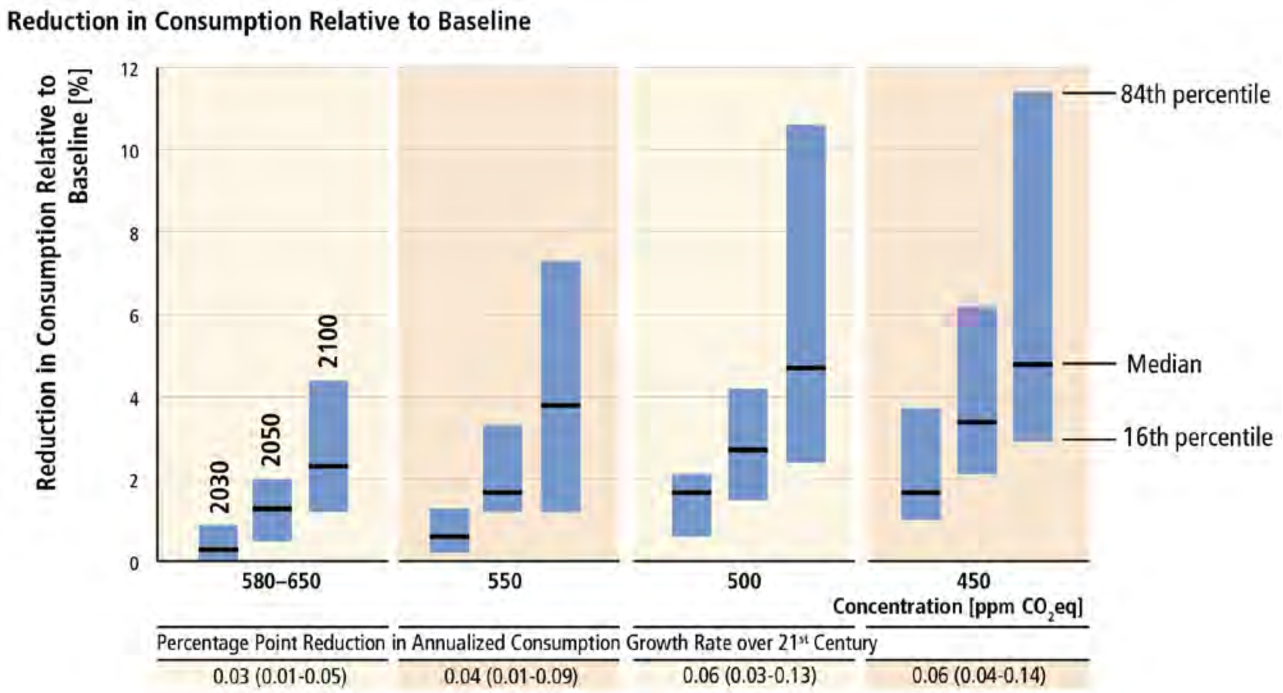


Figure 3.3: Global mitigation costs in cost-effective scenarios[1] at different atmospheric concentrations levels in 2100. Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions. Consumption losses are shown relative to a baseline development without climate policy. The table at the bottom shows annualized consumption growth reductions relative to consumption growth in the baseline of 1.6% to 3% per year. Cost estimates shown in this table do not consider the benefits of reduced climate change as well as co-benefits and adverse side-effects of mitigation. *{WGIII Figures TS.12, 6.23, Table SPM.2}*

Table 3.2: Increase in global mitigation costs due to either limited availability of specific technologies or delays in additional mitigation[1] relative to cost-effective scenarios.[2] The increase in costs is given for the median estimate and the 16th and 84th percentile of the scenarios (in parentheses). In addition, the sample size of each scenario set is provided in square brackets.[3] The colors of the cells indicate the fraction of models from systematic model comparison exercises that could successfully reach the targeted concentration level.[4] *{WGIII Table SPM.1, Figures TS.13, 6.24, 6.25}*

	Increases in total discounted mitigation costs in scenarios with limited availability of technologies[5]				**Increase in medium- and long-term mitigation costs due to delayed additional mitigation until 2030**	
	[%increase in total discounted[6] mitigation costs (2015-2100) relative to default technology assumptions]				**[% increase in mitigation costs relative to immediate mitigation]**	
2100 concentrations (ppm CO_2eq)	**NoCCS**	**Nuclear phase out**	**Limited Solar/Wind**	**Limited Bioenergy**	**2030-2050**	**2050-2100**
450 (430-480)	138 (29-297) [n=4]	7 (4-18) [n=8]	6 (2-29) [n=8]	64 (44-78) [n=8]	44 (2-78) [n=29]	37 (16-82) [n=29]
500 (480-530)	N/A	N/A	N/A	N/A		
550 (530-580)	39 (18-78) [n=11]	13 (2-23) [n=10]	8 (5-15) [n=10]	18 (4-66) [n=12]	15 (3-32) [n=10]	16 (5-24) [n=10]
580-650	N/A	N/A	N/A	N/A		

[1] Delayed mitigation scenarios are associated with GHG emission of more than 55 GtCO2eq in 2030, and the increase in mitigation costs is measured relative to cost-effective mitigation scenarios for the same long-term concentration level.
[2] Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions.
[3] The range is determined by the central scenarios encompassing the 16th and 84th percentile of the scenario set. Only scenarios with a time horizon until 2100 are included. Some models that are included in the cost ranges for concentration levels above 530 ppm CO_2eq in 2100 could not produce associated scenarios for concentration levels below 530 ppm CO_2eq in 2100 with assumptions about limited availability of technologies and/or delayed additional mitigation.
[4] Green - 100%; yellow – 80-99%; orange – 50-79%; red - <50%; no color – data availability on successful model runs too limited.
[5] No CCS: CCS is not included in these scenarios. Nuclear phase out: No addition of nuclear power plants beyond those under construction, and operation of existing plants until the end of their lifetime. Limited Solar/Wind: a maximum of 20% global electricity generation from solar and wind power in any year of these scenarios. Limited Bioenergy: a maximum of 100 EJ/yr modern bioenergy supply globally (modern bioenergy used for heat, power, combinations, and industry was around 18 EJ/yr in 2008.
[6] Percentage increase of net present value of consumption losses in percent of baseline consumption (for scenarios from general equilibrium models) and abatement costs in percent of baseline GDP (for scenarios from partial equilibrium models) for the period 2015–2100, discounted at 5% per year.

Delaying additional mitigation to 2030 or beyond will substantially increase the challenges associated with limiting warming to 2 °C. Emissions by 2030 will be between about 30 $GtCO_2$eq/yr and 50 $GtCO_2$eq/yr in cost-effective scenarios that are *likely* to *about as likely as not* to limit temperature change to less than 2 °C this century (2100 concentration levels of about 450 ppmv CO_2eq to about 500 ppmv CO_2eq) (Figure 3.3). Scenarios with emission levels of above 55 $GtCO_2$eq/yr are characterized by substantially higher rates of emission reductions between 2030 and 2050 (on average 6%/yr as compared to 3%/yr); much more rapid scale-up of low-carbon energy over this period (a quadrupling compared to a doubling of the low-carbon energy share relative to 2010); a larger reliance on CDR technologies in the long term; and higher transitional and long-term economic impacts. *{WG III 6.3.2, 7.5}*

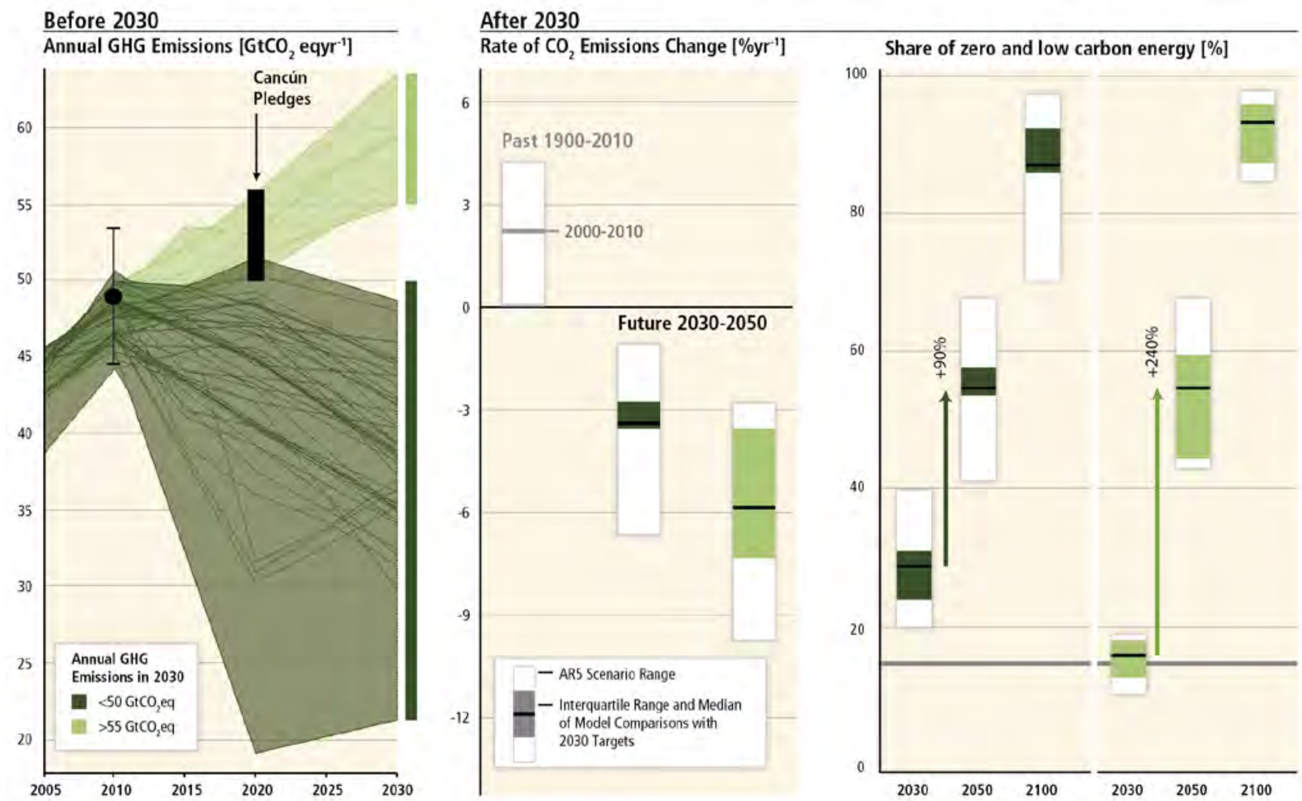


Figure 3.4: The implications of different 2030 GHG emissions levels for the rate of CO_2 emission reductions and low-carbon energy upscaling in mitigation scenarios reaching from about 450 to about 500 (430–530) ppm CO_2eq concentrations by 2100. The scenarios are grouped according to different emissions levels by 2030 (coloured in different shades of green). The left panel shows the pathways of GHG emissions ($GtCO_2$eq/yr) leading to these 2030 levels. The black bar shows the estimated uncertainty range of GHG emissions implied by the Cancún Pledges. The middle panel denotes the average annual CO_2 emission reduction rates for the 2030–2050 period. It compares the median and interquartile range across scenarios from recent intermodel comparisons with explicit 2030 interim goals to the range of scenarios in the Scenario Database for WGIII AR5. Annual rates of historical emission changes (sustained over a period of 20 years) are shown as well. The arrows in the right panel show the magnitude of zero and low-carbon energy supply up-scaling from between 2030 and 2050, subject to different 2030 GHG emission levels. Zero- and low-carbon energy supply includes renewable energy, nuclear energy, and fossil energy with carbon dioxide capture and storage (CCS), or bioenergy with CCS (BECCS). [Note: Only scenarios that apply the full, unconstrained mitigation technology portfolio of the underlying models (default technology assumption) are shown. Scenarios with large net negative global emissions (>20 $GtCO_2$eq/yr), scenarios with exogenous carbon price assumptions, and scenarios with 2010 emission levels that are significantly outside the historical range are excluded.] *{WG III Figure 6.32, Figure 7.16}*

Estimated global emission levels by 2020 based on the Cancun Pledges are not consistent with cost-effective long-term mitigation trajectories that are at least *about as likely as not* to limit temperature change to 2 °C (2100 concentration levels of about 500 ppm CO_2eq or below) but they do not preclude the option of achieving this goal *(high confidence)*. The Cancún Pledges are broadly consistent with cost-effective scenarios that are *likely* to limit temperature change to below 3 °C. *{WG III 6.4, 13.13, Figures TS.9, TS.11}*

Reducing emissions of non-CO_2 agents is an important element of mitigation strategies. Emissions of non-CO_2 gases (methane, N_2O, and fluorinated gases) contribute about 27% to the current total CO_2 equivalent emissions of Kyoto gases (see Topic 1). For most key non-CO_2 gases, near-term, low-cost options are available to reduce their emissions. However, other non-CO_2 sources are difficult to mitigate, such as N_2O emissions from fertilizer use and methane emissions from livestock. As a result, emissions of most non-CO_2 components are not reduced to zero, even under stringent mitigation scenarios. The differences in radiative properties and lifetimes of CO_2 and non-CO_2 components have important implications for mitigation strategies (see also Box 3.2). *{WG III 6.3.2}*

Reducing the emissions of certain short-lived climate forcers can reduce the rate of warming in the short term, but will have only a limited effect on long-term warming, which is driven mainly by CO_2

emissions. There are large uncertainties related to the climate impacts of some of these components. Although the effects of CH_4 emissions are well understood, there are large uncertainties related to the effects of BC. Co-emitted components with cooling effects may further complicate and reduce the climate impacts of emission reductions. Near-term reductions in short-lived forcers can have a relatively fast impact on climate change and possible co-benefits for air pollution. *{WG I 8.2, 8.3, 8.5.1, 8.7.2, FAQ 8.7.2, 12.5; WG III 6.6.2.1}*

Box 3.2: Greenhouse gas metrics and mitigation pathways

This box focuses on emission-based metrics that are used for calculating *CO_2 equivalent emissions* for the formulation and evaluation of mitigation strategies. These emission metrics are distinct from the concentration-based metric also used in SYR (‘*CO_2 equivalent concentration*’) (see Footnotes 1 and 5 in Topic 1, Footnote 2 in Topic 2, Footnote 6 in Topic 3, and the Glossary).

Emission metrics facilitate multi-component climate policies by allowing emissions of different GHGs and other forcing agents to be expressed in a common unit (so-called ‘CO_2 equivalent emissions’). The Global Warming Potential (GWP) was introduced in the IPCC First Assessment Report, where it was also used to illustrate the difficulties in comparing components with differing physical properties using a single metric. The 100-year GWP was adopted by the UNFCCC and its Kyoto Protocol and is now used widely as the default metric, but it is only one of several potentially relevant emission metrics and time horizons. *{WGI 8.7; WG III 3.9}*

The choice of emission metric and time horizon depends on type of application and policy context; hence, no single metric is optimal for all policy goals. All metrics have shortcomings, and choices contain value judgments, such as the climate effect considered and the weighting of effects over time (which explicitly or implicitly discounts impacts over time), the climate policy goal, and the degree to which metrics incorporate economic or only physical considerations. *{WGI 8.7; WGIII 3.9}*

The weight assigned to non-CO_2 components relative to CO_2 depends strongly on the choice of metric and time horizon (*high agreement, robust evidence*). GWP compares components based on radiative forcing, integrated up to a chosen time horizon. Global Temperature change Potential (GTP; see Glossary), a widely discussed alternative, is based on the temperature response at a specific point in time with no weight on temperature response before or after the chosen point in time. Adoption of a fixed horizon of e.g., 20, 100 or 500 years for these metrics will inevitably put no weight on climate outcomes beyond the time horizon; which is significant for CO_2 as well as other long-lived gases. The choice of time horizon markedly affects the weighting of short-lived components, such as CH_4 (see Box 3.2 Table 1; Box 3.2 Figure 1 Panel A). For some metrics (e.g., the dynamic GTP; see Glossary), the weighting changes over time as a chosen target year is approached. *{WG I 8.7; WG III 3.9}*

