IPCC 5th Assessment Report First Order Draft Synthesis Report

IPCC 5th Assessment Report - Synthesis Report

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CLIMATE CHANGE 2014

SYNTHESIS REPORT

21 April 2014

FIRST ORDER DRAFT FOR GOVERNMENT AND EXPERT REVIEW

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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 (SYR) brings forward the main findings of the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). The SYR, the final document in the AR5 cycle, is based on the three underlying Working Group contributions as well as two Special Reports.

Human interference with the climate system is occurring, and climate change poses risks for human and natural systems. This report assesses all aspects of climate change and provides information to support decision making in this field.

Climate change will alter human and natural systems, and responding to it involves issues of equity, justice, fairness, and value. It is a collective action problem at the global scale.

The challenges presented by climate change involve many uncertainties. Because there is a wide range of possible outcomes, responding to climate change involves managing risks. Despite the challenges, there are many opportunities for reducing the risks related to climate change and for building on synergies with other social, economic, and development objectives.

1. Observed Changes

Anthropogenic emissions of greenhouse gases have continued to rise since 1970 with larger absolute increases over the last decade. Human influence on the climate system is clear, and is estimated to have been the dominant cause of the warming observed since 1950. Changing climate has been linked to impacts on natural and human systems on all continents and across the oceans.

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 SPM.1*)*.
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 over the period 1880 to 2012, when 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[1], based on the single longest dataset available . 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, 1983–2012 was *likely* the warmest 30-year period of the last 1400 years (*medium confidence*). *{1.2}*

[1] Ranges in square brackets indicate a 90% uncertainty interval unless otherwise stated.

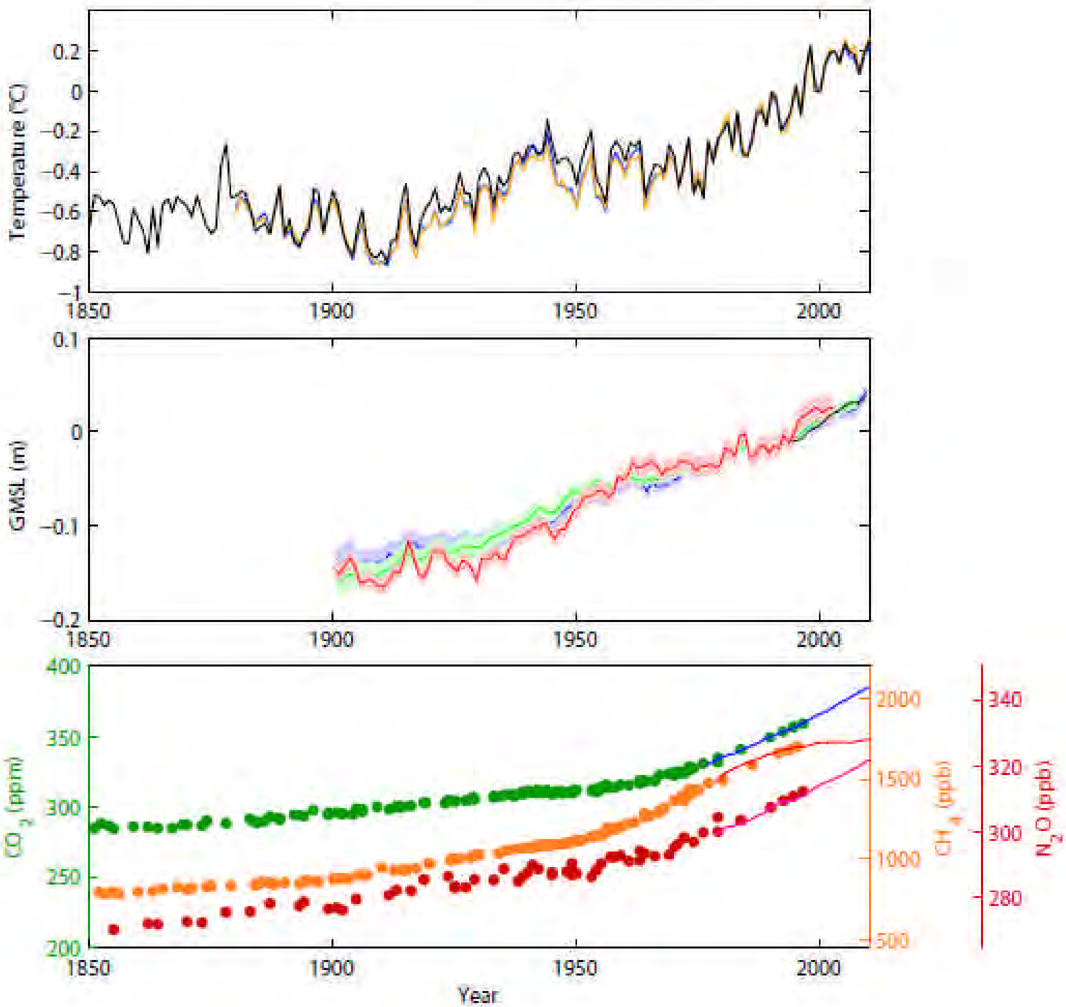


Figure SPM.1: observed indicators of a changing global climate. Top) Observed annually and globally averaged combined land and ocean surface temperature anomalies, middle) global mean sea level change; bottom: Atmospheric concentrations of greenhouse gases carbon dioxide (CO_2) determined from ice core data (green) and from direct atmospheric measurements (blue); methane and Nitrous Oxide (Figure 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. 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*). 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, providing indirect evidence for changes in evaporation and precipitation over ocean. *{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*) (see Figure 1.1). There is *high confidence* that permafrost temperatures have increased in most regions of the Northern Hemisphere since the early 1980s in response to increased air temperature and changing snow cover. *{1.2; 1.4.2}*

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*). Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21]m. *{Figure 1.1, 1.2}*

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. *{1.4}*
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 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*). 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*). 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*).

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 high sea level events, and some of these changes have been linked to human influences . 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**.** There has been increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming (*medium confidence*).*{1.5}*

The character and severity of impacts from climate extremes depends not only on the extremes themselves but also on exposure and vulnerability and consequently so do their associated risks. 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. *{1.5}*

Adaptation experience is accumulating across regions in the public and private sector and within communities; and adaptation is becoming embedded in some planning processes, with more limited implementation of responses. *{1.6}*

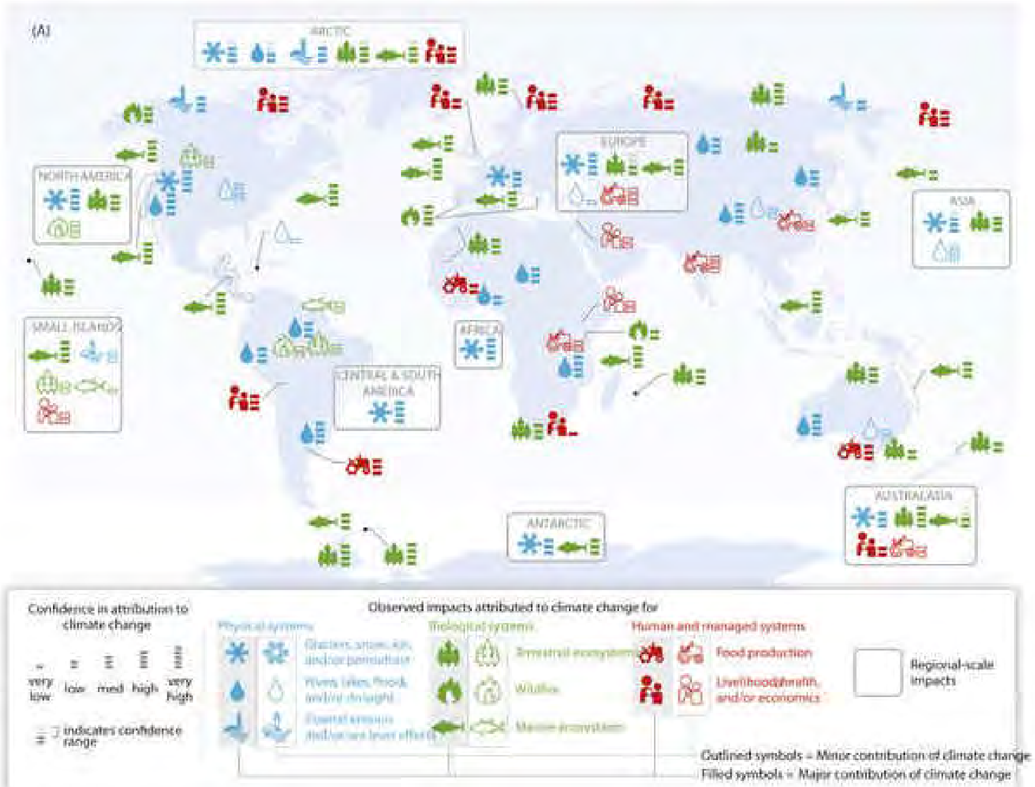


Figure SPM.2: Global patterns of observed climate change impacts in recent decades attributed to climate change, based on studies since the AR4. For categories of attributed impacts, symbols indicate affected systems and sectors, the relative contribution of climate change (major or minor) to the observed change, and confidence in attribution. (Figure 1.8)

Atmospheric concentrations of the well mixed greenhouse gases CO_2, CH_4 and N_2O have all shown large increases since the preindustrial era (Figure SPM.1). Despite multinational institutions and national policies aimed at mitigating emissions, anthropogenic greenhouse gas emissions have risen more rapidly between 2000-2010 than in the preceding decades, driven mainly by economic and population growth (Figure SPM.3). The largest single driver of current climate change is the cumulative increase of anthropogenic CO_2 emissions. The largest share of anthropogenic CO_2 emissions is emitted by a small number of countries. *{1.3}*

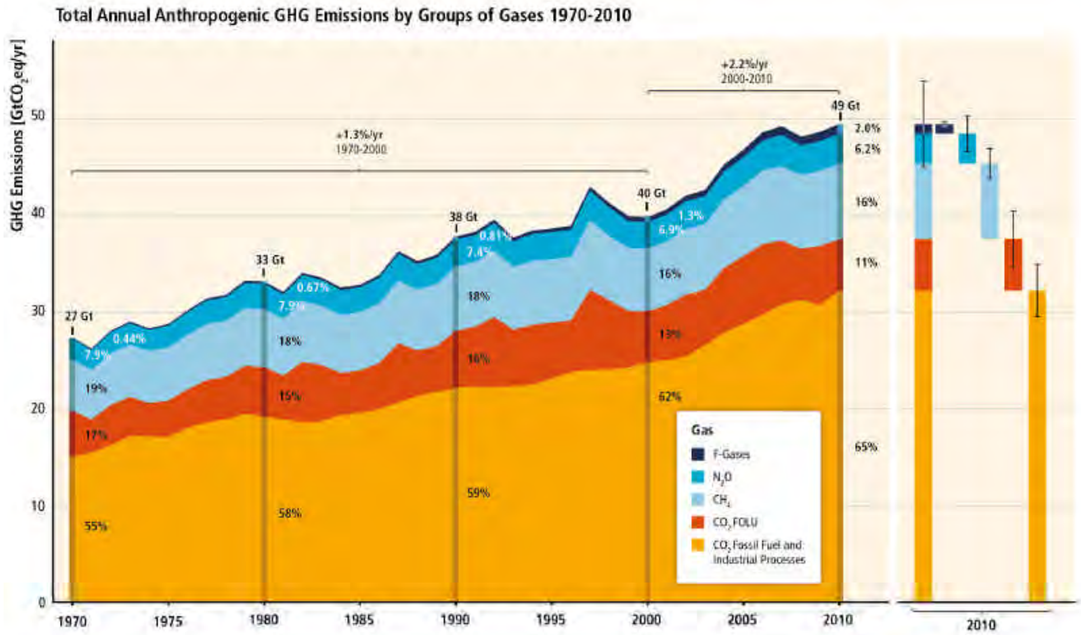


Figure SPM.3: Total annual anthropogenic GHG emissions ($GtCO_2eq/yr$) by groups of gases 1970-2010: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH4); nitrous oxide (N2O); fluorinated gases8 covered under the Kyoto Protocol (F-gases). At 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. Emissions of non-CO_2 gases are converted into CO_2-equivalent emissions based on GWP_{100} from the IPCC Second Assessment Report. (Figure 1.4)

About half of cumulative anthropogenic CO_2 emissions between 1750 and 2010 have occurred in the last 40 years *(high confidence)*. Anthropogenic CO_2 emissions were 2000 ± 310 $GtCO_2$ to the atmosphere between 1750 and 2011.About half 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 the natural carbon cycle reservoirs. Total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute decadal increases toward the end of this period (*high confidence*). CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emission increase from1970 to 2010, with a similar percentage contribution for the period 2000–2010 (*high confidence).*

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 in changes in some climate extremes. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century.*{1.4}*

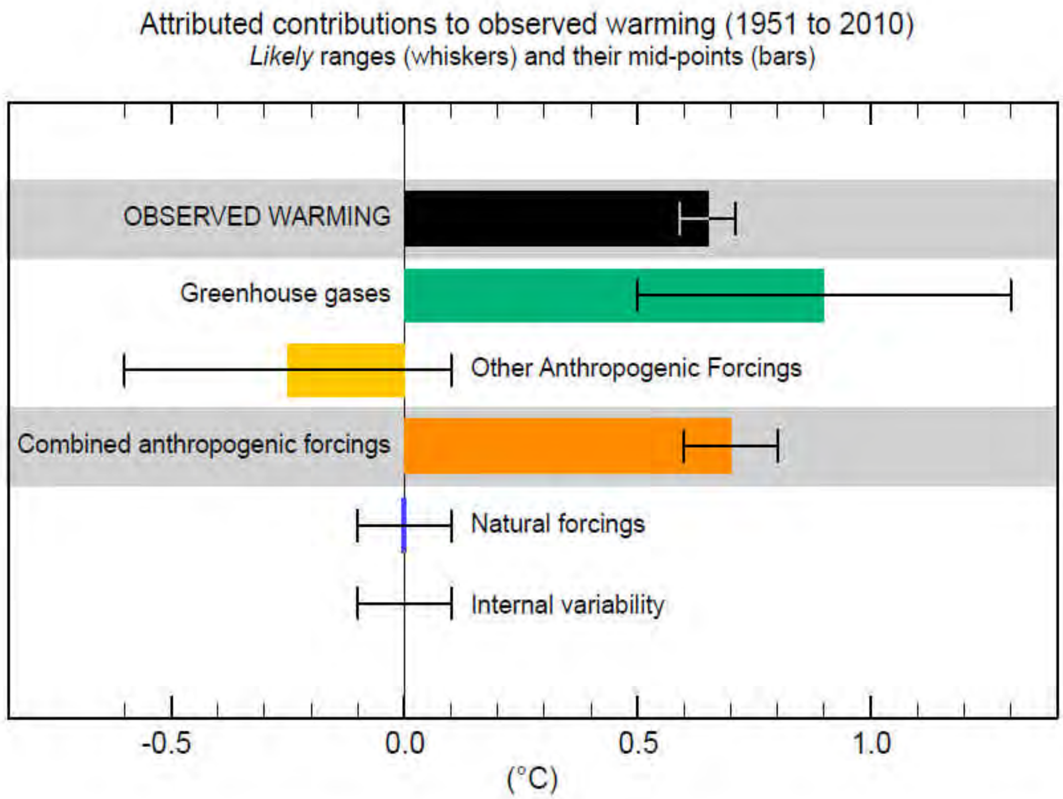


Figure SPM.4: Assessed *likely* ranges (whiskers) and their mid-points (bars) for attributable warming trends over the 1951–2010 period due to well-mixed greenhouse gases, other anthropogenic forcings, combined anthropogenic forcings, natural forcings, and internal climate variability. Observations are shown in black with the 5–95% uncertainty range due to observational uncertainty in this record. These attributed ranges (colours) are based on estimating the contribution to observed warming by fingerprints for external forcing derived from climate model simulations. (Figure SYR 1.2)

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 SPM.4). Over every continental region except Antarctica, anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century. It is *likely* that anthropogenic influences have 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. It is *very likely* that human influences have contributed to Arctic sea ice loss since 1979 and that they have made a substantial contribution to increases in global upper ocean heat content (0–700 m) observed since the 1970s. *{1.4}*

2. Future climate changes, risks and impacts

Continued emissions of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system. Limiting climate change and associated risks to people and ecosystems will require substantial and sustained reductions of greenhouse gases emissions. *{2}*.

Anthropogenic greenhouse gas emissions are mainly determined by population size, economic activity, energy use, land-use patterns, technology change and climate policy *{2.1}*. Livelihoods, lifestyles and behaviors also have significant influences on GHG emissions trajectories. *{4.2}*

The "Representative Concentration Pathways", or RCPs, describe the 21st century evolution of atmospheric greenhouse gas concentrations, land-use changes and emissions of air pollutants under four very different futures *{2.1}*. RCP8.5 represents a high emission scenario with no climate mitigation policies; RCP6.0

represents many middle-of-the-road scenarios with very modest or no climate policies; RCP4.5 represents a medium mitigation scenario; while RCP2.6 represents more aggressive mitigation scenarios which aim to keep global warming below 2°C above pre-industrial temperatures (Figure SPM.5).

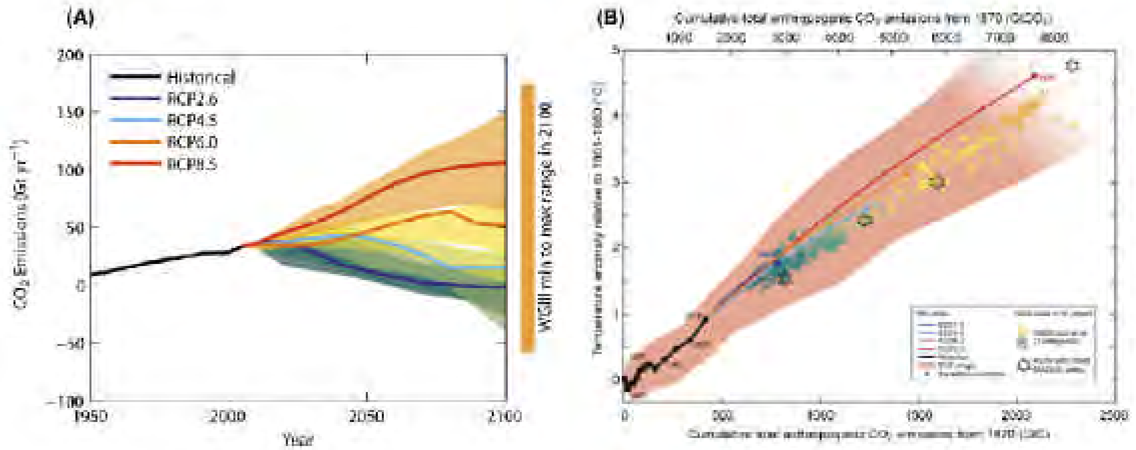


Figure SPM. 5 (a): CO_2 emission and the resulting radiative forcing levels included in the RCPs (lines) and the associated scenarios categories used in WGIII (colored areas) **(b)** Global mean surface temperature increase as a function of cumulative total global CO_2 emissions from various lines of evidence. Multi-model results from a hierarchy of climate-carbon cycle models for each RCP until 2100 are shown (colored lines). Model results over the historical period (1860 to 2010) are indicated in black. The colored plume illustrates the multi-model spread over the four RCP scenarios and fades with the decreasing number of available models in RCP8.5. Decadal averages are labelled using dots with the label referring to the year ending the decade. Triangles correspond to estimates for the year 2100 under 962 scenarios evaluated by WGIII, divided into the 7 categories described in Section 3.2. The four large star symbols are estimates for the 4 RCPs by the MAGICC6 simple model, with the set up used for the WGIII scenarios estimates. Temperature values are always given relative to the 1861-1880 period, and emissions are cumulative since 1870. (Figure 2.1, Figure 2.4)

Cumulative emissions of CO_2 are the dominant factor determining the global mean surface warming by the late 21st century ***{2.4.5}***. There is a strong and consistent relationship between projected 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 2.4). Limiting the warming to less than 2°C above pre-industrial with a probability of 50% or >66% require cumulative CO_2 emissions since 1870 to stay below about 3000 and about 2900 $GtCO_2$, respectively, when accounting for non-CO_2 forcings . An amount of 1890 $GtCO_2$ (1630-2150) was emitted by 2011. Meeting the 2°C goal with a >66% probability will require GHG emissions reductions of roughly 40% to 70% in 2050 relative to 2010 through fundamental changes in energy systems and potentially land use and agriculture, and emission levels near zero $GtCO_2$eq or below in 2100 *{Box Art. 2}*.

Over the 21st century projected warming will affect the atmosphere, ocean and the cryosphere. The global mean surface air temperature change for the period 2016-2035 will *likely* be in the range 0.3˚C-0.7˚C (*medium confidence*). By mid-21st century, the rate of global warming begins to be more strongly dependent on the emissions scenario. *{2.4.1}*

Global-mean surface air temperature change for 2081–2100 will *likely* be 0.3°C–1.7°C under RCP2.6 to 2.6°C–4.8°C under RCP8.5 (Table 2.1).Global surface air temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850-1900 for all RCP scenarios except RCP2.6. It is *likely* to exceed 2°C for RCP6.0 and RCP8.5, *more likely than not* to exceed 2°C for RCP4.5, but *unlikely* to exceed 2°C for RCP2.6 (*medium confidence*). *{2.4.1}*

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 the global mean temperature increases. It is *very likely* that heat waves will tend to occur more often and last longer. Occasional cold winter extremes will continue to occur*{2.4.1}*.

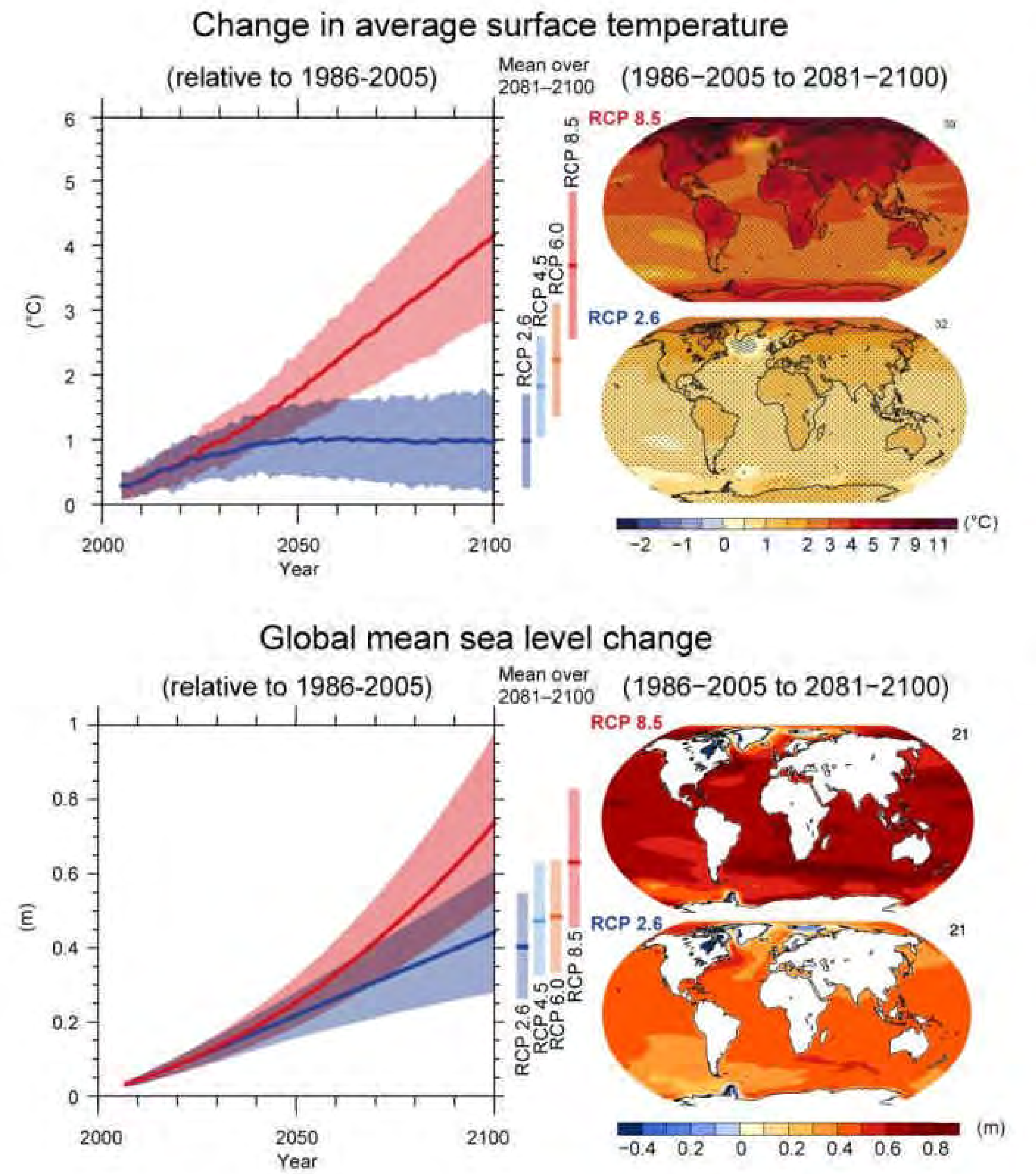


Figure SPM.6: CMIP5 multi-model simulated time series from 2005 to 2100 for change in global annual mean surface temperature (top left) and global mean sea level rise (bottom left). Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). The mean and associated uncertainties averaged over 2081-2100 are given for all RCP scenarios as colored vertical bars at the right end side of each panel. CMIP5 multi-model mean projections 2081– 2100 under the RCP2.6 (top map) and RCP8.5 (bottom map) scenarios for annual mean surface temperature change (top right panel) and annual mean average sea level (bottom right panel). The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Hatching shows regions where the multi-model mean is small compared to internal variability (i.e., less than one standard deviation of internal variability in 20-year means). Stippling shows regions where the multi-model mean is large compared to internal variability (i.e., greater than two standard deviations of internal variability in 20-year means) and where 90% of models agree on the sign of change see WGI, Box 12.1). All changes are relative to 1986–2005. (Figure 2.2, Figure 2.3)

Year-round reductions in Arctic sea ice are projected for all RCP scenarios. Based on an assessment of the subset of models that most closely reproduce the observations, a nearly ice-free Arctic Ocean[2] in September before mid-century is likely for RCP8.5 (*medium confidence*). In the Antarctic, a decrease in sea ice extent and volume is projected with low confidence. *{2.4.3}*

It is virtually certain that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases. *{2.4.3}*

The global glacier volume, excluding glaciers on the periphery of Antarctica, is projected to decrease by 15 to 55% for RCP2.6, and by 35 to 85% for RCP8.5 (*medium confidence*). *{2.4.3}*

Global mean sea level will continue to rise during the 21st century and beyond. Global mean sea level rise will likely be in the ranges of 0.26 to 0.55 m for RCP2.6 to 0.45 to 0.82 m for RCP8.5. 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. About 70% of the coastlines worldwide are projected to experience sea level change within 20% of the global mean sea level change .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*). *{2.4.3, 2.5.1}*

Climate change will create new and amplify existing risks for natural and human systems {2.5}. There is high risk of substantive impacts on terrestrial and aquatic ecosystems as result of climate change, causing mostly negative consequences for biodiversity and ecosystem services (*high confidence*) . Throughout the 21st century, climate change will further challenge food, livelihood and human security and wellbeing, not only in developing countries. To a lesser extent, climate change will reduce some risks and generate benefits. *{2.5, 2.5.1}*

Increasing magnitudes of warming increase the likelihood of severe, pervasive, and irreversible impacts. Some risks of climate change are considerable at 1 or 2°C above preindustrial levels. Global climate change risks are high to very high with global mean temperature increase of 4°C or more above preindustrial levels in all reasons for concern, and include severe and widespread impacts on unique and threatened systems, substantial species extinction, large risks to global and regional food security, and the combination of high temperature and humidity compromising normal human activities, including growing food or working outdoors in some areas for parts of the year (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 multiple tipping points in the earth system or in interlinked human and natural systems increases with rising temperature (*medium confidence*). *{2.5}*

Climate change over the 21st century is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions (*robust evidence*, *high agreement*), intensifying competition for water among sectors (*limited evidence*, *medium agreement*). *{2.5.2}*

For the major crops (wheat, rice, and maize) in tropical and temperature 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*) (Figure SPM.7). *{2.5.2}*

Heat stress, extreme precipitation, sea level rise, inland and coastal flooding, drought, landslides, air pollution, and water scarcity pose risks in urban areas for people, economies, and ecosystems, with risks amplified for those lacking essential infrastructure and services or living in exposed areas (*very high confidence*). *{2.5.2}*

Rural areas will 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*). *{2.5.2}*

[2] when sea ice extent is less than 10^6 km^2 for at least five consecutive years

For most economic sectors, the impacts of changes in population, age structure, income, technology, relative prices, lifestyle, regulation, and governance are projected to be large relative to the impacts of climate change (*medium evidence, high agreement*). *{2.5.2}*

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 be through exacerbating health problems that already exist (*very high confidence*). *{2.5.2}*

Climate change is projected to increase displacement of people (*medium evidence, high agreement*). Many populations that lack the resources for mobility and migration experience higher exposure to extreme weather events, particularly in developing countries with low income. *{2.5.2}*

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*). *{2.5.2}*

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*). *{2.5.2}*

Risks caused by a changing climate depend on the change in climate, but also on the exposure, vulnerability, and ability to adapt of the affected system. Adaptation has the potential to reduce climate change impacts significantly, but its potential differs between sectors and there are constraints and limits to adaptation (Figure SPM.7). ***{2.5, 3.3}***

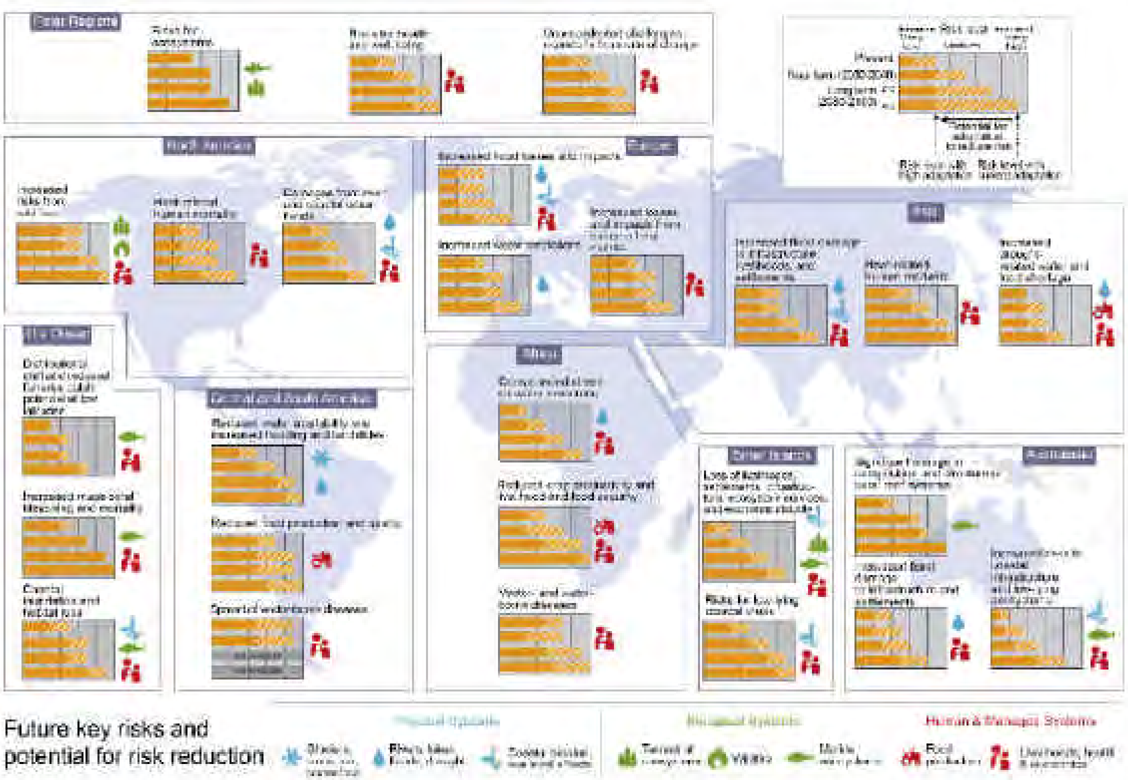


Figure SPM.7: Example of regional key risks for physical, biological, and human and managed systems, and potential for risk reduction through adaptation. Key risks are identified based on assessment of the literature and expert judgment. Each risk is characterized as very low, low, medium, high, or very high. Risk levels are presented at three time frames: present, near-term (2030-2040), and long-term (2080-2100). Near-term indicates that projected levels of global mean temperature do not diverge substantially across emission scenarios. Long-term differentiates between a global mean temperature increase above 2°C and 4°C above pre-industrial levels. For each timeframe, risk levels are estimated for a continuation of current adaptation and for a high adaptation state". *{WGII TS Table 4}*

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 with larger warming and with direct effects of accumulating CO_2 causing ocean acidification . The effects of CO_2 emissions persist for centuries; depending on the scenario, 15-40% of emitted CO_2 will remain in the atmosphere longer than 1,000 years {2.1}. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO_2. *{2.6}*

Some processes such as shifting biomes, re-equilibrating soil carbon, melting ice sheets, warming of the deep ocean and associated sea level rise have intrinsic long timescales which will result in changes detectable hundreds to thousands of years after global surface temperature is stabilized. *{2.6}*

Within this century, magnitudes and rates of climate change associated with medium- to high-emission scenarios (RCP4.5, 6.0, and 8.5) pose high risk of abrupt and irreversible regional-scale change in the composition, structure, and function of terrestrial and freshwater ecosystems, including wetlands (*medium confidence*). Examples that could lead to substantial impact on climate are the boreal-tundra Arctic system (*medium confidence*) and the Amazon forest (*low confidence*). Ocean acidification will affect marine ecosystems for centuries if CO_2 emissions continue (*high confidence*). *{2.6}*

There is little evidence in global climate models of a 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. Sustained mass loss by ice sheets would cause larger sea level rise, and some part of the mass loss might be irreversible. Global mean sea level rise will continue for many centuries beyond 2100 *(virtually certain)*. *{2.6}*

An effectively irreversible reduction in permafrost extent is *virtually certain* with continued rising global temperatures. Carbon accumulated over hundreds to thousands of years in frozen soils could be emitted through decomposition within decades as a result of permafrost thaw. Current permafrost areas are projected to become net emitters of carbon during the 21st century under future warming scenarios. *{2.6}*

3. Transformations and changes in systems

3.1 Mitigation pathways

In the absence of additional mitigation efforts, GHG emissions will continue to grow, and cause a median increase in global mean surface temperature of more than three to almost five degrees Celsius relative to pre-industrial levels by 2100. Deep cuts in GHG emissions to limit warming to 2°C relative to pre-industrial levels remain possible, yet will entail substantial technological, economic, institutional, and behavioural challenges. Similar challenges would have to be faced for less ambitious mitigation, but over a longer period of time.