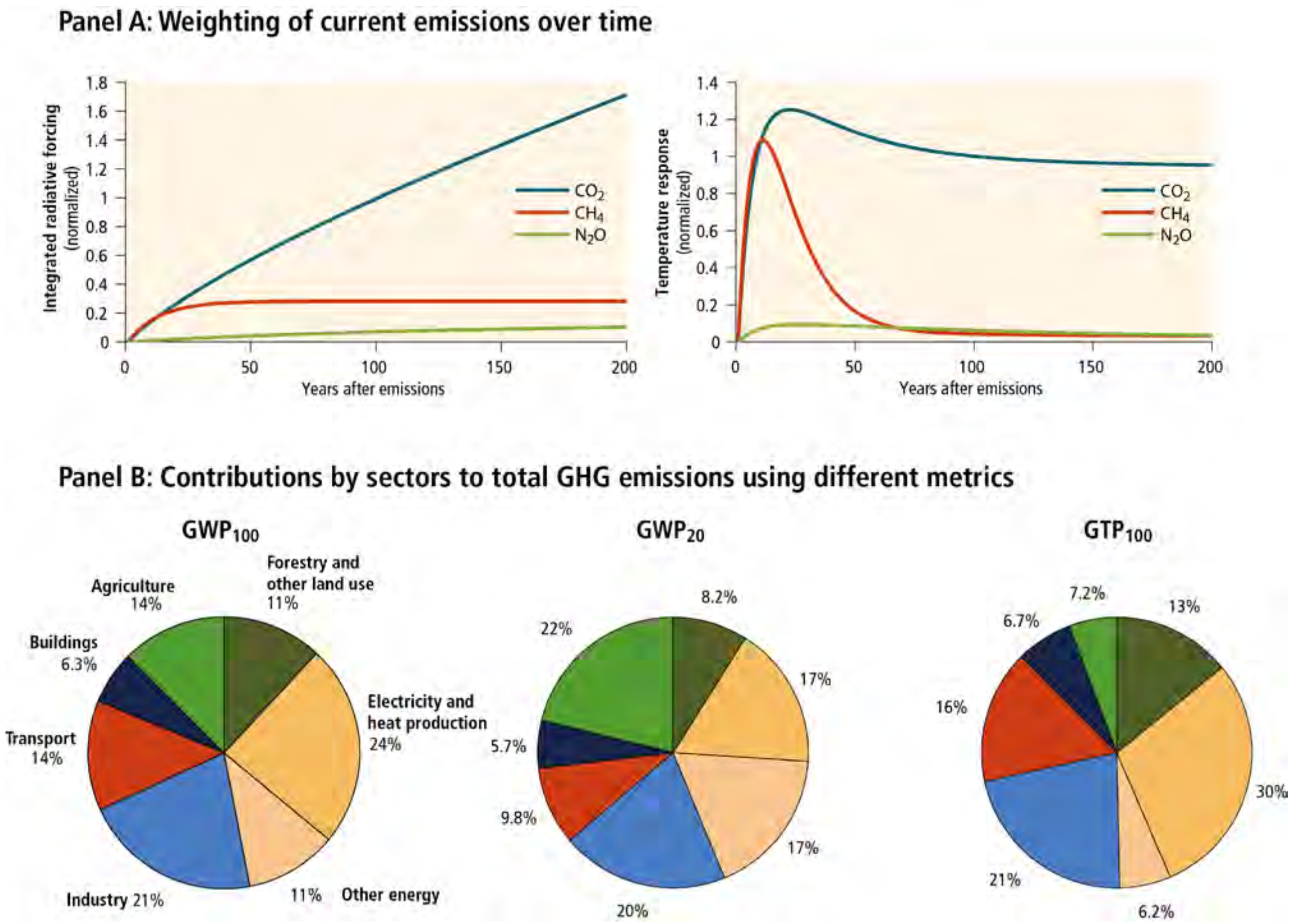
Box 3.2, Table 1: Examples of emission metric values from AR5 WGI*

		GWP		GTP	
	lifetime (yrs)	**20 yr**	**100 yr**	**20 yr**	**100 yr**
CO_2	**	1	1	1	1
CH_4	12.4	84	28	67	4
N_2O	121.0	264	265	277	234
CF_4	50,000.0	4880	6630	5270	8040
HCF-152a	1.5	506	138	174	19

* GWP values have been updated in successive IPCC reports; the AR5 GWP_{100} values are different from those adopted for the Kyoto Protocol's First Commitment Period, which are from the IPCC Second Assessment Report (SAR). Note that for consistency, equivalent CO_2 emissions given elsewhere in this Synthesis Report are also based on SAR, not AR5 values (for a comparison of emissions using SAR and AR5 GWP_{100} values for 2010 emissions, see Figure 1.6).
** No single lifetime can be given for CO_2. *{Box 6.1, 6.1.1, 8.7}*

The choice of emission metric affects the timing and emphasis placed on abating short- and long-lived components. For most metrics, global cost differences are small under scenarios of global participation

and cost-minimizing mitigation pathways, but implications for individual countries and sectors could be more significant (*high agreement, medium evidence*). Alternative metrics and time horizons significantly affect the contributions from various sources/sectors and components; particularly short-lived components (Box 3.2, Figure 1, Panel B). A fixed time independent metric that gives less weight to short-lived components such as methane (e.g., using GTP_{100} instead of GWP_{100}) would require earlier and more stringent CO_2 abatement to achieve the same climate outcome for 2100. Using a time-dependent metric, such as a dynamic GTP, leads to less CH_4 mitigation in the near-term, but to more in the long-term as the target date is being approached. This implies that for some (short-lived) components, the metric choice influences the choice of policies and the timing of mitigation (especially for sectors and countries with high non-CO_2 emission levels). *{WG I Box 6.1, 6.1.1, 12.5; WG III 6.3}*



Box 3.2, Figure 1: Implications of metric choices on the weighting of greenhouse gas emissions and contributions by sectors. Upper panel (A): integrated radiative forcing (left panel) and warming resulting at a given future point in time (right panel) from global emissions of CO_2, CH_4 and N_2O in the year 2010 (and no emissions thereafter), for time horizons of up to 200 years. Integrated radiative forcing is used in the calculation of Global Warming Potentials (GWP), while the warming at a future point in time is used in the calculation of Global Temperature change Potentials (GTP). Radiative forcing and warming were calculated based on global 2010 emission data from WGIII 5.2 and absolute Global Warming Potentials and absolute Global Temperature change Potentials from WGI 8.7, normalized to the integrated radiative forcing and warming, respectively, after 100 years, due to 2010 CO_2 emissions. Lower panel (B): contributions from different sectors to total metric weighted global greenhouse gas emissions in the year 2010, calculated using 100-year GWP (left), 20-year GWP (middle) or 100-year GTP (right) and the WGIII 2010 emissions database. *{WG III 5.2}*

Box 3.3: Carbon Dioxide Removal and Solar Radiation Management geoengineering technologies – possible roles, options, risks and status

Geoengineering refers to a broad set of methods operating on a large scale, which aim to alter the climate system in order to reduce climate change and some of its impacts (see Glossary). There are two clusters of technologies envisioned: Carbon Dioxide Removal (CDR) aims to slow or reverse increases in atmospheric CO_2 concentrations. Solar Radiation Management (SRM) aims to counter the warming by reducing the amount of sunlight absorbed by the climate system. Limited evidence precludes a comprehensive assessment of feasibility, cost, side-effects and environmental impacts of either CDR or SRM. *{WG 1 SPM E.8 6.5, 7.7; WG II 6.4, Table 6-5, Box 20-4; WG III 6.9}*

CDR plays a major role in many of the ambitious mitigation scenarios (in particular below 550 ppm CO_2eq concentration levels). A key implication of the use of CDR in transition pathways is that emission reduction decisions are directly related to expected availability and deployment of CDR in the second half of the century. Similar to mitigation, CDR would need to be deployed on a large scale and over a long time period to be able to significantly reduce CO_2 concentrations. BECCS and afforestation are the only CDR methods included in future scenarios (see Section 3.1). In scenarios aiming at concentration levels of below 550 ppm CO_2eq, BECCS is usually competitive with conventional mitigation technologies, but only after these have been deployed on a very large scale. *{WG II 6.4; WG III 6.9, TS}*

Several CDR techniques could potentially reduce atmospheric GHG levels. However, there are biogeochemical, technical and societal limitations that make it difficult to provide quantitative estimates of the potential for CDR. The resulting emission mitigation is less than the removed CO_2, as some CO_2 is released from that previously stored in oceans and terrestrial carbon reservoirs. Sub-sea geologic storage has been implemented on a regional scale, with to date no evidence of ocean impact from leakage. The climatic and environmental side effects of CDR depend on technology and scale. Examples are associated with altered surface reflectance from afforestation, ocean de-oxygenation from ocean fertilization. Most terrestrial CDR techniques would involve competing demands for land and could involve local and regional risks, while maritime CDR techniques may involve significant risks for ocean ecosystems, so that their deployment could pose additional challenges for cooperation between countries. *{WG I 6.5; Box 6.2; FAQ 7.3; WG II 6.4, Table 6.5}*

SRM is currently untested but, if realisable, could to some degree offset global temperature rise and some of its effects. It could possibly provide rapid cooling in comparison to CO_2 mitigation. There is *medium confidence* that SRM through stratospheric aerosol injection is scalable to counter radiative forcing (RF) from a twofold increase in CO_2 concentrations and some of the climate responses associated with warming. Due to insufficient understanding there is no consensus on whether a similarly large negative counter RF could be achieved from cloud brightening. Land albedo change does not appear to be able to produce a large counter RF. Even if SRM could counter the global mean warming, differences in spatial patterns would remain. The scarcity of literature on other SRM techniques precludes their assessment. *{WG I 7.7, WG III 6.9}*

Research has identified numerous uncertainties, side effects, risks and shortcomings from SRM. Several lines of evidence indicate that SRM would itself produce a small but significant decrease in global precipitation (with larger differences on regional scales). Stratospheric aerosol SRM is *likely* to modestly increase ozone losses in the polar stratosphere. SRM would not prevent the CO_2 effects on ecosystems and ocean acidification that are unrelated to warming. There could also be other unanticipated consequences. For all future scenarios considered in AR5, SRM would need to increase commensurately, to counter the global mean warming, which would exacerbate side effects. Additionally, there is *high confidence* that if SRM were increased to substantial levels and then stopped, surface temperatures would rise rapidly (within a decade or two). This would stress systems that are sensitive to the rate of warming. *{WG I 7.6-7, FAQ 7.3; WG II 4.4, 6.1, 6.3, 6.4, 19.5; WG III 6.9}*

SRM technologies raise questions about costs, risks, governance, and ethical implications of development and deployment. There are special challenges emerging for international institutions and mechanisms that could coordinate research and possibly restrain testing and deployment. *{WG III 1.4, 3.3, 6.9}* Even if SRM would reduce human-made global temperature increase, it would imply spatial and temporal redistributions of risks. SRM, thus, introduces important questions of intragenerational and intergenerational justice. *{WG III 3.3, 6.9}*. Research on SRM, as well as its eventual deployment, has been subject to ethical objections. *{WG III 3.3.7}* In spite of the estimated low potential costs of some SRM deployment technologies, they will not necessarily pass a benefit–cost test that takes account of the range of risks and side effects. *{WG III 6.9}* The governance implications of SRM are particularly challenging, especially as unilateral action might lead to significant effects and costs for others. *{WG III 13.2, 13.4}*

3.5 Interaction among mitigation, adaptation, and sustainable development

Climate change is a threat to equitable and sustainable development. Adaptation, mitigation, and sustainable development are closely related, with potential for synergies and trade-offs.

Climate change poses an increasing threat to equitable and sustainable development *(high confidence)*. Some climate-related impacts on development are already being observed. Climate change is a threat multiplier. It exacerbates other threats to social and natural systems, placing additional burdens particularly on the poor and constraining possible development paths for all. Development along current pathways can contribute to climate risk and vulnerability, further eroding the basis for sustainable development. *{WG II 2.5, 10.9, 13.13, 19, 20.1, 20.2, 20.6, SPM B-2; WG III 3, 4, 4.2}*

Aligning climate policy with sustainable development requires attention to both adaptation and mitigation *(high confidence)*. Interaction among adaptation, mitigation and sustainable development occurs both within and across regions and scales, often in the context of multiple stressors. Some options for responding to climate change could impose risks of other environmental and social costs, have adverse distributional effects, and draw resources away from other development priorities, including poverty. *{WG II 2.5, 8.4, 9.3, 13.3-4, 13.13, 20.2-4, 21.4, 25.9, 26.8, 30.1; WG III 4.8, 6.6}*

Both adaptation and mitigation can bring substantial co-benefits *(medium confidence)*. Examples of actions with co-benefits include (i) improved air quality (see Figure 3.5); (ii) enhanced energy security, (iii) reduced energy and water consumption in urban areas through greening cities and recycling water; (iv) sustainable agriculture and forestry; and (v) protection of ecosystems for carbon storage and other ecosystem services. *{WG II SPM C-1}*

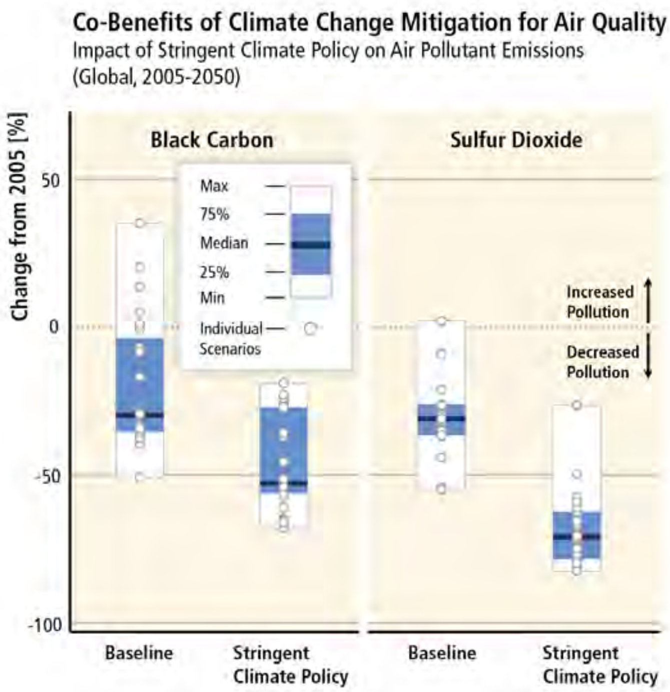


Figure 3.5: Air pollutant emission levels of black carbon (BC) and sulfur dioxide (SO_2) by 2050, relative to 2005 (0=2005 levels). Baseline scenarios without additional efforts to reduce GHG emissions beyond those in place today are compared to scenarios with stringent mitigation policies, which are consistent with reaching about 450 to 500 (430–530) ppm CO_2eq concentration levels by 2100. *{WG III Figure 6.33}*

Strategies and actions can be pursued now that will move towards climate-resilient pathways for sustainable development, while at the same time helping to improve livelihoods, social and economic well-being, and responsible environmental management *(high confidence)*. Prospects for climate-resilient pathways are related fundamentally to what the world accomplishes with climate-change mitigation (*high confidence*). Since mitigation reduces the rate as well as the magnitude of warming, it also increases the time available for adaptation to a particular level of climate change, potentially by several decades.

Delaying mitigation actions may reduce options for climate-resilient pathways in the future. *{WG II 20.2, 20.6.2, SPM C-2}*

Box 3.4: Co-benefits and adverse side effects

A government policy or a measure intended to achieve one objective often affects other objectives, either positively or negatively. For example, mitigation policies can influence local air quality (see Box 3.1, Figure 1 for urban air pollution levels). When the effects are positive they are called ‘co-benefits’, also referred to as ‘ancillary benefits’. Negative effects are referred to as ‘adverse side effects’. The lack of capacity to manage adverse impacts of current climate variability is often referred to as the ‘adaptation deficit’. Some measures are labelled ‘no or low regret’ when their co-benefits are sufficient to justify their implementation, even in the absence of immediate direct benefits. Co-benefits and adverse side effects can be measured in monetary or non-monetary units. The effect of co-benefits and adverse side-effects from climate policies on overall social welfare has not yet been quantitatively examined, with the exception of a few recent multi-objective studies. *{WG II 5.7, 16.3.9, 17.2, 20.4.1; WG III 3.6, 5.7, Box TS.11}*

Co-benefits of mitigation could include effects on objectives, such as energy security, air quality with positive human health and ecosystem impacts, income distribution, labour supply and employment, and urban sprawl (see Table 4.2 and Table 4.5). In the absence of complementary policies, however, some mitigation measures may have adverse side effects (at least in the short term), for example on biodiversity, food security, energy access, economic growth, and income distribution. The co-benefits of adaptation policies may include improved access to infrastructure and services, extended education and health systems, reduced disaster losses, better governance, and others. *{WG II 3.6, 4.4.4, 6.6, 15.2, 11.9, 17.2, 20.3.3, 20.4.1; WG III 6.6, Box TS.11}*

Comprehensive response strategies consistent with sustainable development integrate many context-specific co-benefits from both adaptation and mitigation options. The assessment of overall social welfare impacts is complicated by this interaction between climate change response options and pre-existing non-climate policies. For example, in terms of air quality, the value of the extra tonne of SO_2 reduction that occurs with climate change mitigation through reduced fossil fuel combustion depends greatly on the stringency of SO_2 control policies. If SO_2 policy is weak, the value of SO_2 reductions may be large, but if SO_2 policy is stringent, it may be near zero. Similarly, in terms of disaster risk management, weak policies can lead to an adaptation deficit that increases human and economic losses from natural climate variability. An existing adaptation deficit increases the benefits of adaptation policies that improve the management of climate variability and change. *{WG II 20.4.1; WG III 6.3}*

Topic 4: Adaptation and Mitigation Measures

Many adaptation and mitigation options can help address the climate challenge, but no single option is sufficient by itself. Effective implementation depends on policies that integrate a range of responses as well as policies that focus on specific issues, and can be enhanced through integrated responses that link mitigation and adaptation with other societal objectives.

Topic 3 demonstrates the need and strategic considerations for both adaptation and global-scale mitigation to manage risks from climate change. Building on these insights, Topic 4 presents near-term response options that could help achieve such strategic goals. Near-term adaptation and mitigation actions will differ across sectors and regions, reflecting development status, response capacities, and near- and long-term aspirations with regard to both climate and non-climate outcomes. Because adaptation and mitigation inevitably take place in the context of multiple objectives, particular attention is given to the ability to develop and implement integrated approaches that can build on co-benefits and manage trade-offs.

4.1 Common enabling factors and constraints for adaptation and mitigation responses

Adaptation and mitigation responses are underpinned by common enabling factors. These include appropriate institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, livelihoods, and behavioural and lifestyle choices.

Technological innovation and investments in green infrastructure and environmentally sound technologies can reduce greenhouse gas emissions and enhance societal resilience to climate change (*very high confidence*). Technological innovation and change can expand the availability and/or effectiveness of adaptation and mitigation options. Investments in low-carbon and carbon-neutral energy technologies can reduce the energy intensity of economic development, the carbon intensity of energy, GHG emissions, and the long-term costs of mitigation. Similarly, new technologies and infrastructure can increase the resilience of human systems while reducing adverse impacts on natural systems. Investments in technology and infrastructure rely on an enabling policy environment, access to finance and technology, and broader economic development that builds capacity (Table 4.1, and Section 4.4). *{WGII Tables SPM.1, TS.8; WGIII SPM.4.1, Table SPM.2, TS.3.1.1, TS 3.1.2, TS.3.2.1}*

Adaptation and mitigation are constrained by the inertia of global and regional trends in economic development, greenhouse gas emissions, resource consumption, infrastructure and settlement patterns, institutional behaviour, and technology (*high agreement, medium evidence*). Such constraints may limit the capacity to reduce GHG emissions, remain below particular climate thresholds, or avoid adverse impacts (Table 4.1). Some constraints may be overcome through new technologies, financial resources, increased institutional effectiveness and governance, or changes in social and cultural attitudes and behaviours. *{WGII SPM.C-1; WGIII SPM.3, SPM.4.2, Table SPM.2}*

Livelihoods, lifestyles and behaviours have a considerable influence on GHG emissions and vulnerability to climate change (*medium agreement, medium evidence*). Shifts toward more energy-intensive lifestyles can contribute to higher energy and resource consumption, driving greater energy production and GHG emissions and increasing mitigation costs. In contrast, emissions can be substantially lowered through changes in consumption patterns, adoption of energy savings measures, dietary change and reduction in food wastes. The social acceptability and/or effectiveness of climate policies are influenced by the extent to which they incentivize or depend on changes in lifestyles or behaviours (Table 4.1). Similarly, livelihoods that depend on climate-sensitive sectors or resources may be particularly vulnerable to climate change and climate change policies. Economic development and urbanization of high amenity landscapes exposed to climate hazards may increase the exposure of human settlements and reduce the resilience of natural systems. *{WGII 16.3.2.7, SPM.B-2, Table SPM.1, TS.A-2, TS.C-1, TS.C-2; WGIII SPM.4.2, 4.2, TS.2.2}*

For many regions and sectors, enhanced capacities to mitigate and adapt are part of the foundation essential for managing climate change risks (*high confidence*). Such capacities are place and context-specific and therefore there is no single approach for reducing risk that is appropriate across all settings. For example, developing countries with low income levels have the lowest financial, technological, and institutional capacities to pursue low-carbon, climate-resilient development pathways. Although developed nations generally have greater relative capacity to manage the risks of climate change, such capacity does not necessarily translate into the implementation of adaptation and mitigation options. *{WGII 16.3.1.1, 16.3.2, 16.5, SPM.B-1, SPM.B-2, TS.B-1, TS.B-2; WGIII 4.6, SPM.5.1, TS.4.3, TS.4.5}*

Constraints associated with mitigation, adaptation, and disaster risk reduction are particularly high in regions with weak institutions and/or poor coordination and cooperation in governance (*very high confidence*). Despite the presence of a wide array of multilateral, national, and sub-national institutions focused on adaptation and mitigation, global GHG emissions continue to increase and identified adaptation needs have not been adequately addressed. The implementation of effective adaptation and mitigation options may necessitate new institutions and institutional arrangements that span multiple scales (Table 4.1). *{WGII 14.2.2, 16.3.2.4, 16.8, SPM.B-2, TS.C-1; WGIII SPM.3, SPM.5.1, SPM.5.2, TS.1, TS.3.1.3, TS.4.1, TS.4.2, TS.4.4}*

Table 4.1: Common factors that constrain the implementation of adaptation and mitigation options

Constraining Factor	Potential Implications for Adaptation	Potential Implications for Mitigation
Adverse externalities of population growth and urbanization	Increase exposure of human populations to climate variability and change as well as demands for, and pressures on, natural resources and ecosystem services {WGII 16.3.2.3; Box 16-3}	Drive economic growth, energy demand and energy consumption, resulting in increases in greenhouse gas emissions {WGIII SPM.3}
Deficits of knowledge, education, and human capital	Reduce national, institutional, and individual perceptions of the risks posed by climate change as well as the costs and benefits of different adaptation options {WGII 16.3.2.1}	Reduce national, institutional, and individual risk perception, willingness to change behavioural patterns and practices, and to adopt social and technological innovations to reduce emissions {WGIII 2.4.5.1, 3.9.1.5, 4.3.5, 9.8, 11.8.1, SPM.3, SPM.5.1}
Divergences in social and cultural attitudes, values, and behaviours	Reduce societal consensus regarding climate risk and therefore demand for specific adaptation policies and measures {WGII 16.3.2.7}	Influence emission patterns; societal perceptions of the utility of mitigation policies and technologies; and willingness to pursue sustainable behaviours and technologies {WGIII 2.2.1.3, 2.4.4.3, 3.7.2.2, 3.9.2, 4.3.4, 5.5.2.1, TS.5}
Weak governance and institutional arrangements	Reduce the ability to coordinate adaptation policies and measures and to deliver capacity to actors to plan and implement adaptation {WGII 16.3.2.8}	Undermine policies, incentives, and cooperation regarding the development of mitigation policies and the implementation of efficient, carbon neutral, and renewable energy technologies {WGIII 4.3.2, 6.4.3, 14.2.3.1, 14.3.2.2, 15.12.2, 16.5.3, SPM.3, SPM.5.3}
Lack of access to climate finance	Reduces the scale of investment in adaptation policies and measures and therefore their effectiveness {WGII 16.3.2.5}	Reduces the capacity of developed and, particularly, developing nations to pursue policies and technologies that reduce emissions. {WGIII 12.6.3, 16.2.2.2, TS.5.2}
Inadequate technology	Reduces the range of available adaptation options as well as their effectiveness in reducing or avoiding risk from increasing rates or magnitudes of climate change {WGII 16.3.2.1}	Slows the rate at which society can reduce the carbon intensity of energy services and transition toward low-carbon and carbon-neutral technologies {WGIII 4.3.6, 6.3.2.2, 11.8.4, TS.3.3}
Insufficient quality and/or quantity of natural resources	Reduce the coping range of actors, vulnerability to non-climatic factors, and potential competition for resources that enhances vulnerability {WGII 16.3.2.3}	Reduce the long-term sustainability of different energy technologies {WGIII 4.3.7, 4.4.1, 11.8.3}
Adaptation and	Increase vulnerability to current climate	Reduce mitigative capacity and undermine

development deficits	variability as well as future climate change {WGII 16.3.2.4, TS.A-1, Table TS.5}	international cooperative efforts on climate owing to a contentious legacy of cooperation on development {WGIII 4.3.1, 4.7.3.1}
Inequality	Places the impacts of climate change and the burden of adaptation disproportionately on the most vulnerable and/or transfers them to future generations {WGII Box 13-1, 16.7, TS B-2, Box TS.4}	Constrains the ability for developing nations with low income levels, or different communities or sectors within nations, to contribute to GHG mitigation {WGIII 4.7.3.1}

4.2 Response Options for Adaptation

Adaptation options exist in all sectors, but their context for implementation and potential to reduce climate-related risks differs across sectors and regions. Increasing climate change will erode prospects for some adaptation options. Synergies and trade-offs exist between individual adaptation options.

People, governments and firms are starting to adapt to a changing climate. Since the AR4, understanding of response options has increased, with improved knowledge of their benefits, costs, and links to sustainable development. Adaptation can take a variety of approaches depending on its context in vulnerability reduction, disaster risk management or proactive adaptation planning. These include (see Table 4.2 for examples and details):

- Social, ecological asset and infrastructure development
- Technological process optimization
- Integrated natural resources management
- Institutional, educational and behavioural change or reinforcement
- Financial services, including risk transfer
- Information systems to support early warning and proactive planning

Appropriate strategies and actions depend on co-benefits and opportunities within wider development plans and strategic goals. *{WGII SPM.A-2, SPM.C.1, TS.A-2, 15.3 }*

Table 4.2: Approaches for managing the risks of climate change through adaptation. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Mitigation is considered essential for managing the risks of climate change. It is not addressed in this table as mitigation is the focus of Section 4.3. Examples are presented in no specific order and can be relevant to more than one category. *{WGII Table SPM.1}*

Overlapping Approaches	Category	Examples
Vulnerability & Exposure Reduction through development, planning, & practices including many low-regrets measures	Human development	Improved access to education, nutrition, health facilities, energy, safe housing & settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.
	Poverty alleviation	Improved access to & control of local resources; Land tenure; Disaster risk reduction; Social safety nets & social protection; Insurance schemes.
	Livelihood security	Income, asset, & livelihood diversification; Improved infrastructure; Access to technology & decision-making fora; Increased decision-making power; Changed cropping, livestock, & aquaculture practices; Reliance on social networks.
	Disaster risk management	Early warning systems; Hazard & vulnerability mapping; Diversifying water resources; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements.
	Ecosystem management	Maintaining wetlands & urban green spaces; Coastal afforestation; Watershed & reservoir management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Manipulation of disturbance regimes; Community-based natural resource management.
	Spatial or land-use planning	Provisioning of adequate housing, infrastructure, & services; Managing development in flood prone & other high risk areas; Urban planning & upgrading programs; Land zoning laws; Easements; Protected areas.
Adaptation including incremental & transformational adjustments	Structural/physical	***Engineered & built-environment options***: Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.
		Technological options: New crop & animal varieties; Indigenous, traditional, & local knowledge, technologies, & methods; Efficient irrigation; Water-saving technologies; Desalinization; Conservation agriculture; Food storage & preservation facilities; Hazard & vulnerability mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling; Technology development, transfer, & diffusion.
		Ecosystem-based options: Ecological restoration; Soil conservation; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted species migration & dispersal; Ecological corridors; Seed banks, gene banks, & other *ex situ* conservation; Community-based natural resource management.
		Services: Social safety nets & social protection; Food banks & distribution of food surplus; Municipal services including water & sanitation; Vaccination programs; Essential public health services; Enhanced emergency medical services.
	Institutional	***Economic options***: Financial incentives; Insurance; Catastrophe bonds; Payments for ecosystem services; Pricing water to encourage universal provision and careful use; Microfinance; Disaster contingency funds; Cash transfers; Public-private partnerships.
		Laws & regulations: Land zoning laws; Building standards & practices; Easements; Water regulations & agreements; Laws to support disaster risk reduction; Laws to encourage insurance purchasing; Defined property rights & land tenure security; Protected areas; Fishing quotas; Patent pools & technology transfer.
		National & government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Economic diversification; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.
	Social	***Educational options***: Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing indigenous, traditional, & local knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.
		Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development; Integrated assessments.
		Behavioral options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock, & aquaculture practices; Reliance on social networks.
Transformation	Spheres of change	***Practical***: Social & technical innovations, behavioral shifts, or institutional & managerial changes that produce substantial shifts in outcomes.
		Political: Political, social, cultural, & ecological decisions & actions consistent with reducing vulnerability & risk & supporting adaptation, mitigation, & sustainable development.
		Personal: Individual & collective assumptions, beliefs, values, & worldviews influencing climate-change responses.

Opportunities to enable adaptation planning and implementation exist in all sectors and regions. The needs along with challenges for adaptation are expected to increase with climate change (*very high confidence*). Examples of key adaptation approaches for particular sectors, including constraints and limits, are summarized below. *{WGII SPM.B, SPM.C, 16.4, 16.6, 17.2, 19.6, 19.7, Table 16-3}*

Freshwater resources: **Adaptive water management techniques, including scenario planning, learning-based approaches, and flexible and low-regret solutions, can help adjust to uncertain hydrological changes due to climate change and their impacts (*limited evidence, high agreement*).** Strategies include adopting integrated water management; augmenting supply; reducing the mismatch between water supply and demand; reducing non-climate stressors; strengthening institutional capacities; and adopting more water-efficient technologies and water-saving strategies. *{WGII SPM.B-2, 3.6, 22.3-4, 23.4, 23.7, 24.4, 27.2-3, Box 25-2}*

Terrestrial and freshwater ecosystems: **Management actions can reduce but not eliminate risks of impacts to terrestrial and freshwater ecosystems due to climate change (*high confidence*). Actions include maintenance of genetic diversity, assisted species migration and dispersal, manipulation of disturbance regimes (e.g., fires, floods), and reduction of other stressors.** Management options that reduce non-climatic stressors, such as habitat modification, overexploitation, pollution and invasive species, increase the inherent capacity of ecosystems and their species to adapt to a changing climate. Other options include improving early warning systems and associated response systems. Enhanced connectivity of vulnerable ecosystems may also assist autonomous adaptation. Translocation of species is controversial and is expected to become less feasible where whole ecosystems are at risk. *{WGII SPM.B-2, 4.4, 25.6, 26.4, Box CC-RF, Figure SPM.5}*

Coastal systems and low-lying areas: **Increasingly, coastal adaptation options include those based on integrated coastal zone management, local community participation, ecosystems-based approaches and disaster risk reduction, mainstreamed into relevant strategies and management plans (*high confidence*).** The analysis and implementation of coastal adaptation has progressed more significantly in developed countries than in developing countries (*high confidence*). The relative costs of coastal adaptation are expected to vary strongly among and within regions and countries. *{WGII SPM.B-2, 5.5, 8.3, 22.3, 24.4, 26.8, Box 25-1}*

Marine systems and oceans: **Marine forecasting and early warning systems as well as reducing non-climatic stressors have the potential to reduce risks for some fisheries and aquaculture industries, but options for unique ecosystems such as coral reefs are limited (*high confidence*).** Fisheries and some aquaculture industries with high-technology and/or large investments have high capacities for adaptation due to greater development of environmental monitoring, modelling, and resource assessments. Adaptation options include large-scale translocation of industrial fishing activities and flexible management that can react to variability and change. For smaller-scale fisheries and nations with limited adaptive capacities, building social resilience, alternative livelihoods, and occupational flexibility are important strategies. Human adaptation options for coral reef systems are generally limited to reducing other stressors, mainly by enhancing water quality and limiting pressures from tourism and fishing, but their efficacy will be severely reduced as thermal stress and ocean acidification increase. *{WGII SPM.B-2, 5.5, 6.4, 7.5, 25.6.2, 29.4, 30.6-7, Box CC-MB, Box CC-CR, SPM Assessment Box SPM.2 Table 1}*

Food production system/Rural areas: **Adaptation options for agriculture include technological responses, enhancing smallholder access to credit and other critical production resources, strengthening institutions at local to regional levels, and improving market access through trade reform (*medium confidence*)**. Responses to decreased food production and quality include developing new crop varieties adapted to changes in CO_2, temperature, and drought; enhancing the capacity for climate risk management; and offsetting economic impacts of land-use change. Improving financial support and investing in the production of small-scale farms can also provide benefits. Expanding agricultural markets and improving the predictability and reliability of the world trading system through trade reform could result in reduced market volatility and help manage food supply shortages caused by climate change. *{WGII SPM.B-2, 7.5, 9.3, 22.4, 22.6, 25.9, 27.3}*

Urban areas, key economic sectors and services: **Urban adaptation benefits from effective multi-level governance, alignment of policies and incentives, strengthened local government and community adaptation capacity, synergies with the private sector, and appropriate financing and institutional development (*medium confidence*)**. Enhancing the capacity of low-income groups and vulnerable communities and their partnerships with local governments can also be an effective urban climate adaptation strategy. Examples of adaptation mechanisms include large-scale public-private risk reduction initiatives and economic diversification, and government insurance for the non-diversifiable portion of risk. In some locations, especially at the upper end of projected climate changes, responses could also require transformational changes such as managed retreat. *{WGII SPM.B-2, 8.3-4, 24.4, 24.5, 26.8, Box 25-9}*

Human health, security and livelihoods: **Adaptation options that focus on strengthening existing delivery systems and institutions, as well as insurance and social protection strategies, can improve health, security and livelihoods in the near term (*high confidence*).** Adaptation measures for health in the near-term include programs that implement and improve basic public health measures, provide clean water and sanitation, secure essential health care including vaccination and child health services, increase capacity for disaster preparedness and response, and alleviate poverty (*very high confidence*). Options to address heat related mortality include health warning systems linked to response strategies, urban planning to reduce heat stress, and improvements to the built environment. Robust institutions can manage many transboundary impacts of climate change to reduce risk of conflicts over shared natural resources. Insurance programs, social protection measures, and disaster risk management may enhance long-term livelihood and resilience among the poor and marginalized people, if policies address multi-dimensional poverty. *{WGII SPM.B-2, 8.2, 10.8, 11.7-8,* 12.5-6, *22.3,* 23.9, *25.8, 26.6, Box CC-HS}*