Baseline scenarios, those without additional mitigation, result in global mean surface temperature increases in 2100 from 3.7 to 4.8°C compared to pre-industrial levels (median values; the range is 2.5°C to 7.8°C when including climate uncertainty) *(high confidence)*. Baseline scenarios (scenarios without explicit additional efforts to constrain emissions) exceed 450 parts per million (ppm) CO_2eq by 2030 and reach CO_2eq concentration levels between 750 and more than 1300 ppm CO_2eq by 2100. This is similar to the range in atmospheric concentration levels between the RCP 6.0 and RCP 8.5 pathways in 2100. *{3.2}*

There are multiple scenarios with a range of technological and behavioral options, with different characteristics and implications for sustainable development, that are consistent with different levels of mitigation. Mitigation scenarios span atmospheric concentration levels in 2100 from 430 ppm CO_2eq to above 720 ppm CO_2eq, which is comparable to the 2100 forcing levels between RCP 2.6 and RCP 6.0. Mitigation scenarios in which it is likely that the temperature change caused by anthropogenic GHG emissions can be kept to less than 2°C relative to pre-industrial levels are characterized by atmospheric concentrations in 2100 of about 450 ppm CO_2eq (*high confidence*). Scenarios that reach about 650 ppm CO_2eq by 2100 are unlikely to limit temperature change to below 2°C relative to pre-industrial levels. Only a limited number of studies have explored scenarios that are *more likely than not* to bring temperature change back to below 1.5 °C by 2100 relative to pre-industrial levels; these scenarios bring atmospheric concentrations to below 430 ppm CO_2eq by 2100. *{3.2}*

Scenarios reaching atmospheric concentration levels of about 450 ppm CO_2eq by 2100 include substantial cuts in anthropogenic GHG emissions by mid-century through large-scale changes in energy systems and potentially land use. (high confidence). Scenarios reaching these concentrations by 2100 include 40% to 70% reductions in GHG emissions by 2050 relative to 2010, and those with more modest reductions are characterized by higher overshoot (>0.4 Wm2) and substantial reliance on CDR technologies. Scenarios reaching these concentrations are also characterized a tripling to nearly a quadrupling of the share of zero- and low-carbon energy supply from renewables, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS), or bioenergy with CCS (BECCS) by the year 2050.They describe a wide range of changes in land use, reflecting different assumptions about the scale of bioenergy production, afforestation, and reduced deforestation. Scenarios reaching higher concentrations include similar changes, but on a slower timescale. On the other hand, scenarios reaching lower concentrations require these changes on a shorter timescale. *{3.2}*

Delaying mitigation efforts beyond those in place today through 2030 is estimated to substantially increase the difficulty of the transition to low longer-term emissions levels and narrow the range of options consistent with maintaining temperature change below 2 C relative to pre-industrial levels (*high confidence*). Cost-effective mitigation scenarios that make it at least as likely as not that temperature change will remain below 2°C relative to pre-industrial levels (2100 concentrations between about 450 and 500 ppm CO_2eq) are typically characterized by annual GHG emissions in 2030 of roughly between 30 GtCO_2eq and 50 GtCO_2eq (Figure SPM.8, left panel). Scenarios with annual GHG emissions above 55 GtCO_2eq in 2030 are characterized by substantially higher rates of emissions reductions from 2030 to 2050 (Figure SPM.8, middle panel); much more rapid scale-up of low-carbon energy over this period (Figure SPM.8, right panel); a larger reliance on CDR technologies in the long term and higher transitional and long term economic impacts (Table SPM.1). *{3.2}*

The Cancun Pledges are not consistent with emission pathways that are characterized by annual GHG emissions in 2030 below 50 GtCO_2eq and are therefore subject to increased mitigation challenges, if temperature increase is maintained below 2°C relative to pre-industrial levels.. Due to these increased mitigation challenges, many models with annual 2030 GHG emissions higher than 55 GtCO_2eq could not produce scenarios reaching atmospheric concentration levels that make it as likely as not that temperature change will remain below 2°C relative to pre-industrial levels. *{3.2}*

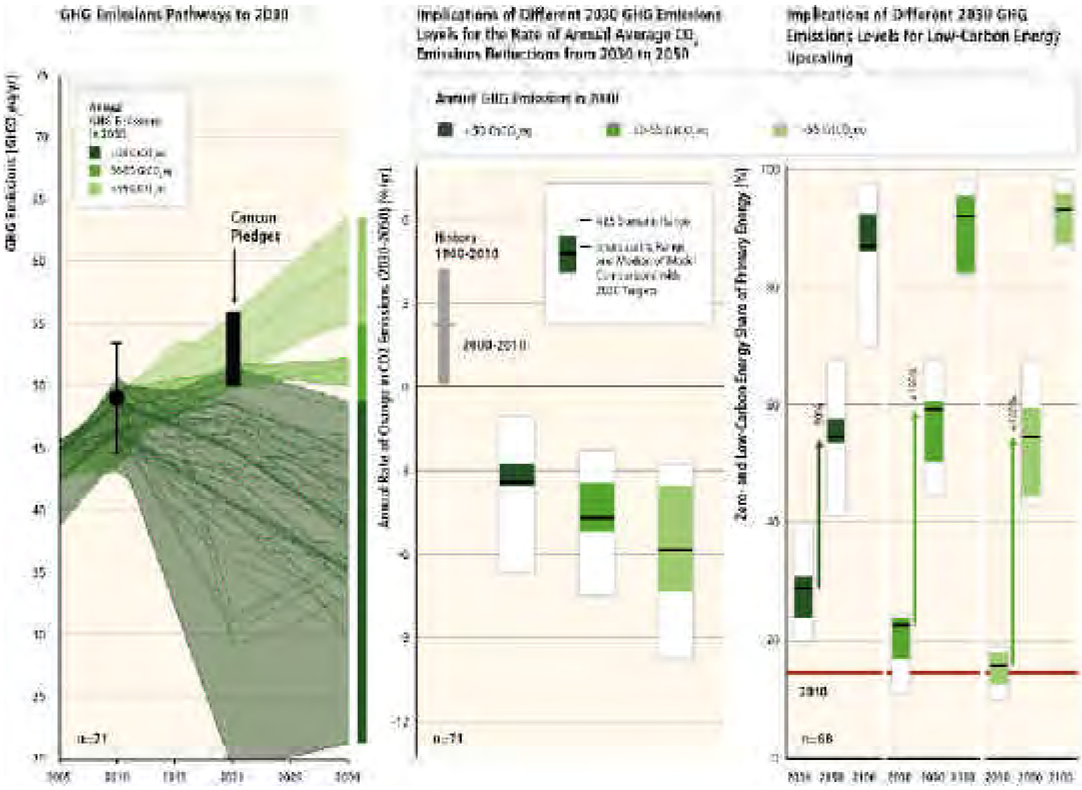


Figure SPM.8: The implications of different 2030 GHG emissions levels for the rate of CO_2 emissions reductions and low-carbon energy upscaling from 2030 to 2050 in mitigation scenarios reaching about 450 to 500 (430–530) ppm CO_2eq concentrations by 2100. The scenarios are grouped according to different emissions levels by 2030 (colored 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) are shown in grey. 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 3.3).

Estimates of the aggregate economic costs of mitigation vary widely and are highly sensitive to model design and assumptions as well as the specification of scenarios, including the characterization of technologies and the timing of mitigation *(high confidence)*. Based on their specific assumptions, mitigation scenarios that reach atmospheric concentrations of about 450ppm CO_2eq by 2100 entail losses in global consumption—not including benefits of reduced climate change as well as co-benefits and adverse side-effects of mitigation[3]—of 1% to 4% (median: 1.7%) in 2030, 2% to 6% (median: 3.4%) in 2050, and 3% to 11% (median: 4.8%) in 2100 relative to consumption in baseline scenarios that grows anywhere from 300% to more than 900% over the century. These numbers correspond to an annualized reduction of consumption growth by 0.04 to 0.14 (median: 0.06) percentage points over the century relative to annualized

[3] The total economic effects at different temperature levels would include mitigation costs, co-benefits of mitigation, adverse side-effects of mitigation, adaptation costs and climate damages. Mitigation cost and climate damage estimates at any given temperature level cannot be compared to evaluate the costs and benefits of mitigation. Rather, the consideration of economic costs and benefits of mitigation should include the reduction of climate damages relative to the case of unabated climate change?

consumption growth in the baseline that is between 1.6% and 3% per year. Under the absence or limited availability of technologies, mitigation costs can increase substantially depending on the technology considered (Table SPM.1, orange segment). Delaying additional mitigation further increases mitigation costs in the medium to long term (Table SPM.1, blue segment). Mitigation scenarios reaching about 450 or 500 ppm CO_2eq by 2100 show reduced costs for achieving air quality and energy security objectives, with significant co-benefits for human health, ecosystem impacts, and sufficiency of resources and resilience of the energy system; these scenarios did not quantify other co-benefits or adverse side-effects. *{3.2}*

Table SPM.1: Global mitigation costs in cost-effective scenarios and estimated cost increases due to assumed limited availability of specific technologies and delayed additional mitigation. 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. The green columns show consumption losses in the years 2030, 2050, and 2100 (green) and annualized consumption growth reductions (bright green) over the century in cost-effective scenarios relative to a baseline development without climate policy.[1] The orange columns show the percentage increase in discounted costs[2] over the century, relative to cost-effective scenarios, in scenarios in which technology is constrained relative to default technology assumptions.[3] The blue columns show the increase in mitigation costs over the periods 2030–2050 and 2050–2100, relative to scenarios with immediate mitigation, due to delayed additional mitigation through 2020 or 2030.[4] These scenarios with delayed additional mitigation are grouped by emission levels of less or more than 55 $GtCO_2eq$ in 2030, and two concentration ranges in 2100 (430–530 ppm CO_2eq and 530–650 CO_2eq). In all figures, the median of the scenario set is shown without parentheses, the range between the 16th and 84th percentile of the scenario set is shown in the parentheses, and the number of scenarios in the set is shown in square brackets.[5] (Table 3.2)

	Consumption losses in cost-effective implementation scenarios				Increase in total discounted mitigation costs in scenarios with limited availability of technologies				Increase in mid- and long term mitigation costs due delayed additional mitigation up to 2030			
	[% reduction in consumption relative to baseline]			[percentage point reduction in annualized consumption growth rate]	[% increase in total discounted mitigation costs (2015–2100) relative to default technology assumptions]				[% increase in mitigation costs relative to immediate mitigation]			
									≤55 $GtCO_2eq$		>55 $GtCO_2eq$	
2100 Concentration (ppm CO_2eq)	2030	2050	2100	2010-2100	No CCS	Nuclear phase out	Limited Solar / Wind	Limited Bio-energy	2030–2050	2050–2100	2030–2050	2050–2100
450 (430–480)	1.7 (1.0–3.7) [N: 14]	3.4 (2.1–6.2)	4.8 (2.9–11.4)	0.06 (0.04–0.14)	138 (29–297) [N: 4]	7 (4–18) [N: 8]	6 (2–29) [N: 8]	64 (44–78) [N: 8]	28 (14–50) [N: 34]	15 (5–59)	44 (2–78) [N: 29]	37 (16–82)
500 (480–530)	1.7 (0.6–2.1) [N: 32]	2.7 (1.5–4.2)	4.7 (2.4–10.6)	0.06 (0.03–0.13)								
550 (530–580)	0.6 (0.2–1.3) [N: 46]	1.7 (1.2–3.3)	3.8 (1.2–7.3)	0.04 (0.01–0.09)	39 (18–78) [N: 11]	13 (2–23) [N: 10]	8 (5–15) [N: 10]	18 (4–66) [N: 12]	3 (-5–16) [N: 14]	4 (-4–11)	15 (3–32) [N: 10]	16 (5–24)
580–650	0.3 (0–0.9) [N: 16]	1.3 (0.5–2.0)	2.3 (1.2–4.4)	0.03 (0.01–0.05)								

Notes:

[1] 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.

[2] 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.

[3] 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 [11.13.5]).

[4] Percentage increase of total undiscounted mitigation costs for the periods 2030–2050 and 2050–2100.

[5] 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 or delayed additional mitigation.

3.2 Adaptation pathways

Adaptation is essential for reducing damages associated with climate change. Adaptation options and their potential benefits are context-specific, differ between sectors and regions and depend on the rate and amount of climate change experienced. Recognizing diverse interests, circumstances, social-cultural contexts, and expectations, as well as building adaptive capacity at all levels, underpins effective selection and implementation of adaptation options and the pursuit of climate-resilient pathways. *{3.3}*

Adaptation can contribute to the wellbeing of current and future populations, the security of assets and the maintenance of ecosystem services now and in the future as the climate changes. 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, risk perceptions and expectations can benefit decision-making processes. Desired adaptation outcomes and pathways to these usually require effective engagement with the range of affected stakeholders, operating in a decision environment with policy support to overcome constraints at various levels. *{3.3}*

Effective adaptation strategies can link with sustainable development to reduce vulnerability but such strategies are challenging to implement and they are related fundamentally to what the world accomplishes with climate-change mitigation (*high confidence*). They are increasingly supported by targeted decision-support processes and tools that help address the many uncertainties, and by institutions that broker knowledge among different actors. *{3.3}*

Large magnitudes of warming increase the likelihood of severe, pervasive and irreversible impacts that make adaptation challenging. A temperature rise above 4°C would risk damaging agricultural production and ecosystems worldwide, and increase the rate of extinction of species (*high confidence*). It would also risk crossing tipping-points that could lead to disproportionately large responses in the earth system (*low confidence*). Precisely how much climate change would trigger tipping-points remains uncertain, but the likelihood of crossing them increases with increasing greenhouse gas emissions (*medium confidence*). *{3.3}*

There are limits to adaptation; greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits(*high confidence*). Poor planning, overemphasising short-term outcomes, or failing to sufficiently anticipate consequences can result in maladaptation (*medium evidence*, *high agreement*), including path-dependent development patterns that increase the vulnerability of some groups to future climate change**.** *{3.3}*

Restricting adaptation responses to incremental changes in existing systems and structures, without considering transformational change, may increase costs and losses, and miss out on opportunities. Transformational adaptation includes introduction of new technologies or practices, formation of new structures or systems of governance, adaptation at greater scale or magnitude and shifts in the location of activities.

3.3 Interactions between mitigation and adaptation

Climate change, mitigation, and adaptation create a large array of risks that differ in nature, magnitude, and their potential to cause irreversible consequences. Adaptation and mitigation can reduce climate change risks, but they do so over different timescales, face limits linked to resource, institutional and capacity constraints, and involves uncertainties and risks related to economic, environmental, and societal outcomes. {*3.4*}

Decisions about mitigation and adaptation involve a broad range of risks and tradeoffs connected with other policy objectives and ethical considerations; it is thus impossible to define a single best mitigation target or balance between mitigation and adaptation. Nevertheless, information on various emissions pathways is useful input into decision-making in the context of climate change. *{3.4}*

***Adaptation and mitigation reduce climate change risks, but* they face limits linked to resource, institutional and capacity constraints, and involve uncertainties and risks related to economic, environmental, and societal outcomes.** Adaptation will have relatively more substantial influence on climate risks in the near future. In the second half of the 21st century and beyond, the risks of climate change will increasingly be affected by cumulative impact of previous mitigation and adaptation actions and by their interaction with development pathways. Key vulnerabilities and risks related to ecosystems, food and water, development and other socioeconomic factors can be integrated into five Reasons for Concern (RfC). Figure SPM.9 uses the RfC to provide an illustration of how climate change risks are reduced by mitigation, for various mitigation scenarios. As illustrated in Figure SPM 9, however, not all risks can be directly linked to temperature change, and other metrics matter such as the rate of change, ocean acidification, and sea level rise also matter. The Box on Article 2 of UNFCCC applies this framework to the context of Article 2 of the UNFCCC and "dangerous" climate change. *{3.4, Box Art.2}*

Mitigation also involves risks and uncertainties. These risks are particularly high for the most ambitious mitigation pathways and include those associated with large-scale deployment of technology options for producing low-carbon energy – including bioenergy, nuclear power, carbon capture with storage, and even wind power – the potential for high aggregate economic costs, large impacts on vulnerable countries and industries. They affect 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 growth of developing countries. *{3.4}*

Risks from mitigation and from climate change are different in nature, magnitude, and in their potential to cause irreversible consequences. In an iterative risk management framework, the level of desirable efforts over the short-term is increased by the inertia in the climate system and the possibility of irreversible and catastrophic impacts from climate change**.** *{3.4}*

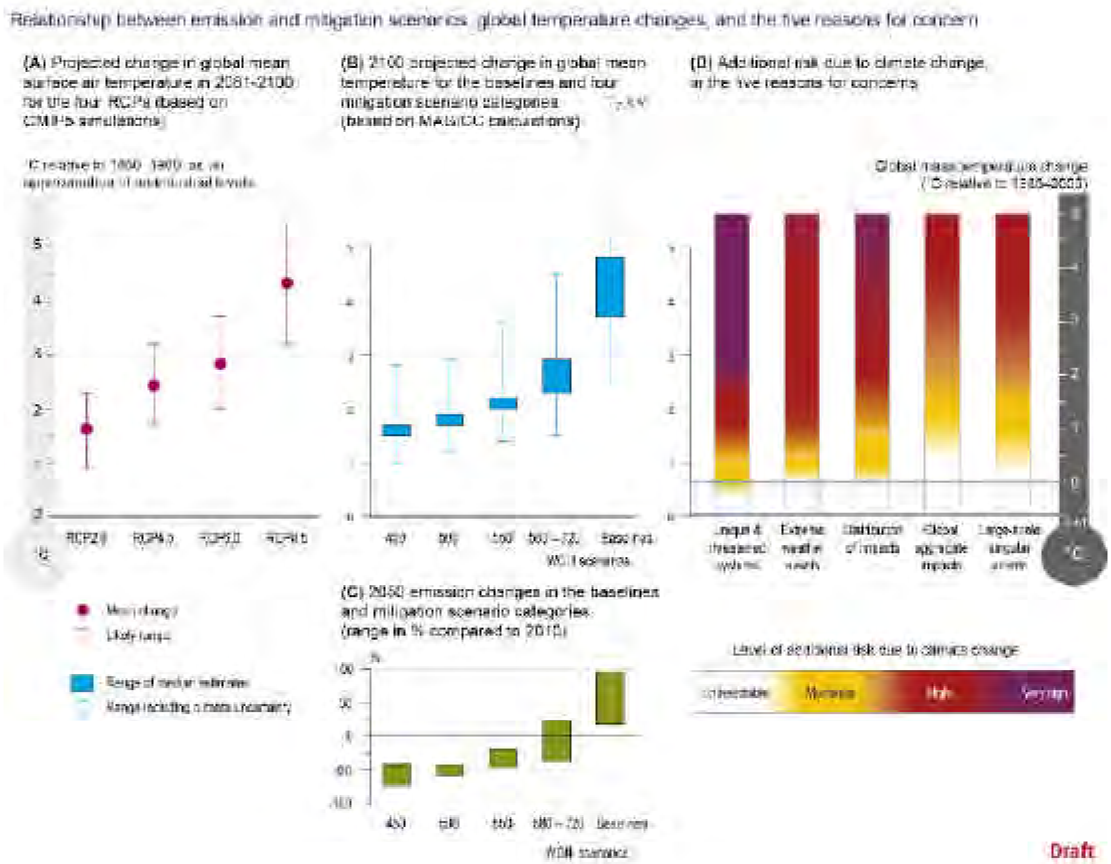


Figure SPM.9: Relationship between emission and mitigation scenarios, global temperature changes, and the five Reasons for Concerns (RfC). Temperature changes shown compared with pre-industrial levels. For reference, the extreme right temperature axis shows temperature changes with respect to the 1986-2005 period. **Panel a** shows projected change in global temperature in 2081-2100 for the four RCPs, based on CMIP5 simulations (see Table 2.1). **Panel b** shows the projected temperature increase in 2100, calculated using the MAGICC climate model for the baselines and four mitigation scenario categories defined in Chapter WGIII.6, indicating the uncertainty range resulting both from the range of emission scenario projections within each category and the uncertainty in the climate system (data from WGIII.6). **Panel c** shows the 2050 changes in emissions in the corresponding baselines and mitigation scenario categories (positive changes refer to cases where emissions in 2050 are larger than 2010). For instance, the mitigation scenarios in the 450 category – i.e. with CO2e concentration in 2100 between 430 and 480ppm – have emissions in 2050 that are between 41 and 72% percent lower than emissions in 2010 (Table WGIII.SPM.1). **Panel d** reproduces the five reasons for concerns from WGII Assessment Box SPM.1 Figure 1, using the same temperature axis than Panel a. Risks associated with reasons for concern (from left to right, denoted as RFC1-5 in Article 2 Box) are shown for increasing levels of climate change. The color shading indicates the additional risk due to climate change when a temperature level is reached and then sustained or exceeded. Examples of risks represented by RFC1 include those to coral reefs and the Arctic system; RFC2, includes risks associated with extreme heat; RFC3, regionally differentiated risks to food and water; RFC4, aggregate economic damages and biodiversity loss; RFC5, risk associated with a large sea level rise due to loss of mass from polar ice sheets. 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, also accounting for the other specific criteria for key risks. High risk (red) indicates severe and widespread impacts, also accounting for the other specific criteria for key risks. Purple, introduced in this assessment, shows that very high risk is indicated by all specific criteria for key risks.*{Ch.19.2}* Note the different temperature baselines used in WGII Assessment Box SPM.1 Figure 1. Beyond 2100, temperature, and therefore risk, decreases in most of the lowest three scenarios and increases further in most of the others.

4. Adaptation and Mitigation Measures

4.1 Mitigation measures

Stabilizing GHG concentrations in the atmosphere at low levels requires mitigation throughout the economy. Efforts in one sector determine the needs in others. Low stabilization scenarios are dependent upon a full decarbonisation of energy supply. Reductions in energy demand can limit the mitigation requirements and provide flexibility in the up-scaling of energy-supply technologies, avoid lock-in into carbon-intensive infrastructure and increase the cost-effectiveness of mitigation scenarios. *{4.3}*

Decarbonizing (i.e. reducing the carbon intensity of) electricity generation is a key component of cost-effective mitigation strategies in achieving low-stabilization levels *(medium evidence, high agreement){4.3}.*Energy supply is the largest and fastest growing contributor to global GHG emissions and offers opportunity for decarbonisation through renewable energy (RE), nuclear power, and carbon dioxide capture and storage (CCS). The wide range of options for decarbonizing energy supply provides flexibility in technology choice. The available technologies differ in their costs, risks and co-benefits. In most ambitious long-term mitigation scenarios, the economy is fully decarbonized at the end of the 21st century Accelerated electrification of energy end use, coupled with decarbonization of the majority of electricity generation by 2050 and an associated phase out of freely emitting coal generation, is a common feature of scenarios reaching roughly 550 ppm $C0_2$eq or less by 2100.*{4.3}*

Demand reductions in the energy end-use sectors are a key mitigation strategy and affect the scale of the mitigation challenge for the energy supply side (*high confidence) {4.3}*. Limiting energy demand: 1) increases policy choices by maintaining flexibility in the technology portfolio; 2) reduces the required pace for up-scaling low-carbon energy supply technologies and hedges against related supply side risks (Figure SPM…); 3) avoids lock-in to new, or potentially premature retirement of, carbon-intensive infrastructures; 4) maximizes co-benefits for other policy objectives, since the number of co-benefits for energy end-use measures outweighs the adverse side-effects which is not the case for all supply-side measures and 5) increases the cost effectiveness of the transformation (as compared to mitigation strategies with higher levels of energy demand) (*medium confidence*). However, energy service demand reductions are unlikely in developing countries or for poorer population segments whose energy service levels are low or partially unmet.*{4.3}*

The AFOLU sector plays a key role in low stabilization scenarios because it provides options to remove carbon dioxide from the atmosphere (high confidence AFOLU plays a central role for food security and sustainable development. 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 .*{4.3}*

Systemic cross-sectoral approaches to mitigation are expected to be more cost-efficient and more effective in cutting emissions than a focus on individual technologies and sectors. In this regard, human settlements play a key role in climate change mitigation. Since most of the world's urban areas in 2030 have not yet been built, spatial planning in these new areas can help avoid locking in carbon intensive patterns of infrastructure and urban form. In established cities, the potential lies in retrofitting existing urban forms and infrastructure. Mitigation in urban areas is most effective when planning strategies and cross-sectoral policy instruments are aligned to increase accessibility, promote land-use mix, and reduce urban sprawl.*{4.3}*

4.2 Mitigation policies

Policies to reduce GHG emissions or to support low-GHG technologies have increased since the AR4.
In many countries these policies have helped to reduce emission intensity. Ambitious mitigation will require policies sufficiently effective to induce fundamental shifts in investment flows. There is an increasing focus on policy design to integrate climate change mitigation with other economic, environmental and social objectives. *{4.5}*

As a global commons problem[4], effective climate change mitigation requires international cooperation.

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. Policy linkages among regional, national, and sub-national climate policies offer potential climate change mitigation and adaptation benefits (medium evidence, medium agreement). Linkages can be established between national policies, various instruments, and through regional cooperation.
The number of national and sub-national plans and strategies for mitigating climate change has increased since AR4, but there is inadequate evidence to assess their impacts on emissions and without coordination, policy instruments may not work as expected. *{4.5.1.2}*

Technology development, deployment and diffusion can be important components of mitigation and adaptation efforts. However, they face challenges with scaling up, and with integration in existing systems and in local contexts. Technology policy includes technology-push (e.g. publicly-funded R&D) and demand-pull (e.g. governmental procurement programs), but for adaptation also includes a strong focus on technology transfer, as adaptation technologies are often familiar and already applied elsewhere but need to be adapted to local circumstances. *{4.5.3}*

Behaviour, lifestyle and culture have considerable influence on energy use and associated GHG emissions (*high agreement, medium evidence*), with high mitigation potential in some sectors, in particular when complementing technological and structural change (*medium evidence, medium agreement*). Shifts toward more emission-intensive lifestyles might contribute to higher energy and resource consumption and therefore higher mitigation costs, but emissions can be substantially lowered through changes in consumption patterns, dietary change and reduction in food wastes. The social acceptability and/or effectiveness of climate policies may be dependent upon the extent to which they incentivise, or are contingent upon, changes in lifestyles or behaviours. *{4.2}*

Effective mitigation and adaptation efforts can require both changes in patterns of investment in all countries and increases in financial support for developing countries. Substantial reductions in emissions would require large changes in investment patterns (high agreement, robust evidence). Within appropriate enabling environments, the private sector, along with the public sector, can play an important role in financing mitigation and adaptation. Limited evidence indicates a gap between global adaptation needs and the funds available for adaptation (*medium confidence*). Appropriate governance arrangements and institutions are essential conditions for efficient, effective, and sustainable financing of mitigation and adaptation measures. *{4.5.4}*

The distribution of mitigation costs across countries can differ from the distribution of the actions themselves (*high confidence*)**.** In globally cost-effective scenarios, the majority of mitigation efforts takes place in countries with the highest future emissions in baseline scenarios. Some studies exploring particular effort-sharing frameworks, under the assumption of a global carbon market, have estimated substantial global financial flows associated with mitigation for scenarios leading to 2100 atmospheric concentrations of about 450 to 550 ppm CO_2eq. *{ 3.2}*

4.3 Adaptation measures

A first step for adaptation is often to reduce current climate-related risks (*high confidence*).
Adaptation options can have multiple and overlapping entry points. Significant co-benefits, synergies, and tradeoffs exist among individual adaptation options. For many natural ecosystems, the adaptation options are limited and focus mostly on reducing other pressures. For many human systems, a wider portfolio of options exists, including transformational responses, but their implementation faces a range of constraints. *{4.4}*

[4] As this expression is used in the social sciences, it has no specific implications for legal arrangements or for particular criteria regarding effort sharing.

A first step for adaptation is often to reduce current climate-related risks (*high confidence*). Integration of appropriate adaptation strategies and actions into development planning and decision-making can proactively prepare for a range of future climates while helping to improve human health and livelihoods, social and economic well-being, and environmental quality now. However, some near-term responses to increasing risks related to climate change may also limit future choices. For example, enhanced protection of exposed assets can lock in dependence on further protection measures. *{4.4}*

Adaptation options can have multiple and overlapping entry points. Significant co-benefits, synergies, and tradeoffs exist among individual adaptation options. Appropriate entry points depend on co-benefits and opportunities within wider development plans and strategic goals, and existing other climate and non-climate pressures. The effectiveness of specific adaptation options is influenced by culture, institutions, risk perception, resources and resource entitlement. Individual adaptation measures can complement each other, but some approaches entail significant trade-offs with and reduce the effectiveness of other actions (*very high confidence*). *{4.4}*

The potential for individual adaptation measures to reduce risk differs between sectors and regions, and changes over time. For many natural ecosystems, the adaptation options are limited and focus mostly on reducing other pressures. For many human systems, a wider portfolio of options exists, including transformational responses, but their implementation faces a range of constraints. *{4.4}*

- *Freshwater resources*: Adaptive water management techniques, including scenario planning, learning-based approaches, and flexible and low-regret solutions, can help create resilience to uncertain hydrological changes and impacts due to climate change (*limited evidence, high agreement*).
- *Terrestrial and freshwater ecosystems*: Management actions, such as maintenance of genetic diversity, assisted species migration and dispersal, manipulation of disturbance regimes (e.g., fires, floods), and reduction of other stressors, can reduce, but not eliminate, risks of impacts to terrestrial and freshwater ecosystems due to climate change, as well as increase the inherent capacity of ecosystems and their species to adapt to a changing climate (*high confidence*).
- *Coastal systems and low-lying areas:* Adaptation can reduce some of the projected damages from flooding in river basins and coasts, driven by increasing urbanization and by increasing sea levels and peak river discharges (*high confidence*), but the relative costs of coastal adaptation vary strongly among and within regions and countries for the 21st century.
- *Marine systems and oceans:* Marine forecasting and early warning systems as well as reducing non-climatic stressors can help reduce risks for some fisheries and aquaculture industries, but options for unique ecosystems such as coral reefs are limited (*high confidence*).
- *Food production system/Rural areas*: Adaptation options for agriculture include technological responses (e.g., stress-tolerant crop varieties, irrigation), enhancing smallholder access to credit and other critical production resources, and strengthening institutions at local to regional levels to support gender-oriented measures (*high confidence*).
- *Urban areas, key economic sectors and services:* Urban adaptation benefits from effective multi-level urban risk 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*).
- *Human health, security and livelihoods*: Adaptation options that focus on strengthening existing delivery systems and institutions as well as insurance and social protection strategies offer the best examples for securing health, security and livelihoods in the near term (*high confidence*).

4.4 Interactions among mitigation, adaptation and sustainable development

Achieving sustainable development and addressing climate change are closely related concerns, and involve trade-offs and synergies between multiple objectives, attention to interactions between different types of policies, and the likely need for transformational change in systems. *{3.5}*

Climate change poses an increasing threat to equitable and sustainable development. Some climate-related impacts on development are already being observed. Climate change is a threat multiplier, exacerbating other threats to social and natural systems in ways that place additional burdens on the poor and constrain possible development paths for all. Development along current pathways can contribute to climate risk and vulnerability, further eroding the basis for sustainable development. *{3.5}*

Casting climate policy in the context of sustainable development includes attention to achieving climate resilience through both adaptation and mitigation. **In the framework of sustainable development the design of climate policy involves the recognition of trade-offs and synergies across multiple objectives**. Most climate policies intersect with other goals, either positively or negatively, creating the possibility of "co-benefits" or "adverse side effects". A multi-objective perspective helps to identify those policies that advance multiple goals and those that involve trade-offs among objectives. 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. *{Box 3.1, 3.5}*

Introduction

This Synthesis Report (SYR) brings forward the main findings of the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). The report integrates the key findings of the Working Group contributions: The Physical Science Basis (Working Group I), Impacts, Adaptation and Vulnerability (Working group II), and Mitigation of Climate Change (Working Group III). In addition , the two Special Reports (Special Report on Extreme Events) and Special Report on Renewable Energy) serve as a source. The Synthesis Report combines observations and understanding climate change, future projections and consequences for humanity and ecosystems. It provides options to cope with climate change by adaptation and mitigation and gives scientific information related to the long term objective of the UN Framework Convention on Climate Change (Article 2).

Human interference with the climate system is occurring, and climate change poses risks for human and natural systems. This report assesses all aspects of climate change and provides information to support decision making in this field. Climate change will alter human and natural systems, and responding to it involves issues of equity, justice, and fairness, requiring collective action at the global scale.

Some of these risks will be limited to a particular sector or region, and others will have cascading effects across natural and economic systems. The IPCC's Fifth Assessment Report (AR5) evaluates the changing climate, the shifting patterns of risks and potential benefits, and opportunities for reducing risks through mitigation and adaptation.

The challenges presented by climate change involve many uncertainties. Because there is a wide range of possible outcomes, responding to climate change involves managing risks. Despite the challenges, there are many opportunities for reducing the risks related to climate change and for capitalizing on synergies with other social, economic, and development objectives.

Near-term choices affect the risks of climate change throughout the 21st century. Societal responses, particularly adaptation actions, will influence near-term outcomes. In the second half of the 21st century and beyond, levels of climate change increasingly diverge across emission scenarios. Near-term and longer-term mitigation and adaptation, interacting with many aspects of social, economic, and technological development, will determine the risks of climate change over this timeframe.

Treatment of uncertainties and risks is important in all Topics of this report. Therefore, the context of these notions is explained in Box Introduction.1.

Box Introduction.1: Risk and uncertainty associated with future climate change

As for many other complex phenomena, our understanding of climate change and its effects is subject to uncertainty. '*Uncertainty*' refers to a state of incomplete knowledge, which may even be irreducible in some cases. Uncertainty can result from a lack of information or from disagreement about what is known.

Uncertainty about past and future climate changes arises from insufficient or imperfect measurements (of atmospheric and ocean temperatures, for example) and our limited ability to understand and model many features of the climate system, including the central role of human behavior and the impact of climate change on a wide range of natural and human-managed systems. Several types of uncertainty discussed in this report are important in evaluating model projections of climate responses and their associated impacts, arising from emissions of greenhouse gas and other forcing agents.

Uncertainty about future emissions is caused by our limited ability to predict factors that underlie those emissions, including future climate policies toward mitigation and adaptation. Uncertainties in emissions scenarios are related to our limited knowledge of future economic output and population growth, the development and deployment of technologies, the likelihood with which regulations will be enacted and enforced over the lifetime of firms' investments, and the impact of these uncertainties on the choices of mitigation and adaptation measures made by key decision makers. *{WGIII:2.3.1}*

Climate change exposes humans, societies, economic sectors, and ecosystems to risk. Risk is also created by policies that aim to mitigate climate change or adapt to it. For example, policies which induce conversion of land from cultivation of crops for food to crops for energy production bear risks for ecosystems. '*Risk*' refers to the potential, when the outcome is uncertain, for adverse effects on lives, livelihoods, health status, assets (economic, social and cultural), environmental and other services, infrastructure and ecosystems. Both risk and uncertainty may be understood qualitatively or quantitatively. *{WGII: 1.1.2; 19.3; WGIII 2.1}*

The risk from an event may be measured by the 'expected value' of resulting harm, which is defined as the event's probability multiplied by the value of the harm that will result from it. To assess a risk defined in this way, the probability must be estimated, and a value attached to the resulting harm. For a quantitative example, it is estimated that without protection, 72 million people would be displaced due to land loss from submergence and erosion assuming global mean sea level increases by 0.5m by 2100. *{WGII: 5.4}* Such a sea level rise is *likely* (17-83% probability, *WGI fig. SPM.9*) under any RCP. So the expected value of harm is between 12M and 60M people displaced. For a qualitative example, it is *more likely than not* that tropical cyclone activity in the Western North Pacific and North Atlantic will increase over the 21st century. Thus the risk from more intense tropical cyclones to human life and wellbeing, to economic value, and to nature increases. In other cases, the value of the resulting harm may take into account its distribution across people and countries. To the extent that likelihood and outcomes are based on personal knowledge or perception that an individual has about a given situation, risk is subjective. *{WGI: Table SPM.1; WGII:19.1; WGIII:2.4}*

Measuring risk by expected value as mentioned above shows that unlikely events may be more important to decision-making than likely events if their consequences are extremely harmful. Concentrating solely on likely events may therefore miss possibilities that are critical in designing policy. Comprehensive risk management takes into account the full range of events, including unlikely ones.
For example, the collapse of a substantial part of the Antarctic ice sheet is *unlikely* in this century but the consequences would be very severe. Accordingly, the probability of such an event is taken into account in assessing risk associated with sea level rise. *{WGIII: Box 3.8.1; WGI: 13.4; WGII: 19.6}*

Comprehensive risk management described in this report recognizes the importance of linking formal approaches with descriptive models of choice that encompass a variety of psychological, cultural, and social assumptions and biases, on the part of both laypeople and experts. This may be an iterative process. Even when only qualitative judgments are possible, the concept of risk as the product of likelihood and consequence is useful as a tool with which to organize ideas and identify opportunities for managing or ameliorating risk. *{WGII: 2.4; 2.5}*

The *Guidance Note on Uncertainty* provides a detailed explanation of the language used to describe uncertainty in a consistent manner throughout theAR5. *{WGI: SPM, WGII: SPM, WGIII:2.1}* The uncertainty language in the SYR is identical to those of the Working Group Reports and consists of the terms '*evidence', 'agreement', 'confidence'* and '(un)*likely'*. The terms to describe evidence are: *limited*, *medium*, or *robust*; and agreement: *low*, *medium*, or *high*. Confidence in the validity of a finding synthesizes the evaluation of evidence and agreement. 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: v*irtually 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 certainty is highest, findings are formulated without using uncertainty qualifiers. *{WG II SPM}*

Topic 1: Observed Changes and their Causes

Human emissions of greenhouse gases have continued to rise since 1970 with larger absolute increases over the last decade.. Human influence on the climate system climate system is clear, and is estimated to have been the dominant cause of warming since 1950. Changing climate has been linked to impacts on natural and human systems on all continents and across the oceans.

1.1 Introduction

Topic 1 focuses on evidence for a changing climate in observations, the impacts caused by it 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 sectors and gases (1.3). Section 1.4 attributes causes to observed changes in human and natural systems and determining the degree to which those impacts can be attributed to climate change. Vulnerability and exposure in the context of extreme events as well as the changing probability of extreme events and their causes are discussed in a separate section (1.5), followed by a brief section on adaptation experience (1.6).

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.

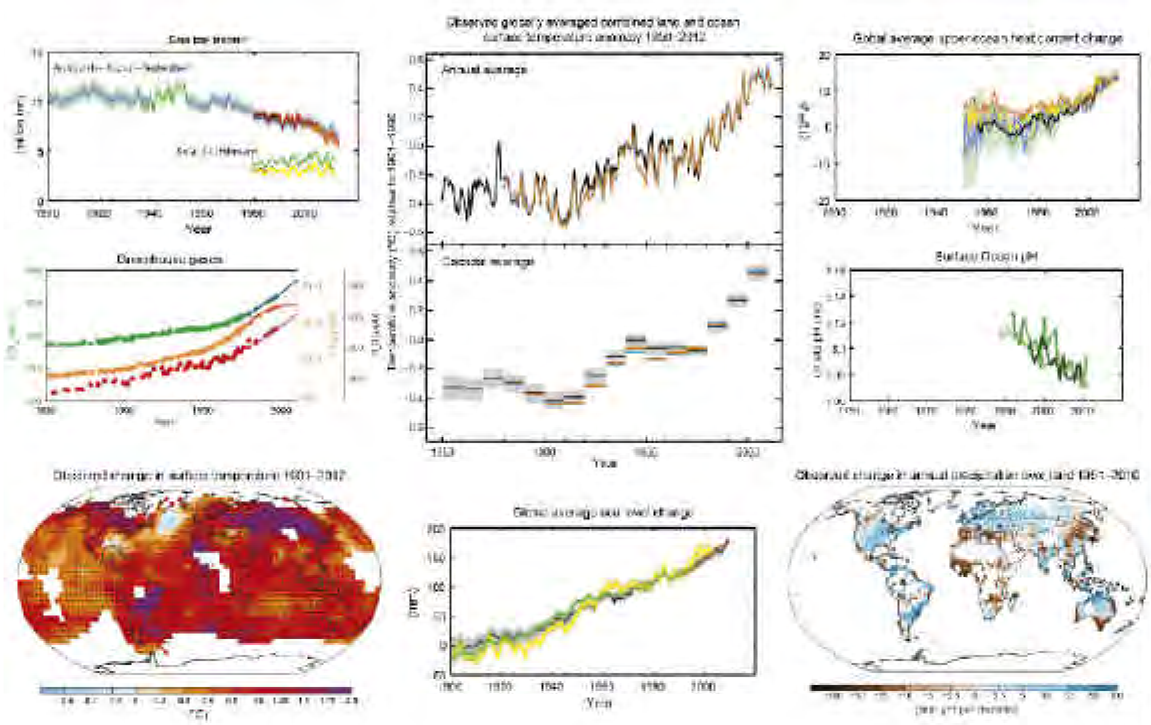


Figure 1.1: Multiple observed indicators of a changing global climate system. Left column, top panel: Arctic (July to September average) and Antarctic (February) sea ice extent; Left column, middle panel: atmospheric concentrations of well mixed greenhouse gases; carbon dioxide (CO_2) determined from ice core data (green dots) and from direct atmospheric measurements (blue line); methane (yellow dots, orange line) and nitrous oxide (red dots, purple line); Left column, bottom panel: map of the observed surface temperature change from 1901 to 2012 from one dataset (orange line in middle columns, top panel); Middle column, top panel: observed globally averaged combined land and ocean surface temperature anomalies (annual and decadal averages) with an estimate of decadal mean uncertainty included for one dataset (grey shading); Middle column, bottom panel: global mean sea level change; Right column, top panel: change in global mean upper ocean (0–700 m) heat content; Right column, middle panel: in situ pH, which is a measure of the acidity of ocean water; Right column, bottom panel: map of observed precipitation change from 1951 to 2010.