Significant co-benefits, synergies, and trade-offs exist between adaptation and mitigation and among different adaptation responses; interactions occur both within and across regions and sectors (*very high confidence*). For example, investments in crop varieties adapted to climate change can increase the capacity to cope with drought, and public health measures to address insect-borne diseases can enhance the capacity of health systems to address other challenges. Similarly, locating infrastructure away from low-lying coastal areas helps settlements and ecosystems adapt to sea level rise while also protecting against tsunamis. However, some adaptation options may have adverse side effects that imply real or perceived trade-offs with other adaptation objectives (see Table 4.3 for examples), mitigation objectives, or broader development goals. For example, while protection of ecosystems can assist adaptation to climate change and enhance carbon storage, increased use of air conditioning to maintain thermal comfort in buildings, or the use of desalination to enhance water resource security, can increase energy demand and therefore GHG emissions. *{WGII SPM.B-2, SPM.C-1, 5.4.2, 16.3.2.9, 17.2.3.1, Table 16-2}*

Table 4.3: Examples of potential trade-offs associated with an illustrative set of adaptation options that could be implemented by actors to achieve specific management objectives. *{WGII Table 16-2}*

Sector	Actor's adaptation objective	Adaptation option	Real or perceived trade-off
Agriculture	Enhance drought and pest resistance; enhance yields	Biotechnology and genetically modified crops	Perceived risk to public health and safety; ecological risks associated with introduction of new genetic variants to natural environments
	Provide financial safety net for farmers to ensure continuation of farming enterprises	Subsidized drought assistance; crop insurance	Creates moral hazard and distributional inequalities if not appropriately administered
	Maintain or enhance crop yields; suppress opportunistic agricultural pests and invasive species	Increased use of chemical fertilizer and pesticides	Increased discharge of nutrients and chemical pollution to the environment; adverse impacts of pesticide use on non-target species; increased emissions of greenhouse gases; increased human exposure to pollutants
Biodiversity	Enhance capacity for natural adaptation and migration to changing climatic conditions	Migration corridors; expansion of conservation areas	Unknown efficacy; concerns over property rights regarding land acquisition; governance challenges
	Enhance regulatory protections for species potentially at risk due to climate and non-climatic changes	Protection of critical habitat for vulnerable species	Addresses secondary rather than primary pressures on species; concerns over property rights; regulatory barriers to regional economic development
	Facilitate conservation of valued species by shifting populations to alternative areas as the climate changes	Assisted migration	Difficult to predict ultimate success of assisted migration; possible adverse impacts on indigenous flora and fauna from introduction of species into new ecological regions
Coasts	Provide near-term protection to financial assets from inundation and/or erosion	Sea walls	High direct and opportunity costs; equity concerns; ecological impacts to coastal wetlands
	Allow natural coastal and ecological processes to proceed; reduce long-term risk to property and assets	Managed retreat	Undermines private property rights; significant governance challenges associated with implementation
	Preserve public health and safety; minimize property damage and risk of stranded assets	Migration out of low-lying areas	Loss of sense of place and cultural identify; erosion of kinship and familial ties; impacts to receiving communities
Water resources management	Increase water resource reliability and drought resilience	Desalination	Ecological risk of saline discharge; high energy demand and associated carbon emissions; creates disincentives for conservation
	Maximize efficiency of water management and use; increase flexibility	Water trading	Undermines public good/social aspects of water
	Enhance efficiency of available water resources	Water recycling/reuse	Perceived risk to public health and safety

4.3 Response options for mitigation

Mitigation options exist in every major sector. Cost-effective mitigation is based on an integrated approach that combines measures to reduce energy use and the GHG intensity of end-use sectors, decarbonize energy supply, and reduce net emissions and enhance carbon sinks in land-based sector

A broad range of sectoral mitigation options is available that can reduce GHG emission intensity, improve energy intensity through enhancements of technology, behaviour, production and resource efficiency, and enable structural changes or changes in activity. In addition, direct options in AFOLU involve reducing CO_2 emissions by reducing deforestation and forest degradation, storing carbon in terrestrial systems (for example, through afforestation) and providing bioenergy feedstocks. Options to reduce non-CO_2 emissions exist across all sectors, but most notably in agriculture, energy supply, and industry. An overview of sectoral mitigation options and potentials is provided in Table 4.4. *{WGIII TS 3.2.1}*

Well-designed systemic and cross-sectoral mitigation strategies are more cost-effective in cutting emissions than a focus on individual technologies and sectors; with efforts in one sector determining the need for mitigation in others (*medium confidence*). In baseline scenarios without new mitigation policies, GHG emissions are projected to grow in all sectors, except for net CO_2 emissions in the AFOLU sector (Figure 4.1, left panel). Mitigation scenarios reaching around 450 ppm CO_2eq[31] concentration by 2100[32] show large-scale global changes in the energy supply sector (Figure 4.1, middle and right panel). While rapid decarbonization of energy supply generally entails more flexibility for end-use and AFOLU sectors, stronger demand reductions lessen the mitigation challenge for the supply side of the energy system (Figures 4.1 and 4.2). There are thus strong interdependencies across sectors and the resulting distribution of the mitigation effort is strongly influenced by the availability and performance of future technologies, particularly BECCS and large scale afforestation (Figure 4.1, middle and right panel). The next two decades present a window of opportunity for mitigation in urban areas, as a large portion of the world's urban areas will be developed during this period. *{WGIII SPM.4.2, TS.3.2}*

Decarbonizing (i.e. reducing the carbon intensity of) electricity generation is a key component of cost-effective mitigation strategies in achieving low stabilization levels (about 430 and 530 ppm CO_2eq) *(medium evidence, high agreement)*. In most integrated modelling scenarios, decarbonization happens more rapidly in electricity generation than in the industry, buildings, and transport sectors**.** *{WGIII SPM, 6.8, 7.11}*

Efficiency enhancements and behavioural changes, in order to reduce energy demand compared to baseline scenarios without compromising development, are a key mitigation strategy in scenarios reaching atmospheric CO_2eq concentrations of about 450 or 500 ppm by 2100 (*robust evidence, high agreement*). Near-term reductions in energy demand are an important element of cost-effective mitigation strategies, provide more flexibility for reducing carbon intensity in the energy supply sector, hedge against related supply-side risks, avoid lock-in to carbon-intensive infrastructures, and are associated with important co-benefits (Figure 4.2, Table 4.4). Emissions can be substantially lowered through changes in consumption patterns (e. g. mobility demand and mode, energy use in households, choice of longer-lasting products) and dietary change and reduction in food wastes. A number of options including monetary and non-monetary incentives as well as information measures may facilitate behavioural changes. *{WGIII SPM.4.2}*

[31] See glossary for definition of CO_2eq concentrations and emissions; also Box 3.2 for metrics to calculate the 'CO_2 equivalence' of non-CO_2 emissions and their influence on sectoral abatement strategies.
[32] For comparison, the CO_2eq concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 – 520 ppm).

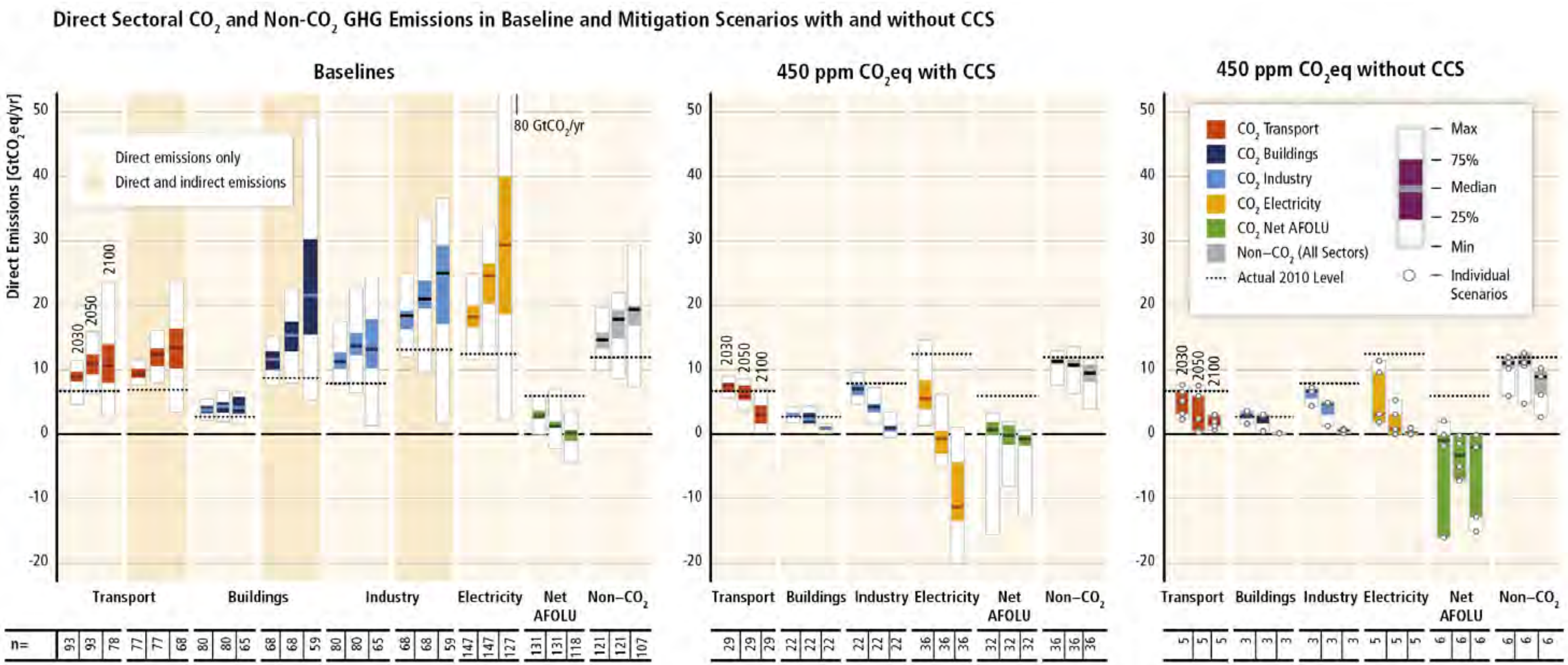
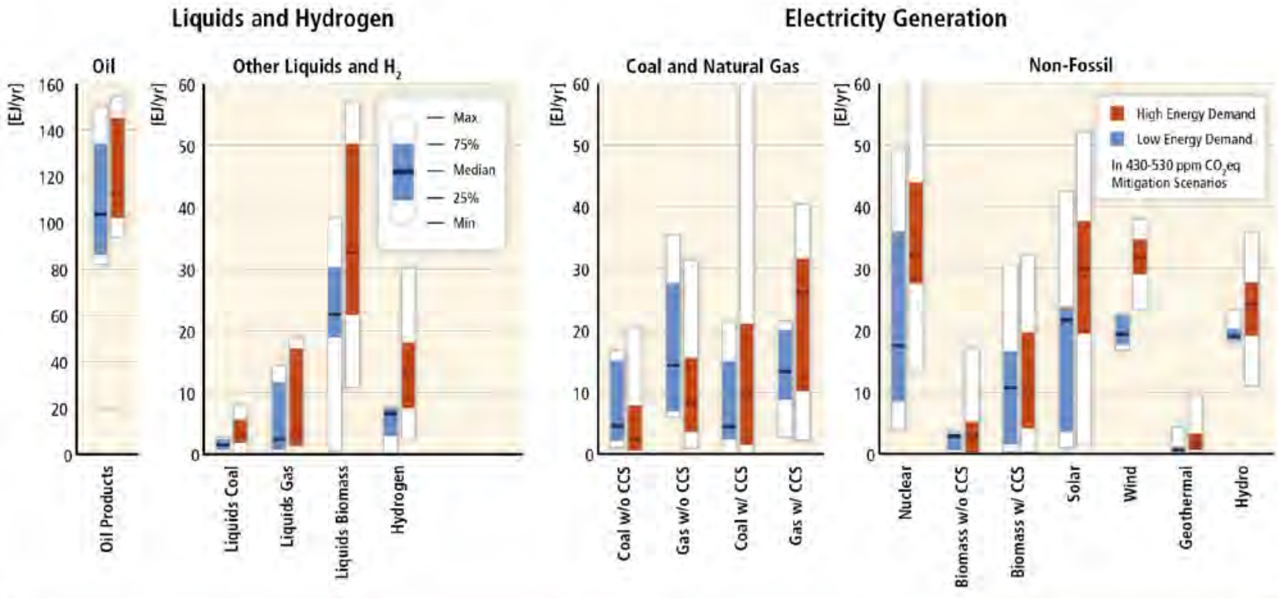


Figure 4.1: CO_2 emissions by sector and total non-CO_2 GHG emissions (Kyoto gases) across sectors in baseline (left panel) and mitigation scenarios that reach around 450 (430 – 480) ppm CO_2eq with CCS (middle panel) and without CCS (right panel). Light yellow background denotes direct CO_2 and non-CO_2 GHG emissions for both the baseline and mitigation scenarios. In addition, for the baseline scenarios, the sum of direct and indirect emissions from the energy end-use sectors (transport, buildings, and industry) is also shown (dark yellow background). Note that for calculating the indirect emissions only electricity emissions are allocated from energy supply to end-use sectors. The numbers at the bottom of the graphs refer to the number of scenarios included in the range, which differs across sectors and time due to different sectoral resolution and time horizon of models. Note that many models cannot reach 450 ppm CO_2eq concentration by 2100 in the absence of CCS, resulting in a low number of scenarios for the right panel. *{Figure WGIII SPM.7, Figure WGIII TS.15}*

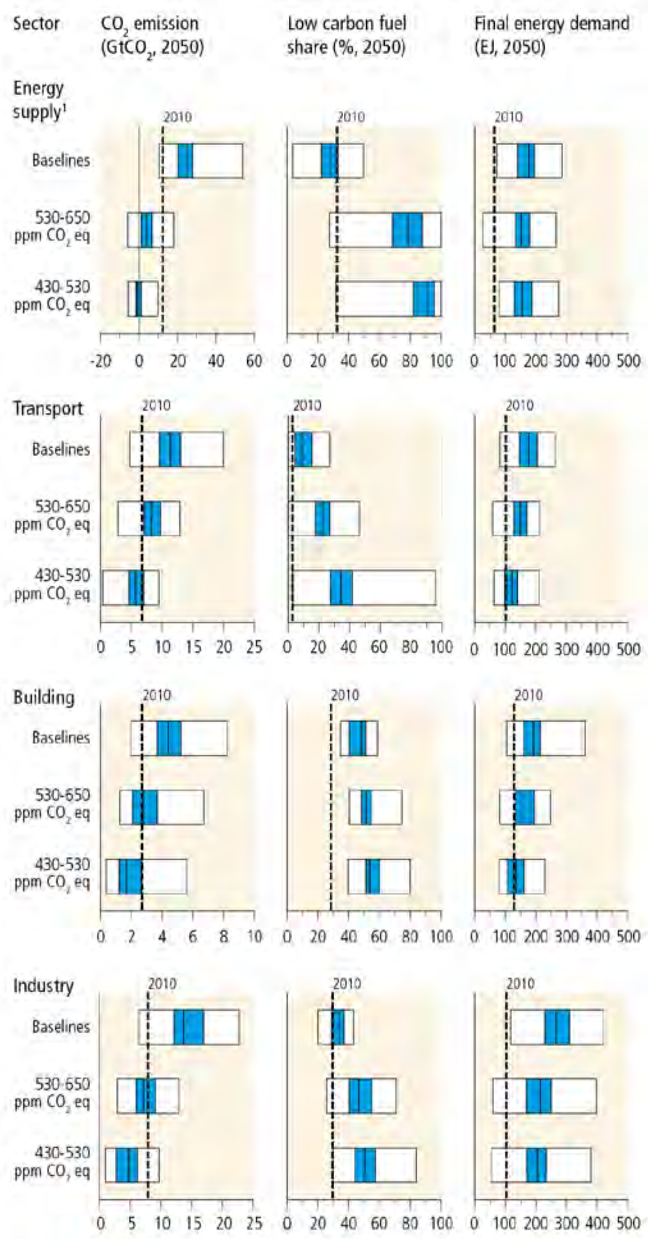


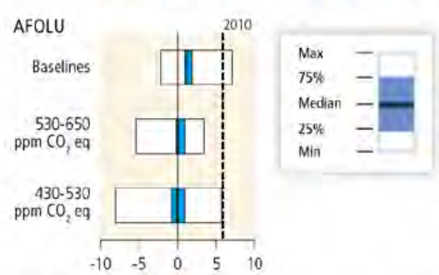
1	2	3	4
High energy demand scenarios show higher levels of oil supply.	In high energy demand scenarios, alternative liquid and hydrogen technologies are scaled up more rapidly.	High energy demand scenarios show a more rapid up-scaling of CCS technologies but a more rapid phase-out of unabated fossil fuel conversion technologies.	In high energy demand scenarios non-fossil electricity generation technologies are scaled up more rapidly.

Figure 4.2: Influence of energy demand on the deployment of energy supply technologies in 2050 in mitigation scenarios reaching 430–530 ppm CO_2eq concentrations by 2100. Blue bars for ‘low energy demand’ show the deployment range of scenarios with limited growth in final energy demand of <20% in 2050 compared to 2010. Red bars show the deployment range of technologies in a case of ‘high energy demand’ (>20% growth in 2050 compared to 2010). For each technology, the median, interquartile, and full deployment range is displayed. Notes: Scenarios assuming technology restrictions are excluded. Ranges include results from many different integrated models. Multiple scenario results from the same model were averaged to avoid sampling biases. *{WGIII Figure TS.16}*

Table 4.4: Sectoral CO_2 emissions, associated energy system changes, and examples of mitigation measures (including for non-CO_2 gases; see Box 3.2 for metrics regarding the weighting and abatement of non-CO_2 emissions). *{WGIII 7.11.3, 7.13, 7.14, Table TS.2, Figures SPM.8, SPM.7}*

Sectoral CO_2 emissions and related energy system changes





Examples for sectoral mitigation measures

Sector	Key low carbon energy options	Key energy saving options	Other options
Energy supply[1]	Renewables (wind, solar bioenergy, geothermal, hydro, etc..), Nuclear, CCS, BECS, fossil fuel switching	Energy efficiency improvements of energy supply technologies, improved transmission and distribution, CHP and cogeneration	Fugitive CH_4 emissions control
Transport	Fuel switching to low carbon fuels (eg., hydrogen/electricity from low-carbon sources), biofuels	Efficiency improvements (engines, vehicle design, appliances, lighter materials), Modal shift (eg, from LDVs to public transport or from aviation to HDVs to rail), eco-driving, improved fright logistics, journey avoidance, higher occupancy rates	Transport (infrastructure) planning, urban planning
Building	Building integrated RES, fuel switching to low carbon fuels (eg, electricity from low-carbon sources, biofuels)	Device efficiency (heating/cooling systems, water heating, cooking, lighting, appliances), Systemic efficiency (integrated design, low/zero energy buildings, district heating/cooling, CHP, smart meters/grids), behavioral and lifestyle changes (eg, appliance use, thermostat setting, dwelling size)	Urban planning, building lifetime, durability of building components and appliances, low energy/GHG intensive construction and materials
Industry	Process emissions reductions, use of waste and CCS in industry, fuel switching among fossil fuels and switch to low-carbon energy (eg, electricity) or biomass	Energy efficiency and BAT (eg, furnace/boilers, steam systems, electric motors and control systems, (waste) heat exchanges, recycling), reduction of demand for goods, more intensive use of goods (eg, improve durability or car sharing)	HFC replacement and leak repair, Material efficiency (eg, process innovation, re-using old materials, product design, etc)

AFOLU			
Emissions reduction measures: Methane (eg, lifestock management), nitrous oxide (eg, fertilizer use), conservation of existing carbon pools (reduced deforestation and forest degradation, fire prevention, agroforestry), reduction in emissions intensity	**Sequestration options:** Increasing existing carbon pools (eg, afforestation, reforestation, integrated systems, carbon sequestration in soils)	**Substitution options:** Use of biological products instead of fossil/GHG intensive products (eg bioenergy, insulation products).	**Demand-side measures:** Reduction of loss and waste of food, changes in human diets, use of long-lives wood products

[1] CO_2 emissions, low carbon fuel shares, and final energy demand are shown for electricity generation only

Decarbonization of the energy supply sector (i.e. reducing the carbon intensity) requires upscaling of low- and zero-carbon electricity generation technologies (*high confidence*). In the majority of low-concentration stabilization scenarios (430-530 ppm CO_2eq), the share of low-carbon electricity supply (comprising renewable energy (RE), nuclear and CCS, including BECCS) increases from the current share of approximately 30% to more than 80% by 2050, and fossil fuel power generation without CCS is phased out almost entirely by 2100. GHG emissions from energy supply can be reduced significantly by replacing current world average coal-fired power plants with modern, highly efficient natural gas combined-cycle power plants or combined heat and power plants, provided that natural gas is available and the fugitive emissions associated with extraction and supply are low or mitigated. *{WGIII SPM.4.2}*

Behaviour, lifestyle and culture have a considerable influence on energy use and associated emissions, with high mitigation potential in some sectors, in particular when complementing technological and structural change (*medium evidence, medium agreement*). In the transport sector, technical and behavioural mitigation measures for all modes, plus new infrastructure and urban redevelopment investments, could reduce final energy demand significantly below baseline levels (*robust evidence, medium agreement*) (Table 4.4). While opportunities for switching to low-carbon fuels exist, the rate of decarbonization in the transport sector might be constrained by challenges associated with energy storage and the relatively low energy density of low-carbon transport fuels (*medium confidence*). In the building sector, recent advances in technologies, know-how and policies provide opportunities to stabilize or reduce global energy use to about current levels by mid-century. In addition, recent improvements in performance and costs make very low energy construction and retrofits of buildings economically attractive, sometimes even at net negative costs (*robust evidence, high agreement*). In the industry sector, improvements in GHG emission efficiency and in the efficiency of material use, recycling and reuse of materials and products, and overall reductions in product demand (e.g., through a more intensive use of products) and service demand could, in addition to energy efficiency, help reduce GHG emissions below the baseline level. Important options for mitigation in waste management are waste reduction, followed by re-use, recycling and energy recovery *(robust evidence, high agreement)*. *{WGIII SPM.4.2, Box TS.12, 3.2.4}*

The most cost-effective mitigation options in forestry are afforestation, sustainable forest management and reducing deforestation, with large differences in their relative importance across regions. In agriculture, the most cost-effective mitigation options are cropland management, grazing land management, and restoration of organic soils (*medium evidence, high agreement*). About a third of mitigation potential in forestry can be achieved at a cost <20 USD/tCO_2eq emission. Demand-side measures, such as changes in diet and reductions of losses in the food supply chain, have a significant, but uncertain, potential to reduce GHG emissions from food production (*medium evidence, medium agreement*). In addition, bioenergy can play a critical role for mitigation, but there are issues to consider, such as the sustainability of practices and the efficiency of bioenergy systems. Evidence suggests that bioenergy options with low lifecycle emissions, some already available, can reduce GHG emissions; outcomes are site-specific and rely on efficient integrated 'biomass-to-bioenergy systems', and sustainable land-use management and governance. Barriers to large-scale deployment of bioenergy include concerns about GHG emissions from land, food security, water resources, biodiversity conservation and livelihoods. *{WGIII SPM.4.2}*

Mitigation measures intersect with other societal goals creating the possibility of co-benefits or adverse side-effects. These intersections, if well-managed, can strengthen the basis for undertaking climate mitigation actions (*robust evidence, medium agreement*). Mitigation can positively or negatively influence the achievement of other societal goals, such as those related to human health, food security, biodiversity, local environmental quality, energy access, livelihoods, and equitable sustainable development (see also Section 4.5). On the other hand, policies towards other societal goals can influence the achievement of mitigation and adaptation objectives. These influences can be substantial, although sometimes difficult to quantify, especially in welfare terms. This multi-objective perspective is important in part because it helps to identify areas where support for policies that advance multiple goals will be robust. Potential co-benefits and adverse side-effects of the main sectoral mitigation measures are summarized in Table 4.5. Overall, the potential for co-benefits for energy end-use measures outweigh the potential for adverse side-effects, whereas the evidence suggests this may not be the case for all energy supply and AFOLU measures. *{WGIII SPM.2.1 }*

Table 4.5: Potential co-benefits (blue text) and adverse side-effects (red text) of the main sectoral mitigation measures. Co-benefits and adverse side-effects, and their overall positive or negative effect, all depend on local circumstances as well as on the implementation practice, pace and scale. For an assessment of macroeconomic, cross-sectoral effects associated with mitigation policies, see Section 3.4. The uncertainty qualifiers between brackets denote the level of evidence and agreement on the respective effect. Abbreviations for evidence: l=limited, m=medium, r=robust; for agreement: l=low, m=medium, h=high. *{WGIII Table 6.7, Tables TS.3, TS.4, TS.5, TS.6, TS.7}*

Sectoral mitigation measures	Effect on additional objectives/concerns		
	Economic	Social	Environmental
Energy Supply	*For possible upstream effects of biomass supply for bioenergy, see AFOLU.*		
Nuclear replacing coal power (and other fossil fuels)	Energy security (reduced exposure to fuel price volatility) **(m/m)**; local employment impact (but uncertain net effect) **(l/m)**; legacy/cost of waste and abandoned reactors **(m/h)**	Mixed health impact via reduced air pollution and coal mining accidents **(m/h)**, nuclear accidents and waste treatment, uranium mining and milling **(m/l)**; safety and waste concerns **(r/h)**; proliferation risk **(m/m)**	Mixed ecosystem impact via reduced air pollution **(m/h)** and coal mining **(l/h)**, nuclear accidents **(m/m)**
Renewable Energy (wind, PV, CSP, hydro, geothermal, bioenergy) replacing coal	Energy security **(r/m)**; local employment (but uncertain net effect)**(m/m)**; water management (for some hydro energy)**(m/h)**; extra measures to match demand (for PV, wind, some CSP) **(r/h)**; higher use of critical metals for PV and direct drive wind turbines **(r/m)**	Reduced health impact via reduced air pollution (except bioenergy) **(r/h)** and coal mining accidents **(m/h)**; contribution to (off-grid) energy access **(m/l)**; threat of displacement (for large hydro installations) **(m/h)**	Mixed ecosystem impact via reduced air pollution (except bioenergy) **(m/h)** and coal mining **(l/h)**, habitat impact (for some hydro energy)**(m/m)**, landscape and wildlife impact **(m/m)**; lower/higher water use (for wind, PV **(m/m)**; bioenergy CSP, geothermal and reservoir hydro **(m/h)**)
Fossil energy with CCS replacing coal	Preservation vs lock-in of human and physical capital in the fossil industry **(m/m)**; long-term monitoring of CO_2 storage **(m/h)**	Health impact via risk of CO_2 leakage **(m/m)**, upstream supply-chain activities **(m/h)**; safety concerns (CO_2 storage and transport) **(m/h)**	Ecosystem impact via upstream supply-chain activities **(m/m)**, higher water use **(m/h)**
CH_4 leakage prevention, capture or treatment	Energy security (potential to use gas in some cases) **(l/h)**	Reduced health impact via reduced air pollution **(m/m)**; occupational safety at coal mines **(m/m)**	Reduced ecosystem impact via reduced air pollution **(l/m)**
Transport	*For possible upstream effects of low-carbon electricity, see Energy Supply. For biomass supply, see AFOLU.*		
Reduction of carbon intensity of fuel	Energy security (diversification, reduced oil dependence and exposure to oil price volatility) **(m/m)**; technological spillovers **(l/l)**	Mixed health impact via increased/reduced urban air pollution by electricity and hydrogen **(r/h)**, diesel **(l/m)**, noise **(l/m)**; road safety (silent electric LDVs) **(l/l)**	Ecosystem impact of electricity and hydrogen via urban air pollution **(m/m)**, material use (unsustainable mining) **(l/l)**
Reduction of energy intensity	Energy security (reduced oil dependence and exposure to oil price volatility) **(m/m)**	Reduced health impact via reduced urban air pollution **(r/h)**; road safety (via higher crash-worthiness) **(m/m)**	Reduced ecosystem and biodiversity impact via reduced urban air pollution **(m/h)**
Compact urban form + improved transport infrastructure Modal shift	Energy security (reduced oil dependence and exposure to oil price volatility) **(m/m)**; productivity (reduced urban congestion and travel times, affordable and accessible transport)**(m/h)**	Mixed health impact for non-motorized modes via increased physical activity **(r/h)**, potentially higher exposure to air pollution **(r/h)**, reduced noise (via modal shift and travel reduction)**(r/h)**; mobility access to employment opportunities **(r/h)**; road safety (via modal shift **(r/h)**)	Reduced ecosystem impact via reduced urban air pollution **(r/h)**; land-use competition **(m/m)**
Journey reduction and avoidance	Energy security (reduced oil dependence and exposure to oil price volatility) **(r/h)**; productivity (reduced urban congestion/travel times, walking) **(r/h)**	Reduced health impact (for non-motorized transport modes) **(r/h)**	Mixed ecosystem impact via reduced urban air pollution **(r/h)**, new/shorter shipping routes **(r/h)**; reduced land-use competition (transport infrastructure)**(r/h)**
Buildings	*For possible upstream effects of fuel switching and RES, see Energy Supply.*		
Reduction of emissions intensity (e.g. fuel switching,	Energy security **(m/h)**; employment impact **(m/m)**; lower need for energy subsidies **(l/l)**; asset values of buildings **(l/m)**	Fuel poverty alleviation via reduced energy demand **(m/h)**; energy access (for higher energy cost) **(l/m)**; productive	Reduced health impact in residential buildings and ecosystem impact (via reduced fuel poverty **(r/h)**, indoor/

RES incorporation, green roofs)		time for women/children (for replaced traditional cookstoves) **(m/h)**	outdoor air pollution **(r/h)**, and UHI effect **(l/m)**); urban biodiversity (for green roofs)**(m/m)**
Retrofits of existing buildings Exemplary new buildings Efficient equipment	Energy security **(m/h)**; employment impact **(m/m)**; productivity (for commercial buildings) **(m/h)**; less need for energy subsidies **(l/l)**; asset value of buildings **(l/m)**; disaster resilience **(l/m)**	Fuel poverty alleviation via reduced energy demand (for retrofits, efficient equipment) **(m/h)**; energy access (higher housing cost)**(l/m)**; thermal comfort **(m/h)**; productive time for women and children (for replaced traditional cookstoves) **(m/h)**	Reduced health and ecosystem impact (e.g. via reduced fuel poverty **(r/h)**, indoor/outdoor air pollution **(r/h)** and UHI effect **(l/m)**, improved indoor environmental conditions **(m/h)**); health risk via insufficient ventilation **(m/m)**; reduced water consumption and sewage production **(l/l)**
Behavioural changes reducing energy demand	Energy security **(m/h)**; less need for energy subsidies **(l/l)**		Reduced health and ecosystem impact (e.g. via improved indoor environmental conditions **(m/h)**and less outdoor air pollution **(r/h)**)
Industry	*For possible upstream effects of low-carbon energy supply (incl. CCS), see Energy Supply and of biomass supply, see AFOLU.*		
Reduction of CO_2/non-CO_2 emission intensity	Competitiveness and productivity **(m/h)**	Reduced health impact via reduced local air pollution and better working conditions (PFC from aluminium) **(m/m)**	Reduced ecosystem impact (via reduced local air and water pollution) **(m/m)**; water conservation **(l/m)**
Energy efficiency improvements via new processes/technologies	Energy security (via lower energy intensity) **(m/m)**; employment impact **(l/l)**; competitiveness and productivity **(m/h)**; technological spillovers in DCs **(l/l)**	Reduced health impact via reduced local pollution **(l/m)**; new business opportunities **(m/m)**; water availability and quality **(l/l)**; safety, working conditions and job satisfaction **(m/m)**	Reduced ecosystem impact via fossil fuel extraction **(l/l)**, reduced local pollution and waste **(m/m)**
Material efficiency of goods, recycling	National sales tax revenue (medium term) **(l/l)**; employment impact (waste recycling) **(l/l)**; competitiveness in manufacturing **(l/l)**; new infrastructure for industrial clusters **(l/l)**	Reduced health impacts and safety concerns **(l/m)**; new business opportunities **(m/m)**; local conflicts (reduced resource extraction)**(l/m)**	Reduced ecosystem impact via reduced local air and water pollution and waste material disposal **(m/m)**; reduced use of raw/virgin materials and natural resources implying reduced unsustainable resource mining **(l/l)**
Product demand reductions	National sales tax revenue (medium term) **(l/l)**	Local conflicts (reduced inequity in consumption) **(l/l)**; new diverse lifestyle concept **(l/l)**	Post-consumption waste **(l/l)**
AFOLU	*Note: co-benefits and adverse side-effects depend on the development context and the scale of the intervention (size).*		
Supply side: forestry, land-based agriculture, livestock, integrated systems and bioenergy Demand side: reduced losses in the food supply chain, changes in human diets and in demand for wood and forestry products	Mixed employment impact via **entrepreneurship development** **(m/h)**, **use of less labour-intensive technologies in agriculture** **(m/m)**; **diversification of income sources and access to markets** **(r/h)**; **additional income to sustainable landscape management** **(m/h)**; **income concentration** **(m/m)**; **energy security (resource sufficiency)** **(m/h)**; Innovative financing mechanisms for sustainable resource management **(m/h)**; technology innovation and transfer **(m/m)**	**Food-crops production through integrated systems and sustainable agriculture intensification** **(r/m)**; **food production (locally) due to large-scale monocultures of non-food crops** **(r/l)**; cultural habitats and recreational areas via (sustainable) forest management and conservation **(m/m)**; **human health and animal welfare e.g. through less use of pesticides, reduced burning practices, and agroforestry & silvo-pastoral systems** **(m/h)**; **human health related to burning practices (in agriculture or bioenergy)** **(m/m)**; mixed impacts on gender, intra- and inter-generational equity via **participation and fair benefit sharing** **(r/h)** and **concentration of benefits** **(m/m)**	Mixed impact on ecosystem services via **large-scale monocultures** **(r/h)**, ecosystem conservation, sustainable management as well as sustainable agriculture **(r/h)**; **land-use competition** **(r/m)**; soil quality **(r/h)**; erosion **(r/h)**; ecosystem resilience **(m/h)**; albedo and evaporation **(r/h)** Mixed impact on **tenure and use rights at the local level (for indigenous people and local communities)****(r/h)** and on access to participative mechanisms for land management decisions **(r/h)**; enforcement of existing policies for sustainable resource management **(r/h)**
Human Settlements and Infrastructure	*For compact urban form and improved transport infrastructure, see also Transport.*		
Compact development and infrastructure	Innovation and efficient resource use **(r/h)**; higher rents and property values **(m/m)**	Health from physical activity: *see Transport*	Preservation of open space **(m/m)**
Increased accessibility	Commute savings **(r/h)**	Health from increased physical activity: *see Transport*; social interaction & mental health **(m/m)**	Air quality and reduced ecosystem and health impacts **(m/h)**
Mixed land use	Commute savings **(r/h)**; higher rents and property values **(m/m)**	Health from increased physical activity **(r/h)**; social interaction and mental health **(l/m)**	Air quality and reduced ecosystem and health impacts **(m/h)**