For all time-series, coloured lines indicate different datasets, and uncertainties (where assessed in the underlying chapters) are indicated by coloured shading. Trends shown in the maps have been calculated only where data availability permits a robust estimate and grid boxes where the trend is significant at the 10% level are indicated by a + sign. Note that the length of the times-series shown differs between quantities, based on the availability of the observations. For full technical information, and details on the datasets shown, refer to the underlying WGI Summary for Policymakers and Chapter figures, and the supplementary material to the Technical Summary. *{Figures SPM 1 – 4; Figure 4.SM.2, Figure 6.11}*

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, 1983–2012 was *likely* the warmest 30-year period of the last 1400 years (*medium confidence*). *{WG1 2.4, 5.3}*

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, over the period 1880 to 2012, when 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[5], based on the single longest dataset available (Figure 1.1). *{WGI 2.4}*

*B*ased upon multiple independent analyses of measurements from radiosondes and satellite sensors it is *virtually certain* that globally the troposphere has warmed and the lower stratosphere has cooled since the mid-20th Century. There is at best *medium confidence* in the rate of change and its vertical structure. *{WG I 2.4}*

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 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}*

Observed changes in extremes are discussed in Section 1.5.

1.2.2 Ocean changes

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. *{WG I 3.2, Box 3.1; Figure 1.1}*

On a global scale, the ocean warming is largest near the surface, with the upper 75 m warming by 0.11 [0.09 to 0.13] °C per decade over the period 1971–2010. *{WGI 3.2}*

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. These regional trends in ocean salinity provide indirect evidence that evaporation and precipitation over the oceans have changed (*medium confidence*). *{WGI 2.5, 3.3, 3.5}*

There is no observational evidence of a long-term trend in the Atlantic Meridional Overturning Circulation (AMOC), based on the decade-long record of the complete AMOC and longer records of individual AMOC components. *{WGI 3.6}*

Oceanic uptake of anthropogenic CO_2 results in gradual acidification of the ocean. The pH of surface seawater has decreased by 0.1 since the beginning of the industrial era, corresponding to a 26% increase in hydrogen ion concentration (*high confidence*). *{WGI SPM, 3.8}*

[5] Ranges in square brackets indicate a 90% uncertainty interval unless otherwise stated.

High agreement among analyses provides *medium confidence* that oxygen concentrations have decreased in the open ocean thermocline in many ocean regions since the 1960s. It is *likely* that the tropical oxygen minimum zones have expanded in recent decades. *{WGI 3.8, Figure 3.20; WGII 6.1.1.3; 30.3.2.3}*

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 and Northern Hemisphere spring snow cover have continued to decrease in extent (*high confidence*) (Figure 1.1). *{WGI 4.2–4.7}*

The average rate of ice loss from the Greenland ice sheet has *very likely* substantially increased from 34 [–6 to 74] Gt yr–1 over the period 1992 to 2001 to 215 [157 to 274] Gt yr–1 over the period 2002 to 2011. The average rate of ice loss from the Antarctic ice sheet has *likely* increased from 30 [–37 to 97] Gt yr–1 over the period 1992–2001 to 147 [72 to 221] Gt yr–1 over the period 2002 to 2011. There is *very high confidence* that these losses are mainly from the northern Antarctic Peninsula and the Amundsen Sea sector of West Antarctica. *{WGI 4.4}*

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. The annual mean Arctic sea ice extent decreased over the period 1979 to 2012 with a rate that was *very likely* in the range 3.5 to 4.1% per decade (range of 0.45 to 0.51 million km^2 per decade), and *very likely* in the range 9.4 to 13.6% per decade (range of 0.73 to 1.07 million km^2 per decade) for the summer sea ice minimum. {*WG1 Figure SPM.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}*

There is *high confidence* that permafrost temperatures have increased in most regions of the Northern Hemisphere since the early 1980s in response to increased air temperature and changing snow cover. *{WG1 4.7.2}*

1.2.4 Changes in Sea Level

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*). Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (Figure 1.1). *{WGI SPM, 3.7, 5.6, 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, 2.0 [1.7 to 2.3] mm yr^{-1} between 1971 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 of the latter period. It is *likely* that similarly high rates occurred between 1920 and 1950. *{WGI SPM,3.7, 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, 13.3}*

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 are known globally to high precision using satellite altimetry, with rates in the western Pacific up to three times larger than the global mean, while rates over much of the Eastern Pacific are near zero or negative. *{WGI 3.7, 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, 5.3, 5.6, 13.2}*

1.3 Past and recent drivers of climate change

Atmospheric concentrations of the main well mixed greenhouse gas (CO_2, CH_4 and N_2O) have all shown large increases since the preindustrial era. Despite of multinational institutions and national policies aimed at mitigating emissions, anthropogenic greenhouse gas emissions have risen more rapidly between 2000-2010 than in the preceding decade, driven mainly by economic and population growth.

1.3.1 Natural and anthropogenic forcings

Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change. Radiative forcing (RF) quantifies the variation in energy fluxes caused by these drivers. All RF values are for the industrial era, defined here as the period from 1750 to 2011, unless otherwise indicated. 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 representing observed processes.

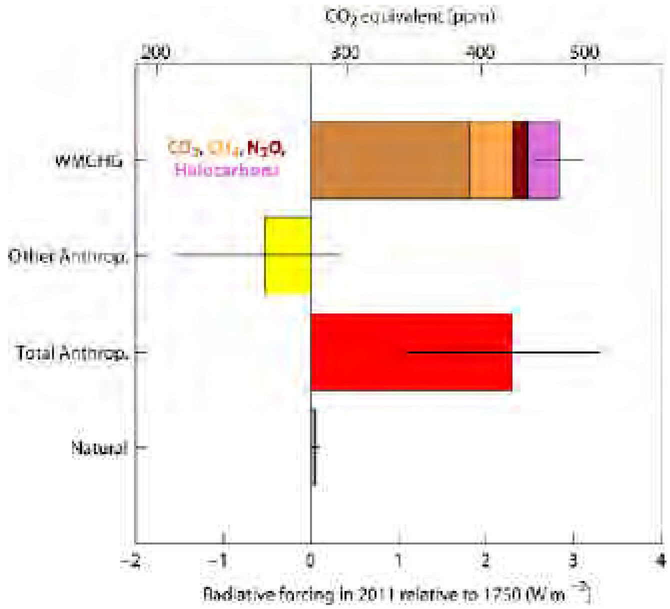
Atmospheric concentrations of the main well mixed greenhouse gases (CO_2, CH_4 and N_2O) have all shown large increases since the preindustrial era (40%, 150% and 20% respectively). The CO_2 concentration (Figure 1.1) is substantially higher than anytime within the last 800,000 years and is now rising at its fastest-observed decadal rate of change (2.0 ± 0.1 ppm yr^{-1}). After almost one decade of stable CH_4 concentrations since the early 1990's, atmospheric measurements have shown renewed growth since 2007. N_2O concentrations are increasing at a current rate of about 0.75 ppb yr^{-1}. {*WGI 2.2, 6.1 6.3*}

Changes in carbon dioxide are the largest single contributor to historical RF from either the emission based or concentration based perspective. The relative importance of other forcing agents varies with the perspective chosen, however. For example methane emissions have a much larger forcing (about 1.0 W m^{-2} over the industrial era) than methane concentration increases (about 0.5 W m^{-2}) due to several indirect effects through atmospheric chemistry.

The total anthropogenic RF since 1750 is 2.29 [1.13 to 3.33] W m^{-2} (Figure 1.2), and it has increased more rapidly since 1970 than during prior decades. The total anthropogenic RF estimate for 2011 is substantially higher 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 improved estimates of RF by aerosols indicating a weaker net cooling effect. *{WGI SPM, 8.5}*

The other anthropogenic forcing bar shown in Figure 1.2 include a warming contribution from ozone changes and cooling contributions from land-use albedo and aerosol changes. **The RF of the total aerosol effect, which includes cloud adjustments due to aerosols, is –0.9 [–1.9 to −0.1] W m^{-2} *(medium confidence)*. RF from aerosols has two competing components: a dominating negative forcing from most aerosols and an offsetting positive contribution from black carbon**. There is *high confidence* that the combined impact of aerosols has counteracted a substantial portion of global mean forcing from well-mixed greenhouse gases. Aerosols continue to contribute the largest uncertainty to the total RF estimate. *{WGI SPM, 7.5, 8.3, 8.5}*

Changes in solar irradiance and volcanoes can cause natural forcings (Figure 1.2). The forcing from stratospheric volcanic aerosols can have a large impact on the climate system for some years after volcanic eruptions. Several small eruptions have caused an additional RF of −0.11 [–0.15 to –0.08] W m^{-2} for the years 2008−2011. Changes in total solar irradiance contribute only a small fraction, 0.05 [0.00 to 0.10] W m^{-2}, of the total radiative forcing during the industrial era. There was a strong solar minimum in 2008/2009, which contributed a small cooling effect over the last 15 years. The effect of cosmic rays on the concentration of cloud condensation nuclei is too weak to have any detectable climatic influence during a solar cycle or over the last century (*medium evidence, high agreement*). *{WG-I 7.4 8.4}*



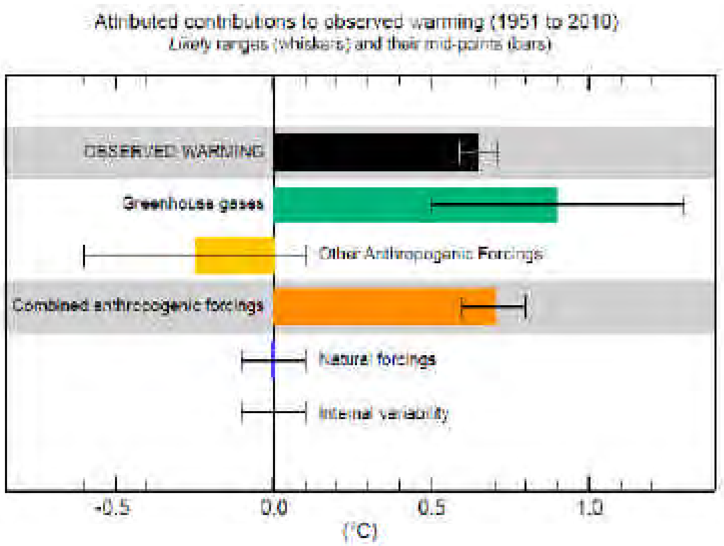


Figure 1.2: Top diagram: Radiative forcing (RF) of climate change during the industrial era (1750-2011) from well-mixed greenhouse gases (WMGHG), other anthropogenic forcings, combined anthropogenic forcings and natural forcings. The error lines indicate the 5%-95% uncertainty. Other Anthropogenic forcings include aerosol, land-use albedo and ozone changes. *{Data from WGI Table 8.6 and Section 7.5}*
Bottom diagram: Assessed *likely* ranges (whiskers) and their mid-points (bars) for attributable warming trends over the 1951–2010 period due to well-mixed greenhouse gases, other anthropogenic forcings, combined anthropogenic forcings, natural forcings, and internal variability. Observations are shown in black with the 5–95% uncertainty range due to observational uncertainty in this record. These attributed ranges (colours) are based on estimating the contribution to observed warming by fingerprints for external forcing derived from climate model simulations; and do not rely on the estimated radiative forcing magnitudes from the top panel. Errorbars are larger when greenhouse gases and other anthropogenic forcing is estimated separately compared to when they are estimated in combination (grey shading). This is because uncertainty in warming attributable to greenhouse gases is correlated with that in cooling attributable to aerosols. Hence while uncertainty is small in the overall anthropogenic contribution, there is uncertainty in how much greenhouse warming is offset by aerosol cooling. *{WGI Figure TS.10, 10.3}*

1.3.2 Human activities affecting climate drivers

About half of cumulative anthropogenic CO_2 emissions between 1750 and 2010 have occurred in the last 40 years (*high confidence*). Anthropogenic CO_2 emissions were 2000 ± 310 $GtCO_2$ to the atmosphere between 1750 and 2011. In 1970, cumulative CO_2 emissions from fossil fuel combustion, cement production and flaring since 1750 were 420±35 $GtCO_2$; in 2010, that cumulative total had tripled to 1300 ±110 $GtCO_2$. Cumulative CO_2 emissions from Forestry and Other Land Use (FOLU) since 1750 increased from 490±180 $GtCO_2$ in 1970 to 680±300 $GtCO_2$ in 2010 (Figure 1.3). *{WGI 6.3, WGIII 5.2}*

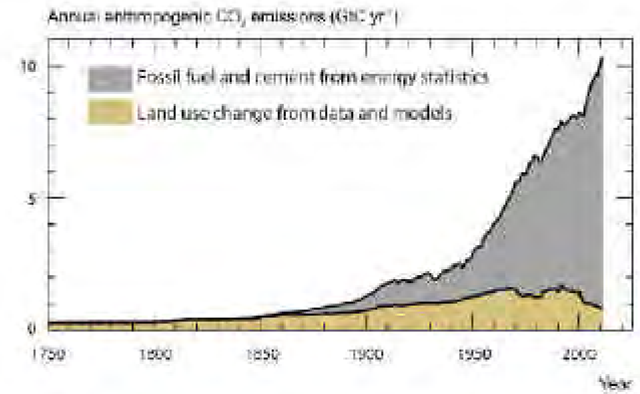


Figure 1.3: Annual anthropogenic CO2 emissions from fossil fuel combustion, flaring, cement, Forestry and Other Land Use (FOLU) 1750-2011. Emissions are reported in gigatonnes carbon per year (Gt/yr). *{WG I Figure TS.4}*

About half of these anthropogenic CO_2 emissions remained in the atmosphere (880 ± 35 $GtCO_2$) since 1750. The rest was removed from the atmosphere by sinks, and stored in the natural carbon cycle reservoirs. It is virtually certain that the ocean is taking up anthropogenic carbon dioxide from the atmosphere since pre-industrial times. This estimate is 570 ± 110 $GtCO_2$ from 1750 to 2011. *{WG1 3.8.1, 6.3}* Vegetation biomass and soils stored 585 ± 330 $GtCO_2$ over the 1750-2011 period. *{WG1 6.3}*

Total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute decadal increases toward 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 giga tonne carbon dioxide equivalent ($GtCO_2eq$) (2.2%) per year from 2000 to 2010 compared to 0.4 $GtCO_2eq$ (1.3%) per year from 1970 to 2000 (Figure 1.4).[6,7] Total anthropogenic GHG emissions were the highest in human history from 2000 to 2010 and reached 49 (±4.5) $GtCO_2eq$/yr in 2010. The global economic crisis 2007/2008 only temporarily reduced emissions. *{WG III 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% of the total GHG emission increase from 1970 to 2010, with a similar percentage contribution for the period 2000–2010 (*high confidence*). Fossil fuel-related CO_2 emissions reached 32 (±2.7) $GtCO_2$/yr, in 2010, and grew further by about 3% between 2010 and 2011 and by about 1-2% between 2011 and 2012. Of the 49 (±4.5) $GtCO_2eq$/yr in total anthropogenic GHG emissions in 2010, CO_2 remains the major anthropogenic GHG accounting for 76% (38±3.8 $GtCO_2eq$/yr) of total anthropogenic GHG emissions in 2010. 16% (7.8±1.6 $GtCO_2eq$/yr) come from methane (CH_4), 6.2% (3.1±1.9 $GtCO_2eq$/yr) from nitrous oxide (N_2O), and 2.0% (1.0±0.2 $GtCO_2eq$/yr) from fluorinated gases (Figure 1.4). Annually, since 1970, about 25% of anthropogenic GHG emissions have been in the form of non-CO_2 gases.[8] *{WG III 1.2, 5.2}*

[6] Throughout the SYR, when emissions of GHGs are provided in $GtCO_2eq$, they are weighted by Global Warming Potentials with a 100-year time horizon (GWP_{100}) from the IPCC Second Assessment Report. All metrics have limitations and uncertainties in assessing consequences of different emissions. *{3.9.6, Box TS.5, Annex II.2.9, WGI AR5 SPM}*

[7] Uncertainty in historic GHG emission data is reported using 90% uncertainty intervals unless otherwise stated. GHG emission levels are rounded to two significant digits throughout this document.

[8] In this report, data on non-CO_2 GHGs, including fluorinated gases, is taken from the EDGAR database (Annex II.9), which covers substances included in the Kyoto Protocol in its first commitment period.

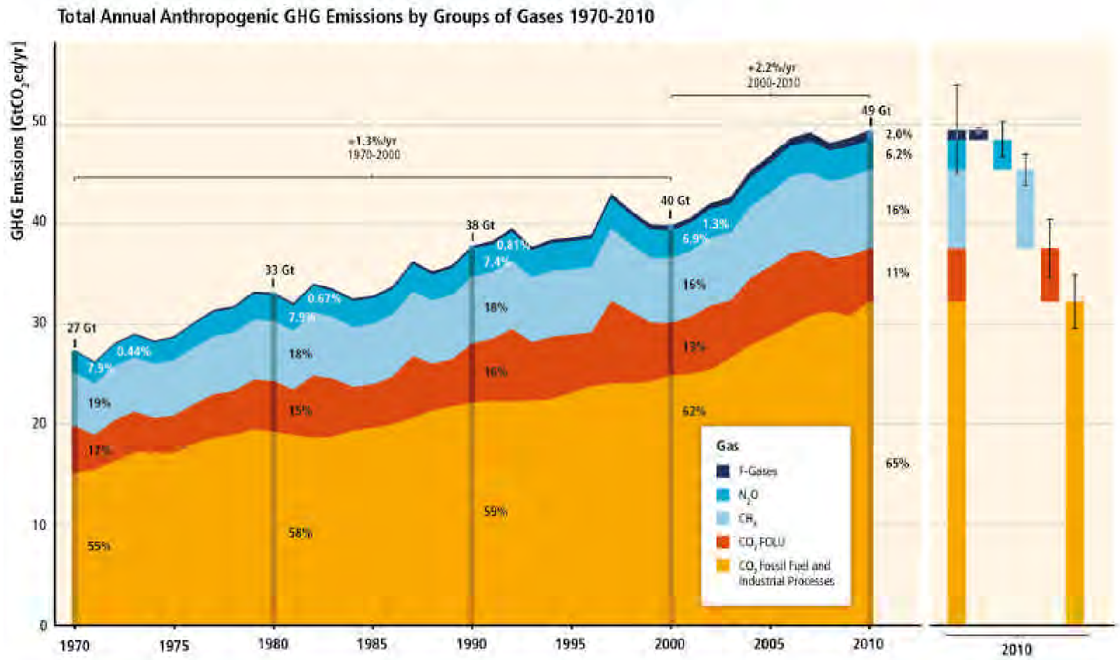


Figure 1.4: Total annual anthropogenic GHG emissions ($GtCO_2eq/yr$) by groups of gases 1970 - 2010: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (N_2O); fluorinated gases covered under the Kyoto Protocol (F-gases). At 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. *{WG III Figure SPM.1}*

Annual anthropogenic GHG emissions have increased by 10 $GtCO_2eq$ between 2000 and 2010, with this increase directly coming from energy supply (47%), industry (30%), transport (11%) and buildings (3%) sectors (*medium confidence*). Accounting for indirect emissions raises the contributions of the buildings and industry sectors (*high confidence*). Since 2000, GHG emissions have been growing in all sectors, except AFOLU. Of the 49 (±4.5) $GtCO_2eq$ emissions in 2010, 35% (17 $GtCO_2eq$) of GHG emissions were released in the energy supply sector, 24% (12 $GtCO_2eq$, net emissions) in AFOLU, 21% (10 $GtCO_2eq$) in industry, 14% (7.0 $GtCO_2eq$) in transport and 6.4 % (3.2 $GtCO_2eq$) in buildings. 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 buildings sectors in global GHG emissions are increased to 31% and 19%, respectively (Figure SPM.2). *{WG III 7.3, 8.2, 9.2, 10.3, 11.2}*

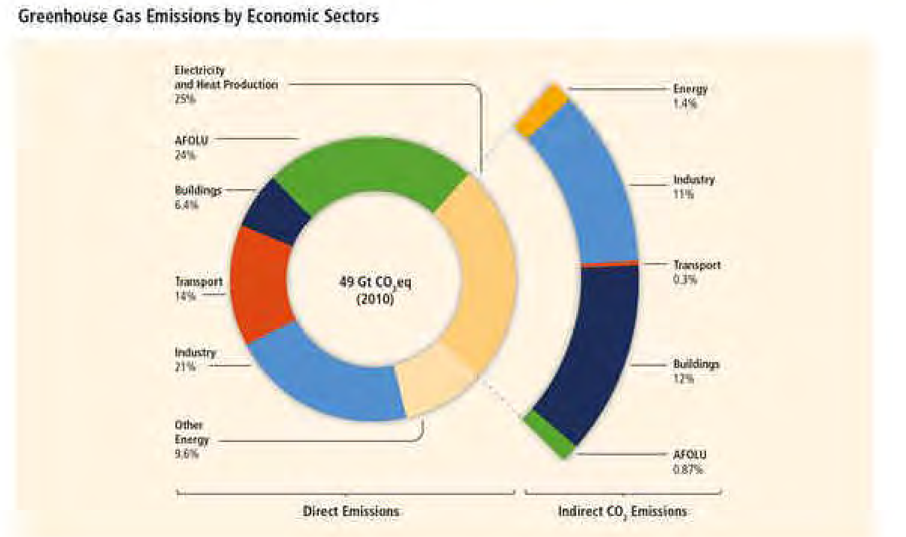


Figure 1.5: Total anthropogenic GHG emissions (GtCO_2eq/yr) by economic sectors. Inner circle shows direct GHG emission shares (in % of total anthropogenic GHG emissions) of five economic sectors in 2010. Pull-out shows how indirect CO_2 emission shares (in % of total anthropogenic GHG emissions) from 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 [A.II.9.1]. The emissions data from 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 Forestry and Other Land Use (FOLU) sub-sector as described in Chapter 11 of this report. Emissions are converted into CO_2-equivalents based on GWP_{100}[6] from the IPCC Second Assessment Report. Sector definitions are provided in Annex II.9. *{WGIII Figure SPM.2}*

Regardless of the perspective taken, the largest share of anthropogenic CO_2 emissions is emitted by a small number of countries *(high confidence)*. In 2010, 10 countries accounted for about 70% of CO_2 emissions from fossil fuel combustion and industrial processes. A similarly small number of countries emit the largest share of consumption-based CO_2 emissions as well as cumulative CO_2 emissions going back to 1750. *{WGIII 1.3}*

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 the previous three decades, while the contribution of economic growth has risen sharply (*high confidence*). Between 2000 and 2010, both drivers outpaced emission reductions from improvements in energy intensity (Figure 1.6). Increased use of coal relative to other energy sources has reversed the long-standing trend of gradual decarbonization of the world's energy supply. *{WG III 1.3, 5.3, 7.2, 14.3, TS.2.2}*

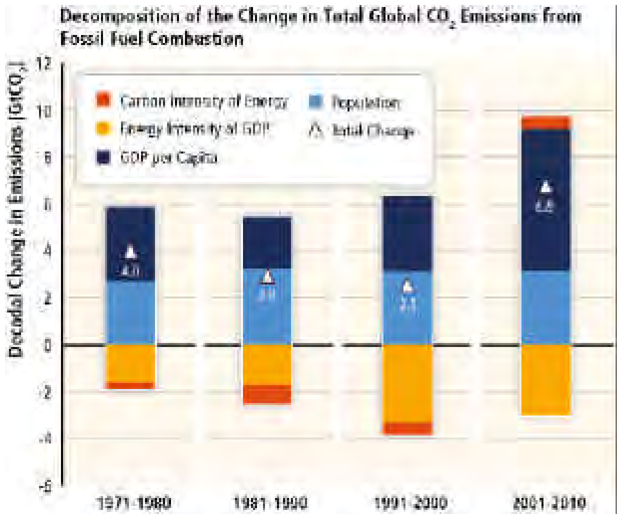


Figure 1.6: Decomposition of the decadal change in total global CO_2 emissions from fossil fuel combustion by four driving factors; population, income (GDP) per capita, energy intensity of GDP and carbon intensity of energy. The bar segments show the changes associated with each factor alone, holding the respective other factors constant. Total decadal changes are indicated by a triangle. Changes are measured in giga tonnes (Gt) of CO_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

Human influence has been detected and attributed 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 has been *extremely likely* 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.

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 for detection and attribution that have been developed across working groups (IPCC GPGP, 2010). Detection addresses the question of whether climate or a natural or human systems affected by climate has actually changed in a statistical sense, while attribution evaluates (to the extent possible) the relative contributions of multiple causal factors to a change or event with an assignment of confidence (IPCC GPGP, 2010). The assessment accounts very carefully for the extent to which 'confounding' factors have been considered. Results from attribution studies support projections of future climate change (Topic 2). *{WGI 10}* as well as analyses of the sensitivity of natural or human systems to future climate change including the risks associated with these sensitivities. *{WGII 18, 19}*

Attribution of observed impacts to climate change *{WGII}* considers the links between impacts on natural or human systems and observed climate change, regardless of its cause. By comparison, attribution of climate change to causes *{WGI}* quantifies the links between observed climate change and human activity, as well as other external climate drivers. On local scales, such as local precipitation or temperature change, attribution of causes to climate change is much more difficult, due to larger climate variability, the greater role played by dynamical factors (circulation changes), a greater range of forcings or confounding factors that may be regionally important, and the greater difficulty of modelling relevant processes at regional scales. This is why attribution results that directly link impacts of climate change to human drivers are not easy to achieve.

Section 1.4.1 focuses on attribution of climate change to anthropogenic forcing, while section 1.4.2 discusses observed impacts on natural and human systems attributable to climate change. Where possible, section 1.4.2 also presents connections of such impacts to changes in climate for which human influence has been assessed.

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

Human influence has been detected and attributed 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 (Figure 1.6; note that extremes are discussed in section 1.5). This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century. *{WG1 SPM, 10.9, Table 10.1}*

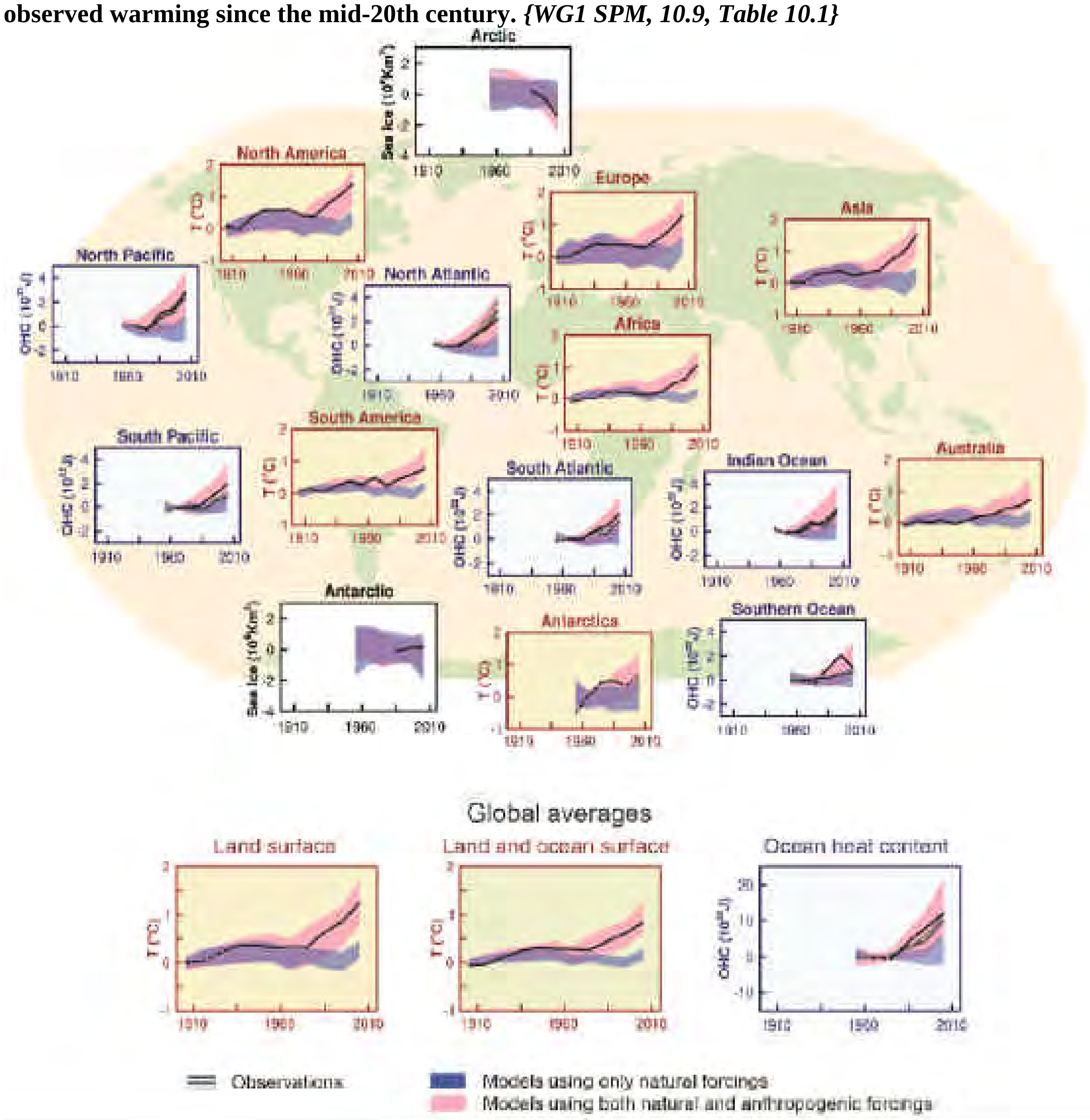


Figure 1.7: Comparison of observed and simulated climate change for change in continental land surface air temperatures (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels). Global average changes are also given. Anomalies are given relative to 1880–1919 for surface temperatures, 1960–1980 for ocean heat content and 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 datasets; 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}*

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. 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 1951−2010, with further contributions from other anthropogenic forcings, including the cooling effect of aerosols (*likely* in the range of −0.6°C to 0.1°C), natural forcings (*likely* in the range of −0.1°C to 0.1°C), and from internal variability (*likely* in the range of −0.1°C to 0.1°C). Together these assessed contributions are consistent with the observed warming of approximately 0.6°C to 0.7°C over this period (Figure 1.2). *{WGI SPM, 10.3}*

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, 2.4, 9.4, 10.3}*

Over every continental region except Antarctica, anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century (Figure 1.6). For Antarctica, however, large observational uncertainties result in *low confidence* that anthropogenic forcings have contributed to the observed warming averaged over available stations. By 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, 10.3, TS 4.8}*

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 in the atmosphere (*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*), and to changes in surface and subsurface ocean salinity (*very likely*). *{WG1 2.5, 2.6, 3.3, 7.6, 10.3, 10.4}*

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 1.6). 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 that is thermal expansion and glacier mass loss. Oceanic uptake of anthropogenic carbon dioxide has resulted in the acidification of ocean surface waters. *{WGI SPM, 3.2, 3.8, 10.4, 10.5, 13.3, Box 3.2, TS 4.4; WGII 6.1.1.2}*

Anthropogenic influences have *very likely* contributed to Arctic sea ice loss since 1979 (Figure 1.6). 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 10.5, 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, 10.5}*

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. 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 1.8). *{WGII 18.1, 18.3-6}*

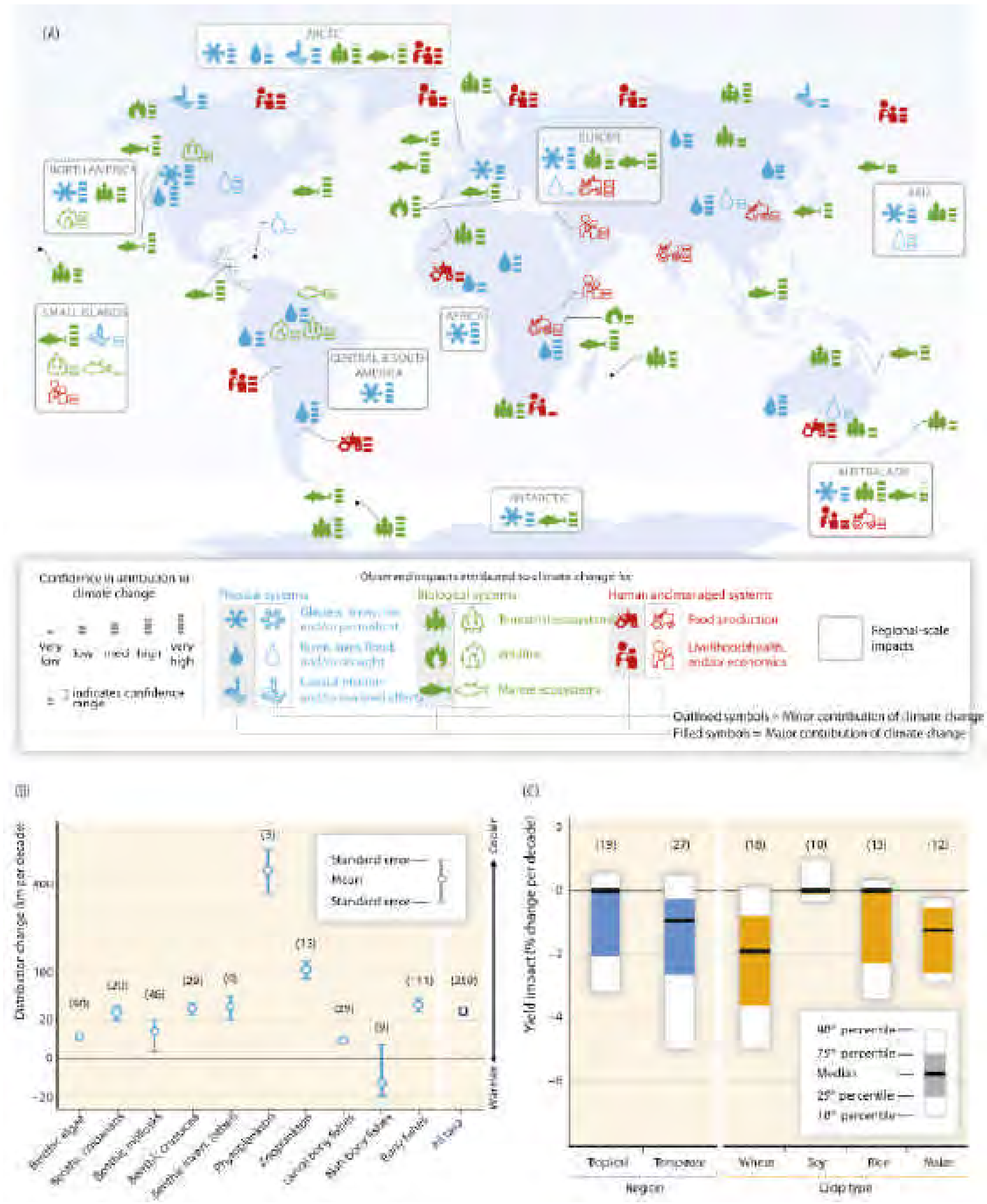


Figure 1.8: Widespread indicators of a changing climate. (A) Global patterns of observed climate change impacts in recent decades attributed to climate change, based on studies since the AR4. For categories of attributed impacts, symbols indicate affected systems and sectors, the relative contribution of climate change (major or minor) to the observed change, 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 analyzed 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 analyzed given for each category. *{WGII Figures 3-3, 4-7, 7-2, 18-3, WGII MB-2, and WG II 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 3.2, 4.3, 18.3, 18.5, 24.4, 26.2, 28.2, WGII Tables 3-1 and 25-1, WGII Figures 18-2 and 26-1}*

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*). *{ WGII SPM.2B, WGII 4.2-4, 5.3-4, 6.1, 6.3-4, 18.3, 18.5, 22.3, 24.4, 25.6, 28.2, 30.4-5, WGII Boxes 4-2, 4-3, 25-3, CC-CR, and CC-MB}*

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 SPM.2C. 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.2C, WGII 7.2, 18.4, 22.3, 26.5, WGII Figures 7-2, 7-3, and 7-7}*

At present the world-wide 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*). *{WG 11.4-6, 18.4, 25.8}*

"Cascading" impacts of climate change from physical climate through ecosystems on people can now be detected along chains of evidence. Examples include systems in the cryosphere, the oceans, and forests (Figure 1.9). *{WGII 18.6.3}* The changes in climate feeding into the cascade are in some cases linked to human drivers through studies (e.g., North American snowpack). In other cases, results from available studies linking climate change to human drivers are only available for different spatial and temporal scales, making it difficult to estimate the magnitude of the contribution by human influences to the observed impacts. *{WGI, 10; WGII 18.6.3}*

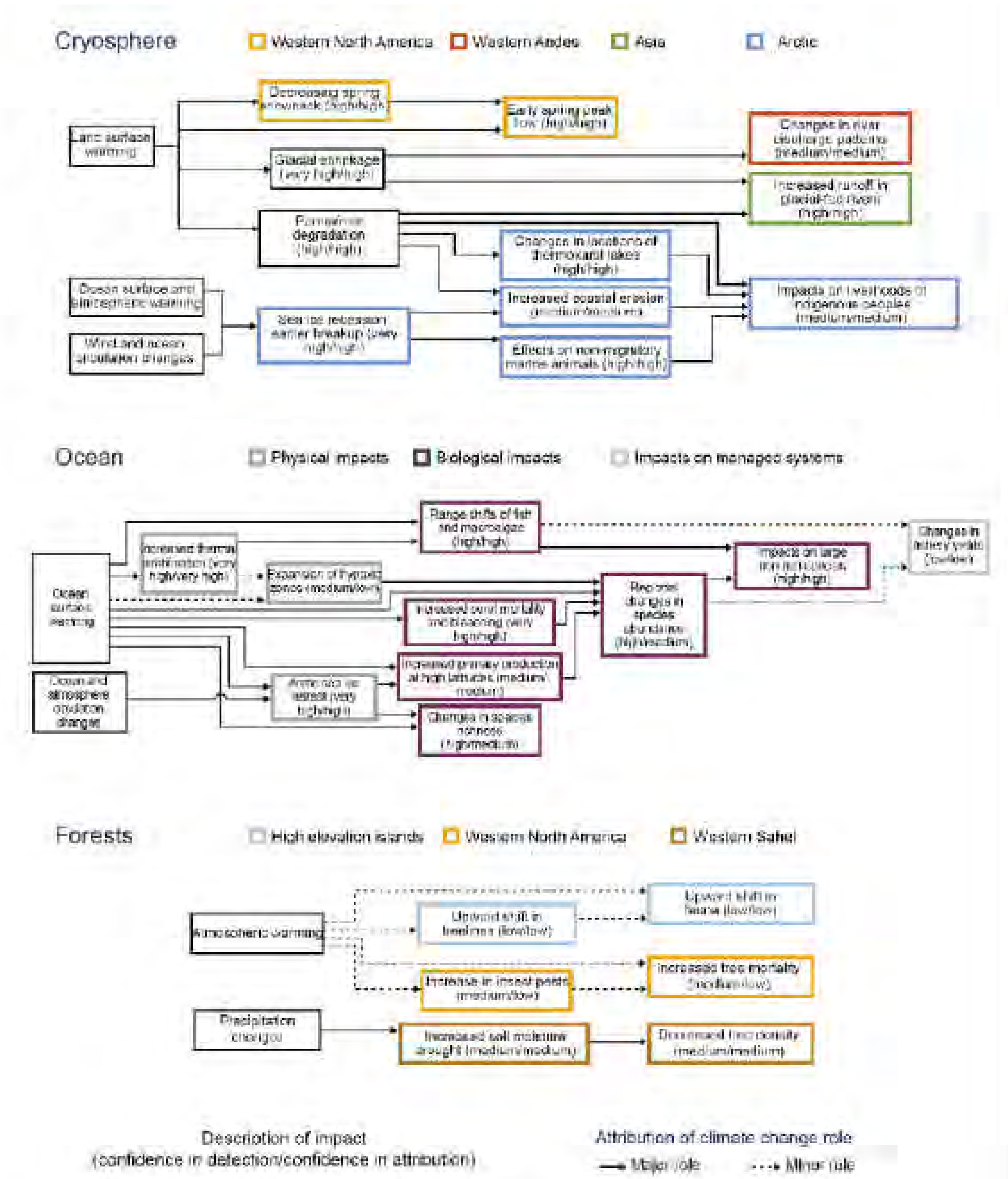


Figure 1.9: Major systems where new evidence indicates interconnected, 'cascading' impacts from recent climate change through several natural and human subsystems. Bracketed text indicates confidence in the detection of a climate change effect and the attribution of observed impacts to climate change. The role of climate change can be major (solid arrow) or minor (dashed arrow). *{WGII Figure 18-4; confidence assessed in WGII 18.3, 18.4, 18.5, and 18.6}*

1.5 Vulnerability, exposure and extreme events

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 high sea level events, and some of these changes have been linked to human influences. 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.

The character and severity of impacts from climate extremes depends not only on the extremes themselves but also on exposure and vulnerability and consequently does their associated risks. Exposure and vulnerability are influenced by a wide range of social and economic factors *{SREX SPM A}*, which make difficult to make quantitative assessments of their trends.

Changes in many extreme weather and climate events have been observed since about 1950. 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. *{WGI Table SPM.1, WGI FAQ 2.2, 2.6; 10.6; Table SPM.1}*

There has been increased heat-related mortality and decreased cold-related 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*), with impacts that vary by age, location and socioeconomic factors (*high confidence*). *{WGII 26.6.1.2}* In Europe, the summer 2003, which was the hottest summer in the last 500 years, caused 35,000 excess deaths. *{WGII Table 23.1}* An extreme warm event occurred in Moscow during July and August 2010 in the hottest summer since 1500 with estimated 10,000 excess deaths. *{WGII SPM A-1, WGII Table 23.1, 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. It is *very likely* that global near surface and tropospheric air specific humidity have increased since the 1970s. The frequency or intensity of heavy precipitation events has *likely* increased in North America and Europe. In other continents, *confidence* in changes in heavy precipitation events is at most *medium*. 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 2.6, 10.6, 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 floods at global scale. The strength of the evidence is limited mainly by lack of long-term records from unmanaged catchments. Moreover, floods are strongly influenced by direct management of the catchments, making the attribution of detected changes to climate change difficult. **However, recent detection of trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale (*medium confidence*).** Flood damage costs worldwide have been increasing since the 1970s, although this is partly due to increasing exposure of people and assets. *{WGI 2.6.2; Figure 2.33; WGII 3.2.3}*

There is *low confidence* in observed global- scale trends in drought, due to lack of direct observations, dependencies of inferred trends on the choice of drought index, 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 2.6.2.2, Fig. 2-33b; 10.6}*

After accounting for changes in observing capabilities, there is *low confidence* that long-term changes in tropical cyclone activity are robust and there is *low confidence* in attribution of global changes to any particular cause. However, it is *virtually certain* that tropical cyclone intensity has increased in the North Atlantic since 1970. *{WG1: SPM, 2.6.3, 10.6}*

It is *likely* that extreme sea levels have increased since 1970, being mainly a result of rising mean sea level. Due to a shortage of studies and the difficulty to distinguish any such impacts from other modifications of coastal systems, limited evidence is available on impacts of sea level rise. *{WG1 3.7.4, 3.7.5, Figure 3-14, WGII 5.3.2.1}*

While changes in climate variables depend on the variable itself, as well as in geography, impact changes are even more geographically heterogeneous since they not only depend on changes of climate variables, but also on social and economic factors. Therefore is more frequent that they could be identified locally or regionally than at global scale.

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 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}*

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, 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, 25.6-8, 26.6-7, 30.5, WGII Tables 18-3 and 23-1, WGII Figure 26-2, 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. *{SREX 4.5.3.3, WGII 10.7.3}* Most of this increase has been attributed to increasing exposure of more assets in risk areas. *{SREX 4.5.3.3, WGII 10.7.3, SREX SPM B}*

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 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}*

1.6 Adaptation experience

Adaptation experience is accumulating across regions in the public and private sector and within communities; and adaptation is becoming embedded in some planning processes, with more limited implementation of responses.

Throughout history, people and societies have adjusted to and coped with climate, climate variability, and extremes, with varying degrees of success. This section focuses on adaptive human responses to observed and projected climate-change impacts, which can also address broader risk-reduction and development objectives. Mitigation experience is discussed in Topic 4, Section 4.5.

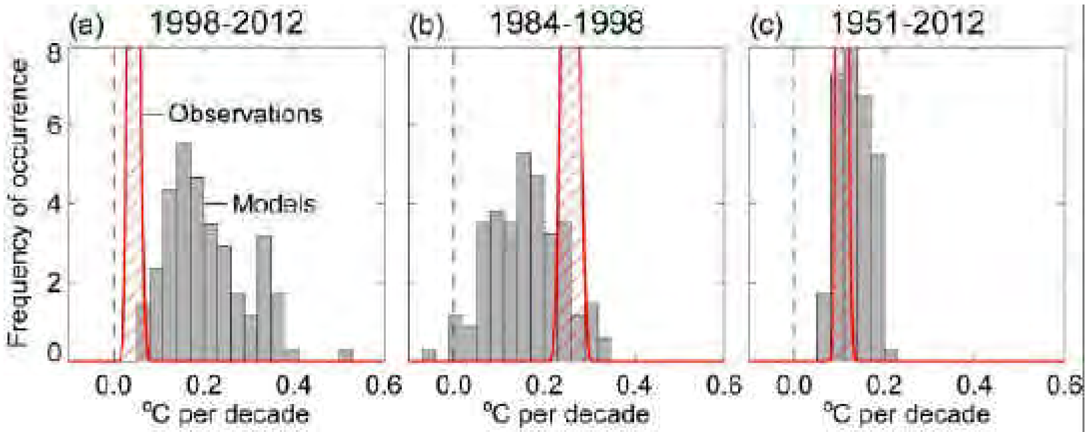
Adaptation is becoming embedded in some planning processes, with more limited implementation of responses (*high confidence*). Engineered and technological options are commonly implemented adaptive responses, often integrated within existing programs such as disaster risk management and water management. There is increasing recognition of the value of social, institutional, and ecosystem-based measures and of the extent of constraints to adaptation. Adaptation options adopted to date continue to 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}*

Adaptation experience is accumulating across regions in the public and private sector and within communities (*high confidence*). Governments at various levels are starting to develop adaptation plans and policies and to integrate climate-change considerations into broader development plans. Examples of adaptation across regions include the following.

- In 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.
- In 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.
- In 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.
- In 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.
- In 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.
- In 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.
- In the Arctic, some communities have begun to deploy adaptive co-management strategies and communications infrastructure, combining traditional and scientific knowledge.
- In small islands, which have diverse physical and human attributes, community-based adaptation has been shown to generate larger benefits when delivered in conjunction with other development activities.
- In the 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. *{WGII SPM}*

Box 1.1: Recent temperature trends and their implications

There is *very high confidence* that climate models reproduce the general features of the global-scale annual mean surface temperature increase over the historical period, including the more rapid warming in the second half of the 20th century, and the cooling immediately following large volcanic eruptions. The observed recent decrease in the rate of surface warming is attributable in roughly equal measure to a cooling contribution from internal natural variability and a reduced trend in external forcing (expert judgment, *medium confidence*) (Box 1.1, Figure 1). {*WG1 Box TS.3,4, 2.4, 3.2, 3.7, 8.5, 9.4; Table 2.7; Box 9.2, Box 12.2, Box 13.2*}



Box 1.1, Figure 1: Trends in the global-mean surface temperature over the periods 1998–2012 (a), 1984–1998 (b), and 1951–2012 (c), from observations (red) and the 114 available simulations with current-generation climate models (grey bars). The width of the red-hatched area indicates the statistical uncertainty that arises from constructing a global average from individual station data. The height of each grey bar indicates how often a trend of a certain magnitude (in °C per decade) occurs among the 114 simulations. *{based on WG1 Box 9.2 Figure 1}*

The long-term surface-warming trend observed over 1951–2012 (Figure 1.1a) is consistent with simulations of the historical period with current climate models over the same period (Box SYR.1, Figure 1c, *very high confidence*). The record of observed climate change has also allowed characterisation of the basic properties of the climate system that have implications for future warming, including the equilibrium climate sensitivity (ECS) and the transient climate response (TCR) and thus contributes to the assessment of both climate system properties (see SYR topic 2; WGI 10.8, Box 12.2). Conversely, the independent estimates of radiative forcing, of observed heat storage, and of surface warming that have been 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)[9].

The rate of warming of the observed global-mean surface temperature has been smaller over the past 15 years (1998–2012) than over the past 30 to 60 years (Box 1.1, Figure 1) and is estimated to be around one-third to one-half of the trend over the period 1951–2012. Nevertheless, the decade of the 2000s has been the warmest in the instrumental record (Figure SYR.1a). *{WGI Box TS.3}*

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. Consistent with this radiative forcing, the climate system has *very likely* continued to accumulate heat since 1998, and sea level has continued to rise. The radiative forcing of the climate system has been increasing to a lesser rate over the period 1998–2011 compared to 1984 to 1998 or 1951–2011, due to a downward forcing trend from volcanic eruptions and the downward phase of the solar cycle over 2000 2009. However, there is *low confidence* in quantifying the role of forcing trend in causing the reduction in the rate of surface warming, because of uncertainty in the magnitude of the

[9] The connection of the heat budget to 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 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.

volcanic forcing trend and *low confidence* in the forcing trend due to tropospheric aerosol. *{WG1 8.5; WG1 Box 9.2}*

For the period 1998–2012, 111 of the 114 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 unpredictable internal climate variability. Variability sometimes enhances and sometimes counteracts the long-term externally forced warming trend (Box 1.1, Figure 1). 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 too strong a response to increasing greenhouse gases and other anthropogenic factors. *{WG1 2.4, 9.3, 9.4; 10.3, 11.2, 11.3, WG1 Box 9.2}*

Topic 2: Future climate changes, risks and impacts

Projecting changes in the climate system is done using a hierarchy of simulation models ranging from the simple, through intermediate complexity, to comprehensive Global Climate Models (GCMs), including Earth System Models (ESMs) that simulate the carbon cycle. The models are science-based and extensively tested against historical observations. Climate projections are driven by scenarios of natural and anthropogenic forcings, the standard set for AR5 being the Representative Concentration Pathways (RCPs). *{WGI Box SPM.1}* Impacts and risks are assessed using a variety of methods, including Integrated Assessment Models (IAMs). *{WGII 19.2}* Modelled future impacts assessed in this report are generally based on climate-model projections using the RCPs, and in some cases, the older SRES scenarios. *{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}*

Continued emissions of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system. Limiting climate change and associated risks to people and ecosystems will require substantial and sustained reductions of greenhouse gases emissions.

2.1 Drivers and scenarios of future change in climate

Scenarios of greenhouse gas and air pollutant emissions and land-use changes are used to explore how changes in these factors influence the future climate on different timescales. *{WGI 11.3, 12.4; WGIII 6.1}* The effects of CO_2 emissions persist for centuries; depending on the scenario, 15-40% of emitted CO_2 will remain in the atmosphere longer than 1,000 years. *{WGI SPM; Box 6-1; 8.7}* Nitrous oxide has a lifetime of about a century; methane a decade, while air pollutants like ozone and aerosols and their precursors have lifetimes of the order of days to weeks. *{WGI 8.7, 11.3}*

The key factors determining anthropogenic greenhouse gas emissions are population size, economic activity, energy use, land-use patterns, technology change, and climate policy. *{WGIII 5}* Scenarios are generated by a range of approaches, from simple idealised experiments to Integrated Assessment Models (IAMs), which provide comprehensive and internally consistent scenarios of future socio-economic change, emissions and climate response.

The “Representative Concentration Pathways”, or RCPs, describe the 21st century evolution of atmospheric greenhouse gas concentrations, land-use changes and emissions of air pollutants under four very different futures. Developed using IAMs, the RCPs are used as input to a wide range of climate model simulations to project their consequences for the climate system. *{WGI 11-14}* These climate projections are then used for impacts and adaptation assessment. *{WGII 19}* The RCPs can also be compared to a wider set of scenarios to assess the costs associated with emission reductions consistent with these concentration pathways. *{WGIII 6.3.2, 6.3.6}*

RCP8.5 represents a high emission scenario with no climate mitigation policies; RCP6.0 represents many middle-of-the-road scenarios with very modest or no climate policies; RCP4.5 represents a medium mitigation scenario; while RCP2.6 represents more aggressive mitigation scenarios which aim to keep global warming below 2°C above pre-industrial temperatures. Many models indicate that meeting the RCP2.6 scenario will require substantial net negative emissions by 2100, in some cases of about 2 $GtCO_2$/yr. *{WGIII 6.3.2; WGI 6}* Land-use changes in the RCPs range from strong reforestation to further deforestation. For air pollution, the RCP scenarios point to more consistent improvements in air quality as a consequence of assumed air pollution control and greenhouse gas mitigation policy (Figure 2.1). For each scenario, there is significant uncertainty in the response to aerosol emissions.

Compared with the SRES scenarios used in previous Assessments, the RCPs cover a wider range of possible outcomes for greenhouse gas and overall forcing levels. In terms of overall forcing, RCP8.5 is broadly comparable to the SRES A2 scenario, RCP6.0 to B2 and RCP4.5 to B1. For RCP2.6, there is no equivalent scenario in SRES.

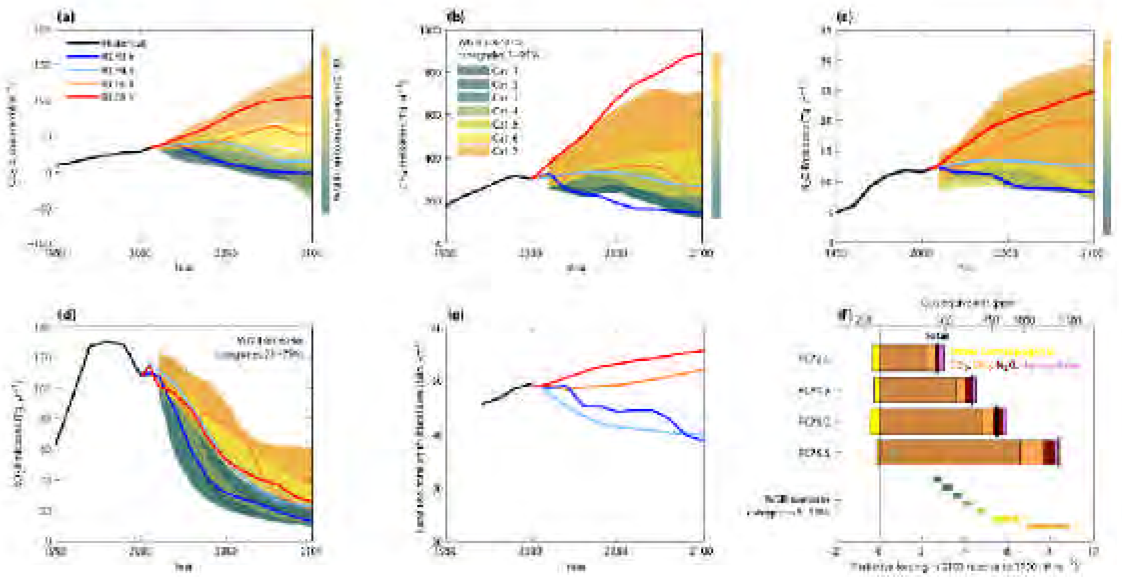


Figure 2.1: Emission and land use scenarios and the resulting radiative forcing levels included in the RCPs (lines) and the associated scenarios categories used in WGIII which are defined based on CO_2eq concentrations[10] by 2100 (colored areas; Topic 3.2). Panel a-d show the emissions of CO_2, CH_4, N_2O and SO_2. Panel e shows the sum of crop and pasture land for the RCPs. Panel f shows future radiative forcing levels calculated using the MAGICC-6 simple model for the RCPs (by forcing agent) and for the WGIII scenario categories (total). *{WG1 8.2, 8.5, Annex II, WG III Tables SPM.1 and 6.3}*

Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. *{WGII SPM}* 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 19.2.4, Figure 19-1, Box 19-2}* Understanding future vulnerability, as well as exposure, of 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 aging, access to technology and information, labour force participation, the quality of adaptive responses, societal values, and mechanisms and institutions to resolve conflicts. These factors have been incompletely considered to date. *{WGII 11.3, 21.3-5, 25.3-4, 25.11, 26.2}*

2.2 The methods used to make projections

Climate and impact models have improved since the AR4. In particular, confidence in projections of sea level rise has increased.

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[10] CO_2-equivalent concentrations are different from CO_2-equivalent emissions.

Equivalent carbon dioxide (CO_2) emissions:

The amount of carbon dioxide emission that would cause the same integrated radiative forcing, over a given time horizon, as an emitted amount of a greenhouse gas or a mixture of greenhouse gases. The equivalent carbon dioxide emission is obtained by multiplying the emission of a greenhouse gas by its Global Warming Potential for the given time horizon. For a mix of greenhouse gases it is obtained by summing the equivalent carbon dioxide emissions of each gas. Equivalent carbon dioxide emission is a common scale for comparing emissions of different greenhouse gases but does not imply equivalence of the corresponding climate change responses.

Equivalent carbon dioxide (CO_2) concentrations:

The concentration of carbon dioxide that would cause the same radiative forcing as a given mixture of carbon dioxide and other forcing components. Those values may consider only greenhouse gases concentrations, or a combination of greenhouse gases and aerosols concentrations. Equivalent carbon dioxide concentration is a metric for comparing radiative forcing of a mix of different greenhouse gases at a particular time but does not imply equivalence of the corresponding climate change responses nor future forcing. There is generally no connection between equivalent carbon dioxide emissions and resulting equivalent carbon dioxide concentrations

2.2.1 Models of the Earth System: atmosphere, ocean and land

Climate models are mathematical representations of processes important to the simulation of the Earth's climate system. They are based on verifiable physical and biogeochemical principles and are evaluated by comparison with observed climate. They simulate many aspects of climate, including the temperature of the atmosphere and ocean, precipitation, winds, clouds, aerosols, ocean currents, and sea-ice extent. When combined with future climate forcings, they are used to make projections of future climate. *{WGI 1, 9}*

Improvements in climate models since the AR4 are evident in simulations of continental-scale surface temperature and 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 trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions (*very high confidence*). *{WGI SPM, 7.3, 7.6, 9.5-7, 10.3}* 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. *Confidence* in the representation of processes involving clouds and aerosols remains *low*. *{WGI SPM, 7.3, 7.6, 9.1, 9.2, 9.4, 9.6, 9.8}*

2.2.2 Models and methods for estimating the risks, vulnerability and impacts of climate change

The experiments, observations and models used to estimate risks and future impacts have all improved since the AR4. In most instances, the range of future uncertainty has narrowed. In some cases, new knowledge has revealed previously unaccounted sources of uncertainty. *{WGII 4.3.2.5}*

Future risks, vulnerabilities and impacts of climate change are estimated in the AR5 and previous assessments through experiments, analogies and models. "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. For instance, the Free Air Concentration Experiments or Free Ocean Concentration Experiments reveal the effects of rising CO_2 and O_3 on ecosystems, species or crops. "Analogies" are 'natural' experiments, used when controlled experiments are impractical due to ethical constrains, the large area or long time required, or high system complexity. Two types of analogies are used in projections. Spatial analogies identify another part of the world currently experiencing similar conditions to those anticipated to be experienced in the future. For example, niche envelope models project future distributions of species based on their current distribution. Temporal analogies are changes in the past that are used to make inferences about changes in the future. Conditions in the past are sometimes inferred from paleo-ecological data. Models in this context are typically numerical simulations of simplified systems, calibrated and validated using observations from experiments or analogies, and then run using input data representing future climates. Models can also include largely descriptive narratives of possible futures, such as those used in scenario construction; quantitative, process-based models and descriptive models are often used together. Models, including those with socio-economic components, are not independent of the value judgments, world views, or preferences of the modeller. The impacts are modelled for water resources, biodiversity and ecosystem services on land, for inland water and the oceans, 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. 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 and likelihoods into an evaluation of risk. An example is the calibrated language on uncertainty used by the IPCC over the past three assessments, and its extension into the evaluation of risk as a function of hazards, exposure, and vulnerability in the AR5 WGII. *{WGII 19.2, 21.1}*

2.3 Confidence in projections

While relevant scientific understanding and capability has advanced since the last report {WGI 1.1, 12.1, FAQ 1.1, FAQ 9.1; WGII 21.3 21.5}, the degree of confidence in climate change projections and associated impacts varies, depending on which aspect of the future is considered. Confidence varies because the quality, amount and degree of agreement among different sources of evidence for particular projections and impacts vary. Some projected changes and impacts are provided as statements of fact, while others are assigned confidence levels ranging from very high to very low. *{WGI 1.4, 11.2, 11.3, 12.2; WGII 1.1, Box 1-1}* For example, "continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system" is stated as a fact. *{WGI SPM}* There is *high confidence* that an increase in high sea level extremes will primarily be the result of an increase in mean sea level *{WGI SPM}* and in the assessment that 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 globally and regionally. *{WGII SPM, Chapter7 ES}* There is *medium confidence* that risks of global aggregate impacts are moderate for additional warming between 1-2°C, reflecting impacts to both Earth's biodiversity and the overall global economy *{WGII SPM}*; but there is only *low confidence* in projected changes in the frequency of tropical cyclones at the regional scale *{WGI 14}*. All of the assessments of confidence are based on the opinions of the expert authors, informed by the best available information. *{WG 1 SPM, 1}*

2.4 Projected changes in the climate system

Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system across the globe.

Projected changes described below are for 2081-2100 relative to 1986-2005 unless otherwise indicated. The period 1986-2005 is approximately 0.61˚C [0.55 to 0.67] ˚C warmer than 1850-1900. *{WGI SPM}*

2.4.1 Air Temperature

Global-mean surface air temperature is projected to rise over the 21st century under all of the GHG concentration pathways represented by the RCPs. The projected increase will occur in conjunction with naturally occurring climatic variability. *{WGI 11.3, 12.4}*

The global mean surface air temperature change for the period 2016-2035 will *likely* be in the range 0.3˚C-0.7˚C (*medium confidence*). By mid-21st century, the rate of global warming begins to be more strongly dependent on the emissions scenario. *{WGI SPM, 11.3, 12.3}*

Global-mean surface air temperature change for 2081–2100 will *likely* be 0.3°C–1.7°C (under RCP2.6) to 2.6°C–4.8°C (under RCP8.5) (Figure 2.2, Table 2.1). *{WGI SPM, 11.3, 12.3}*

Global surface air temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850-1900 for all RCP scenarios except RCP2.6. It is *likely* to exceed 2°C for RCP6.0 and RCP8.5, *more likely than not* to exceed 2°C for RCP4.5, but *unlikely* to exceed 2°C for RCP2.6 (*medium confidence*). *{WGI SPM, 12.3}*

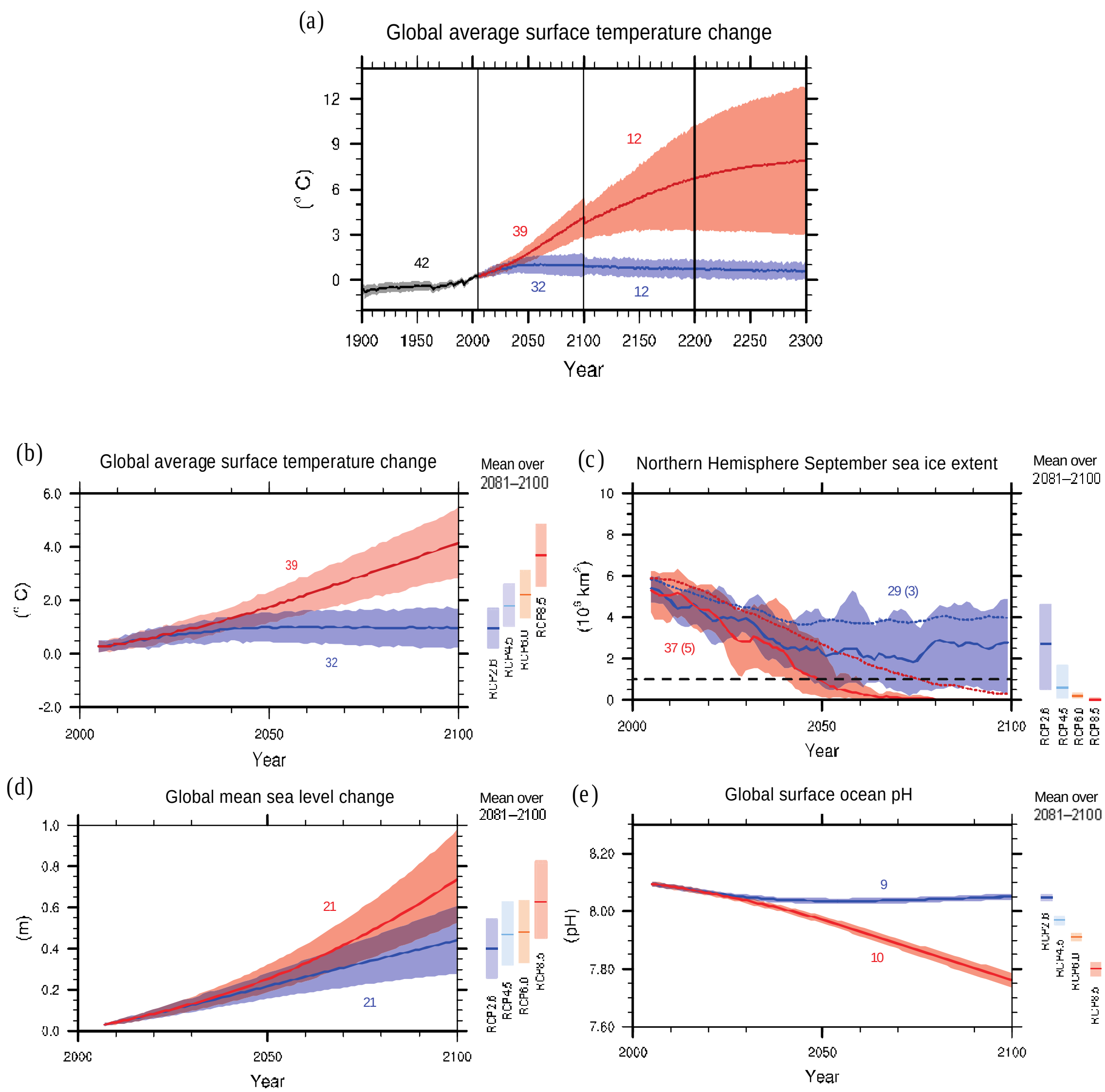


Figure 2.2: CMIP5 multi-model simulated time series from 1900 to 2300 for change in global annual mean surface temperature, (b) Same as (a) but for the 2005-2100 period, (c) Northern Hemisphere September sea ice extent change relative to (5 year running mean). (d) global mean sea level rise, and (e) ocean surface pH. 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 colored vertical bars at the right end side of each panel. 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) of the subset of models that most closely reproduce the climatological mean state and 1979-2012 trend of the Arctic sea ice is given (number of models given in brackets). For completeness, the CMIP5 multi-model mean Arctic sea-ice is also indicated with dotted lines. *{WGI Figure SPM.7}* 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.

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 reference period (1986-2005). *{WG1 SPM, 12.4, Table 12.2, Table 13.5}*

		2045-2065		2081-2100	
	Scenario	**Mean**	***Likely* range**	**Mean**	***Likely* range**
Global Mean Surface Temperature Change (°C)	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**	**Mean**	***Likely* range**
Global Mean Sea Level Rise[a] (m)	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 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.

The Arctic region will warm more rapidly than the global mean, and warming will be larger over the land than over the ocean *(very high confidence)* (Figure 2.3). *{WGI SPM, 11.3, 12.3, 12.4, 14.8}*

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 temperatures increases. It is *very likely* that heat waves will tend to occur more often and last longer. Occasional cold winter extremes will continue to occur. *{WGI SPM, 12.4}*

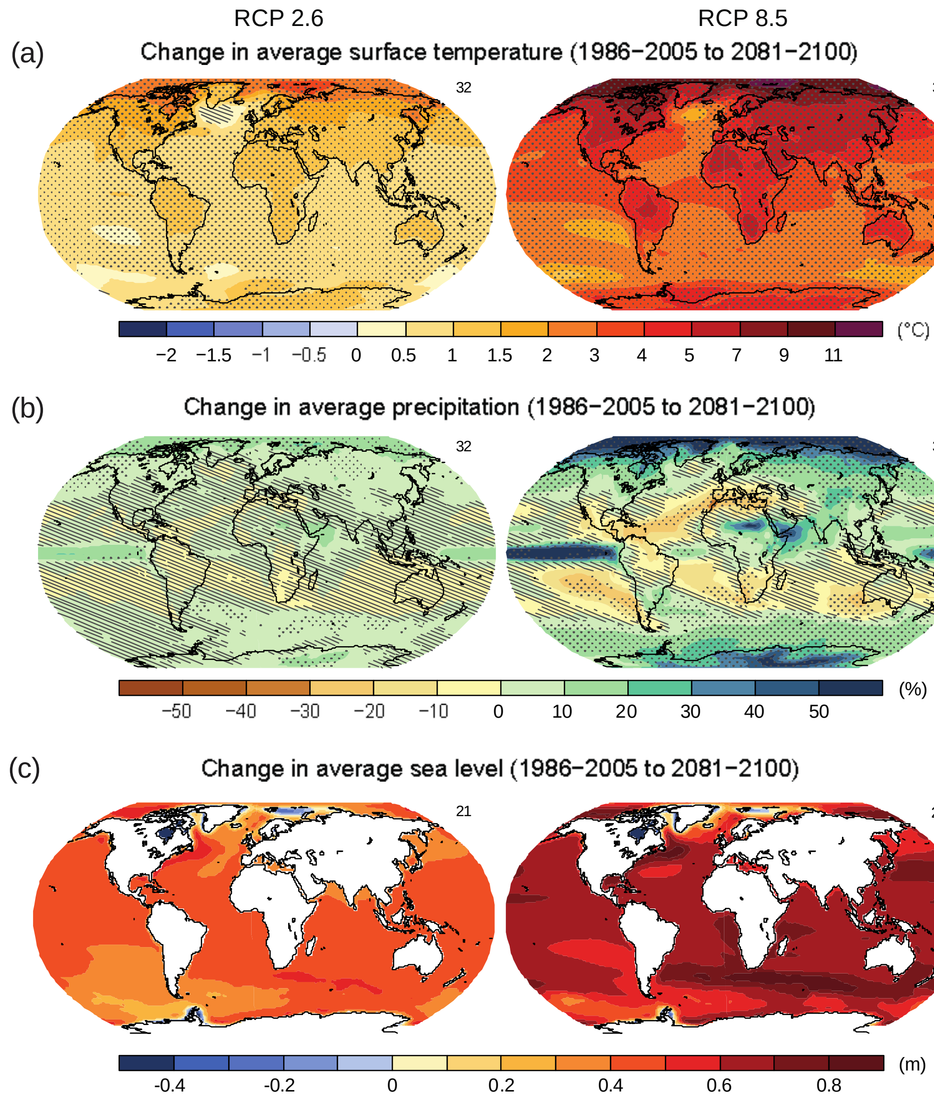


Figure 2.3: CMIP5 multi-model mean projections 2081– 2100 under the RCP2.6 (left) and RCP8.5 (right) scenarios for (a) annual mean surface temperature change and (b) average percent change in annual mean precipitation and (c) average sea level. Changes are shown relative to 1986–2005. The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Hatching on (a) and (b) shows regions where the multi-model mean is small compared to internal variability (i.e., less than one standard deviation of internal variability in 20-year means). Stippling on (a) and (b) indicates regions where the multi-model mean is large compared to internal variability (i.e., greater than two standard deviations of internal variability in 20-year means) and where 90% of models agree on the sign of change. See WGI, Box 12.1). *{WGI Figure SPM.8, Figure 13.20}*

2.4.2 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 2.3). *{WGI 7.6, 12.4, 14.3}*

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, 7.6, 12.4}*

Globally, it is *likely* that the area encompassed by monsoon systems will increase and monsoon precipitation is *likely* to intensify due to the increase in atmospheric moisture. {WGI 14.2} Due to the increase in moisture availability, El Niño-Southern Oscillation (ENSO) related precipitation variability on regional scales will *likely* intensify. *{WGI 14.4}*

It is *likely* that the number of tropical cyclones across the globe will either decrease or remain essentially unchanged, concurrent with a *likely* increase in both global mean tropical cyclone maximum wind speed and rain rates. There is low confidence in projected regional changes in tropical cyclones. *{WGI 14.6, 14.8}*

2.4.3 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*). *{WGI 12.4}*

Year-round reductions in Arctic sea ice are projected for all RCP scenarios. Based on an assessment of the subset of models that most closely reproduce the observations[11], a nearly ice-free Arctic Ocean[12] in September before mid-century is *likely* for RCP8.5 (*medium confidence*) (Figure 2.2). In the Antarctic, a decrease in sea ice extent and volume is projected with *low confidence*. *{WGI 12.4}*

The area of Northern Hemisphere spring snow cover is projected to decrease by 7% for RCP2.6 and by 25% in RCP8. (*medium confidence*). *{WGI 12.4}*

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 projected to decrease by between 37% (RCP2.6) to 81% (RCP8.5) (*medium confidence*). *{WGI 12.4}*

The global glacier volume, excluding glaciers on the periphery of Antarctica, is projected to decrease by 15 to 55% for RCP2.6, and by 35 to 85% for RCP8.5 (*medium confidence*). *{WGI 13.4, 13.5}*

Global mean sea level will continue to rise during the 21st century and beyond. Under all RCP scenarios, the rate of sea level rise will *very likely* exceed that observed during 1971–2010. *{WGI 13.3-5}*

Global mean sea level rise will *likely* be in the ranges of 0.26 to 0.55 m for RCP2.6 to 0.45 to 0.82 m for RCP8.5. For RCP8.5, the rise by the year 2100 is 0.52 to 0.98 m, with a rate during 2081–2100 of 8 to 16 mm yr^{-1} (*medium confidence*). (Figure 2.2, Table 2.1). *{WGI 13.5}* 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, 13.4,13.5}*

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. About 70% of the coastlines worldwide are projected to experience sea level change within 20% of the global mean sea level change (Figure 2.3). *{WGI 13.1, 13.6}*

2.4.4 Carbon cycle

There is *high confidence* that the feedback between climate and the carbon cycle is positive in the 21st century. 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. *{WGI 6.4}* Earth System Models project a global increase in ocean acidification for all RCP scenarios, with a

[11] climatological mean state and 1979 to 2012 trend of the Arctic sea ice extent
[12] when sea ice extent is less than 10^6 km^2 for at least five consecutive years

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 2.2). *{WGI 6.4}*

2.4.5 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. *{WGI 10.8, Box 12.2}* The equilibrium climate sensitivity (ECS)[13] 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 Box 12.2}*

Cumulative emissions of CO_2 are the dominant factor determining the global mean surface warming by the late 21st century. *{WGI 12.5}* There is a strong and consistent relationship between projected cumulative CO_2 emissions and projected 21[st] century temperature change in both the RCPs and the wider set of mitigation scenarios analyzed in WGIII. Uncertainty in the carbon cycle and climate responses and in emissions of other gases and aerosols both contribute to the uncertainty in this relationship (Figure 2.4).