4.4 Policy approaches at different scales, including technology development/transfer and finance

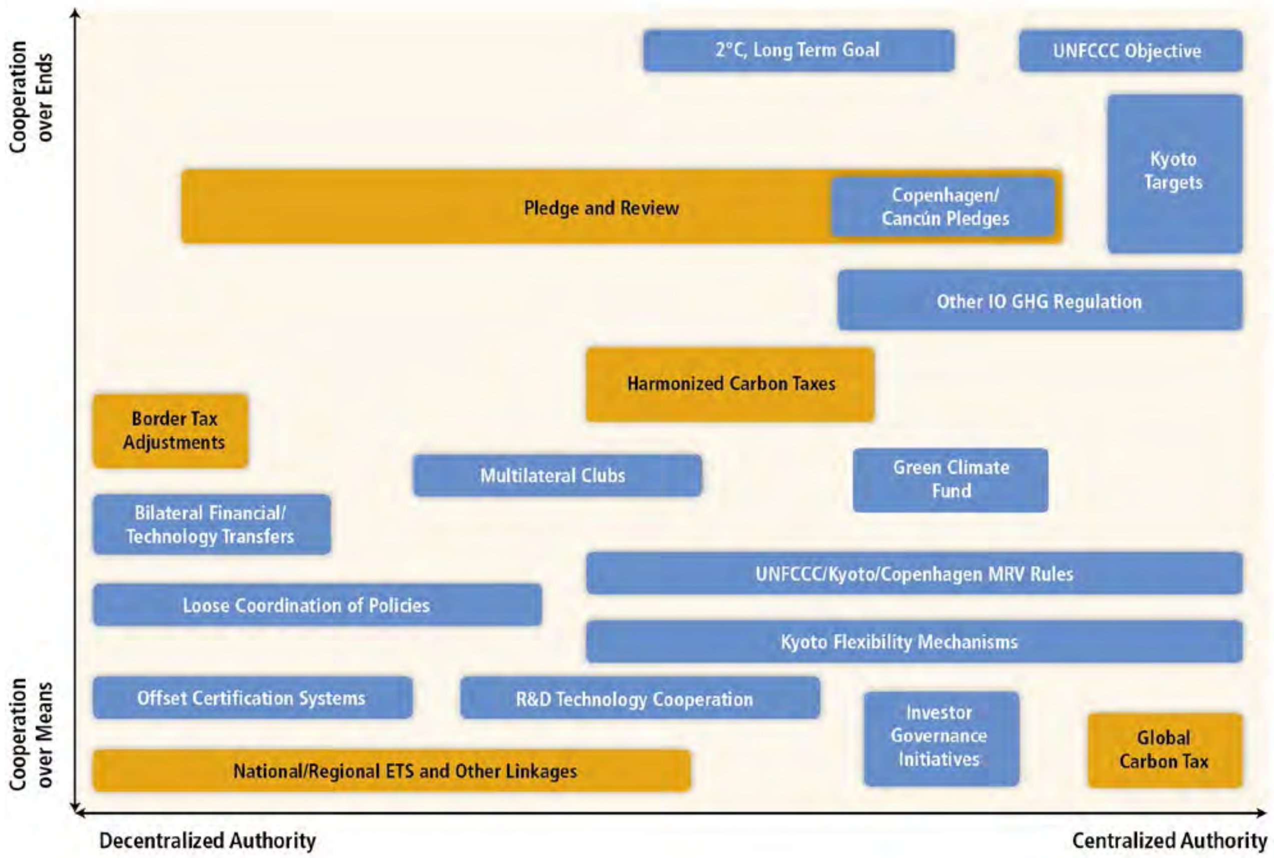
Effective adaptation and mitigation responses will depend on policies and measures across multiple scales. Support for technology development and transfer, and finance for climate responses, can complement policies that directly promote adaptation and mitigation.

4.4.1 International and Regional Cooperation on Adaptation and Mitigations

Because climate change has the characteristics of a collective action problem at the global scale (see 3.1), effective mitigation will not be achieved if individual agents advance their own interests independently, even though mitigation can also have local co-benefits. Adaptation focuses primarily on local to national scale outcomes, but its effectiveness can depend on coordination across governance scales, including international cooperation. A variety of climate policy instruments have been employed, and even more could be employed, at international and regional levels to address mitigation and to support and promote adaptation at national and sub-national scales. *{SREX SPM, 7.ES; WGII.2.2, 15.2; WGIII 13.ES, 14.3, 15.8}*

The United Nations Framework Convention on Climate Change (UNFCCC) is the main multilateral forum focused on addressing climate change, with nearly universal participation. UNFCCC activities since 2007, which include the 2010 Cancun Agreement and the 2011 Durban Platform for Enhanced Action, have sought to enhance actions under the Convention, and have led to an increasing number of institutions and other arrangements for international climate change cooperation. Other institutions organized at different levels of governance have resulted in diversifying international climate change cooperation. *{WGIII SPM.5.2, 13.5}*

Existing and proposed international climate change cooperation arrangements vary in their focus and degree of centralization and coordination. They span: multilateral agreements, harmonized national policies and decentralized but coordinated national policies, as well as regional and regionally-coordinated policies (see Figure 4.3). *{WGIII SPM.5.2}*



Legend: Loose coordination of policies: examples include transnational city networks or NAMAs; R&D technology cooperation: examples include the Major Economies Forum on Energy and Climate (MEF), Global Methane Initiative (GMI), Renewable Energy and Energy Efficiency Partnership (REEEP); Other international organization (IO) GHG regulation: examples include the Montreal Protocol, International Civil Aviation Organization (ICAO), International Maritime Organization (IMO); see WGIII Figure 13.1 for details of these examples.

Figure 4.3: International cooperation over ends / means and degrees of centralized authority. Examples in blue are existing agreements. Examples in orange are structures for agreements proposed in the literature. The width of individual boxes indicates the range of possible degrees of centralization for a particular agreement. The degree of centralization indicates the authority an agreement confers on an international institution, not the process of negotiating the agreement. *{WGIII Figure 13.2}*

While a number of new institutions are focused on adaptation funding and coordination, adaptation has historically received less attention than mitigation in international climate policy *(robust evidence, medium agreement)*. Inclusion of adaptation is increasingly important to reduce the risk of damages and may engage a greater number of countries. Other possible synergies and trade-offs between adaptation and mitigation, particularly those related to the timing of actions, are not well understood. *{WGIII 13.2, 13.3.3, 13.5.1.1, 13.14}*

The Kyoto Protocol offers lessons towards achieving the ultimate objective of the UNFCCC, particularly with respect to participation, implementation, flexibility mechanisms, and environmental effectiveness (*medium evidence, low agreement*). Annex I Parties surpassed their collective emission reduction target in the first commitment period, but some emissions reductions that would have occurred even in its absence were also credited. The total effect on global emissions may have been limited by the fact that some countries did not ratify the Protocol, others who had ratified did not meet their commitments, and its commitments applied only to a portion of the global economy. The Kyoto Protocol's Clean Development Mechanism (CDM), which created a market for emissions offsets from developing countries, had generated credits equivalent to emissions of over 1.4 Gt CO_2eq[33] by October 2013. Its environmental effectiveness has been questioned by some, due to concerns about the additionality of projects (that is, whether projects bring about emissions that are different from BAU circumstances), the validity of baselines, and the possibility of

[33] See Box 3.2 for metrics to calculate the 'CO_2 equivalence' of non-CO_2 emissions.

emissions leakage *(medium evidence; medium agreement)*. The majority of single CDM projects are concentrated in a limited number of countries, while Programmes of Activities have been more evenly distributed. *{WGIII SPM.5.2, 13.7, 13.13.1.1, 14.3, Table TS.9}*

Several models for burden sharing – among both developed and developing countries – have been identified in research. Distributional impacts from international cooperative agreements depend on the approach taken, criteria applied to operationalize equity, and the manner in which developing countries' emissions plans are financed. *{WGIII 4.6, 13.4}*

Policy linkages among regional, national, and sub-national climate policies offer potential climate change mitigation benefits *(medium evidence, medium agreement)*. Linkages have been established between carbon markets, and in principle could also be established between and among a heterogeneous set of policy instruments including non-market-based policies, such as performance standards. Potential advantages include lower mitigation costs, decreased emission leakage, and increased market liquidity. *{WGIII SPM.5.2, 13.3, 13.5 13.6, 13.7, 14.5}*

Regional initiatives between national and global scales are being developed and implemented, but their impact on global mitigation has been limited to date *(medium confidence)*. Some climate policies could be more environmentally and economically effective if implemented across broad regions, such as by embodying mitigation objectives in trade agreements or jointly constructing infrastructures that facilitate reduction in carbon emissions. *{WGIII Table TS.9, 13.13, 14.4, 14.5}*

International mechanisms for supporting adaptation planning have assisted in the creation of adaptation strategies, plans, and actions at national, sub-national, and local levels *(high confidence)*. For example, a range of multilateral and regionally targeted funding mechanisms have been established for adaptation; UN agencies, international development organizations and NGOs have provided information, methodologies and guidelines; and global and regional initiatives supported and promoted the creation of national adaptation strategies in both developing and developed countries. Closer integration of disaster risk reduction and climate change adaptation at the international level, and the mainstreaming of both into international development assistance, may foster greater efficiency in the use of resources and capacity. However, stronger efforts at the international level do not necessarily lead to substantive and rapid results at the local level. *{WGII 15.2, 15.3; SREX SPM, 7.4, 8.2, 8.5}*

4.4.2 National and Sub-National Policies

4.4.2.1 Adaptation

Adaptation experience is accumulating across regions in the public and private sector and within communities (*high confidence*). Adaptation options adopted to date (see Table 4.6) emphasize incremental adjustments and co-benefits and are starting to emphasize flexibility and learning (*medium evidence, medium agreement*). Most assessments of adaptation have been restricted to impacts, vulnerability, and adaptation planning, with very few assessing the processes of implementation or the effects of adaptation actions (*medium evidence, high agreement*). *{WGII SPM.A-2, TS.A-2}*

Table 4.6: Recent adaptation actions in the public and private sector across regions. *{WGII SPM}*

Region	Example of actions
Africa	Most national governments are initiating governance systems for adaptation. Disaster risk management, adjustments in technologies and infrastructure, ecosystem-based approaches, basic public health measures, and livelihood diversification are reducing vulnerability, although efforts to date tend to be isolated.
Europe	Adaptation policy has been developed across all levels of government, with some adaptation planning integrated into coastal and water management, into environmental protection and land planning, and into disaster risk management.
Asia	Adaptation is being facilitated in some areas through mainstreaming climate adaptation action into subnational development planning, early warning systems, integrated water resources

	management, agroforestry, and coastal reforestation of mangroves.
Australasia	Planning for sea-level rise, and in southern Australia for reduced water availability, is becoming adopted widely. Planning for sea-level rise has evolved considerably over the past two decades and shows a diversity of approaches, although its implementation remains piecemeal.
North America	Governments are engaging in incremental adaptation assessment and planning, particularly at the municipal level. Some proactive adaptation is occurring to protect longer-term investments in energy and public infrastructure.
Central and South America	Ecosystem-based adaptation including protected areas, conservation agreements, and community management of natural areas is occurring. Resilient crop varieties, climate forecasts, and integrated water resources management are being adopted within the agricultural sector in some areas.
The Arctic	Some communities have begun to deploy adaptive co-management strategies and communications infrastructure, combining traditional and scientific knowledge.
Small Islands	Small islands have diverse physical and human attributes; community-based adaptation has been shown to generate larger benefits when delivered in conjunction with other development activities.
Open Ocean	International cooperation and marine spatial planning are starting to facilitate adaptation to climate change, with constraints from challenges of spatial scale and governance issues.

National governments play a key role in adaptation planning and implementation (*high agreement, robust evidence*). There has been substantial progress since the AR4 in the development of national adaptation strategies and plans. This includes National Adaptation Programmes of Action (NAPAs) by least developed countries, National Adaptation Plans, and strategic frameworks for national adaptation in OECD countries. National governments can coordinate adaptation efforts of local and subnational governments, for example by protecting vulnerable groups, by supporting economic diversification, and by providing information, policy and legal frameworks, and financial support. *{WGII SPM.C-1, 15.2}*

Subnational government and the private sector are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households, and civil society and in managing risk information and financing (*medium evidence*, *high agreement*). There is a significant increase in the number of planned adaptation responses at the local level in rural and urban communities of developed and developing countries since the AR4. However, local councils and planners are often confronted by the complexity of adaptation without adequate access to guiding information or data on local vulnerabilities and potential impacts. Steps for mainstreaming adaptation into local decision-making have been identified but challenges remain in their implementation. Hence, scholars stress the important role of linkages with national and subnational levels of government as well as partnerships among public, civic, and private sectors in implementing local adaptation responses. *{WGII SPM.A-2, SPM.C-1, 14.2, 15.2}*

Institutional dimensions of adaptation governance play a key role in promoting the transition from planning to implementation of adaptation (*high agreement, robust evidence*). The most commonly emphasized institutional barriers or enablers for adaptation planning and implementation are: 1) multilevel institutional co-ordination between different political and administrative levels in society; 2) key actors, advocates and champions initiating, mainstreaming and sustaining momentum for climate adaptation; 3) horizontal interplay between sectors, actors and policies operating at similar administrative levels; 4) political dimensions in planning and implementation; and 5) coordination between formal governmental, administrative agencies and private sectors and stakeholders to increase efficiency, representation and support for climate adaptation measures. *{WGII 15.2, 15.5, 16.3, Box 15-1}*

Existing and emerging economic instruments can foster adaptation by providing incentives for anticipating and reducing impacts *(medium confidence)*. Instruments include public-private finance partnerships, loans, payments for environmental services, improved resource pricing, charges and subsidies, norms and regulations, and risk sharing and transfer mechanisms. Risk financing mechanisms in the public and private sector, such as insurance and risk pools, can contribute to increasing resilience, but without attention to major design challenges, they can also provide disincentives, cause market failure, and decrease equity. Governments often play key roles as regulators, providers, or insurers of last resort. *{WGII SPM.C-1}*

4.4.2.2 Mitigation

There has been a considerable increase in national and sub-national mitigation plans and strategies since AR4. In 2012, 67% of global GHG emissions[34] were subject to national legislation or strategies versus 45% in 2007. However, there has not yet been a substantial deviation in global emissions from the past trend. These plans and strategies are in their early stages of development and implementation in many countries, making it difficult to assess their aggregate impact on future global emissions (*medium evidence, high agreement*). *{WGIII SPM.5.1}*

Since AR4, there has been an increased focus on policies designed to integrate multiple objectives, increase co-benefits and reduce adverse side-effects *(high confidence)*. Governments often explicitly reference co-benefits in climate and sectoral plans and strategies. *{WGIII SPM.5.1}*

Sector-specific policies have been more widely used than economy-wide policies (see Table 4.7; *high agreement, medium evidence)*. Although most economic theory suggests that economy-wide policies for mitigation would be more cost-effective than sector-specific policies, administrative and political barriers may make economy-wide policies harder to design and implement than sector-specific policies. The latter may be better suited to address barriers or market failures specific to certain sectors, and may be bundled in packages of complementary policies *{WGIII SPM*.5.1*}*

Various carbon pricing regimes have been implemented with diverse effects. The short-run environmental effects of cap and trade systems have been limited as a result of loose caps or caps that have not proved to be constraining *(limited evidence, medium agreement)*. Tax-based policies specifically aimed at reducing GHG emissions – alongside technology and other policies – have helped to weaken the link between GHG emissions and GDP (*high confidence*). In many countries, fuel taxes have had effects that are akin to sectoral carbon taxes (*robust evidence, medium agreement*). Revenues from carbon taxes or auctioned emission allowances reduce other taxes and/or to provide transfers to low-income groups. This illustrates the general principle that mitigation policies that raise government revenue generally have lower social costs than approaches which do not. *{WGIII SPM*.5.1*}*

[34] Kyoto gases expressed in CO_2eq; see Box 3.2 for metrics to calculate the 'CO_2 equivalence' of non-CO_2 emissions.