The transient climate response to cumulative carbon emissions (TCRE)[14] is *likely* in the range of 0.8°C to 2.5°C, and applies for cumulative emissions up to about 2000 GtC until the time temperatures peak. *{WGI 12.5, Box 12.2}*

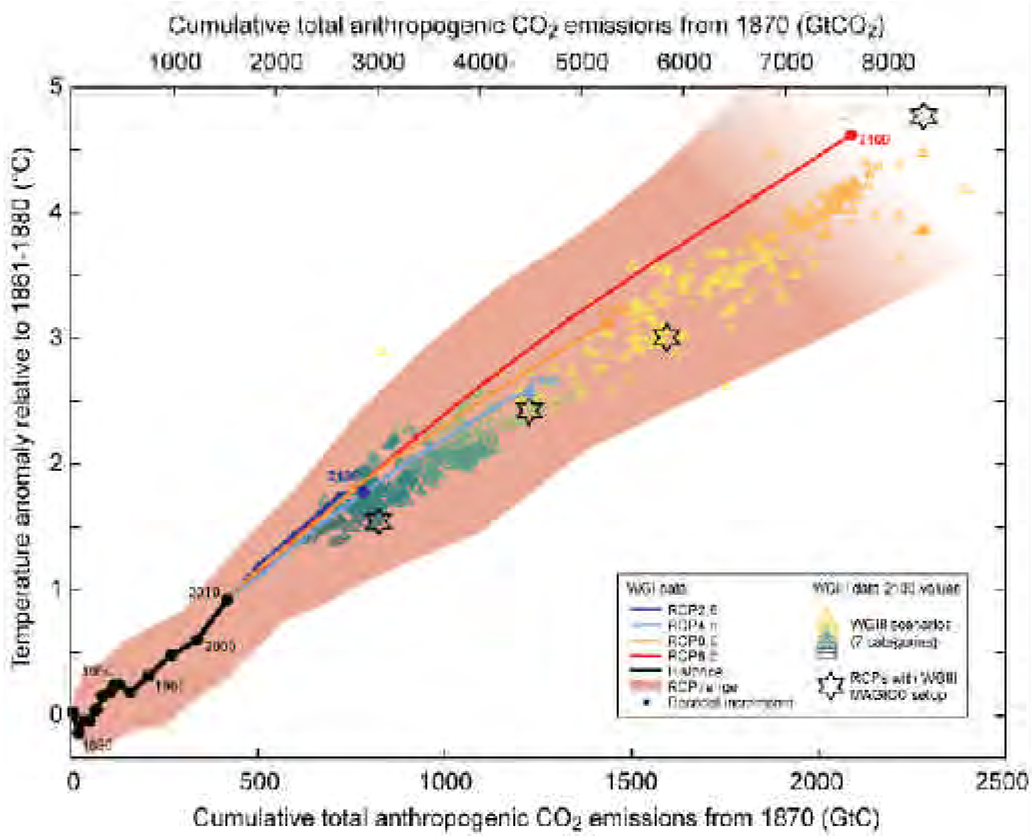


Figure 2.4: Global mean surface temperature increase as a function of cumulative total global CO_2 emissions from various lines of evidence. Multi-model results from a hierarchy of climate-carbon cycle models for each RCP until 2100 are shown (coloured lines). Model results over the historical period (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. Decadal averages are labelled using dots with the label referring to the year ending the decade. Triangles correspond to estimates for the year 2100 under 962 scenarios evaluated by WGIII, divided into the 7

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

[14] defined as the global mean surface temperature change per 1000 GtC of carbon dioxide emitted to the atmosphere.

categories described in Section 3.2. The four large star symbols are estimates for the 4 RCPs by the MAGICC6 simple model, with the set up used for the WGIII scenarios estimates. Temperature values are always given relative to the 1861-1880 period, and emissions are cumulative since 1870. *{WGI SPM, Figure 12.45; TS TFE.8, Figure 1 and TS Supplementary material, WG III Tables SPM.1 and 6.3}*

If total accumulated CO_2 emissions from all anthropogenic sources remain below about 3665 $GtCO_2$ over the 21st century, then warming, relative to 1861-1880, will *likely* be less than 2°C. This figure is reduced to about 2895 $GtCO_2$ when accounting for non-CO_2 forcings as in RCP2.6. An amount of 1890 [1630 to 2145] $GtCO_2$ has already been emitted by 2011 (Table 2.2). *{WGI 12.5}*

Table 2.2: Cumulative CO_2 emission budgets consistent with limiting warming to less than stated temperature goals at different levels of probability. *{WG1, 12.5; WGIII}*

Cumulative carbon budgets consistent with temperature goals [a]									
Assessed probability, multiple lines of evidence, CO_2-induced warming alone [b]	*Likely* less than 2°C			*About as likely as not* <2°C			*Unlikely* less than 2°C		
	3665 $GtCO_2$ (1000 GtC)			4435 $GtCO_2$ (1210 GtC)			5760 $GtCO_2$ (1570 GtC)		
Cumulative CO_2 emissions from 1870 in $GtCO_2$									
Fraction of simulations	66%			50%			33%		
Net anthropogenic warming	<1.5°C	<2°C	<3°C	<1.5°C	<2°C	<3°C	<1.5°C	<2°C	<3°C
Complex models, RCP scenarios only[c]	2250	2900	4200	2250	3000	4500	2550	3300	4850
Simple model, multiple parameters & WGIII scenarios[d]	2400-2850	2900-3600	4300-5400	2500-2950	3100-3800	4850-5950	2600-3100	3350-4050	5200-6550
Cumulative CO_2 emissions from 2011 in $GtCO_2$ [e]									
Simple model, multiple parameters & WGIII scenarios[d]	550-1000	1050-1750	2450-3550	650-1100	1250-1950	3000-4100	750-1250	1500-2200	3350-4700

[a] Temperature values are given relative to the 1861-1880 base period, and emissions are cumulated from 1870; cumulative CO_2 emissions are rounded to the nearest 50$GtCO_2$.
[b] Based on the assessed likely range for Transient Climate Response to Emissions (TCRE) of 0.8-2.5°C per 1000GtC cumulative emissions, modelled as the 1-standard deviation range of a Gaussian distribution.
[c] The figures show 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. Lower non-CO_2 forcing would imply a higher CO_2 budget consistent with a given temperature threshold, but comparing budgets implied by RCP2.6 with RCP8.5 suggests this is a limited effect if attention is restricted to RCP scenarios alone. Note that 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 models simulations consistent with meeting various climate targets.
[d] As note c, but showing the impact of variation in CO_2 budgets across scenarios. For each WGIII scenario, cumulative CO_2 emission budgets were diagnosed (with the simple model used by WGIII) that would cause temperatures to exceed the given threshold for 66%, 50% or 33% of simulations in an ensemble representing climate system and carbon cycle uncertainty. Figures show 5%-95% range of cumulative CO_2 emission budgets across the 962 scenarios considered by WGIII, accounting for variations across scenarios in non-CO_2 emissions and the (small) impact of the timing of CO_2 emissions. Note that these figures do not account for uncertainty in model structure.
[e] Provided for information, assuming 1850$GtCO_2$ for anthropogenic CO_2 emissions over the 1870-2010 period.

2.5 Future risks and impacts caused by a changing climate

Climate change is projected to amplify existing climate-related risks and create new risks for natural and human systems. Some of these risks will be limited to a particular sector or region, and others will have cascading effects. Large magnitudes of warming often increase the likelihood of more severe and pervasive impacts (Figure 2.5, Table 2.3). To a lesser extent, climate change is also projected to have some potential benefits. The precise levels of climate change that breach critical thresholds in the earth system, including its coupled human and natural subsystems, remain uncertain.

Increasing magnitudes of warming increase the likelihood of severe, pervasive, and irreversible impacts. Some risks of climate change are considerable at 1 or 2°C above preindustrial levels. Global climate change risks are high to very high with global mean temperature increase of 4°C or more above preindustrial levels in all reasons for concern, and include severe and widespread impacts on unique and threatened systems, substantial species extinction, large risks to global and regional food security, and the combination of high temperature and humidity compromising normal human activities, including growing food or working outdoors in some areas for parts of the year (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 multiple tipping points in the earth system or in interlinked human and natural systems increases with rising temperature *(medium confidence). {WGII SPM}*

Risks caused by a changing climate depend on the magnitude and rate of climate change, but also on the exposure, vulnerability, and ability of affected systems to adapt. Risk levels are considered low when climate change-induced impacts remain within the range of natural variability characterizing pre-industrial climates. Risks are considered high or very high once projected impacts become widespread and detrimental for present-day natural or human systems. Adaptation has the potential to reduce climate change impacts significantly, but its potential differs between sectors and there are constraints and limits to adaptation. Such constraints and limits vary significantly among global regions, institutions, sectors, communities, and ecological systems. Constraints and limits to adaptation depend on other stresses, change over time, and are closely linked to socioeconomic development pathways. Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). For each key risk in Figure 2.5, risk levels were assessed for three timeframes with current and high adaptation levels, considering the potential for and limits to adaptation. *{WGII TS Table 4}*

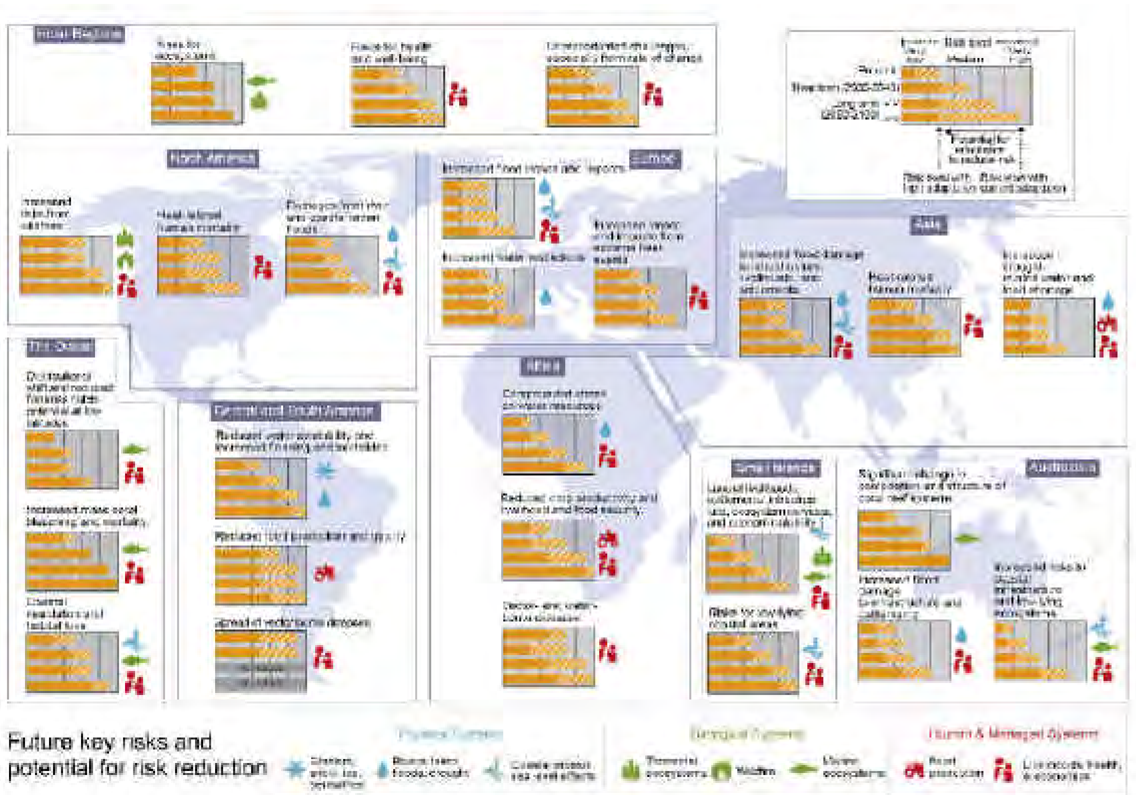


Figure 2.5: Example of regional key risks for physical, biological, and human and managed systems, and potential for risk reduction through adaptation. Key risks are identified based on assessment of the literature and expert judgment. Each risk is characterized as very low, low, medium, high, or very high. Risk levels are presented at three time frames: present, near-term (2030-2040), and long-term (2080-2100). Near-term indicates that projected levels of global mean temperature do not diverge substantially across emission scenarios. Long-term differentiates between a global mean temperature increase above 2°C and 4°C above pre-industrial levels. For each timeframe, risk levels are estimated for a continuation of current adaptation and for a high adaptation state. *{WGII TS Table 4}*

2.5.1 Ecosystems and their services in the oceans, at coasts, in freshwater and on land

There is high risk of substantive impacts on terrestrial and aquatic ecosystems as result of climate change, causing mostly negative consequences for biodiversity and ecosystem services (*high confidence*). Risks of harmful effects on ecosystems and human systems increase with the rate of warming, the magnitudes of ocean acidification and warming and the rates and magnitudes of sea level rise (Figure 2.6).

The current and projected rate of anthropogenic climate change is much faster than natural climate change during the past millions of years, which led to significant ecosystem shifts and species extinctions on land and in the oceans; there is thus a strong basis for expecting major climate change-induced risks to species and ecosystems (*high confidence*). Many 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 2.6). *{WGII 4.3-4, 6.1, 6.3, 6.5, 25.6, 26.4, Box CC-RF, Box CC-MB}*

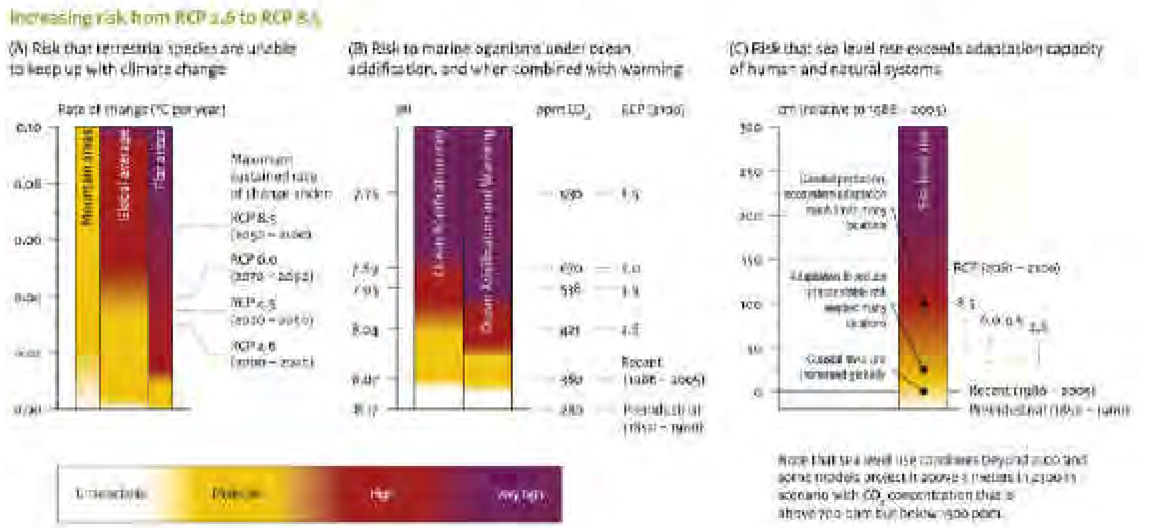


Figure 2.6: [PLACEHOLDER: CAPTION TO BE SHORTENED] There is increasing risk from RCP 2.6 to RCP 8.5 that (A) major groups of terrestrial and freshwater species are unable to move fast enough to stay within the climate envelopes to which they are adapted, (B) that sensitive marine organisms (e.g. those forming a calcium carbonate exoskeleton) are impacted by ocean acidification (OA) and combined OA and warming extremes and (C) that sea level rise exceeds adaptation capacity of human and natural systems. (A) Ember translates RCPs 2.6 to 8.5 to a rate of climate change (°C y^{-1}, averaged over the period of 20-30 years during which each RCP showed its maximum rate of change during the 21st century). The ability of various groups of organisms to track this rate of change by following their preferred temperatures is determined from their observed or modelled rates of movement, in km y^{-1}. This is converted to its equivalent in rate of climate change, which differs for flat landscapes and mountainous landscapes, with the global average in between. Zero rate of climate change corresponds to no additional risk (white colour). The yellow colour (moderate risk) begins when the rate of change exceeds the lower bound for trees, which move more slowly and where dieback has been detected on the hot end of their temperature range and accordingly, distributions. The transition to red (high risk) reflects the median limits to movement of several important groups of organisms, including trees, herbs, small mammals, molluscs and certain insects. Transition to purple (very high risk) occurs when none of the assessed groups are able to keep up. Only large, hoofed animals are able to keep up with the maximum rates of change shown on this graphic (birds were not assessed), thus all other groups are at high risk below this maximum. (B) Risks of harmful ecosystem effects of ocean acidification (OA) are moderate at present day CO_2 levels (380 ppm) which have caused detectable ocean acidification and a decline in calcification of some foraminifera and pteropods. Studies of sensitivity distribution among species (OA only, warming excluded) reflects onset of significant effects in 20 to 50 % of extant vulnerable taxa (corals, echinoderms, molluscs) beyond about 500 ppm turning risk into high. This percentage is rising progressively as more calcifying taxa are being affected, turning risk into very high beyond about 700 ppm. Current knowledge indicates that the combined pressures of warming extremes and acidification lead to a shift in sensitivity thresholds to lower CO_2 concentrations, as seen in corals and crustaceans. For corals this comes with the risk that OA will increasingly contribute to the marginalization of a whole ecosystem, a process that has already started due to a combination of various stressors (extreme events, predation, bleaching). Knowledge of the capacity for evolutionary adaptation and its limits is scarce (esp. in fishes). (C) For sea level rise, the height of a 50-yr flood event has already increased (by between 2 and 10 cm per decade) in many coastal locations, increasing risks for ecosystems and human systems from coastal floods and coastal erosion, in addition to the impact of population and socio-economic changes and non-climatic man-made stress. A 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. For a 1 m sea level rise, local adaptation (and in particular protection) will reach limits for ecosystems and human systems in many places. At that point, only a limited number of adaptation options remain, abandoned land will become more widespread, with significant investments in defense of cities and other key coastal infrastructure. *{WGI, 3.7.5, Figure 13.25, WGII, Figure 4.5, Figure 6.10, CC-OA, 5.2, 5.3-5, 5.4.4, 5.5.6}*

A large fraction of terrestrial, freshwater and marine species face increasing extinction risk, to a large degree due to climate change (*high confidence*). Extinctions will be driven by several climate-associated drivers (warming, reduced flows in rivers, ocean acidification and hypoxia) and the interactions of these drivers among themselves and with simultaneous habitat modification, over-exploitation of stocks, pollution, eutrophication and invasive species (*high confidence*). Extinction risk is increased under all RCP scenarios, as a result of both the magnitude and rate of climate change, *likely* reducing biodiversity and ecosystem services (*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 mid-21st century under 2°C global warming relative to 2001-2010, 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 (*medium confidence*). The progressive expansion of Oxygen Minimum Zones (OMZs) and anoxic "dead zones" in the oceans will further constrain fish habitat (*medium confidence*). Open-ocean net primary production is projected to redistribute and to fall 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, 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 a group 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*). Ocean acidification acts together with other global environmental 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 2.6 and 2.7). *{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}*

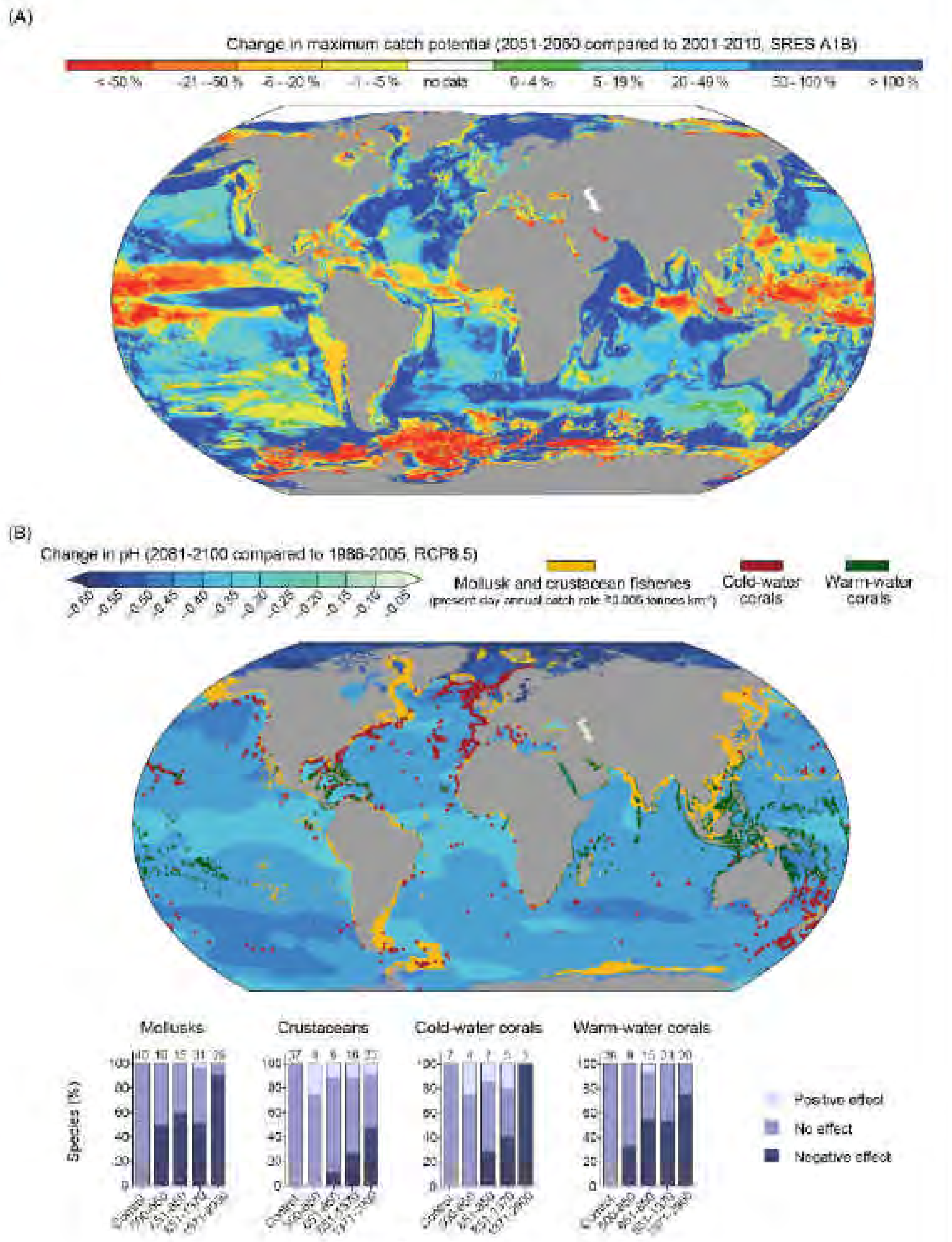


Figure 2.7: Climate change risks for fisheries. (A) For 2°C increase from preindustrial levels using SRES A1B (≈RCP6.0), projected global redistribution of maximum catch potential of 1000 species of exploited fishes and invertebrates, comparing the 10-year averages 2001-2010 and 2051-2060, without analysis of potential impacts of overfishing. (B) Marine mollusc and crustacean fisheries (estimated catch rates ≥0.005 tonnes per sq. km) and known locations of warm- and cold-water corals, depicted on a global map showing the distribution of ocean acidification in 2100 under RCP8.5. *{WGI AR5 Figure SPM.8}* The bottom panel compares sensitivity to ocean acidification across corals, molluscs, and crustaceans, vulnerable animal phyla with socioeconomic relevance (e.g., for coastal protection and fisheries). The number of species analyzed across studies is given 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 more or less equal to the unit ppm, WGII, Figure SPM.6). *{6.1, 6.3, 30.5, Figures 6-10 and 6-14; WGI AR5 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*). Increased tree mortality and associated forest dieback will occur in many places in the next one to three decades (*medium confidence*), posing risks for carbon storage, biodiversity, wood production, water quality, amenity, and economic activity. *{WGII SPM, 4.2-3, 25.6, 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 corals and coral reefs will erode habitats, increase coastline exposure to waves and storms, and degrade environmental features important to industries such as fisheries or tourism (*high confidence*). Some low-lying developing countries and small island states are expected to face very high impacts that, in some cases, could have associated damage and adaptation costs of several percentage points of GDP (Figure 2.6). *{WGII 5.3-5, 22.3, 24.4, 25.6, 26.3, 26.8, Table 26-1, Boxes 25-1 and CC-CR}*

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

Throughout the 21st century, climate change will further challenge food, livelihood and human security and wellbeing, not only in low-income countries.

Freshwater-related risks of climate change increase significantly with increasing greenhouse gas concentrations (*robust evidence, high agreement*). The fraction of global population experiencing water scarcity and the fraction affected by major river floods increase with the level of warming in the 21st century. *{WGII 3.4-5, 26.3, Table 3-2, Box 25-8}*

Climate change over the 21st century is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions (*robust evidence, high agreement*), intensifying competition for water among sectors (*limited evidence, medium agreement*). In presently dry regions, drought frequency 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*). Climate change is projected to reduce raw water quality and pose risks to drinking water quality even with conventional treatment, due to interacting factors: increased temperature; increased sediment, nutrient, and pollutant loadings from heavy rainfall; increased concentration of pollutants during droughts; and disruption of treatment facilities during floods (*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}*

For the major crops (wheat, rice, and maize) in tropical and temperature 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*). 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 with the late 20^{th} 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 globally and regionally (*high confidence*) (Figure 2.5, 2.8). *{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}*

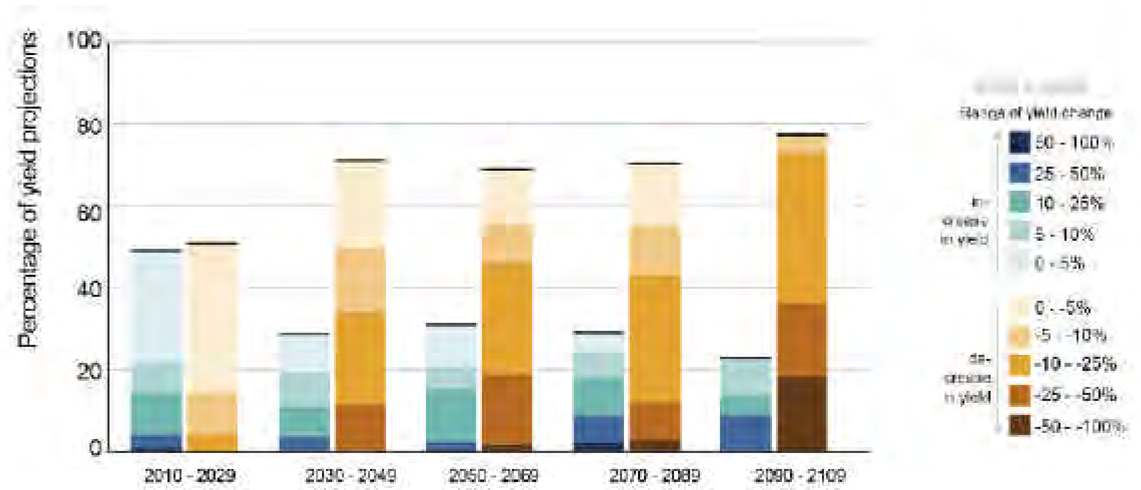


Figure 2.8: Summary of projected changes in crop yields, due to climate change over the 21st century. The figure includes projections for different emission scenarios, for tropical and temperature regions, and for adaptation and no-adaptation cases combined. Relatively few studies have considered impacts on cropping systems for scenarios where global mean temperatures increase by 4°C or more. For five timeframes in the near-term and long-term, data (n=1090) are plotted in the 20-year period on the horizontal axis that includes the midpoint of each future projection period. Changes in crop yields are relative to the late-20th-century levels. Date for each time frame sum to 100%. *{WGII, Figure SPM.7}*

Heat stress, extreme precipitation, sea level rise, inland and coastal flooding, drought, landslides, air pollution, and water scarcity pose risks in urban areas for people, economies, and ecosystems, with risks amplified for those lacking essential infrastructure and services or living in exposed areas (*very high confidence*). *{WGII 3.5, 8.2-4, 22.3, 24.4, 26.8, Boxes 25-9 and CC-HS}*

Rural areas will 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 are expected to 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 9.3, 25.9, 26.8, Box 25-5}*

For most economic sectors, the impacts of changes in population, age structure, income, technology, relative prices, lifestyle, regulation, and governance are projected to be large relative to the impacts of climate change (*medium evidence, high agreement*). Climate change is projected to reduce residential and commercial energy demand for heating and increase it for cooling (*robust evidence, high agreement*). More severe and/or frequent weather hazards are projected to increase disaster losses and loss variability, posing challenges for affordable insurance, particularly in low- and middle-income countries. *{WGII 3.5, 10.2, 10.7, 10.10, 25.7, 26.7, Box 25-7}*

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 be through exacerbating health problems that already exist (*very high confidence*). Health impacts include greater likelihood of injury, food- and water-borne diseases, malnutrition, and death; and risks from lost work capacity and reduced labor productivity. Fewer cold extremes and reduced capacity of disease-carrying vectors are expected to result in modestly lower cold-related mortality and morbidity in some areas (*medium confidence*). Globally, positive impacts are projected to be outweighed by the magnitude and severity of negative impacts (*high confidence*). *{WGII 8.2, 11.3-8, 19.3, 22.3, 25.8, 26.6, Figure 25-5, Box CC-HS}*

Climate change is projected to increase displacement of people (*medium evidence, high agreement*). Many populations that lack the resources for mobility and migration experience higher exposure to extreme weather events, particularly in developing countries with low income. Change in the incidence of extreme events is projected to amplify the risks of displacement. Expanding opportunities for mobility can reduce vulnerability, but altered migration flows can also create risks as well as potential benefits for migrants and for sending and receiving regions and states. *{WGII 9.3, 12.4, 19.4, 22.3, 25.9}*

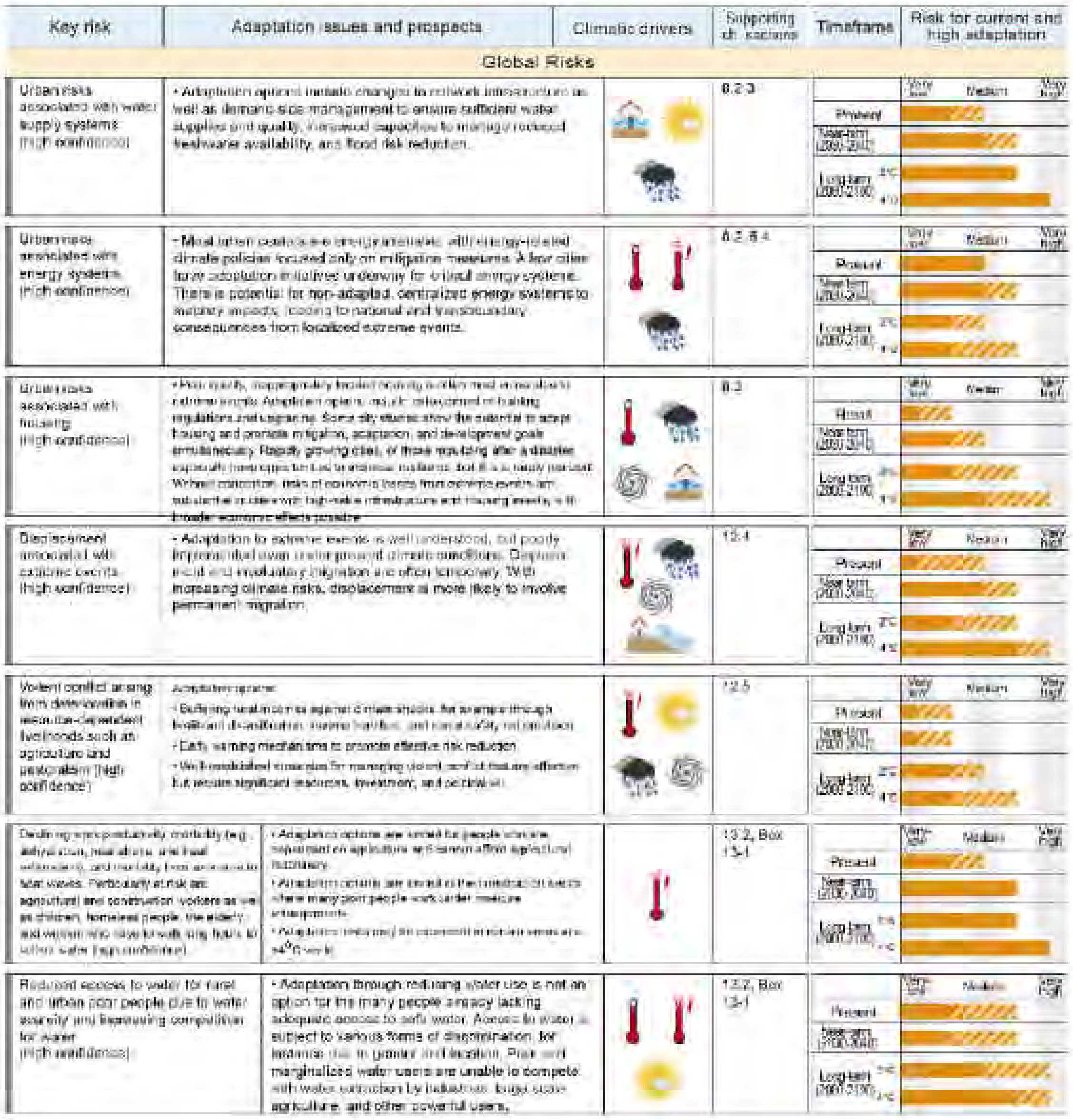
Climate change can indirectly increase risks of violent conflicts in the form of civil war and intergroup violence by amplifying well-documented drivers of these conflicts such as poverty and economic shocks (*medium confidence*). Multiple lines of evidence relate climate variability to these forms of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

Climate change impacts are projected to slow 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*). 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 2.5). *{WGII 8.1, 8.4, 9.3, 10.9, 13.2-4, 22.3, 26.8}*

Table 2.3: Key sectoral risks from climate change and the potential for reducing risks through mitigation and adaptation. Risks have been identified based on assessment of the relevant scientific, technical, and socioeconomic literature, as detailed in supporting chapter sections. Each key risk is characterized as very low to very high for three timeframes: the present, near-term (here, assessed over 2030-2040), and longer-term (here, assessed over 2080-2100). Assessed risk levels integrate probability and consequence over the full range of possible outcomes, acknowledging the importance of differences in values and objectives in interpretation of the assessed risk levels. In the near-term, projected levels of global mean temperature increase do not diverge substantially across emission scenarios. In the longer-term, risk levels are presented for global mean temperature increase of 2°C and 4°C above preindustrial levels, illustrating the potential role of mitigation in reducing risks. For the present, risk levels are estimated for current adaptation and a hypothetical highly adapted state, identifying current adaptation deficits. For the future, risk levels are estimated for a continuation of current adaptation and for a highly adapted state, representing the potential for and limits to adaptation. Relevant climate variables are indicated by icons. Risk levels are not necessarily comparable across sectors because the assessment considers potential impacts and adaptation across diverse physical, biological, and human systems. *{WGII Table TS.4}*

Climate-related drivers of impacts									Risk & potential for adaptation
Warming trend	Extreme temperature	Drying trend	Extreme precipitation	Damaging cyclone	Flooding	Storm surge	Ocean acidification	Carbon dioxide concentration	Potential for adaptation to reduce risk; Risk level with high adaptation; Risk level with current adaptation

Key risk	Adaptation issues and prospects	Climatic drivers	Supporting ch. sections	Timeframe	Risk for current and high adaptation
Global Risks					
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)	• Adaptation options include managing land use (including deforestation), fire and other disturbances, and non-climatic stressors.		4.2.3	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)	• There are few adaptation options in the Arctic.		4.3, Box 4.4	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 (medium confidence)	• Policy and market measures can reduce deforestation and fire.		4.3, Box 4.3	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)	• Adaptation options include reduction of habitat modification and fragmentation, pollution, over-exploitation, and invasive species; protected area expansion; assisted dispersal and ex-situ conservation.		4.3-4	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)	• 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.		5.3, 6.1, 6.3-4, 30.3, Box CC-OA	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)	• Adaptation options are limited to reducing other stresses, mainly pollution, and limiting pressures from coastal human activities such as tourism and fishing.		6.3-4, Table 30-4, Box CC-MB	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C	Very low – Medium – Very high
Negative impacts on average crop yields and increases in yield variability due to climate change (high confidence)	• With or without adaptation, negative impacts on average yields become likely from the 2030s with median yield impacts of 0 to -2% per decade projected for the rest of the century, and after 2050 the risk of more severe impacts increases.		7.2-5, Box 7.1	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C	Very low – Medium – Very high



Key risk	Adaptation issues and prospects	Climatic drivers	Supporting ch. sections	Timeframe	Risk for current and high adaptation
Global Risks					
Urban risks associated with water supply systems (High confidence)	• 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.		8.2.3	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C	Very low – Medium – Very high
Urban risks associated with energy systems (High confidence)	• 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.		8.2, 8.4	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C	Very low – Medium – Very high
Urban risks associated with housing (High confidence)	• 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.		8.2	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C	Very low – Medium – Very high
Displacement associated with extreme events (High confidence)	• 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.		12.4	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C	Very low – Medium – Very high
Violent conflict arising from deterioration in resource-dependent livelihoods such as agriculture and pastoralism (High confidence)	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.		12.5	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C	Very low – Medium – Very high
Declining work productivity, 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)	• 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.		13.2, Box 13-1	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C	Very low – Medium – Very high
Reduced access to water for rural and urban poor people due to water scarcity and increasing competition for water (High confidence)	• 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.		13.2, Box 13-1	Present; Near-term (2030-2040); Long-term (2080-2100) 2°C, 4°C	Very low – Medium – Very high

2.6 Long-term, irreversible and abrupt changes[15]

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 with larger warming.

The climate change already underway represents a substantial multi-century commitment created by human activities today, effectively irreversible over a period of many human generations. *{WGI 12.5.2}* Stabilization of the radiative forcing would not lead to an instantaneous stabilization of the warming (Figure 2.9). *{WGI 12.5.2}*

[15] 'Abrupt' refers to a sharp steepening of the rate of change relative to the present and recent past. Abrupt change in slow processes may therefore unfold over decades. Not all irreversible changes are abrupt, nor are all abrupt changes irreversible.

For scenarios driven by carbon dioxide alone, global average temperature is projected to remain above the twentieth century average for many centuries following a complete cessation of emissions. To accelerate the return to past regional temperature regimes, a large fraction of the anthropogenic greenhouse gases already emitted would need to be extracted from the atmosphere. *{WGI 12.5.2}*

Stabilization of global average surface temperature does not imply stabilization for all aspects of the climate system. Some processes related to shifting biomes, re-equilibrating soil carbon, melting ice sheets, warming of the deep ocean and associated sea level rise have their own intrinsic long timescales which will result in changes detectable hundreds to thousands of years after global surface temperature is stabilized. *{WGI 12.5.2}*

Ocean acidification will affect marine ecosystems for centuries if emissions continue (*high confidence*). Ocean acidifications is caused by rising atmospheric CO_2, and has impacts on physiology, behaviour and population dynamics of organisms (*medium* to *high confidence*). *{WGI 3.8.2, 6.4.4, WGII 6.3.2, CC-OA}*

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.. Nevertheless, it is *very unlikely* that the AMOC will undergo an abrupt collapse in the 21st century, and it is *unlikely* that the AMOC will collapse beyond the 21st century for the scenarios considered. *{WGI SPM, 12.4.7}*

There is little evidence in global climate models of a 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}*

Global mean sea level rise will continue for many centuries beyond 2100 *(virtually certain)*. *{WGI 6.4.9, 12.5.2, 13.5.2}* 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_2eq, as in scenario RCP2.6. For a radiative forcing that corresponds to a CO_2eq concentration in 2100 that is above 700 ppm, as in scenario RCP8.5, the projected rise is 1 m to more than 3 m by 2300 (*medium confidence*) (Figure 2.9). 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 underestimate of projected sea level rise beyond 2100. *{WGI 13.5}*

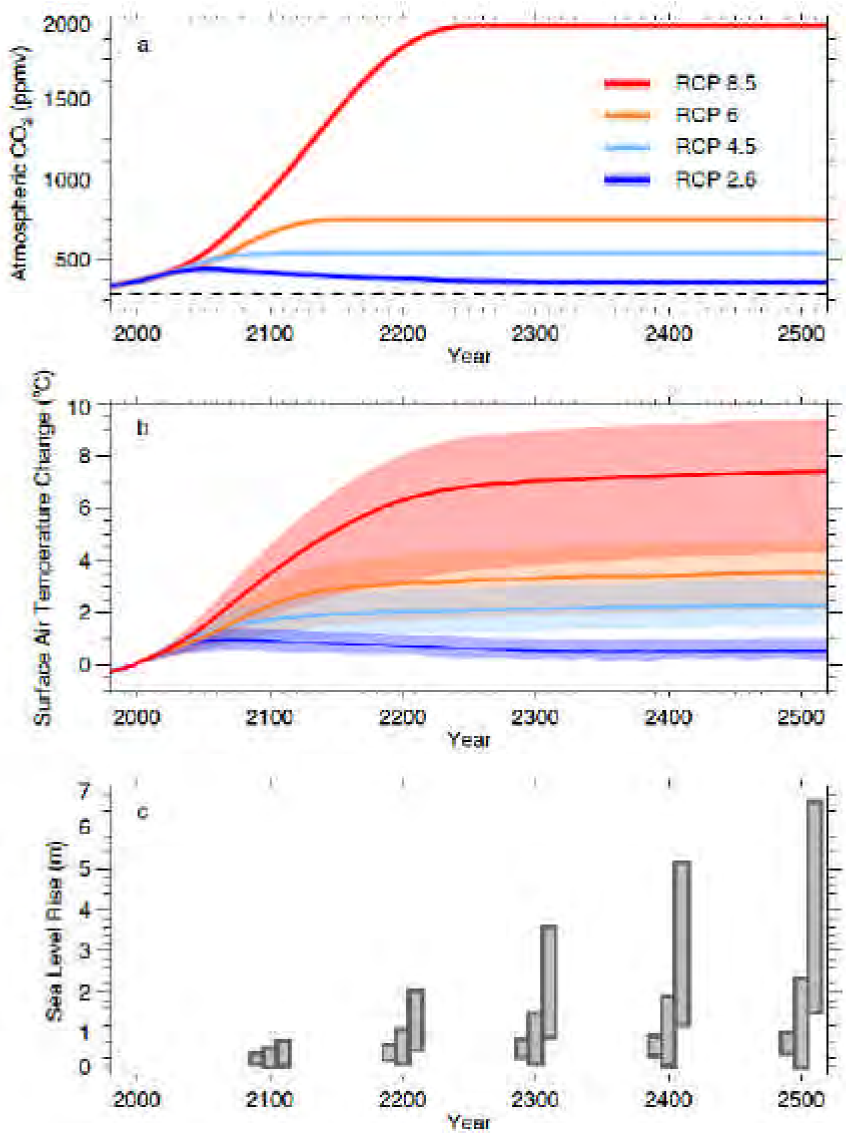


Figure 2.9: (a) Atmospheric CO_2 and (b) projected global mean surface temperature change as simulated by Earth System Models of Intermediate Complexity (EMICs) for the 4 RCPs up to 2300 followed by a constant (year 2300 level) radiative forcing. A 10-year smoothing was applied. Shadings and bars denote the minimum to maximum range. 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_2-eq) in the year 2100 (left: concentrations that peak and decline and remain below 500 ppm, as in scenario RCP2.6; Centre: 500–700 ppm, including RCP4.5; right: concentrations that are above 700 ppm, as in scenario RCP6.0 and RCP8.5). The bars 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 underestimate of projected sea level rise beyond 2100. *{WGI Figure 12.43 and Table 13.8}*

Sustained mass loss by ice sheets would cause larger sea level rise, and some part of the mass loss might be irreversible. There is *high confidence* that sustained global mean warming greater than some 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 5.8, 13.4, 13.5}*

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 and freshwater ecosystems, including wetlands (*medium confidence*). Examples that could lead to substantial impact on climate 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}*

An effectively irreversible reduction in permafrost extent is *virtually certain* with continued rising global temperatures. Carbon accumulated over hundreds to thousands of years in frozen soils could be lost through decomposition within decades as a result of permafrost thaw. Current permafrost areas are projected to become a net emitter of carbon during the 21st century under future warming scenarios. *{WGI 12.5.5, WGII 4.3.3.4, 28.2}*

Topic 3: Transformations and Changes in Systems

3.1 Human responses: An integrated approach

Climate change will inevitably lead to a range of transformations and alterations in natural and human systems, as a result either of responding to climate change or of failing to do so. While failure to respond increases risks, transformational responses can contribute to sustainability.

Climate change will transform natural and human systems. It will transform terrestrial and freshwater ecosystems, coastal areas, urban systems, human health and livelihoods, food systems, and much else. *{WG II SPM Assessment Box SPM.1 Figure 1, Table 19.4, CC-KR Table}* The scale of these transformations will be influenced by the rate and magnitude of climate change and by development pathways chosen. The impacts, however, will not be distributed evenly or equitably: The poorest are most vulnerable. *{WG II 2.2, 7.3, 8.2, 9.3, 10.9, 11.4, 11.6, 11.7. 12.6, Box CC-HS, 13.2, 13.4,17.3, SPM}*

Near-term response options for climate change range from incremental to transformational, but successful responses to climate change cannot be accomplished over the long-term without large-scale transformations and changes to systems. Successful mitigation will ultimately involve transformations in the way that human societies produce and use energy and in how they use the land surface. {*WG III 6-12*} Some adaptive responses may be incremental, but many will be transformative. *{WG II 1.1, 2.5, 16.4, 16.8, 20.3-4}* Climate change and climate change responses often result from and lead to changes in goals, values or paradigms. {*WG II 20.5 WG III 13-16*} The outcomes of transformations will depend on a combination of mitigation, adaptation and sustainable development policies. *{WG II 1.1, 20.3, 20.5; WG III 4}*

Climate change has important ethical dimensions that raise widespread concerns and trigger debates among analysts, policy-makers and stakeholders.

Because the atmosphere is a global commons, effective mitigation will not be achieved by actors who independently pursue their own interests. Moreover, while the costs of mitigation are often tangible and immediate, the benefits are uncertain and distant, and many will come to people who are not yet born. *{WG III 3}* International cooperation can make effective responses possible, but it poses its own challenges. *{WG III 6, 13, 14}*

Because the damage done by each country's emissions of greenhouse gases is distributed across the world and continues for generations, climate change raises issues of intergenerational, intragenerational and procedural justice and equity, many of which are subsumed under the goal of sustainable development. *{WG II 17.3, 20.2; WG III 3.3, 4; SYR 3.5}*For example, mitigation may involve a sacrifice by present people for the sake of distant future generations, whereas delaying action on climate change shifts burdens from the present towards future generations. Adaptation often has distributional effects on both small and large scales. *{WG II, 2.2}* Procedural justice requires decisions to be made in a way that respects the rights and views of all those affected, in circumstances where some lack information and understanding, some benefit more than others from past and future emissions, and some are not yet born. *{WG II 2.2, 2.3, 20.5}* Achieving distributive and procedural fairness between actors can also contribute to developing cooperation and effective governance. *{WG III, 3.10, 4.2, 4.6}*

Decision-making about climate change involves valuation and mediation among diverse values. *{WG III 3.4, SPM}* Ethical analysis takes account of many sorts of value. {*WG III 3.4*} Recent literature in political philosophy has analyzed the question of responsibility for the effects of emissions. *{WGIII 3.2, 3.3}* Economics provides systematic methods of valuation for mitigation and adaptation options. They can be used for estimating the social cost of carbon *{WGIII: 3.9.4}*, in cost-benefit and cost-effectiveness analysis, in optimization using IAMs, and elsewhere. *{WG III: 3.6}* Economic methods can take account of non-marketed goods, equity, behavioural biases, and ancillary benefits and costs. They are subject to well-documented limitations, but they can be given some basis in ethics provided they take account of the different value of money to different people. *{WG III, 3.5, 3.6, Box TS.2}*

The challenges presented by climate change involve many uncertainties that make climate policy a task of risk management. There are many options for responding to the challenges.

Predicting the effects of climate change and climate policy is beset with uncertainty. *{WG II 2.3, 17.3; WG III 2}* However, adaptation and mitigation choices in the near-term will affect the risks of climate change throughout the 21st century, and prospects for climate-resilient pathways for sustainable development are related 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 the limits to adaptation are exceeded. *{WGII 2.5, 16.4, 20.2, SPM}*

Decision-making and risk management in the complex environment of climate change is likely to be iterative: strategies can be adjusted as new information and understanding develops during implementation. *{WG II 2.1-4, 3.6, 14.1-3, 15.2-4, 17.1-3, 17.5, 20.6; WG III 2}* Effective risk management strategies are likely to take into account how relevant stakeholders perceive risk and respond to uncertainty. Methods for decision making under uncertainty focus attention on both short and long-term consequences, and avoid bias towards the status quo.

An integrated approach recognizes the importance of both adaptation to the effects of climate change and mitigation of the rate and magnitude of climate change. Both of these responses involve policies and processes that involve co-benefits, tradeoffs and synergies, and they will both affect and be affected by development pathways. *{WG II 20.3, WG III 4, 6}*

3.2 Characteristics and risks of (evolving) mitigation pathways

Even with major improvements in energy supply and end-use technologies, emissions are likely to increase over the century without dedicated political effort.

Without additional efforts to reduce GHG emissions beyond those in place today, emissions growth is expected to persist driven by growth in global population and economic activities (Figure 3.1). (*high confidence*) Baseline scenarios, those without additional mitigation, exceed 450 parts per million (ppm) CO_2eq by 2030 and reach CO_2eq concentration levels between 750 and more than 1300 ppm CO_2eq by 2100. This is similar to the range in atmospheric concentration levels between the RCP 6.0 and RCP 8.5 pathways in 2100 (Figure 3.2, upper panel). For comparison, the CO_2eq concentration in 2011 is estimated to be 430 ppm (uncertainty range 340–520 ppm). Baseline scenarios result in global mean surface temperature increases in 2100 from 3.7 to 4.8°C (median values; the range is 2.5°C to 7.8°C when including climate uncertainty). *{WGI 8.5 12.3, Figure SPM.5; WGIII 6.3, Box TS.6}*

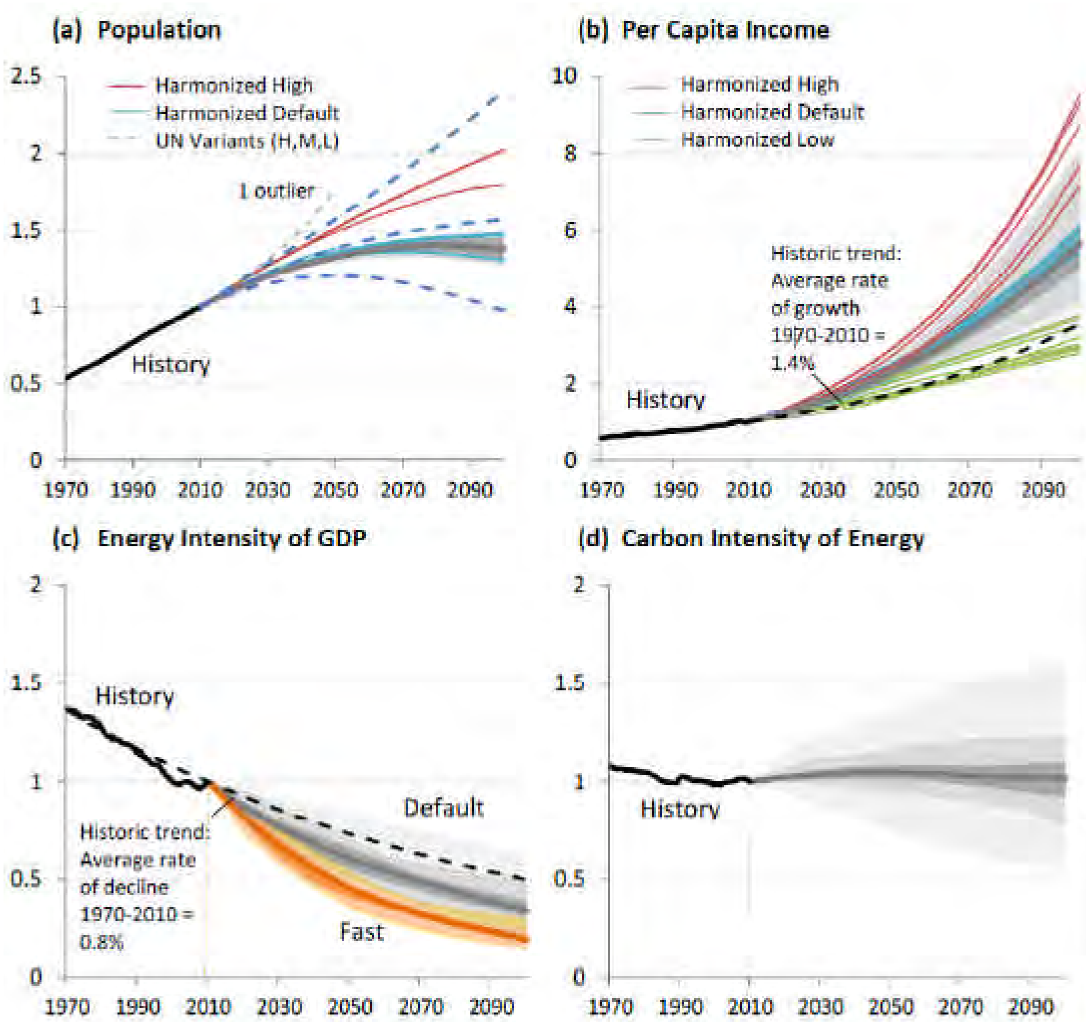


Figure 3.1: Global Baseline Projection Ranges from Integrated Models for Kaya Factors. Scenarios from the Scenario Database for AR5. Scenarios harmonized with respect to a particular factor are depicted with individual lines. Other scenarios depicted as a range with median emboldened; shading reflects interquartile range (darkest), 5th – 95th percentile range (lighter), and full extremes (lightest), excluding one indicated outlier in population panel. Scenarios are filtered by model and study for each indicator to avoid redundancy. Model projections and historic data are normalized to 1 in 2010. GDP is aggregated using base-year market exchange rates. Energy and carbon intensity are measured with respect to total primary energy.

It is technically possible to meet reach 450 ppmv CO_2eqq by 2100, which roughly corresponds to a likely chance of maintaining temperature change remaining below 2°C this century (Topic 2); however, implementing the necessary technological and behavioral options poses substantial social, institutional, and technical challenges.

A range of technological, behavioral, and policy options could be applied to meet reduce emissions, including reductions that would likely maintain temperature change below 2°C. *(high confidence)* For this assessment, about 900 mitigation scenarios were collected in a database based on published integrated models. This range spans atmospheric concentration levels in 2100 from 430 ppm CO_2eq to above 720 CO_2eq, which is comparable to the 2100 forcing levels between RCP 2.6 and RCP 6.0 (Figure 3.2, upper panel). Scenarios outside this range were also assessed, including some scenarios with concentrations in 21000 below 430 ppm CO_2eq. The mitigation scenarios involve a wide range of technological, socioeconomic, and institutional transformations.

Mitigation scenarios in which it is *likely* that the temperature change can be kept to less than 2°C are characterized by atmospheric concentrations in 2100 of about 450 ppm CO_2eq (*high confidence*)**.** Mitigation 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 they temporarily 'overshoot' concentration levels of roughly 530 ppm CO_2eq before 2100. In this case, they are *about as likely as not* to achieve that goal. 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 concentrations in 2100 of below 430 ppm CO_2eq. Temperature peaks during the century and then declines in these scenarios. *{WGIII 6.3, Box TS.6, Table SPM.1}*

Mitigation scenarios reaching about 450 ppm CO_2eq in 2100, typically involve temporary overshoot of atmospheric concentrations, as do many scenarios reaching about 500 ppm to 550 ppm CO_2eq in 2100. Overshoot scenarios typically rely on the widespread deployment of BECCS and afforestation in the second half of the century. The magnitude of this deployment depends on the degree of overshoot. (*high confidence*) 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 Section SPM 4.2)**.** CDR is also prevalent in many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive. *{WGIII 2.6, 6.3, 6.9.1, Figure 6.7, 7.11, 11.13, Table SPM.1}*

Reaching 450 ppm CO_2eq by 2100 will involve substantial cuts in anthropogenic GHG emissions by mid-century through large-scale changes in energy systems and potentially land use. Scenarios reaching higher (lower) concentrations include these same changes on a slower (faster) timescale. (*high confidence*)**.** Scenarios reaching these concentrations by 2100 include 40% to 70% reductions in GHG emissions by 2050 relative to 2010, and those with more modest reductions are characterized by higher overshoot (>0.4 Wm2) and substantial reliance on CDR technologies (Table 3.1). Scenarios reaching these concentrations are also characterized a tripling to nearly a quadrupling of the share of zero- and low-carbon energy supply from renewables, 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). They describe a wide range of changes in land use, reflecting different assumptions about the scale of bioenergy production, afforestation, and reduced deforestation. *{WGIII, 6.3, 7.11}*

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]. *{WG3 SPM Table SPM1, Table 6.3}*

CO_2eq Concentrations in 2100 (CO_2eq) *Category label (conc. range)*	*Subcategories*	*Relative position of the RCPs*	*Change in CO_2eq emissions compared to 2010 (in %)[3]*	
			2050	*2100*
< 430	*Only a limited number of individual model studies have explored levels below 430 ppm CO2eq*			
450 (430 – 480)	Total range[1,4]	*RCP2.6*	-72 to -41	-118 to -78
500 (480 – 530)	No overshoot of 530 ppm CO_2eq		-52 to -42	-107 to -73
	Overshoot of 530 ppm CO_2eq		-55 to -25	-114 to -90
550 (530 – 580)	No overshoot of 580 ppm CO_2eq		-47 to -19	-81 to -59
	Overshoot of 580 ppm CO_2eq		-16 to 7	-183 to -86
(580 – 650)	Total range	*RCP4.5*	-38 to 24	-134 to -50
(650 – 720)	Total range		-11 to 17	-54 to -21
(720 – 1000)	Total range	*RCP6.0*	18 to 54	-7 to 72
>1000	Total range	*RCP8.5*	52 to 95	74 to 178

[1]The 'total range' for the 430 to 480 ppm CO_2eq scenarios corresponds to the range of the 10-90th 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 CO2eq 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 preindustrial in 2100. Together with the baseline scenarios in the >1000 ppm CO_2eq category, this leads to an overall 2100 temperature range of 2.5–7.8°C (median: 3.7–4.8°C) for baseline scenarios across both concentration categories.

[3] The global 2010 emissions are 31% above the 1990 emissions (consistent with the historic 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).
[4] The vast majority of scenarios in this category overshoot the category boundary of 480 ppm CO_2eq concentration.

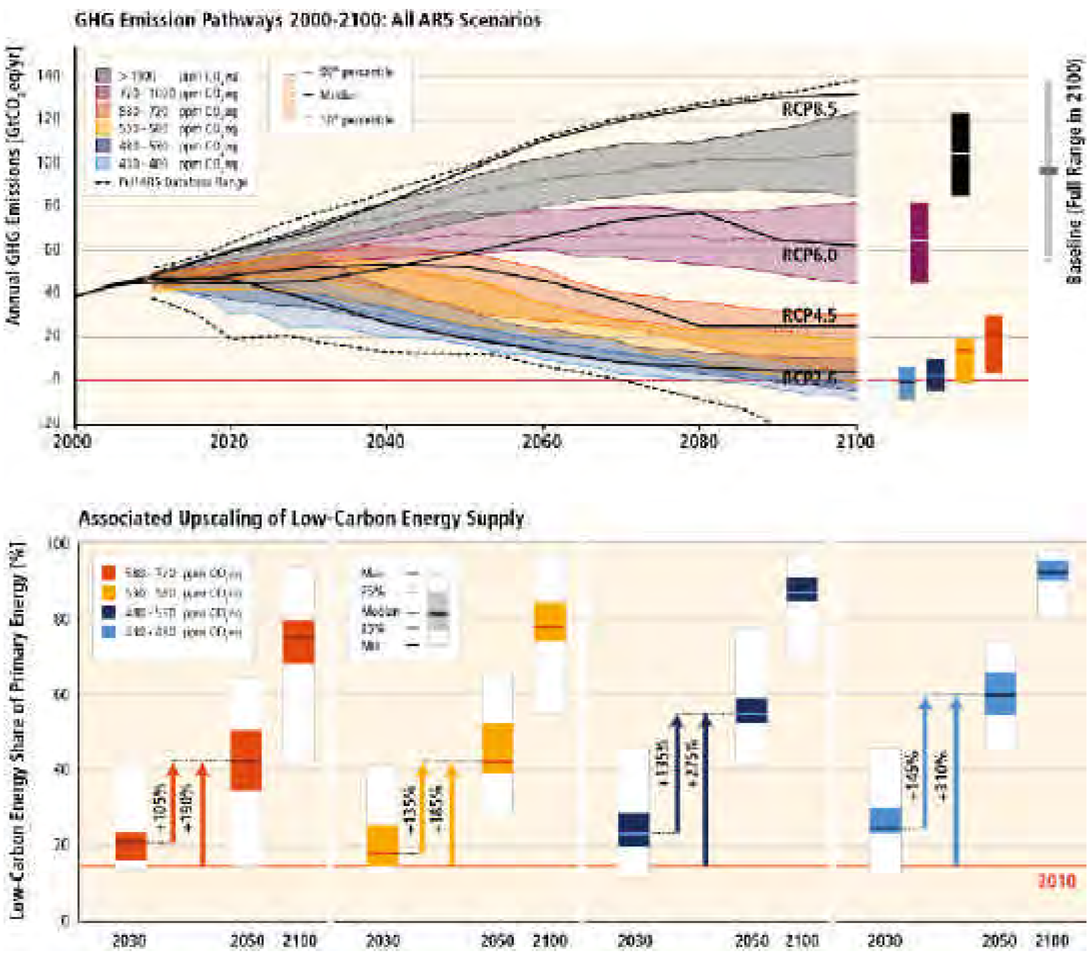


Figure 3.2: Pathways of global GHG emissions ($GtCO_2eq/yr$) in baseline and mitigation scenarios for different long-term concentration levels (upper panel) and associated upscaling requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100 compared to 2010 levels in mitigation scenarios (lower panel). The upper and lower panels exclude scenarios with limited technology availability and the lower panel in addition excludes scenarios that assume exogenous carbon price trajectories. *{WGIII: Figure 6.7, Figure 7.16}*

Estimates of the aggregate economic costs of mitigation vary widely based on methodologies and other assumptions (*high confidence*)**.** Scenarios in which all countries of the world begin mitigation immediately, there is a single global carbon price, and all key technologies are available, have been used as a cost-effective benchmark for estimating macroeconomic mitigation costs (Table 3.2, green segments). Even under these circumstances, mitigation cost estimates vary widely across scenarios depending on models, their methodologies, and their assumptions (Table 3.2). To put aggregate economic cost estimates in context, they arise in scenarios in which the global economy grows 300% to more than 900% over the century (roughly 1.6% and 3% annual growth). Under the absence or limited availability of technologies, mitigation costs can increase substantially (Table 3.2, orange segment). Delaying additional mitigation further increases mitigation costs in the medium to long term. (Table 3.2, blue segment). *{WGIII 6.3}*

Table 3.2: Global mitigation costs in cost-effective scenarios and estimated cost increases due to assumed limited availability of specific technologies and delayed additional mitigation. 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. The green columns show consumption losses in the years 2030, 2050, and 2100 (green) and annualized consumption growth reductions (bright green) over the century in cost-effective scenarios relative to a baseline development without climate policy.[1] The orange columns show the percentage increase in discounted costs[2] over the century, relative to cost-effective scenarios, in scenarios in which technology is constrained relative to default technology assumptions.[3] The blue columns show the increase in mitigation costs over the periods 2030–2050 and 2050–2100, relative to scenarios with immediate mitigation, due to delayed additional mitigation through 2020 or 2030.[4] These scenarios with delayed additional mitigation are grouped by emission levels of less or more than 55 $GtCO_2eq$ in 2030, and two concentration ranges in 2100 (430–530 ppm CO_2eq and 530–650 CO_2eq). In all figures, the median of the scenario set is shown without parentheses, the range between the 16th and 84th percentile of the scenario set is shown in the parentheses, and the number of scenarios in the set is shown in square brackets.[5] *{WGIII Figures TS.12, TS.13, 6.21, 6.24, 6.25, Annex II.10}*

	Consumption losses in cost-effective implementation scenarios				Increase in total discounted mitigation costs in scenarios with limited availability of technologies				Increase in mid- and long term mitigation costs due delayed additional mitigation up to 2030			
	[% reduction in consumption relative to baseline]			[percentage point reduction in annualized consumption growth rate]	[% increase in total discounted mitigation costs (2015–2100) relative to default technology assumptions]				[% increase in mitigation costs relative to immediate mitigation]			
									≤55 $GtCO_2eq$		>55 $GtCO_2eq$	
2100 Concentration (ppm CO_2eq)	2030	2050	2100	2010–2100	No CCS	Nuclear phase out	Limited Solar / Wind	Limited Bio-energy	2030–2050	2050–2100	2030–2050	2050–2100
450 (430–480)	1.7 (1.0–3.7) [N: 14]	3.4 (2.1–6.2)	4.8 (2.9–11.4)	0.06 (0.04–0.14)	138 (29–297) [N: 4]	7 (4–18) [N: 8]	6 (2–29) [N: 8]	64 (44–78) [N: 8]	28 (14–50) [N: 34]	15 (5–59)	44 (2–78) [N: 29]	37 (16–82)
500 (480–530)	1.7 (0.6–2.1) [N: 32]	2.7 (1.5–4.2)	4.7 (2.4–10.6)	0.06 (0.03–0.13)								
550 (530–580)	0.6 (0.2–1.3) [N: 46]	1.7 (1.2–3.3)	3.8 (1.2–7.3)	0.04 (0.01–0.09)	39 (18–78) [N: 11]	13 (2–23) [N: 10]	8 (5–15) [N: 10]	18 (4–66) [N: 12]	3 (-5–16) [N: 14]	4 (-4–11)	15 (3–32) [N: 10]	16 (5–24)
580–650	0.3 (0–0.9) [N: 16]	1.3 (0.5–2.0)	2.3 (1.2–4.4)	0.03 (0.01–0.05)								

Notes: [1] 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. [2] 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. [3] 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 *{WGIII 11.13.5}*).

[4] Percentage increase of total undiscounted mitigation costs for the periods 2030–2050 and 2050–2100. [5] 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 or delayed additional mitigation.

Meeting deep reductions would require building effective global and national institutions (Topic 4). Climate policy involves building institutions and capacity for governance. Responding effectively to the climate challenge is not merely a technical exercise. It involves diverse actors and institutions at the international, regional, national and sub-national scales. It also involves issues related to procedural equity and the distribution of power, resources, and decision-making authority among the potential winners and losers. *{WG II 2.2, 20.3; WG III 13 – 16}*

Delaying additional mitigation will substantially increase the challenges of, and reduce the options for, limiting temperature increase to 2°C or reaching 450 ppmv CO_2eq by 2100.

Allowing emission to rise above 50 GtCO_2eq in 2030 while still bringing concentrations to about 450 to 500 ppmv CO_2eq by 2100 will call for a rapid increase in emissions reductions in the following two decades, with an associated increase in costs, technological challenges, and institutional challenges. The majority of mitigation scenarios leading to atmospheric concentrations between 430 ppm CO_2eq and 530 ppm CO_2eq at the end of the 21st century are characterized by 2030 emissions roughly between 30 GtCO_2eq and 50 GtCO_2eq (Figure 3.3). *{WG III, 6}* Scenarios with emissions above 55 GtCO_2e are characterized by substantially higher rates of emissions reductions from 2030 to 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); a larger reliance on CDR technologies in the long term; and higher transitional and long-term economic impacts. *{WG III 6, 7}*

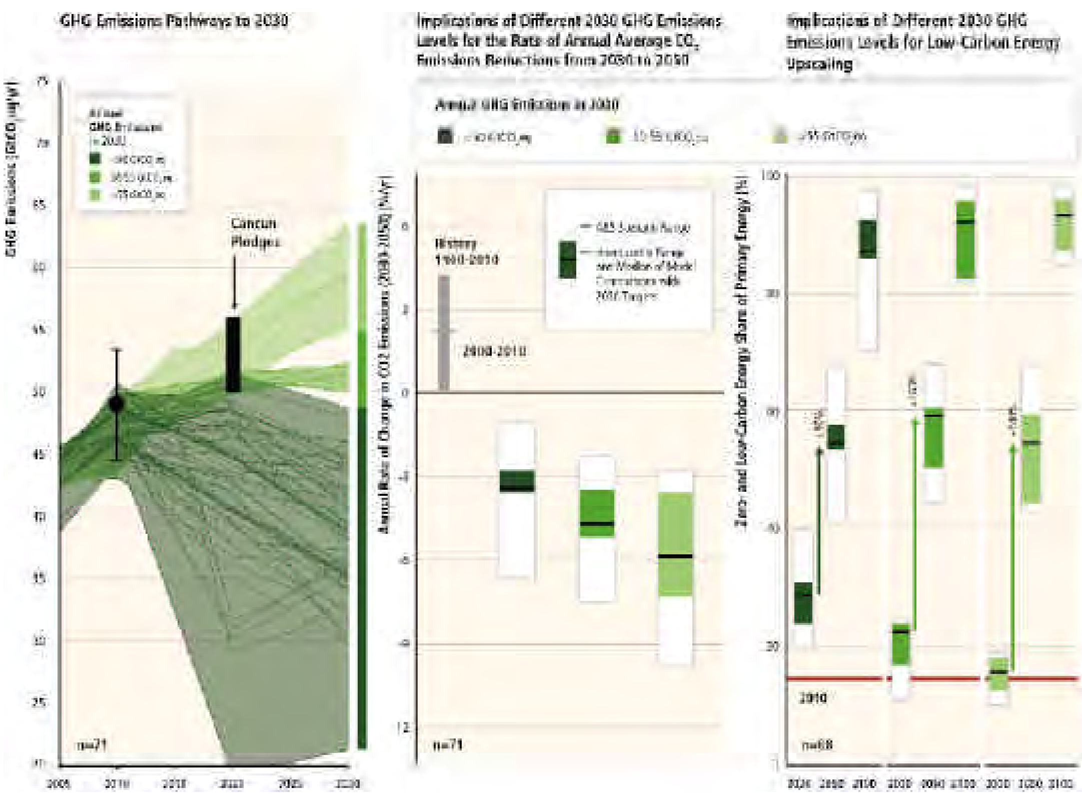


Figure 3.3: The implications of different 2030 GHG emissions levels for the rate of CO_2 emissions reductions and low-carbon energy upscaling from 2030 to 2050 in mitigation scenarios reaching about 450 to 500 (430–530) ppm CO_2eq concentrations by 2100. The scenarios are grouped according to different emissions levels by 2030 (coloured in different shades of green). The left panel shows the pathways of GHG emissions (GtCO_2eq/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) are shown in grey. 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 $GtCO_2eq$/yr), scenarios with exogenous carbon price assumptions, and scenarios with 2010 emissions significantly outside the historical range are excluded. *{WGIII, Figure 6.32, 7.16}*

The Cancun Pledges do not do not eliminate the option to maintain likely temperature change below 2°C or an end-of-century concentration of about 450 to 500 ppmv CO_2eq or below (medium confidence); however, they are not on a pathway to most cost-effectively meet these goal and increase the challenge of doing so *(high confidence).* The Cancún Pledges are broadly consistent with cost-effective scenarios that reach concentrations of about 550 ppmv CO_2eq by 2100. *{WGIII 6.4, 13.13, Figures TS.9, TS.11}*

Reducing emissions of short-lived forcers in the near term may contribute to a reduced rate of warming but have a limited effect on long-term concentrations. There are many low-cost options to reduce non-CO_2 gases relative to opportunities to reduce CO_2 emissions, and reducing emissions of short-lived species may contribute to reducing the rate of near-term warming. {*WG III 6*} There are, however, large uncertainties related to the climate impacts of some of these components. {*WG I 8*} and the effect on long-term warming is limited. {*WG I 8; WG III 6*} See also Box 3.2 on metrics.

All major emitting regions would need to make substantial emissions reductions over the coming decades to reach 2100 concentrations of 450 ppmv CO_2eq by 2100 or to limit likely temperature change to below 2°C; however, the distribution of costs across countries can differ from the distribution of the actions themselves.

Mitigation efforts and associated costs vary between countries in mitigation scenarios. The distribution of costs across countries can differ from the distribution of the actions themselves (*high confidence*)**.** In globally cost-effective scenarios, the majority of mitigation efforts takes place in countries with the highest future emissions in baseline scenarios. Some studies exploring particular effort-sharing frameworks, under the assumption of a global carbon market, have estimated substantial global financial flows associated with mitigation for scenarios leading to 2100 atmospheric concentrations of about 450 to 550 ppm CO_2eq. *{WG III 6, 13}*

3.3 Characteristics and risks of (evolving) adaptation pathways

Adaptation is essential for reducing damages associated with climate change. Adaptation options and their potential benefits are context-specific, differ between sectors and regions and depend on the rate and amount of climate change experienced.

Adaptation can contribute to the wellbeing of current and future populations, the security of assets and the maintenance of ecosystem services now and in the future as the climate changes. Research since the AR4 has broadened from a dominant consideration of engineering and technological options to include more ecosystem-based, institutional, and social measures, and from cost-benefit analysis, optimisation and efficiency approaches to the development of multi-metric evaluations, including risk and uncertainty dimensions integrated within wider policy and ethical frameworks to assess trade-offs and constraints**.** *{WGII.14.1, 14.3, 15.2, 15.5, 17.2, 17.3, SPM Table 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, risk perceptions and expectations can benefit decision-making processes. Desired adaptation outcomes and pathways to these usually require effective engagement with the range of affected stakeholders, operating in a decision environment with policy support to overcome constraints at various levels (Topic 4.5). Adaptation decision support is most effective when it is sensitive to context and the diversity of decision types, decision processes, and constituencies (*robust evidence, high agreement*). Adaptation planning and implementation can be enhanced through complementary actions across levels, from individuals to governments, for example through improved coordination, increasing awareness of climate change risks and the uncertainties in these, learning from experience with climate variability, and achieving synergies with disaster risk reduction. *{WGII SPM, 2.2, 15.2, 15.3, 15.5, 16.3, 16.4, 17.3, 19.6, 20.3}*

There are constraints and limits to adaptation, as well as the potential for maladaptation. Recognizing diverse interests, circumstances, social-cultural contexts, and expectations, as well as building adaptive capacity at all levels, underpins effective selection and implementation of adaptation options and the pursuit of climate-resilient pathways.