Table 4.7: Sectoral Policy Instruments. *{WGIII Table 15.2}*

Policy Instruments	Energy	Transport	Buildings	Industry	AFOLU	Human Settlements and Infrastructure
Economic Instruments – Taxes (carbon taxes may be economy-wide)	- Carbon tax (e.g. applied to electricity or fuels)	- Fuel taxes - Congestion charges, vehicle registration fees, road tolls - Vehicle taxes	- Carbon and/or energy taxes (either sectoral or economy-wide)	- Carbon tax or energy tax - Waste disposal taxes or charges	- Fertilizer or nitrogen taxes to reduce nitrous oxide (N_2O)	- Sprawl taxes, Impact fees, exactions, split-rate property taxes, tax increment finance, betterment taxes, congestion charges
Economic Instruments – Tradable Allowances (may be economy-wide)	- Emission trading - Emission credits under the Clean Development Mechanism (CDM) - Tradable Green Certificates	- Fuel and vehicle standards	- Tradable certificates for energy efficiency improvements (white certificates)	- Emission trading - Emission credit under CDM - Tradable Green Certificates	- Emission credits under CDM - Compliance schemes outside Kyoto protocol (national schemes) - Voluntary carbon markets	- Urban-scale cap and trade
Economic Instruments – Subsidies	- Fossil fuel subsidy removal - Feed in tariffs (FITs) for renewable energy	- Biofuel subsidies - Vehicle purchase subsidies - Feebates	- Subsidies or tax exemptions for investment in efficient buildings, retrofits and products - Subsidized loans	- Subsidies (e.g., for energy audits) - Fiscal incentives (e.g. for fuel switching)	- Credit lines for low-carbon agriculture, sustainable forestry.	- Special Improvement or Redevelopment Districts
Regulatory Approaches	- Efficiency or environmental performance standards - Renewable Portfolio Standards (RPS) for renewable energy (RE) - Equitable access to electricity grid - Legal status of long term CO_2 storage	- Fuel economy performance standards - Fuel quality standards - GHG emission performance standards - Regulatory restrictions to encourage modal shifts (road to rail) - Restriction on use of vehicles in certain areas - Environmental capacity constraints on airports - Urban planning and zoning restrictions	- Building codes and standards - Equipment and appliance standards - Mandates for energy retailers to assist customers invest in energy efficiency	- Energy efficiency standards for equipment - Energy management systems (also voluntary) - Voluntary agreements (where bound by regulation) - Labelling and public procurement regulations	- National policies to support REDD+ including monitoring, reporting and verification - Forest laws to reduce deforestation - Air and water pollution control GHG precursors - Land-use planning and governance	- Mixed use zoning - Development restrictions - Affordable housing mandates - Site access controls - Transfer development rights - Design codes - Building codes - Street codes - Design standards
Information Programmes		- Fuel labelling - Vehicle efficiency labelling	- Energy audits - Labelling programmes - Energy advice programmes	- Energy audits - Benchmarking - Brokerage for industrial cooperation	- Certification schemes for sustainable forest practices - Information policies to support REDD+ including monitoring, reporting and	-

Policy Instruments	Energy	Transport	Buildings	Industry	AFOLU	Human Settlements and Infrastructure
					verification	
Government Provision of Public Goods or Services	- Research and development - Infrastructure expansion (district heating/cooling or common carrier)	- Investment in transit and human powered transport - Investment in alternative fuel infrastructure - Low-emission vehicle procurement	- Public procurement of efficient buildings and appliances	- Training and education - Brokerage for industrial cooperation	- Protection of national, state, and local forests. - Investment in improvement and diffusion of innovative technologies in agriculture and forestry	- Provision of utility infrastructure, such as electricity distribution, district heating/cooling and wastewater connections, etc. - Park improvements - Trail improvements - Urban rail
Voluntary Actions			- Labelling programmes for efficient buildings - Product eco-labelling	- Voluntary agreements on energy targets, adoption of energy management systems, or resource efficiency	- Promotion of sustainability by developing standards and educational campaigns	

The reduction of subsidies for GHG-related activities in various sectors can achieve emission reductions, depending on the social and economic context (*high confidence*). While subsidies can affect emissions in many sectors, most of the recent literature has focused on subsidies for fossil fuels. Since AR4 a small but growing literature based on economy-wide models has projected that complete removal of subsidies to fossil fuels in all countries could result in reductions in global aggregate emissions by mid-century (*medium evidence, medium agreement).* Studies vary in methodology, the type and definition of subsidies and the time frame for phase out considered. In particular, the studies assess the impacts of complete removal of all fossil fuel subsides without seeking to assess which subsidies are wasteful and inefficient, keeping in mind national circumstances. *{WGIII SPM}*

Regulatory approaches and information measures are widely used and are often environmentally effective *(medium evidence, medium agreement)*. Examples of regulatory approaches include energy efficiency standards; examples of information programs include labelling programs that can help consumers make better-informed decisions. *{WGIII SPM}*

Mitigation policy could devalue fossil fuel assets and reduce revenues for fossil fuel exporters, but differences between regions and fuels exist (*high confidence*). Most mitigation scenarios are associated with reduced revenues from coal and oil trade for major exporters. The effect on natural gas export revenues is more uncertain. The availability of CCS would reduce the adverse effect of mitigation on the value of fossil fuel assets (*medium confidence*). *{WGIII SPM.5.1}*

Interactions between or among mitigation policies may be synergistic or may have no additive effect on reducing emissions (*medium evidence, high agreement*). For instance, a carbon tax can have an additive environmental effect to policies such as subsidies for the supply of RE. By contrast, if a cap and trade system has a sufficiently stringent cap to affect emission-related decisions, then other policies have no further impact on reducing emissions (although they may affect costs and possibly the viability of more stringent future targets) (*medium evidence, high agreement*). In either case, additional policies may be needed to address market failures relating to innovation and technology diffusion. *{WGIII SPM.5.1}*

Sub-national climate policies are increasingly prevalent, both in countries with national policies and in those without. These policies include state and provincial climate plans combining market, regulatory and information instruments, and sub-national cap-and-trade systems. In addition, transnational cooperation has arisen among sub-national actors, notably among institutional investors, NGOs seeking to govern carbon offset markets, and networks of cities seeking to collaborate in generating low-carbon urban development. *{WGIII SPM.5.1, 13.5.2, 15.2.4, 15.8}*

Some mitigation policies raise the prices for some energy services and could hamper the ability of societies to expand access to modern energy services to underserved populations (*low confidence*). These potential adverse side-effects can be avoided with the adoption of complementary policies such as income tax rebates or other benefit transfer mechanisms (*medium confidence*). The costs of achieving nearly universal access to electricity and clean fuels for cooking and heating are projected to be between USD 72 to 95 billion per year until 2030 with minimal effects on GHG emissions (*limited evidence, medium agreement*) and multiple benefits in health and air pollutant reduction (*high confidence*). *{WGIII SPM.5.1}*

4.4.3 Technology development and transfer

Technology policy complements other mitigation policies, but worldwide investment in research in support of GHG mitigation is small relative to overall public research spending *(high confidence)*. Technology policy includes technology-push (e.g. publicly-funded R&D) and demand-pull (e.g. governmental procurement programs). Such policies address a pervasive market failure because, in the absence of government policy such as patent protection, the invention of new technologies and practices from R&D efforts has aspects of a public good and thus tends to be under-provided by market forces alone. Technology support policies have promoted substantial innovation and diffusion of new technologies, but the cost-effectiveness of such policies is often difficult to assess. Technology policy can increase incentives for participation and compliance with international cooperative efforts, particularly in the long run. *{WGIII SPM.5.1, 2.6.5, 3.11, 13.9, 13.12, 15.6.5}*

Many adaptation efforts critically rely on development and diffusion of technologies and management practices, but their effective use depends on an appropriate institutional, regulatory, social and cultural context *(high confidence)*. Adaptation technologies are often familiar and already applied elsewhere. However, the success of technology transfer may involve not only the provision of finance and information, but also strengthening of policy and regulatory environments, and capacities to absorb, employ and improve technologies appropriate to local circumstances. *{WGII 15.4}*

4.4.4 Investment and Finance

Substantial reductions in emissions would require large changes in investment patterns (*high agreement, robust evidence*). Over the next two decades (2010-2029), for mitigation scenarios that stabilize concentrations within the range of approximately 430-530 ppm CO_2eq by 2100, annual investments in conventional fossil fuel technologies associated with the electricity supply sector is projected to decline while annual investment in low carbon electricity supply and energy efficiency in key sectors is projected to rise by several hundred billion dollars per year. Global total annual investment in the energy system is presently about USD 1,200 billion. This number includes only energy supply of electricity and heat and respective upstream and downstream activities. Energy efficiency investment or underlying sector investment is not included (Figure 4.4). *{WGIII SPM.5.1, 16.2}*

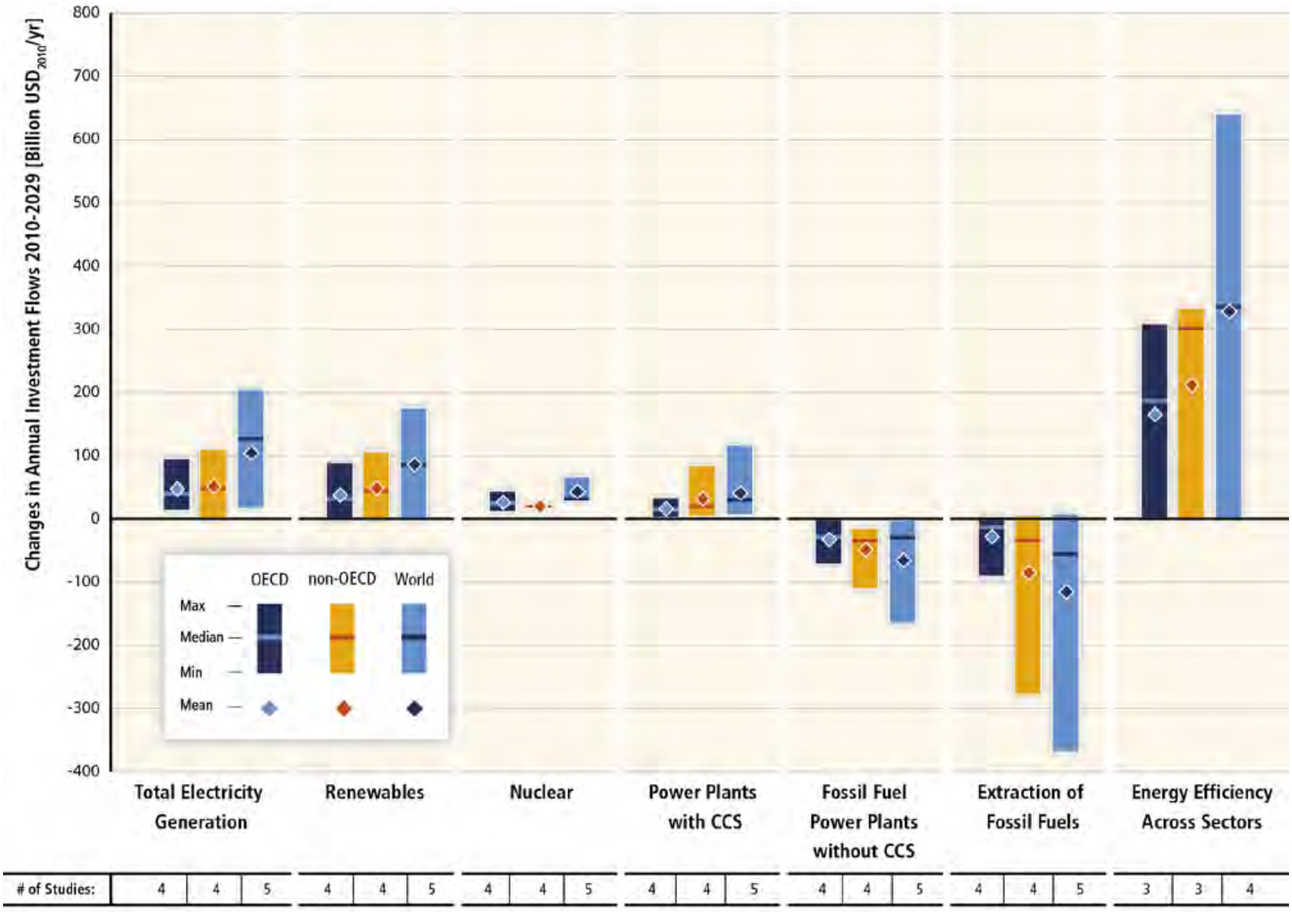


Figure 4.4: Change in annual investment flows from the average baseline level over the next two decades (2010 to 2029) for mitigation scenarios that stabilize concentrations within the range of approximately 430-530 ppm CO_2eq by 2100. Total electricity generation (leftmost column) is the sum of renewable and nuclear energy, power plants with CCS, and fossil-fuel power plants without CCS. The vertical bars indicate the range between the minimum and maximum estimate; the horizontal bar indicates the median. The numbers in the bottom row show the total number of studies in the literature used in the assessment. Individual technologies shown are found to be used in different model scenarios in either a complementary or a synergistic way, depending largely on technology-specific assumptions and the timing and ambition level of the phase-in of global climate policies. *{WGIII Figure SPM 9}*

There is no widely agreed definition of what constitutes climate finance, but estimates of the financial flows associated with climate change mitigation and adaptation are available. Published assessments of all current annual financial flows whose expected effect is to reduce net GHG emissions and / or to enhance resilience to climate change and climate variability show USD 343-385 billion per year globally (medium confidence). Out of this, total public climate finance that flowed to developing countries is estimated to be between USD 35 and 49 billion/yr in 2011 and 2012 (*medium confidence*). Estimates of international private climate finance flowing to developing countries range from USD 10 to 72 billion/yr including foreign direct investment as equity and loans in the range of USD 10 to 37 billion/yr over the period of 2008-2011 (*medium confidence*). *{WGIII SPM.5.1}*

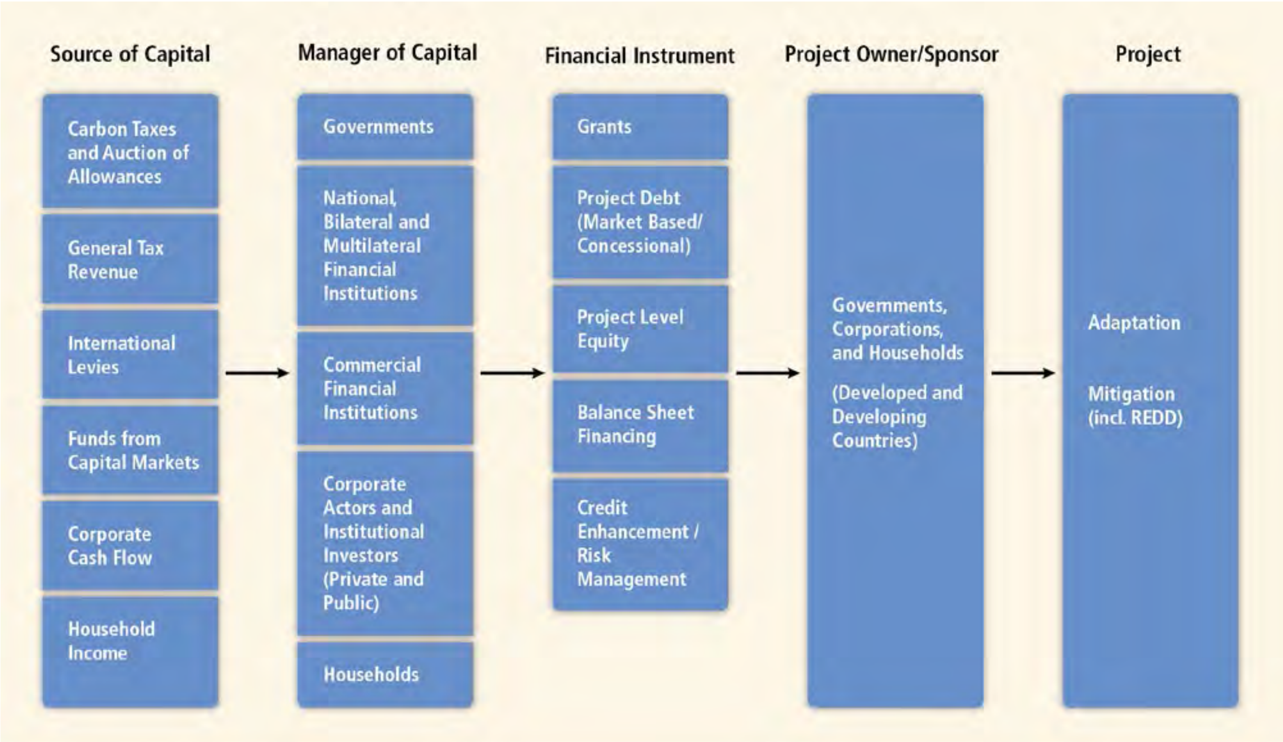


Figure 4.5: Overview of climate finance flows. Note: Capital should be understood to include all relevant financial flows. The size of the boxes is not related to the magnitude of the financial flow. *{WGIII Figure TS.4.5}*

In many countries, the private sector plays central roles in the processes that lead to emissions as well as to mitigation and adaptation. Within appropriate enabling environments, the private sector, along with the public sector, can play an important role in financing mitigation and adaptation (*medium evidence, high agreement*). The share of total mitigation finance from the private sector, acknowledging data limitations, is estimated to be on average between two-thirds and three-fourths on the global level (2010-2012) (*limited evidence, medium agreement*). In many countries, public finance interventions by governments and international development banks encourage climate investments by the private sector and provide finance where private sector investment is limited. The quality of a country's enabling environment includes the effectiveness of its institutions, regulations and guidelines regarding the private sector, security of property rights, credibility of policies and other factors that have a substantial impact on whether private firms invest in new technologies and infrastructures. Dedicated policy instruments and financial arrangements, for example, credit insurance, feed-in tariffs, concessional finance or rebates provide an incentive for mitigation investment by improving the return adjusted for the risk for private actors. Public-private risk reduction initiatives (such as in the context of insurance systems) and economic diversification are examples of adaptation action enabling and relying on private sector participation. *{WGII SPM.C-1; WGIII SPM.5.1}*

Limited evidence indicates a gap between global adaptation needs and the funds available for adaptation (*medium confidence*). Financial resources have been slower to become available for adaptation than for mitigation in both developed and developing countries. Potential synergies between international finance for disaster risk management and adaptation to climate change have not yet been fully realized (*high confidence*). There is a need for better assessment of global adaptation costs, funding and investment. Studies estimating the global cost of adaptation are characterized by shortcomings in data, methods and coverage (*high confidence*). *{WGII SPM.C-1, 14.2; SREX SPM}*

4.5 Trade-offs, synergies, and integrated responses

There are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through integrated responses (*high confidence*). Successful implementation relies on relevant tools, appropriate governance structures, and enhanced capacity to respond (*medium confidence*).