There are limits to adaptation; greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits and of severe, pervasive, and irreversible impacts (*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. This can arise from poor implementation, but include the impacts exceeding the capacity of adaptation (*high confidence*). Value-based judgments of what constitutes an intolerable risk may differ, and both limits to adaptation and residual impacts will differ between systems, sectors and regions due to different levels of climate change, levels of sensitivity, differing availability and effectiveness of adaptation options, and differing levels of adaptive capacity. In some parts of the world, insufficient responses to emerging impacts are already eroding the basis for sustainable development. Some adaptation limits may be able to be alleviated whereas others may not. As a result, there appears to be no single temperature threshold where the limits to adaptation are reached at a global scale (*low confidence*). Both the costs and benefits of adaptation are expected to increase with the magnitude and rate of climate change and associated impacts, but implementation may also become more challenging. *{WGII 16.4, 16.6, Table 16-3, Box 16-1,17.2, SPM, SPM Table 1}*

Effective adaptation strategies can link with sustainable development to reduce vulnerability but such strategies are challenging to implement and they are related fundamentally to what the world accomplishes with climate-change mitigation (*high confidence*). *{WGII 20.2-3}* They are increasingly supported by targeted decision-support processes and tools that help address the many uncertainties, and by institutions that broker knowledge among different actors. *{WGII SPM, 15.4}* Integration of a range of climate scenarios and available adaptation strategies and actions into development planning and decision-making can proactively prepare for future climates, while also helping to manage existing climate risk and contributing to multiple social benefits in the present (*high confidence*). *{WGII 4.6, 14, 15, 16}* However, there is a tendency to consider adaptation planning a problem-free process capable of delivering positive outcomes, underestimating the complexity of adaptation and the challenges for coordination across public and private goods and interests and spheres of governance. This can create unrealistic expectations and may overestimate the capacity to deliver intended outcomes. *{WG II 2.1-4, 16.2-5}*

Poor planning, overemphasising short-term outcomes, or failing to sufficiently anticipate consequences can result in maladaptation (*medium evidence, high agreement*), including path-dependent development patterns that increase the vulnerability of some groups to future climate change. Maladaptation can increase the vulnerability or exposure of the target group in the future, or the vulnerability of other people, places or sectors. Some near-term responses to increasing climate risks, such as enhancing protection of exposed assets, can lock-in a dependence on increasing protection measures that progressively make other adaptation options less feasible. *{WGII.5.5, 8.4, 14.6, Table 14.4, 14.6, 14.7, 15.5, 16.3, 17.2, 17.3, 20.2, 24.4, 25.10, Box 25-1, 26.8}*

Restricting adaptation responses to incremental changes in existing systems and structures, without considering transformational change, may increase costs and losses, and miss out on opportunities. For example, enhancing infrastructure to protect other built assets can be expensive and ultimately not defray increasing risk, whereas other options such as relocation or using ecosystem services to adapt may provide a range of benefits now and in the future. Real or perceived limits to incremental adaptation, particularly in relation to climate extremes, means that transformational adaptation is an important consideration for decisions involving long life- or lead-times. Transformational adaptation includes introduction of new technologies or practices, formation of new structures or systems of governance, adaptation at greater scale or magnitude and shifts in the location of activities. Societal debates over risks from forced and reactive transformations compared with planned and deliberate transformations to reduce climate risks may place new and increased demands on governance structures to reconcile conflicting goals and visions for the future and to address possible equity and ethical implications; transformations to sustainability are therefore considered to benefit from iterative learning, deliberative processes, and innovation. *{WGII 1.1, 5.5, 8.4, 14.1, 14.3, Table 14.4, 15.5, 16.3, 20.3.3, Box 25-1, 26.8, 16.2-7, 20.5, 25.10, Table 16-3, Box 16-1, Box16-4, SPM}*

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 building the adaptive capacity of human and natural systems (*Topic 4.2*) (*high agreement, medium evidence*). This can involve complex governance challenges and new institutions and institutional arrangements. The convergence between building adaptive capacity and disaster risk management has been further strengthened since AR4. Indigenous, local and traditional knowledge systems can be a major resource for adapting to climate change, except when the type, patterns and magnitude of changes exceed the knowledge repertoire. *{WGII 12.3,14.1, 14.2, 14.3, 16.2, 16.3, 16.5, 16.8}*

3.4 Climate Change Risks Reduced by Mitigation and Adaptation

Decisions about mitigation and adaptation can be informed by a broad range of risks and tradeoffs connected with other policy objectives, and these involve ethical considerations.

To support decision-making about adaptation and mitigation, this report provides information regarding a range of emissions pathways leading to different degrees of climate change. It uses a combination of methods – including multi-metric risk analysis and cost-effectiveness analysis for different emission pathways – to describe the consequences of each pathway in terms of mitigation risks and co-benefits, adaptation options costs and co-benefits, and the residual climate change risks, and therefore to inform decisions regarding climate policies.

Because of ethical consideration and the limits of available tools, it is impossible to translate this information into a single best mitigation target or balance between mitigation and adaptation. *{WGII 2, 17, WGIII 2, 3, 4}* Nevertheless, information on the consequences of various emissions pathways can be useful input into decision-making approaches that are designed to deal with contexts of large uncertainty, inter-generational and intra-generational distributional issues, disagreement over values and ethical considerations, and learning over time. *{WGII 2, 19, WGIII 7.2}* These approaches include iterative risk management, cost-effectiveness analysis, multi-criteria analysis and robust decision-making. They share some characteristics, including explicit accounting for the uncertainty, regular revision as new knowledge becomes available, and participatory processes to account for diversity in values.

Climate change, mitigation, and adaptation create a large array of risks that differ in nature, magnitude, and their potential to cause irreversible consequences. Adaptation and mitigation can reduce climate change risks, but they do so over different timescales, face limits linked to resource, institutional and capacity constraints, and involve uncertainties and risks related to economic, environmental, and societal outcomes.

Adaptation and mitigation interact with one another in several ways, meaning that decisions about both cannot be made independently (see also Topic 4). Mitigation reduces climate change and therefore reduces the need for adaptation and influences the scope of possible adaptation options. Conversely, the ability to adapt and reduce climate change impact affects required mitigation efforts to limit overall risks. Many mitigation and adaptation measures are directly linked because they may involve trade-offs or synergies at local to global scales (Topic 4.6). For example, bioenergy for mitigation will be subject to climate change and therefore in need of adaptive responses, and large-scale land conversions may influence the ability of other sectors (e.g. ecosystems, urban and rural areas) to adapt to climate change.

Adaptation has the potential to reduce climate change impacts significantly, but its potential differs between sectors. Adaptation will not reach its full potential because of resource, institutional and capacity constraints, increasing the benefits of mitigation. *{WGII 16, WGII 17}* *(high agreement, robust evidence)* There are many studies of local and sectoral adaptation costs and benefits, but few global analyses and there is very low confidence in their results. *{WG2.17}* Adaptation will have relatively more substantial influence on climate risks in the near future, considering the delay between mitigation action and the impact on climate change. *{WGI 11.3, 12.4}* In the second half of the 21st century and beyond, the risks of climate change will increasingly be affected by cumulative impact of previous mitigation and adaptation actions and by their interaction with development pathways. *{WGII, 2.5, 21.2, 21.5}*

Mitigating emissions can reduce many of the risks associated with climate change impacts over the 21st century, but it is almost impossible to reduce short-term risks through mitigation. *{WG2.19.7.1, WG3, high confidence}*. Key vulnerabilities and risks related to ecosystems, food and water, development and other socioeconomic factors can be integrated into five Reasons for Concern (RfC). Figure 3.4 uses the RfC to provide an illustration of how climate change risks are reduced by mitigation, for various mitigation scenarios. As illustrated in Figure 2.6, however, not all risks can be directly linked to temperature change, and other metrics such as the rate of change of climate variables, ocean acidification, and sea level rise also matter. Impacts increase with both the rate and magnitude of warming. Some impacts are affected by the peak warming that forms part of an overshoot trajectory. Fewer impacts will be averted by mitigation if emissions peak later and are then reduced very rapidly than if emissions peak earlier and are reduced more slowly and steadily. *{WGII 19.7}* The Article 2 box applies this framework to the context of Article 2 of the UNFCCC and "dangerous" climate change.

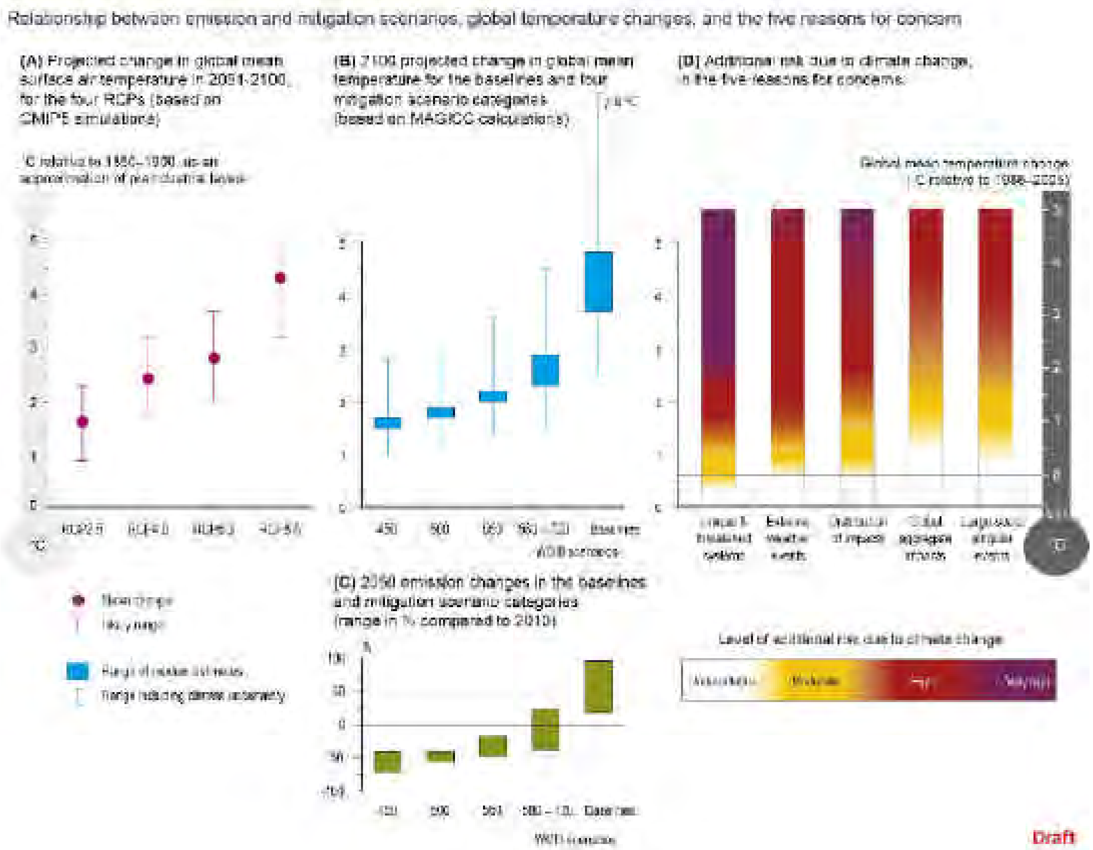


Figure 3.4: Relationship between emission and mitigation scenarios, global temperature changes, and the five Reasons for Concerns (RfC). Temperature changes shown compared with pre-industrial levels. For reference, the extreme right temperature axis shows temperature changes with respect to the 1986-2005 period. **Panel a** shows projected change in global temperature in 2081-2100 for the four RCPs, based on CMIP5 simulations (Table 2.1). **Panel b** shows the projected temperature increase in 2100, calculated using the MAGICC climate model for the baselines and four mitigation scenario categories defined in Chapter WGIII.6, indicating the uncertainty range resulting both from the range of emission scenario projections within each category and the uncertainty in the climate system *{data from WGIII.6}*. **Panel c** shows the 2050 changes in emissions in the corresponding baselines and mitigation scenario categories (positive changes refer to cases where emissions in 2050 are larger than 2010). For instance, the mitigation scenarios in the 450 category – i.e. with CO2e concentration in 2100 between 430 and 480ppm – have emissions in 2050 that are between 41 and 72% percent lower than emissions in 2010 (Table WGIII.SPM.1). **Panel d** reproduces the five reasons for concerns from WGII Assessment Box SPM.1 Figure 1, using the same temperature axis than Panel a. Risks associated with reasons for concern (from left to right, denoted as RFC1-5 in Article 2 Box) are shown for increasing levels of climate change. The color shading indicates the additional risk due to climate change when a temperature level is reached and then sustained or exceeded. Examples of risks represented by RFC1 include those to

coral reefs and the Arctic system; RFC2, includes risks associated with extreme heat; RFC3, regionally differentiated risks to food and water; RFC4, aggregate economic damages and biodiversity loss; RFC5, risk associated with a large sea level rise due to loss of mass from polar ice sheets. 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, also accounting for the other specific criteria for key risks. High risk (red) indicates severe and widespread impacts, also accounting for the other specific criteria for key risks. Purple, introduced in this assessment, shows that very high risk is indicated by all specific criteria for key risks.*{Ch.19.2}* Note the different temperature baselines used in WGII Assessment Box SPM.1 Figure 1. Beyond 2100, temperature, and therefore risk, decreases in most of the lowest three scenarios and increases further in most of the others.

Large magnitudes of warming increase the likelihood of severe and pervasive impacts that make adaptation challenging. A temperature rise above 4°C would risk damaging agricultural production and ecosystems worldwide, and increase the rate of extinction of species (*high confidence*). It would also risk crossing tipping-points that could lead to disproportionately large responses in the earth system. Precisely how much climate change would trigger tipping-points remains uncertain, but the likelihood of crossing them increases with increasing greenhouse gas emissions (*medium confidence*).[16]

Mitigation also involves risks and uncertainties. These risks are particularly high for the most ambitious mitigation pathways. {*WGIII 2.1, 2.3-2.5}* Risks increased by mitigation include those associated with large-scale deployment of technology options for producing low-carbon energy – including bioenergy, nuclear power, carbon capture with storage, and even wind power – the potential for high aggregate economic costs, large impacts on vulnerable countries and industries, and other risks. This includes linkages to 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 growth of developing countries.

Estimates of the aggregate economic benefits of mitigation and adaptation have been used to inform decision-making, but they are attended by important limitations and have not been explored at large magnitudes of warming. In addition, there is no consensus on how they should be used to aid in decision-making.

Estimates of the benefits the economic risks are attended by important conceptual and empirical limitations. In addition, very little is known about the economic impacts of warming above 3C. *{WGII10, 17, 19}* A set of modeling studies suggest that scenarios with ambitious mitigation (with a global mean temperature increase of 2.5°C above preindustrial levels) may lead to global aggregate economic losses between 0.2 and 2.0% of income. These estimates are partial, vary in their coverage of subsets of economic sectors and depend on a large number of assumptions, many of which are disputable, and many estimates do not account for catastrophic changes, tipping points, and other important factors. *{WGII 19.6}* The possibility of catastrophic damages can make it difficult or impossible to calculate robust and meaningful estimates of avoided risks. *{WGII 19.6}* One additional reason that estimates vary widely is that they depend on ethical considerations and few empirical applications of economic valuation to climate change have been well-founded in this respect. *{WGIII 3.6}*

Estimates of the incremental aggregate economic impact of emitting a ton of carbon dioxide (the social cost of carbon) vary by orders of magnitude, in large part because little is know about impacts at high levels of warming. Moreover, there is no agreement on how to use these estimates to design climate policies (*robust evidence, low agreement*).[17] Estimates of the social cost of carbon vary between a few dollars and several hundred dollars per ton of carbon (in 2010 dollars, for emissions in the first fifteen years of the twenty-first century)**.** Views differ over the propriety of using (imperfect and uncertain) global aggregate estimates of the social cost of carbon in decision-making about global mitigation. Some limitations on current estimates can be overcome with more knowledge, while others may be unavoidable such as issues with aggregating impacts over time and across individuals.

[16] 4.2-3, 11.8, 19.5, 19.7, 26.5, Box CC-HS
[17] 10.9

Estimates of aggregate costs mask significant differences in impacts across sectors, regions, countries and populations. *(high confidence)* For some, the net costs per capita will be significantly larger than the global average. *{WGII 13, 17, 18.4, 19.6}*

Risks from mitigation and from climate change are different in nature, magnitude, and in their potential to cause irreversible consequences. As a result, these differences increase the level of desirable efforts over the short term in an iterative risk management framework.

The actions taken today constrain the options available in the future to limit temperature change, adapt, and reduce emissions, and therefore create a significant irreversibility that is important for decision-making. Risks from mitigation do not involve the same possibility of catastrophic damages and do not imply the same inertia than risks from climate change. In particular, the stringency of climate policies can be adjusted to observed consequences and costs *{WGIII 2.5}*, while carbon emissions and climate change impacts create long-term irreversibility *{WGI 12.4, 12.5, 13.5,WGII 19.6}*, at least with current technologies. *{WGIII 7.5, 7.9, 11.13; SYR Box 3.3}* In an iterative risk management framework, the inertia in the climate system and the possibility of irreversible impact from climate change increase the level of desirable efforts over the short-term. *{WGIII 2.6}*

3.5 Interactions among mitigation, adaptation, and sustainable development

Achieving sustainable development and addressing climate change are closely related concerns, and involve trade-offs and synergies between multiple objectives, attention to interactions between different types of policies, and the likely need for transformational change in systems.

Climate change poses an increasing threat to equitable and sustainable development. {*WG II 2.5, 20.2; WG III 3, 4*} Some climate-related impacts on development are already being observed. Climate change is a threat multiplier, exacerbating other threats to social and natural systems in ways that place additional burdens on the poor and constrain possible development paths for all. *{WG II 10.9, 13.13, 19, 20.1}*. Development along current pathways can contribute to climate risk and vulnerability, further eroding the basis for sustainable development. *{WG II 20.6; WG III 4.2}*

Casting climate policy in the context of sustainable development includes attention to achieving climate resilience through both adaptation and mitigation.*{WG II 2.5, 13.4, 20.2-4}* Interactions among adaptation, mitigation and sustainable development occur both within and across regions and scales, often in the context of multiple stressors.*{WG II 8.4, 9.3, 13.3, 21.4, 25.x, 26.8}* Climate-resilient pathways include iterative processes to ensure that effective risk management can be implemented and sustained (Figure 3.5).Some options for responding to climate change could impose other environmental and social costs, have adverse distributional effects, and draw resources away from other developmental priorities, including poverty eradication. *{WG II 13.13, 30.1; WG III 4.8, 6.6}*

In the framework of sustainable development the design of climate policy involves the recognition of trade-offs and synergies across multiple objectives. *{WG II 11.9, 17.2, 15.3; WG III 3.6, 4.8}* Most climate policies intersect with other goals, either positively or negatively, creating the possibility of "co-benefits" or "adverse side effects" (Box 3.1). A multi-objective perspective helps to identify those policies that advance multiple goals and those that involve trade-offs among objectives. *{WG II 20.4}*

Mitigation scenarios reaching about 450 or 500 ppm by 2100 show reduced costs for achieving air quality and energy security objectives, with significant co-benefits for human health, ecosystem impacts, and sufficiency of resources and resilience of the energy system; these scenarios did not quantify other co-benefits or adverse side-effects (*medium confidence*)**.** These mitigation scenarios show improvements in terms of the sufficiency of resources to meet national energy demand as well as the resilience of energy supply, resulting in energy systems that are less vulnerable to price volatility and supply disruptions. The benefits from reduced impacts to health and ecosystems associated with major cuts in air pollutant emissions (Box 3.2, Figure 1) are particularly high where currently legislated and planned air pollution controls are weak. There is a wide range of co-benefits and adverse side-effects for additional objectives other than air quality and energy security. 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. *{WGII 11.9; WGIII 4.8, 5.7, 6.3.6, 6.6, 7.9, 8.7, 9.7, 10.8, 11.7, 11.13.6, 12.8, Figure TS.14, Table 6.7, Tables TS.3 TS.7}*

Climate resilient pathways for sustainable development can be supported by transformations that facilitate both adaptation and mitigation. Examples of transformations include the introduction of new technologies or practices (e.g., changes in land allocation and farming systems), formation of new structures or systems of governance (e.g., cooperative multilevel governance), or shifts in the types or locations of activities (e.g., harnessing off-shore wind energy). Some transformation processes also involve risks that may have inequitable consequences. 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. *{WG II 1.1, 2.5, 14.3, 20.5, 22.4, 25.4, SPM; WG III 4.3}*

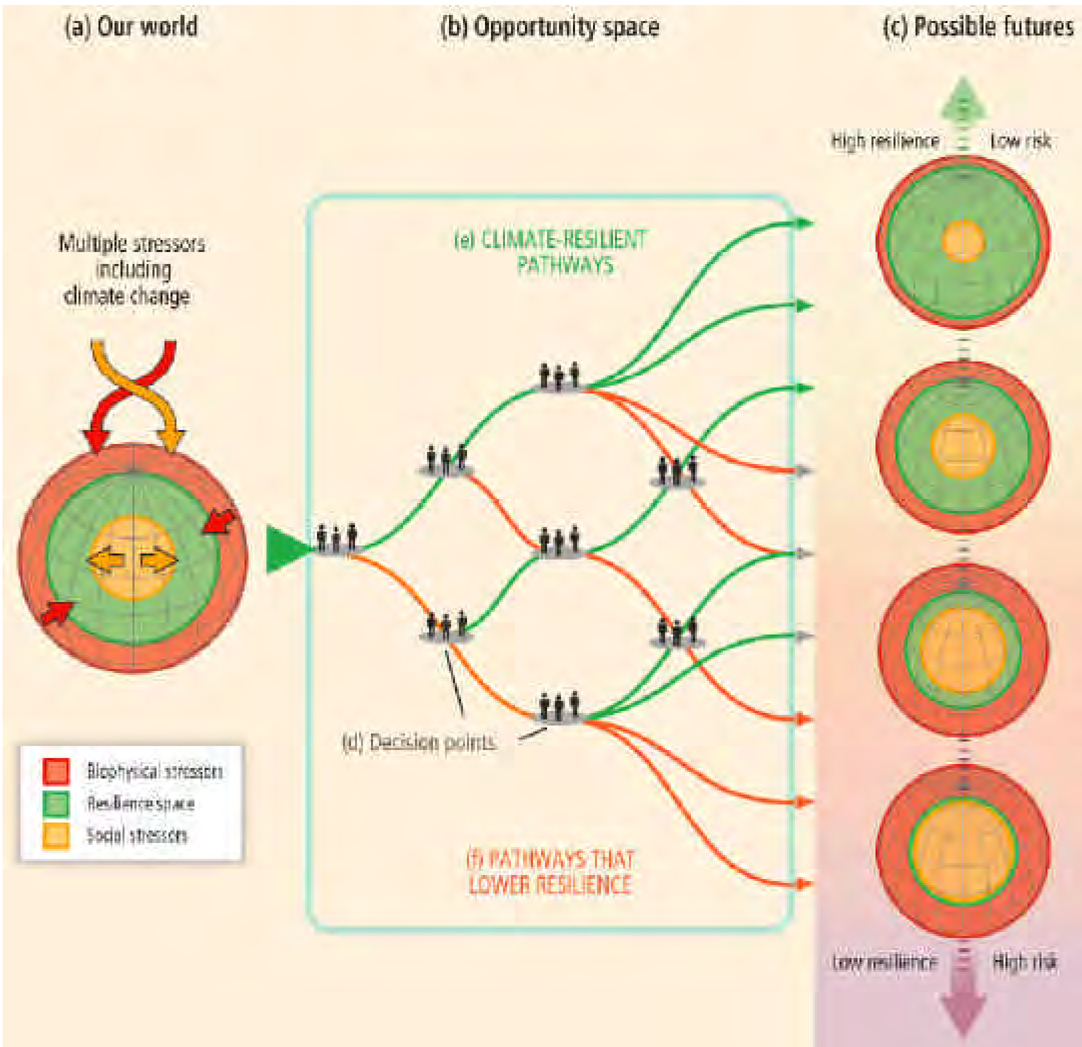


Figure 3.5: Opportunity space and climate-resilient pathways. (a) Our world [A-1, B-1] is threatened by multiple stressors that impinge on resilience from many directions, represented here simply as biophysical and social stressors. Stressors include climate change, climate variability, land-use change, degradation of ecosystems, poverty and inequality, and cultural factors. (b) Opportunity space [A-2, A-3, B-2, C-1, C-2] refers to decision points and pathways that lead to a range of (c) possible futures [C, B-3] with differing levels of resilience and risk. (d) Decision points result in actions or failures-to-act throughout the opportunity space, and together they constitute the process of managing or failing to manage risks related to climate change. (e) Climate-resilient pathways (in green) within the opportunity space lead to a more resilient world through adaptive learning, increasing scientific knowledge, effective adaptation and mitigation measures, and other choices that reduce risks. (f) Pathways that lower resilience (in red) can involve

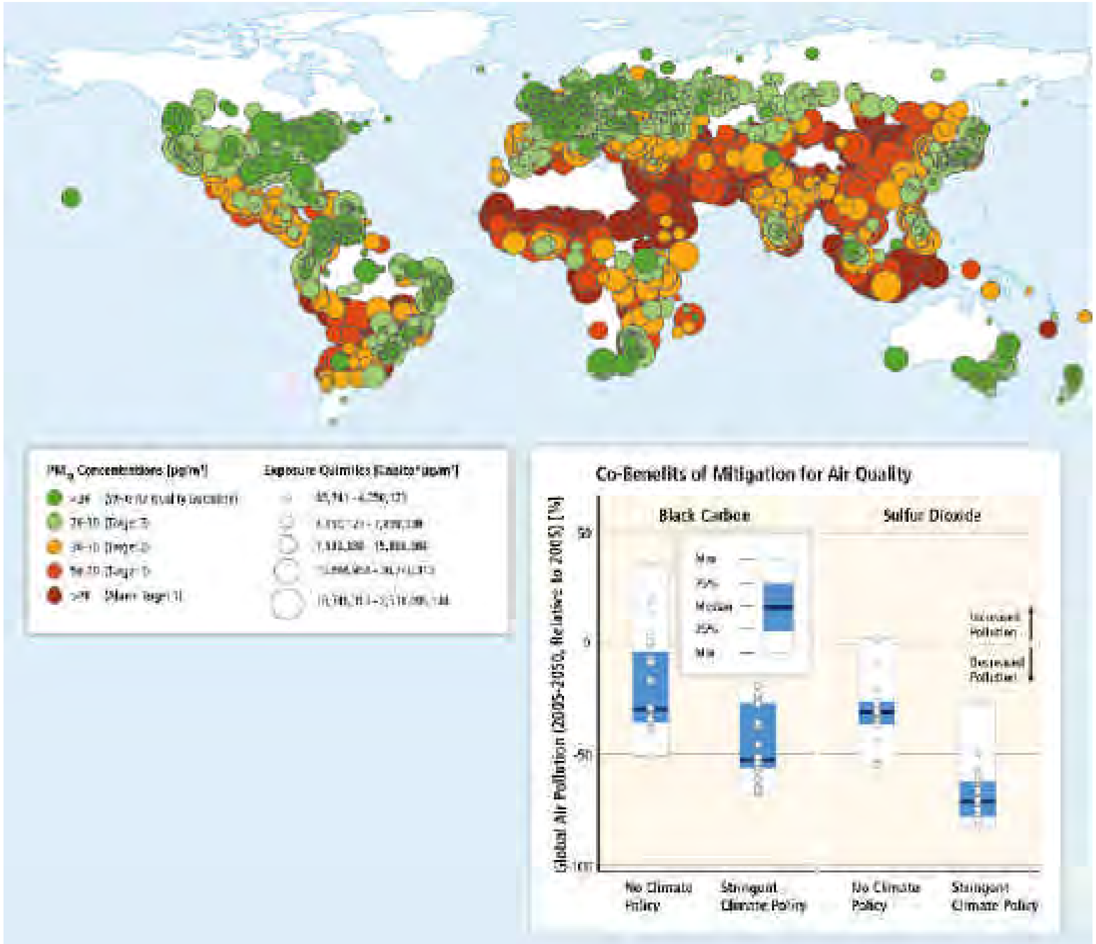
insufficient mitigation, maladaptation, failure to learn and use knowledge, and other actions that lower resilience; and they can be irreversible in terms of possible futures. *{WGII Figure SPM.9}*

Box 3.1: Co-benefits

A government policy or a measure intended to achieve one objective often affects other objectives (for example, mitigation policies can influence local air quality; 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', and the lack of capacity to better manage the impacts of current climate variability is often referred to as the "adaptation deficit". Some measures are labelled 'no regret' when their co-benefits are sufficient to justify their implementation, even in the absence of immediate direct benefits. *{WG II 17.2, 17.3}* Co-benefits and adverse side-effects are most often measured in non-monetary units. Their effect on overall social welfare has not yet been quantitatively examined, with exception of a few recent multi-objective studies. It has been shown that both co-benefits or adverse side-effects depend on local circumstances and implementation rate, scale and practices.

The existence of trade-offs among multiple objectives and significant co-benefits and adverse side-effects make it difficult to meaningfully compare the costs and benefits of climate change mitigation and derive an optimal mitigation pathway. Although a comprehensive analysis of the social value of co-benefits is difficult, it is still possible to identify positive impacts on other sectors. For example, mitigation scenarios leading to atmospheric concentration levels between 430 and 530 ppm CO_2eq in 2100 are associated with significant co-benefits for air quality *{WG II 11.9, Figure 3.6}*, resulting in reduced human health and ecosystem impacts, as well as energy security. {*WG III TS 3.1*} In absence of complementary policies, some mitigation measures may, however, have adverse side-effects (at least in the short term), for example on biodiversity, food security, economic growth and income distribution. *{WG II 3.6, 4.8, 6.6, 15.2}* The ancillary benefits of adaptation policies may include expanded communications networks, extended education and health systems, improved infrastructure, and others. *{WG II 11.9, 17.2}*

Climate policy may affect many market and non-market activities of households and businesses, some of which are already the targets of pre-existing non-climate policies. The valuation of overall social welfare impacts is made difficult by this interaction between climate policies and pre-existing non-climate policies, as well as (for market outputs) externalities and non-competitive behaviour. *{WGIII 6.3}* For example, the value of the extra ton of SO2 reduction that occurs with climate change mitigation depends greatly on the stringency of existing SO2 control policies: in the case of weak existing SO2 policy the value of SO2 reductions may be large, but in the case of stringent existing SO2 policy it may be near zero. Similarly, where risk management is weak, natural climate variability is responsible larger human and economic losses than would otherwise occur. This 'adaptation deficit' makes the benefits of adaptation policies that improve the management of climate variability and change higher than in contexts where current risk management is effective. Comprehensive climate policy consistent with sustainable development entails the integration of the many context-specific co-benefits from both adaptation and mitigation options.



Box 3.2, Figure 1: Human risk exposure to PM_{10} pollution in 3200 cities worldwide *{WG III.12.8}* and co-benefits of stringent mitigation policies for air quality in scenarios reaching concentrations of 430-530 ppm CO_2eq in 2100. *{WG III 6.6}*

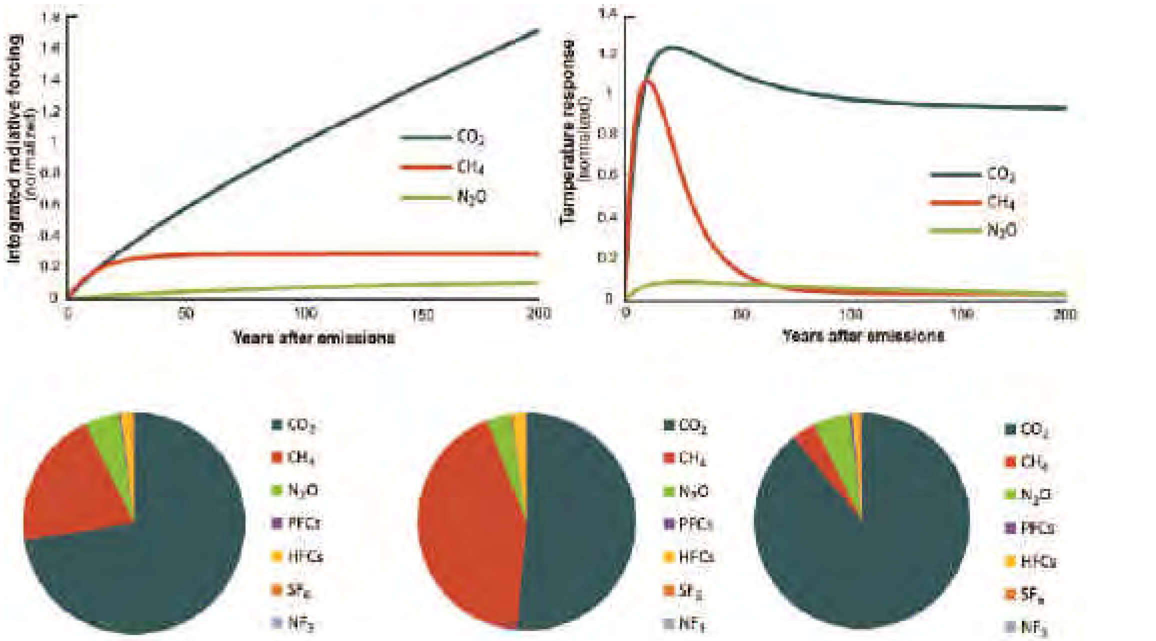
Box 3.2: GHG metrics and transformation pathways

Emission metrics underpin multi-component climate policies by allowing emissions of different GHGs and other forcing agents to be expressed in a common unit (“CO_2equivalents”). The Global Warming Potential (GWP) was introduced in the FAR to illustrate 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 default metric, including in successive IPCC reports, to compare climate effects of different emissions and allow substitution among gases. Alternative metrics have been proposed and a suite of metrics is assessed. *{WG I 8.7; WG III 3.9}*

The choice of metric and time horizon depends on application and policy context and no recommendations are given here. 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. Metrics can be applied to emissions as a single basket, or separate metrics could be applied based on contributions of different gases and aerosols to short- and long-term climate change. *{WG I 8.7; WG III 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*). The GWP compares components based on the radiative forcing resulting from an emission, integrated up to a chosen time horizon, while the Global Temperature change Potential (GTP) is based on the temperature response at a specific point in time. The relative uncertainty is larger for GTP. Adoption of a fixed horizon of e.g., 20, 100 or 500 years will inevitably put no weight on the long-term effect of CO_2 beyond the time horizon. The choice of horizon markedly affects the weighting of short-lived components. For example, today’s global emissions of CO_2 and CH_4 have similar warming effects over the next couple of decades. But the warming due to CO_2 is dominant the longer the time horizon, particularly for GTP-based metrics, due to the large fraction of excess CO_2 that remains in the atmosphere, whilst CH_4 decay on a shorter timescale (Box 3.2, Figure 1, Panel A). For some metrics, the weighting changes over time as a chosen target year is approached. *{WG I 8.7; WG III 3.9}*

The choice of 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 optimal 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 calculated contributions from various components and sources (Box 3.2, Figure 1, Panel B). Metrics that consistently result in less abatement of short-lived components than GWP_{100} (e.g. GTP_{100}) would require earlier and more stringent CO_2-abatement to achieve the same climate outcome and would increase net global mitigation costs. By contrast, using a time-dependent metric such as a dynamic GTP instead of GWP_{100} leads to less CH_4 mitigation in the near-term but more in the long-term. This implies that for some (short-lived) gases, the metric choice influences abatement technology development, the choice of policies, and the timing of mitigation (especially for sectors with high non-CO_2 emissions). The impacts of metric choice on the global CO_2 emission reduction profile and global mitigation costs in most studies are small and depend on policy goals and model assumptions. Given the long response time of CO_2, its emissions must fall to very low levels, regardless of the choice of metric, for any stabilization scenario. *{WG I 6.1, 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 gases. 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, for time horizons 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 emissions 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 of different gases (regulated by the Kyoto Protocol) to total CO_2eqquivalent global greenhouse gas emissions in the year 2010, calculated using 100-year GWP (left), 20-year GWP (middle) or 100-year GTP (right).

Box 3.3: Geo-engineering – possible role, options, risks and status

Geoengineering refers to a broad set of methods that aim to alter the climate system in order to reduce climate change and some impacts. There are two clusters of technologies: Carbon Dioxide Reduction (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. *{WG I 6.5, 7.7, WG II Box 20-4, WGIII 6.9}*

CDR methods vary greatly in their costs, their risks to humans and the environment, and their potential scalability, as well as in the amount of research there has been about their potentials and risks. Land-based CDR methods, like Bioenergy with Carbon Capture and Storage (BECCS) and afforestation is discussed in 4.3. Ocean-based CDR methods are discussed in WG II Ch. 6.

Knowledge about the possible beneficial or harmful effects of Solar Radiation Management (SRM) is highly preliminary. SRM is currently untested but, if realisable, could offset a global temperature rise and some of its effects. There is *medium confidence* that SRM through stratospheric aerosol injection is scalable to counter radiative forcing (RF) and some climate responses. Due to insufficient understanding, there is no consensus on whether a similarly large negative counter RF could be achieved from cloud brightening. It does not appear that land albedo change could produce a large counter RF. The scarcity of literature on other SRM techniques precludes their assessment. *{WG I 7.7}*

SRM has attracted attention given its potential for rapid cooling effects in case of climate emergency. The suggestion that deployment costs for individual technologies could potentially be very low could result in new challenges for international cooperation because nations may be tempted to deploy unilaterally systems that are perceived to be inexpensive and may have negative spillovers for other jurisdictions. SRM technologies raise questions about costs, risks, governance, and ethical implications of developing and deploying SRM, with special challenges emerging for international institutions, norms and other mechanisms that could coordinate research and possibly restrain testing and deployment. *{WG III 1.4, 3.3, 6.9, 13.4}* Even if SRM would reduce man-made global temperature increase, it would imply spatial and temporal redistributions of risks. SRM thus introduces important questions of intra- and intergenerational justice. *{WG III 3.3, 6.9}* Assessments of SRM are still few. Even research on SRM, as well as its eventual deployment, has been subject to ethical objections. *{WGIII-3.3.7}* Despite the low costs of some SRM techniques, they will not necessarily pass a benefit-cost test that takes account of the risks of termination as well as costly side-effects. *{WG III 6.9}* The governance implications of this characteristic of SRM are particularly challenging, since some countries may find it advantageous to be first-movers with SRM. Unilateral action, however, might produce significant costs for others. *{WG III 13.2, 13.4}*

Numerous side-effects, risks and shortcomings from SRM have been identified. SRM would produce an inexact spatial compensation for the RF by GHGs. Several lines of evidence indicate that SRM would itself decrease global precipitation. Another side-effect is that stratospheric aerosol SRM is likely to deplete ozone in the polar stratosphere. SRM would not prevent the negative effects of CO_2 on ecosystems and ocean acidification. There could also be other unanticipated consequences. *{WG I 7.6, 7.7; WG II 6.4, 19.5; WG III 6.9}* As long as GHG concentrations continue to increase, SRM would need to increase commensurately, 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 7.7; WG II 4.4, 6.1, 6.3}*

Topic 4: Adaptation and Mitigation Measures

4.1 Implementing responses consistent with long-term and strategic goals

Although responses to climate change must be viewed within a strategic long-term context consistent with achieving long-term goals such as limiting global average temperature increase to 2 degrees above pre-industrial levels (Topic 3), the options available today are only those that can be implemented in the near-term. Hence, the near-term responses and operational decisions will have a significant bearing on the outcome of the long-term climate goals. This calls for pursuing climate resilient development pathways, supported by policies and strategies with long-term perspectives and enduring effects, such as investments in capital infrastructure and the sustainable development of human settlements that often have long lifetimes.