A growing evidence base indicates close links between adaptation and mitigation, their co-benefits and adverse side-effects, and recognizes sustainable development as the overarching context for climate policy (see Sections 3.5, 4.1, 4.2 and 4.3). Developing tools to address these linkages is critical to the success of climate policy in the context of sustainable development (see also Sections 4.4 and 3.5). This section presents examples of integrated responses in specific policy arenas, as well as some of the factors that promote or impede policies aimed at multiple objectives.

Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, encompassing connections among human health, water, energy, land use, and biodiversity (*very high confidence*). Mitigation can support the achievement of other societal goals, such as those related to human health, food security, environmental quality, energy access, livelihoods, and sustainable development, although there can also be negative effects. Adaptation measures also have the potential to deliver mitigation co-benefits, and vice versa, and support other societal goals, though trade-offs can also arise. *{WGII SPM.C-2, 9.3-4, 8.4, 11.9, Box CC-WE; WGIII Tables TS.3-TS.7}*

Integration of adaptation and mitigation into planning and decision-making can create synergies with sustainable development (*high confidence*). Synergies and trade-offs among mitigation and adaptation policies and policies advancing other societal goals can be substantial, although sometimes difficult to quantify especially in welfare terms (see also Section 3.5). A multi-objective approach to policy-making can help manage these synergies and trade-offs. Policies advancing multiple goals may also attract greater support. *{WGII SPM.C-2, 20.3; WGIII 1.2.1, 3.6.3, 4.3, 4.6, 4.8, 6.6.1}*

Effective integrated responses depend on appropriate tools and governance structures, as well as adequate capacity (*medium confidence*). Managing trade-offs and synergies is challenging and requires tools to help understand interactions and support decision-making at local and regional scales. Integrated responses also depend on governance that enables coordination across scales and sectors, supported by appropriate institutions. Developing and implementing appropriate tools and governance structures often requires upgrading the human and institutional capacity to design and deploy integrated responses. *{WGII 2.2, 2.4, 15.4, 15.5, 16.3, Table 14-1, Table 16-1; WGIII TS.1, TS.3, 15.2}*

An integrated approach to energy planning and implementation that explicitly assesses the potential for co-benefits and the presence of adverse side-effects can capture complementarities across multiple climate, social and environmental objectives (*medium confidence*). There are strong interactive effects across various energy policy objectives, such as energy security, air quality, health and energy access (see Figure 3.5) and between a range of social and environmental objectives and climate mitigation objectives (see Table 4.5). An integrated approach can be assisted by tools such as cost-benefit analysis, cost-effectiveness analysis, multi-criteria analysis and expected utility theory. It also requires appropriate coordinating institutions. *{WGIII Figure SPM.6, TS.1, TS.3}*

Explicit consideration of interactions among water use, food and fibre production, energy generation, and carbon sequestration plays an important role in supporting effective decisions for climate resilient pathways (*medium evidence, high agreement*). Both biofuel-based power generation and large-scale afforestation designed to mitigate climate change can reduce catchment run-off, which may conflict with alternative water uses for food production, human consumption, or the maintenance of ecosystem function and services (see also Box 3.4). Conversely, irrigation can increase the climate resilience of food and fibre production but reduces water availability for other uses. *{WGII Box CC-WE}*

An integrated response to urbanization provides substantial opportunities for enhanced resilience, reduced emissions, and more sustainable development (*medium confidence*). Urban areas account for more than half of global primary energy use and energy-related CO_2 emissions (*high agreement, medium* *evidence*), and contain a high proportion of the population and economic activities at risk from climate change. In rapidly growing and urbanizing regions, mitigation strategies based on spatial planning and efficient infrastructure supply can avoid the lock-in of high emission patterns. Mixed-use zoning, transport-oriented development, increased density, and co-located jobs and homes can reduce direct and indirect energy use across sectors. Compact development of urban spaces and intelligent densification can preserve land carbon stocks and land for agriculture and bioenergy. Reduced energy and water consumption in urban areas through greening cities and recycling water are examples of mitigation actions with adaptation benefits. Building resilient infrastructure systems can reduce vulnerability of urban settlements and cities to coastal flooding, sea level rise and other climate-induced stresses. *{WGII SPM.B-2, TS; WGIII SPM.4.2.5, TS.3}*

Box: Information relevant to Article 2 of the UNFCCC

Article 2 states the objective of the Convention: *''…stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."* At their 16th Conference, in Cancún (2010), the Parties to the UNFCCC agreed that "*deep cuts in global greenhouse gas emissions are required… with a view to reducing global greenhouse gas emissions, so as to hold the increase in global average temperature below 2°C above pre-industrial levels''* (Decision 1/CP.16). This Box presents the findings of the Synthesis Report that are relevant to Article 2, in a policy-neutral way.

''…dangerous anthropogenic interference with the climate system…''

Human influence on the climate system is clear. Many of the observed changes since the 1950s are unprecedented over decades to millennia. The atmosphere and oceans have warmed, the amounts of snow and ice have diminished, and sea level has risen. Extreme heat and heavy precipitation events have become more frequent. (1.2)

Changes in climate that have already occurred have caused impacts on natural and human systems on all continents and across the oceans. Widespread ecosystem impacts have included changes in the geographic ranges of species and species interactions (*high confidence*) and some unique and threatened ecosystems are already at risk from climate change: Warm-water coral reefs and Arctic ecosystems are experiencing irreversible regime shifts (*medium confidence*). Wheat and maize yields have been negatively affected in many regions and in the global aggregate (*medium confidence*). In many regions, changing precipitation or melting snow and ice have affected water resources (*medium confidence*). (1.4)

Determining whether anthropogenic interference is 'dangerous' involves both risk assessment and value judgments and would be outside the IPCC mandate. However, the IPCC assessments provides a basis for such judgment by determining the magnitude of current and future projected climate change, by assessing risks across contexts and over time, and also by assessing the approaches to valuing and reducing these risks. As climate-related impacts are expected to disproportionately affect poor populations, conditions which might characterize dangerous anthropogenic interference could affect some communities and locations well before they are experienced in other parts of the globe. Depending on value judgements and specific circumstances, currently observed impacts might already be considered dangerous in specific sectors and locations, or globally (1.5, 3.1). *{WGII Box TS.5, WGIII Box TS.1}*

Climate change entails diverse risks and uncertainties related to both impacts and human responses (Introduction Box 1.1). Risk of impacts in a changing climate emerges from the overlap of hazard, vulnerability, and exposure. Vulnerability and exposure vary per location, setting, and degree of inequality and marginalization. Risks of impacts pose particular challenges for the least developed countries and most vulnerable communities (Topic 3.4). *{WGI SPM, WGII SPM}.* The overall risk of climate change impacts, including low-probability outcomes with large consequences, can be reduced by limiting the rate and magnitude of climate change. *{WG II SPM}* Assessment of the widest possible range of impacts, including low-probability outcomes with large consequences, is central to evaluating human responses to climate change and appreciating the benefits of mitigation. Mitigation actions also entail risks arising from uncertainties in, e.g., the rate of economic growth and the evolution of technology. *{WG III SPM}* Risks related to mitigation can be large-scale, but do not involve the same possibility of severe, pervasive and challenging impacts and long-term commitment as the risks related to climate change. (3.2)

Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. *{WGI SPM}* Increasing magnitudes of warming increase the likelihood of severe, pervasive, and irreversible impacts. Five overarching Reasons for Concern {RFCs; right panel of Figure Box Art. 2 and Box 2.3} are used to categorize the diversity of risks of climate change impacts in relation to different levels of climate change (left panel of Figure Box Art. 2). These risks illustrate the implications of warming and of adaptation limits for people, economies, and ecosystems in consonance with Article 2:

- ***Future climate change commitments and irreversible changes:*** A large fraction of anthropogenic climate change is irreversible on a multi-century to millennial time scale, because 15% to 40% of emitted CO_2 will effectively remain in the atmosphere longer than 1,000 years except in the case of a large net removal of CO_2 from the atmosphere over a sustained period. Sea level will continue to rise for many centuries beyond 2100. Global mean warming larger than some threshold, estimated between 1 and 4 °C, would lead to near-complete loss of the Greenland ice sheet over a millennium or more, contributing up to 7 m to global mean sea level rise (RFC5) *{WGI SPM}*.

- ***Future ecosystem impacts:*** Many species will be unable to track suitable climates under medium- and high-range rates of climate change (scenarios higher than RCP 2.6), risking extinction in part or all of their ranges (*medium confidence*, see Topic 2.1). Many species and systems with limited adaptive capacity are subject to very high risks with a warming of about 2.5 °C. For medium to high emission scenarios, ocean acidification poses substantial risks to marine ecosystems, together with simultaneous warming, decreasing oxygen levels and other drivers. Risk of extensive biodiversity loss, with associated loss of ecosystem goods and services, becomes high around 3.5 °C warming. (RFC 1, 4).

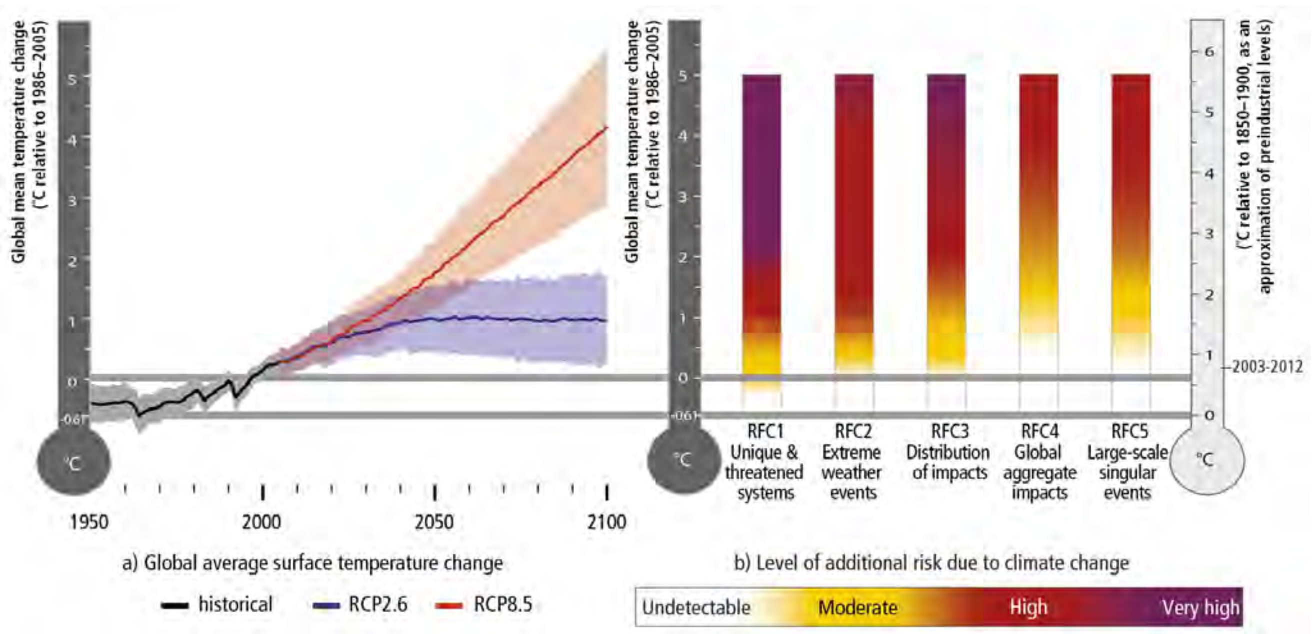


Figure Box Art. 2:. **Risk associated with the Reasons for Concern (RFCs) as a function of the level of climate change.** Panel (a): CMIP5 multi-model simulated time series from 1950 to 2100 for the change in global annual mean surface temperature relative to the 1986–2005 period. The blue and the red colours correspond to the lowest (RCP2.6) and highest (RCP8.5) forcing scenarios. The right panel (b): shows the five RFCs: **RFC1:** risks to **unique and threatened systems,** including ecosystems and cultures; **RFC2:** risks associated with **extreme weather events,** such as heatwaves, extreme precipitation, and coastal flooding, which can interfere with development; **RFC3:** risks associated with the **distribution of impacts,** because risks are unevenly distributed and generally greater for disadvantaged people and communities in countries of all levels of development; **RFC4:** risks of g**lobal aggregate impacts** to both biodiversity and the overall global economy; **RFC5:** risks associated with **large-scale singular events**, such as abrupt and irreversible changes in Arctic ecosystems or ice sheets. Colour shading indicates additional risk due to climate change when a certain temperature level is reached and then sustained or exceeded. Undetectable risk (white) indicates no associated impacts are detectable and attributable to climate change. Moderate risk (yellow) indicates that associated impacts are both detectable and attributable to climate change with at least *medium confidence,* and high risk (red) indicates severe and widespread impacts. Purple shows that very high risk is indicated by all specific criteria for key risks, e.g., magnitude, persistence, irreversibility and timing (Topic 2, Box 2.3).

- ***Future impacts related to food production:*** For the major crops (wheat, rice, and maize) in tropical and temperate regions, climate change without adaptation is projected to negatively impact aggregate production at local temperature increases of about 2.5 °C or more, although individual locations may benefit (*medium confidence*). Global temperature increases of about 4.5 °C or more, combined with increasing food demand, would pose large risks to food security, both globally and regionally. Risks to food security are generally greater in low-latitude areas. {WGII SPM}. Climate change is projected to significantly reduce renewable surface water and groundwater resources in most dry subtropical regions (RFC 2, 3, 4) (2.3).

- ***Future economic impacts:*** Throughout the 21st century, climate-change impacts, especially without additional mitigation, are projected to slow economic growth, make poverty reduction more difficult, prolong existing poverty traps and create new ones. Climate-related hazards exacerbate other stressors, often with negative outcomes for livelihoods, especially for people living in poverty. {WGII SPM A-1, B-}. Aggregate economic losses accelerate with increasing temperature. Differences between and within countries are large. With a global mean temperature increase of 4 °C or more, normal human activities could be compromised in some areas for parts of the year (RFC 3, 4) (3.4). *{WGII B-2, WGII TS}*

''…Such a level should be achieved within a time frame sufficient to…''

Scenario analyses show that rapid and deep emission reductions are necessary in order to achieve the goal of holding the warming to 2 °C or less. Cumulative CO_2 emissions largely determine global mean surface warming by the late 21st century and beyond. In order to hold warming *likely* below 2 °C, the remaining 21[st] century emissions need to be constrained to around 1000 $GtCO_2$ (scenario range 750–1400 $GtCO_2$ given different scenarios of non-CO_2 climate drivers), which is about half the amount already emitted over the past 250 years. At current rates, this remaining budget will be exhausted in the next 20 to 30 years. Mitigation scenarios limiting temperature increases to 2 °C show GHG net emission reductions of 40% to 70% between 2010 and 2050, with emissions falling towards zero or below by 2100 (3.4).

Scenarios that are *likely* to keep global mean temperature change below 2 °C, or even 3 °C involve large-scale changes in energy systems and potentially also in land use, over the coming decades. This requires a rapid upscaling of zero- and low-carbon energy supply and potentially large-scale changes in land use and deployment of negative emissions technologies during the second half of the 21st century. Scenarios that are *likely* to stabilize temperatures at higher levels, such as 3 °C, include similar changes, but on a slower timescale (3.4).

''…and to enable economic development to proceed in a sustainable manner…''

Climate change risk estimates and those on the costs and benefits of mitigation cannot be directly compared or used to identify a single best climate change goal or a best combination of mitigation, adaptation, residual climate impacts, and their associated benefits and risks. (3.2, 3.4)
Cost estimates on impacts are incomplete and depend on a large number of assumptions. Similarly, estimates on the aggregate economic costs of mitigation vary widely, depending on methodologies and assumptions. However, economic costs will increase with the stringency of mitigation, particularly if mitigation action is delayed or key technologies are unavailable (2.3, Box 3.1, 3.4). Estimates of global annual economic losses and economic damages, with recognized limitations are provided in topic 2.3.2. Estimates of the aggregate economic costs of mitigation are, however, provided under topic 3.4.

Prospects for climate-resilient pathways for sustainable development are related fundamentally to what the world accomplishes with climate-change mitigation. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if limits to adaptation are exceeded. In some parts of the world, insufficient responses to emerging impacts are already eroding the basis for sustainable development. *{WGII SPM}*