Topic 4 highlights the range of mitigation and adaptation options available, along with the enabling factors and constraints in their deployment. This Topic also considers policies and measures across a range of scales and sectors, their trade-offs and synergies, as well as the potential for integrating adaptation and mitigation policies.

4.2 Enabling factors, constraints and limits to adaptation and mitigation

Progress in research, policy, and practice since the AR4 has enhanced understanding of the enabling factors and constraints associated with the implementation of mitigation and adaptation options

Enhancing the mitigative and adaptive capacities of actors is necessary to successfully manage the risks posed by climate change to human and natural systems (*very high confidence*). Such capacities vary significantly among global regions, institutions, sectors, communities, and ecological systems and are closely linked to socioeconomic development pathways. For example, low-income countries have the lowest financial, technological, and institutional capacities to pursue low-carbon, climate-resilient development pathways. Although developed nations generally have greater capacity to manage the risks of climate change, that capacity does not necessarily translate into the implementation of mitigation and adaptation options. *{WGII 1.1, 15.1, 16.3, 16.4, 20.2, 20.6, Box 20-1, SPM, TS; WGIII 4.5, 4.6, SPM, TS}*

Path dependence in global and regional economic development, greenhouse gas emissions, resource consumption, infrastructure and settlement patterns, institutional behaviour, and technology constrains mitigation and adaptation options (*high agreement, medium evidence*). Such constraints may limit the capacity of human and natural systems to remain below particular GHG emissions or climate thresholds or avoid adverse impacts to vulnerable regions, sectors, or ecological systems (Table 4.1). Some constraints may be overcome given the introduction of new technologies and financial resources, increased institutional effectiveness and governance, or through changes in social and cultural attitudes and behaviours. *{WGII 16.3, 16.4, 19.5, SPM, TS; WGIII 1.3, 1.4, 4.5, 5.2, 5.3, SPM, TS}*

Adaptive institutions and systems of governance are essential for creating enabling conditions for the planning and implementation of mitigation and adaptation options (*very high confidence*). Despite the presence of a wide array of multilateral, national, and sub-national institutions focused on mitigation and adaptation, global GHG emissions continue to increase and identified adaptation needs have not been adequately addressed. Constraints associated with mitigation, adaptation, and disaster risk reduction are particularly high in regions with weak institutions and/or that exhibit poor coordination and cooperation in governance. The implementation of effective mitigation and adaptation options may necessitate new institutions and institutional arrangements that span multiple scales (Table 4.1). *{WGII 2.2, 5.5, 8.4, 11.7, 12.5, 14.2, 15.5, 16.3, 25.4, 28.2, Table 14-1, Table 16-1, SPM, TS; WGIII 4.1, 12.6, 13, 14, 15.2, 16}*

Technological innovation and investments in green and sustainable infrastructure can reduce greenhouse gas emissions and enhance societal resilience to climate change (*very high confidence*). Technological innovation and change can expand the availability of mitigation and adaptation options and/or their effectiveness. The enhanced uptake of low carbon and carbon neutral energy technologies can reduce the energy intensity of development, the carbon intensity of energy, and therefore the costs of mitigation. Similarly, new technologies and infrastructure can increase the resilience of human systems while reducing adverse externalities on natural systems. However, investments in technology and infrastructure can be contingent upon access to finance and technology, as well as broader economic development that builds capacity (Table 4.1). *{WGII 14.2, 14.3, 15.4, 16.3, 20.2, 20.6, Table 14-1, Table 16-1, Box 16-2, SPM, TS; WGIII 4.3, 4.5, 5.6, 6, 15.12, 16.2, 16.5, SPM, TS}*

Behaviour, lifestyle and culture have considerable influence on energy use and associated GHG emissions and the vulnerability of human and natural systems to climate change (*high agreement, medium evidence*), with high mitigation potential in some sectors, in particular when complementing technological and structural change (*medium evidence, medium agreement*). Shifts toward more emission-intensive lifestyles might contribute to higher energy and resource consumption and therefore higher mitigation costs, but emissions can be substantially lowered through changes in consumption patterns, dietary change and reduction in food wastes. The social acceptability and/or effectiveness of climate policies may be dependent upon the extent to which they incentivise, or are contingent upon, changes in lifestyles or behaviours (Table 4.1). Similarly, livelihoods that are dependent upon climate-sensitive sectors or resources may be particularly vulnerable to climate change and climate change policies. Individual preferences for lifestyles with a high perceived amenity value may increase exposure of human settlements to climate hazards and affect the resilience of natural systems. *{WGII 2.2, 9.3, 11.3, 12.3, 13.2, 13.3, 16.3, 16.7, 22.4, 23.4, 24.4, 24.5, 25.7, 26.8, 27.3, 28.3, 29.3, 29.4, SPM, TS; WGIII 2.2, 3.9, 4.3, 5.5, SPM, TS}*

Table 4.1: Common constraints influencing mitigative and adaptive capacity.

Constraining Factor	Implications for Mitigation	Implications for Adaptation
Demographic change	Population growth contributes to economic growth, energy demand and consumption, and greenhouse gas emissions. *{WGIII 4.3, 5.3, SPM, TS}*	Population growth associated with hazardous landscapes can increase exposure to climate variability and change as well as demands for, and pressures on, natural resources and ecosystem services. {WGII, Box 16-3}
Knowledge, education, and human capital	Influences national, institutional, and individual risk perception, willingness to change behavioral patterns and practices, and adopt social and technological innovations to reduce emissions. *{WGIII 2.2, 4.3, 11.8, SPM, TS}*	Constrains awareness among actors with respect to climate risk, the relative utility of different types of knowledge, and the costs and benefits of different adaptation options. *{WGII 14.2, 16.3, 16.5, Box 16-2}*
Social attitudes and behaviors	Influences societal perceptions of the utility of mitigation policies and technologies and willingness to pursue sustainable behaviors and technologies. *{WGIII 2.2, 3.7, 3.9, 4.3, 5.5, 11.8, SPM, TS}*	Influences framing of adaptation, perceptions of acceptable vs. intolerable risks, as well as preferences for specific adaptation policies and measures. *{WGII 16.3, 16.5, 17.3, 17.5, SPM, TS}*
Governance, institutions and policy	Influences policies, incentives, and cooperation to develop or impede climate policy and deployment of efficient, carbon neutral, and renewable energy technologies. *{WGIII 4.1, 4.3, 6.4, 14.1, 14.2, 14.3, SPM, TS}*	Influences ability to coordinate adaptation policies and measures and to deliver capacity to actors to plan and implement adaptation. *{WGII 14.2, 15.5, 16.3, 16.5, SPM, TS}*
Finance	Influences the capacity of developed and, particularly, developing nations to pursue policies and technologies that reduce emissions. *{WGIII 12.6, 13.12, 15.12, 16.2, 16.5, SPM, TS}*	Influences the scale of investment in adaptation policies and measures and therefore their effectiveness. *{WGII 14.2, 16.3, 16.5, 17.3, 17.5, SPM, TS}*
Technology	Influences the rate and scale at which society can reduce the carbon intensity of energy production and use and transition toward renewable technologies. *{WGIII 2.4, 4.3, 6.3, 6.5, 6.6, 11.8, TS}*	Influences the range of adaptation options available to actors as well as their effectiveness in reducing or avoiding risk from increasing rates or magnitudes of climate change. *{WGII 16.3, 16.5}*

Natural resources	Influences the relative long-term sustainability of different energy technologies. *{WGIII 4.3, 4.4., 4.5, 11.6, 11.8, TS}*	Influences the coping range of actors, vulnerability to non-climatic factors, and potential competition for resources that enhances vulnerability. *{WGII 16.3, 16.5}*
Adaptation and development deficits	Constrains mitigative capacity and undermines international cooperative efforts on climate owing to a contentious legacy of cooperation on development. *{WGIII 4.3, 4.6}*	Increases vulnerability to current climate variability as well as future climate change. *{WGII 2.4, 14.3, 17.2, TS}*
Inequality	Constrains the ability for poor nations, or different communities or sectors within nations, to contribute to GHG mitigation. *{WGIII 4.7}*	Places the impacts of climate change and the burden of adaptation disproportionately on the most vulnerable and/or displaces them onto future generations. *{WGII 13.2, 16.7}*

4.3 Response options for mitigation

A comprehensive approach to mitigation will include actions across all sectors, with the nature of opportunities and options for mitigation varying substantially across sectors.

In baseline scenarios, GHG emissions are projected to grow (Figure 4.1) in all sectors, except for net CO_2 emissions in the AFOLU sector *(robust evidence, medium agreement)*. In 2010, 35% of direct GHG emissions were released in the energy supply sector, 24% in AFOLU, 21% in industry, 14% in transport and 6% in buildings. Energy supply sector emissions are expected to continue to be the major source of direct GHG emissions in baseline scenarios, while the industry and building sectors dominate if indirect emissions are allocated to the sectors where the energy (mainly electricity) is used. Deforestation decreases in most of the baseline scenarios, leading to a decline in CO_2 emissions in that sector. *{WGIII SPM. 4.2.2}*

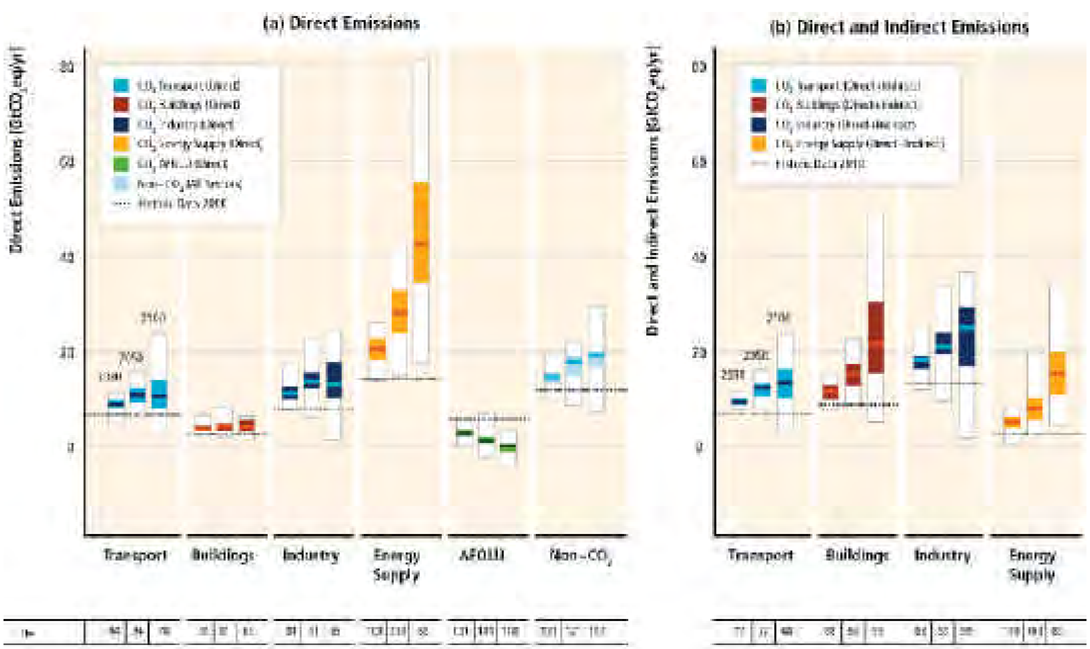


Figure 4.1: Evolution of direct and indirect (CO_2 from electricity generation only) GHG emissions over time by sector in the baseline scenarios of the AR5 scenario database. Non CO_2 GHGs are converted to CO_2 equivalents using 100-year global warming potentials from the IPCC SAR. The emissions shown under "Energy Supply" are the residual emissions, i.e. direct emissions minus those emissions from electricity generation that have been reallocated to the end-use sectors. The thick black lines corresponds to the median, the coloured boxes to the inter-quartile range (25th to 75th percentile) and the whiskers to the total range across scenarios. The numbers below the graphs refer to the number of

scenarios included in the ranges which differs across sectors and time due to different sectoral resolution and time horizon of models; includes only baseline scenarios.

Stabilizing GHG concentrations in the atmosphere at low level; requires mitigation throughout the economy. Efforts in one sector determine the need for mitigation in others (*medium confidence*). Mitigation measures interact through various economic linkages. Low stabilization scenarios are dependent upon a full decarbonization of energy supply in the long term. This entails more flexibility for the end-use sectors. Conversely, demand reductions in the energy end-use sectors decrease emissions directly and reduce the scale of the mitigation challenge for the energy supply side. *{WGIII SPM. 4.2.1}*

Urbanization is expected to continue to be a major driver of energy use and therefore human settlements in rapidly urbanizing areas where urban form and infrastructure are not locked in offer a large mitigation opportunity; but there are often limited governance, technical, financial, and institutional capacities (*robust evidence, high agreement*)**.** Infrastructure developments and long-lived products that lock societies into GHG intensive emissions pathways may be difficult or very costly to change (*robust evidence, high agreement*). However, material, products and infrastructure with long lifetimes and low lifecycle emissions can facilitate a transition to low-emission pathways while also reducing emissions through lower levels of material use. *{WGIII SPM, 4.2.1, 5.6.3, 9.4, 12.3, 12.4}*

Decarbonizing (i.e. reducing the carbon intensity of) electricity generation is a key component of cost-effective mitigation strategies in achieving low-stabilization levels *(medium evidence, high agreement).* In most ambitious long-term mitigation scenarios, the economy is fully decarbonized at the end of the 21st century with many scenarios relying on a net removal of CO_2 from the atmosphere. Accelerated electrification of energy end use, coupled with decarbonization of the majority of electricity generation by 2050 and an associated phase out of freely emitting coal generation, is a common feature of scenarios reaching roughly 550 ppm $C0_2$eq or less by 2100. *{WGIII SPM, 6.8, 7.11, Figures 7.14, TS.18}*

Demand reductions in the energy end-use sectors are a key mitigation strategy and affect the scale of the mitigation challenge for the energy supply side (*high confidence*). Limiting energy demand: 1) increases policy choices by maintaining flexibility in the technology portfolio; 2) reduces the required pace for up-scaling low-carbon energy supply technologies and hedges against related supply side risks (Figure 4.2); 3) avoids lock-in to new, or potentially premature retirement of, carbon-intensive infrastructures; 4) maximizes co-benefits for other policy objectives, since the number of co-benefits for energy end-use measures outweighs the adverse side-effects which is not the case for all supply-side measures *{WGIII Table 4.6, WGIII Tables TS.3–7}*; and 5) increases the cost effectiveness of the transformation (as compared to mitigation strategies with higher levels of energy demand) (*medium confidence*). However, energy service demand reductions are unlikely in developing countries or for poorer population segments whose energy service levels are low or partially unmet. *{WGIII 6.3.4, 6.6, 7.11, 10.4}*

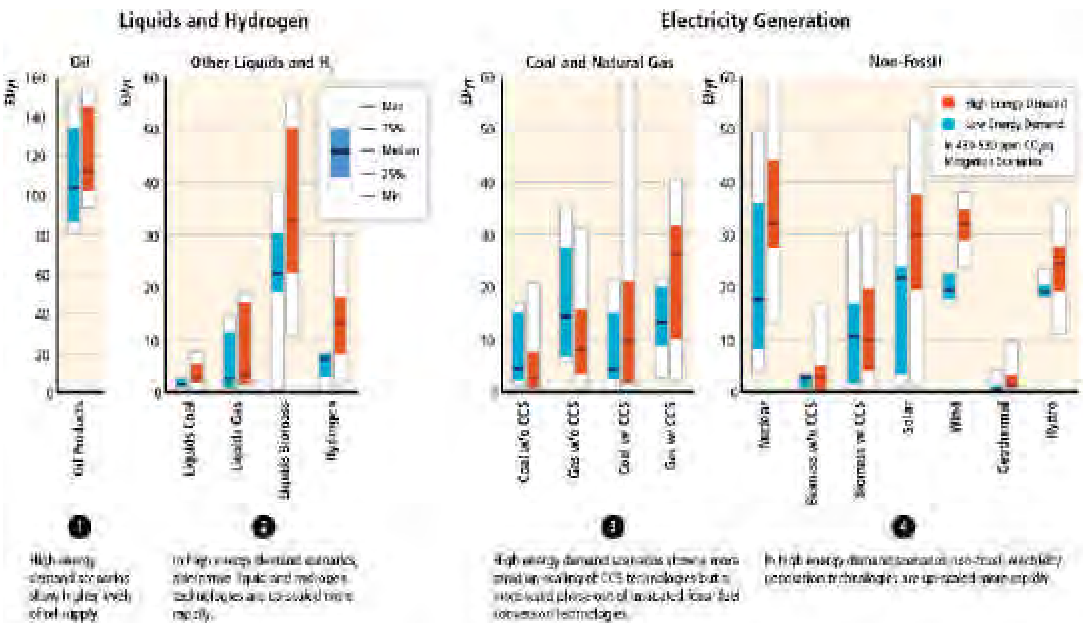


Figure 4.2: Influence of energy demand on the deployment of energy supply technologies in 2050 in mitigation scenarios reaching 430–530 ppm CO_2eq **concentrations by 2100. Blue bars for 'low energy demand' show the** deployment range of scenarios with limited growth of final energy of <20% in 2050 compared to 2010. Red bars show **the deployment range of technologies in 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; see Chapter 6 for further details. *{WGIII Figure 7.11}*

The broad range of sectoral mitigation options available mainly relate to achieving reductions in GHG emission intensity, energy intensity reduction through improvements in technical efficiency, production and resource efficiency improvements, structural and system efficiency improvement, and changes in activity (Table 4.2). Direct options in AFOLU involve storing carbon in terrestrial systems (for example, through afforestation) and providing bioenergy feedstocks. Options to reduce non-CO_2 emissions exist across all these sectors, but most notably in agriculture, energy supply, and industry.

Table 4.2: Main sectoral mitigation measures categorized by key mitigation strategies and associated sectoral indicators (highlighted in grey). *{WG III Table TS.2}*

	GHG emission intensity reduction	Energy intensity reduction by improving technical efficiency	Production and resource efficiency improvement	Structural and systems efficiency improvement	Activity indicator change
Energy	*Emissions / secondary energy output*	*Energy input / energy output*	*Embodied energy / energy output*		*Final energy use*
	Greater deployment of RES, nuclear energy, and (BE)CCS; fuel switching within the group of fossil fuels; reduction of fugitive (methane) emissions in the fossil fuel chain	Extraction, transport, conversion of fossil fuels; electricity, heat, fuel transmission, distribution, and storage; CHP (cogeneration, *see Buildings*);	Energy embodied in manufacturing of energy extraction, conversion, transmission and distribution technologies.	Addressing integration needs	Demand from end-use sectors for different energy carriers (see *Transport, Buildings and Industry*)
Transport	*Emissions / final energy*	*Final energy/transport service*		*Shares for each mode*	*Total distance per year*
	Fuel carbon intensity (CO_2eq/MJ): Fuel switching to low-carbon fuels (e.g. electricity/hydrogen from low-carbon sources (*see Energy*); specific biofuels in various modes(*see AFOLU*)	Energy intensity (MJ/p-km, t-km): Fuel-efficient engines and vehicle designs; more advanced propulsion systems and designs; use of lighter materials in vehicles	Embodied emissions during vehicle manufacture, material efficiency; and recycling of materials (*see Industry*); infrastructure life-cycle emissions (*see Human Settlements*)	Modal shifts from LDVs to public transit, cycling/walking, and from aviation and HDVs to rail; eco-driving; improved freight logistics; transport (infrastructure) planning	Journey avoidance; higher occupancy/loading rates; reduced transport demand; urban planning (*see Human Settlements*)
Buildings	*Emissions / final energy*	*Final energy / useful energy*	*Embodied energy / operating energy*	*Useful energy / energy service*	*Energy service demand*
	Fuel carbon intensity (CO_2eq/MJ): Building integrated RES; Fuel switching to low-carbon fuels, e.g. electricity (*see Energy*)	Device efficiency: heating/ cooling (high-performance boilers, ventilation, air-conditioning, heat pumps), water heating, cooking (advanced biomass stoves), lighting, appliances	Building lifetime; component, equipment and appliance durability; low(er) energy & emission material choice for construction (*see Industry*)	Systemic efficiency: integrated design process; low/zero energy buildings; building automation and controls; urban planning; district heating/cooling and CHP; smart meters/grids; commissioning	Behavioural change (e.g. thermostat setting, appliance use); lifestyle change (e.g. per capita dwelling size, adaptive comfort)
Industry	*Emissions / Final energy*	*Final energy / material production*	*Material input / product output*	*Product demand / service demand*	*Service demand*
	Emissions intensity: Process emissions reductions; use of waste (e.g., MSP/ sewage sludge in cement kilns) and CCS in industry; HFC replacement and leak repair; Fuel switching among fossil fuels, to low-carbon electricity (*see Energy*) or biomass (*see AFOLU*)	Energy efficiency/BAT: Efficient steam systems; furnace and boiler systems; electric motor (pumps, fans, air compressor, refrigerators and material handling) and electronic control systems; (waste) heat exchanges; recycling	Material efficiency: Reducing yield losses; Manufacturing/construction: process innovations, new design approaches, re-using old material (e.g. structural steel); Product design (e.g. light weight car design); Fly ash substituting clinker	Product-service efficiency: More intensive use of products (e.g. car sharing, using of clothing for longer, new more durable products)	Reduced demand for, e.g., clothing; alternative forms of travel leading to reduced demand for car manufacturing
Human Settlements	*Emissions / Final energy*	*Final energy / useful energy*	*Material input in infrastructure*	*Useful energy / energy service*	*Service demand per capita*
	Integration of urban renewables; urban scale fuel switching programs	Cogeneration, heat cascading, waste to energy	Managed infrastructure supply; reduce primary materials input for infrastructure	Compact urban form; increased accessibility; mixed land use	Increasing accessibility: shorter travel time, more transport mode options
Agriculture, Forestry and other Land use	Supply-side improvements			Demand-side measures	
	Emissions / area or unit product (conserved, restored)			*Animal/crop product consumption per capita*	
	Emission reduction: of methane (e.g. livestock management) and nitrous oxide (fertilizer and manure management) and prevention of emissions to the atmosphere by conserving existing carbon pools in soils or vegetation (reducing deforestation and forest degradation, fire prevention/control, agroforestry), Reduced emissions intensity (GHG/unit product).	Sequestration: Increasing the size of existing carbon pools, and thereby extracting carbon dioxide from the atmosphere (e.g. afforestation, reforestation, integrated systems, carbon sequestration in soils)	Substitution: of biological products for fossil fuels or energy-intensive products, thereby reducing CO_2 emissions, e.g. biomass co-fring/CHP (*see Energy*), biofuels (*see Transport*), biomass-based stoves, insulation products (*see Buildings*)	Demand-side measures: Reducing losses and wastes of food, changes in human diets towards less emission-intensive products, use of long-lived wood products)	

Energy system related mitigation measures include the decarbonization of the energy supply sector, final energy demand reductions, and switching to low-carbon fuels, including decarbonized electricity. Their relative importance varies with the availability of advanced technologies, cost and the level of behavioural, lifestyle and cultural change.

The energy supply sector is the largest contributor to global GHG emissions and offers opportunity for decarbonisation through renewable energy (RE), nuclear power, and carbon dioxide capture and storage (CCS). Near-term GHG emissions can be reduced by replacing current world average coal-fired plants with highly efficient natural gas combined cycle (NGCC) plants or combined heat and power (CHP) plants, provided that natural gas is available and the fugitive emissions associated with extraction and supply are low or mitigated (*robust evidence, high agreement*). *{WGIII TS 3.2.2}*

- **Renewable energy (RE) technologies have demonstrated substantial performance improvements and cost reductions, and a growing number of RE technologies have achieved maturity to enable deployment at significant scale** (*robust evidence, high agreement*) (SPM. 4.2.2)**.** Some technologies are already economically competitive in various settings. Decentralized RE utilization to meet rural energy needs has also increased, including various modern and advanced traditional biomass options as well as small hydropower, PV, and wind. *{WGIII TS 3.2.2}*
- **Nuclear energy is a mature low GHG emission source of baseload power but its share of global electricity generation has been declining since 1993 (***robust evidence, high agreement***).** Barriers and risks to an increasing use of nuclear energy include concerns about operational risks and the associated concerns, uranium mining risks, financial and regulatory risks, unresolved waste management issues, nuclear weapon proliferation concerns, and adverse public opinion (*robust evidence, high agreement*).New fuel cell cycles and reactor technologies addressing some of these issues are being investigated and progress in research and development has been made concerning safety and waste disposal. *{WGIII 7.5.4, 7.8, 7.9, 7.12, Figure TS.19}*
- **Carbon dioxide capture and storage (CCS) technologies could reduce the life-cycle GHG emissions of fossil fuel power plants and industries** *(medium evidence, medium agreement)***. Among CCS options, BECCS offers prospects of large-scale net negative GHG emissions, which plays an important role in many low stabilization scenarios (e.g., 430-480 ppm), while it entails challenges and risks** *(limited evidence, medium agreement).* Barriers to large-scale deployment of CCS technologies include concerns about the operational safety and long-term integrity of CO_2 storage, as well as risks related to transport and provision of biomass feedstock. *{WGIII SPM 4.2.2, TS 3.2.2}*

An overview of the projections of final demand reduction and low-carbon energy carrier share in end use sectors Transport, Buildings and Industry is given in Figure 4.3.

Transport: Technical and behavioural mitigation measures for all transport modes, plus in new infrastructure and urban redevelopment investments, could reduce final energy demand in 2050 by up to 40% below the baseline. The cost-effectiveness of different carbon reduction measures in the transport sector, including reducing the energy intensity of aircraft, trains, watercraft and road vehicles, varies significantly with vehicle type, transport mode and region. Strategies to reduce the carbon intensities of transport fuels are constrained by energy storage and low energy densities. Mitigation strategies, when associated with non-climate policies, can help decouple transport GHG emissions from economic growth in all regions but will require strong and mutually-reinforcing policies. *{WGIII SPM 4.2.3, TS 3.2.3}*

Buildings: Recent advances in technologies, know-how and policies in the building sector provide opportunities to stabilize or reduce global building sector energy use by mid-century. In addition to technologies and architecture, lifestyle, culture and other behavioural changes may lead to further large reductions in building and appliance energy requirements. A three- to five fold difference in energy use has been shown for provision of similar building-related energy service levels. For developed countries, scenarios indicate that lifestyle and behavioural changes could reduce energy demand by up to 20% in the short term and by up to 50% of present levels by mid-century. In developing countries, integrating elements of traditional lifestyles into building practices and architecture could facilitate the provision of high levels of energy services with much lower energy inputs than baseline. *{WGIII SPM, TS 3.2.4, 4.2.3, 9.3}*

Industry: An absolute reduction in emissions from the industry sector will require deployment of a broad set of mitigation options beyond energy efficiency measures, such as material use efficiency, product use efficiency, or demand reduction, recycling, re-use and deployment of CCS.. Besides sector-specific technologies, cross-cutting technologies (e.g., electronic control systems) and measures applicable in both large energy intensive industries and Small and Medium Enterprises (SMEs) and industrial clustering of SMEs are other options to reduce GHG emissions. *{WGIII SPM, TS 3.2.5}*

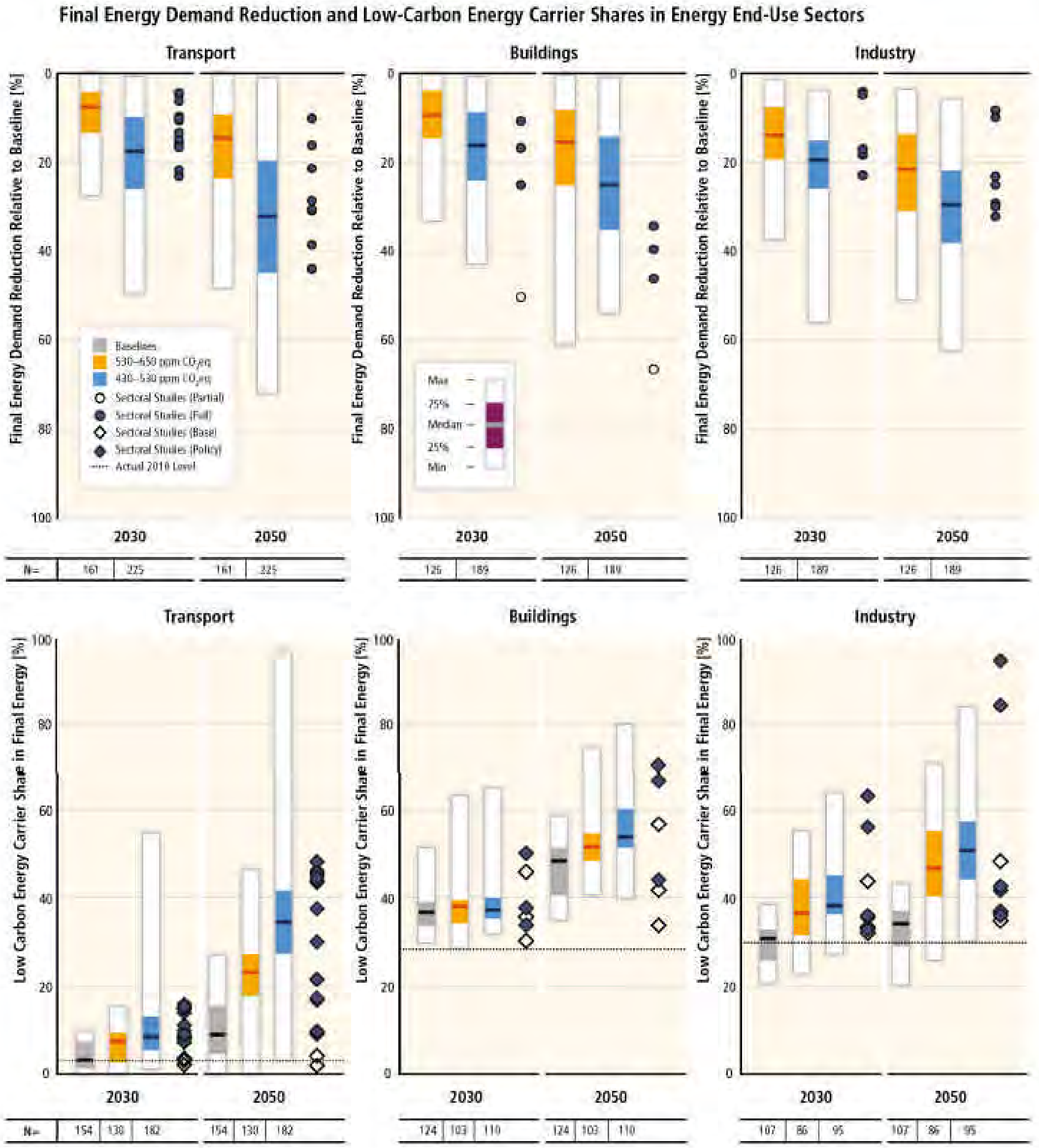


Figure 4.3: Final energy demand reduction relative to baseline (upper row) and low-carbon energy carrier shares in final energy (lower row) in the , transport, buildings, and industry sectors by 2030 and 2050 in mitigation scenarios from two different CO_2-eq concentration categories (see Section 6.3.2) compared to sectoral studies assessed in Chapters 8-10. Low-carbon fuels include electricity, hydrogen and liquid biofuels in transport, electricity in buildings and electricity, heat, hydrogen and bioenergy in industry. The numbers at the bottom of the graphs refer to the number of scenarios included in the ranges which differs across sectors and time due to different sectoral resolution and time horizon of models. *{WG III figure SPM.11}*

REDD+ and sustainable bioenergy have a critical role to play in mitigating climate change, especially in the near term, if food security, socioeconomic and biodiversity concerns are addressed.

The AFOLU sector accounts for about a quarter (~10–12GtCO_2eq/yr) of net anthropogenic GHG emissions (*medium evidence, high agreement*)**.** Most recent estimates indicate a decline in AFOLU CO_2 fluxes, largely due to decreasing deforestation rates and increased afforestation.

The most cost-effective mitigation options in forestry are reducing deforestation, afforestation, and sustainable forest management. In agriculture, the most cost-effective mitigation options are cropland management, grazing land management, and restoration of organic soils (*medium evidence, high agreement*)**..** The economic mitigation potential of supply-side measures is estimated to be 7.2 to 11 GtCO_2eq/year in 2030 (at <100 USD/tCO_2eq), about a third of which can be achieved at a <20 USD/tCO_2eq (*medium evidence, medium agreement*). Demand-side measures, such as changes in diet and reductions of losses in the food supply chain, have a significant, potential to reduce GHG emissions (0.76–8.6 GtCO_2eq/yr by 2050) (*medium evidence, medium agreement*). *{WGIII SPM. 4.2.3}*

Bioenergy can play a critical role for mitigation. However, barriers to large-scale deployment of bioenergy include concerns about GHG emissions from land, food security, water resources, biodiversity conservation and livelihoods. Evidence suggests that options with low lifecycle emissions (e.g., sugar cane, Miscanthus, and sustainable use of biomass residues), can reduce GHG emissions; outcomes are site-specific and rely on sustainable land-use management and governance. In some regions, bioenergy options, such as improved cookstoves, and small-scale biogas and biopower production, could reduce GHG emissions and improve livelihoods and health (*medium evidence, medium agreement*). *{WGIII 11.13}*

4.4 Response Options for Adaptation

A first step for adaptation is often to reduce current climate-related risks. Adaptation options can have multiple and overlapping entry points, and combine to form a portfolio of responses. However, trade-offs exist between some adaptation options.

A first step toward adaptation to future climate change is reducing vulnerability and exposure to present climate variability (*high confidence*). Strategies include actions with co-benefits for other objectives. Integration of appropriate adaptation strategies and actions into development planning and decision-making can proactively prepare for a range of future climates while helping to improve human health and livelihoods, social and economic well-being, and environmental quality now. Such strategies include improved social protection, improved water and land governance, enhanced water storage and services, reduce pollution, greater involvement of affected people in planning, and elevated attention to urban and peri-urban areas heavily affected by migration of poor people. *{WGII Table TS.7, 3.6, 9.4, 11.2, 14.2, 15.2-3, 15.5, 17.2, 20.4, 20.6, 22.4, 24.4, 25.10, 27.3-5, Boxes 25-2, 25-6, 25-8, and 25-9}*

An increased range of adaptation options has been assessed since the AR4 and clarity of the benefits and costs of these options and their links to sustainable development has improved. Adaptations employ a diverse portfolio of planning and practices, including:

- Infrastructure and asset development
- Technological process optimization
- Institutional and behavioural change or reinforcement
- Integrated natural resources management (such as for watersheds and coastal zones)
- Financial services, including risk transfer
- Information systems to support early warning and proactive planning

These approaches (Table 4.3 for examples and details) have a diversity of entry points in vulnerability reduction, disaster risk management and proactive adaptation planning. Appropriate entry points depend on co-benefits and opportunities within wider development plans and strategic goals, and existing other climate and non-climate pressures. *{WGII 15.3, 15.4, 15.6, FAQ 15-2}*

Individual adaptation measures can complement each other, but some approaches entail significant trade-offs with and reduce the effectiveness of other actions (*very high confidence*). Local governments and actors may face difficulties in identifying the most suitable and efficient approaches because of the diversity of possible approaches, from infrastructure development to "softer" approaches such as integrated watershed and coastal zone management. The effectiveness of specific adaptation options is influenced by cultural characteristics, institutional context and capacity, perception of risks, sense of place and role and entitlements to resources, which differ between individuals and institutions. Trade-offs (Table 4.4) often arise from differential values of societal actors and the degree to which individual adaptation options address those values and constrain or enable the simultaneous pursuit of other adaptation objectives. Some near-term responses to increasing risks related to climate change may also limit future choices. For example, enhanced protection of exposed assets can lock in dependence on further protection measures. *{WGII 15.2.1, 15.5.1, 16.2, 16.3.2, Table 16-2}*

The potential for individual adaptation measures to reduce risk differs between sectors and regions, and changes over time. For many natural ecosystems, the adaptation options are limited and focus mostly on reducing other pressures. For many human systems, a wider portfolio of options exists, including transformational responses, but their implementation faces a range of constraints.

Examples of key adaptation approaches for particular sectors are summarized below.

Freshwater resources: **Adaptive water management techniques, including scenario planning, learning-based approaches, and flexible and low-regret solutions, can help create resilience to uncertain hydrological changes and impacts due to climate change (*limited evidence, high agreement*).** Strategies include integrated water management; augmenting supply; reduced mismatch between water supply and demand and reducing non-climate stressors; strengthening institutional capacities; adoption of more water-efficient technologies and water-saving strategies through a range of incentives. *{WGII 3.6, 3.7, Table 16-2, 22.3-4, 23.4, 23.7, 24.4, Box 25-2, 27.2-3}*

Terrestrial and freshwater ecosystems: **Management actions, such as maintenance of genetic diversity, assisted species migration and dispersal, manipulation of disturbance regimes (e.g., fires, floods), and reduction of other stressors, can reduce, but not eliminate, risks of impacts to terrestrial and freshwater ecosystems due to climate change, as well as increase the inherent capacity of ecosystems and their species to adapt to a changing climate (*high confidence*).** Main management adaptation options are to reduce other pressures (e.g., pollution, runoff, fishing, tourism, introduced predators and pests); improve early warning systems and the associated response systems; and incorporate fire protection measures (e.g., prescribed burning, introduction of resilient vegetation). Enhancement of migration corridors can also assist autonomous adaptation. Translocation of species is controversial and becomes less feasible where whole ecosystems are at risk. *{WGII Figure SPM.5, 4.3-4, 25.6, 25.10, 26.4, Box CC-RF}*

Coastal systems and low-lying areas: **Adaptation can reduce some of the projected damages from flooding in river basins and coasts, driven by increasing urbanization and by increasing sea levels and peak river discharges (*high confidence*), but the relative costs of coastal adaptation vary strongly among and within regions and countries for the 21st century.** Significant experience exists in hard flood-protection technologies, but there are high costs for increasing flood protections. *{WGII 23.2-3, 23.7}* Successive building and protection cycles can increase exposure by constraining flexible responses to increasing risks to coastal infrastructure and low-lying ecosystems from sea-level rise; and coastal outfalls can impede drainage with increased water levels (section 3.3). Effective adaptation includes land-use controls and ultimately relocation as well as protection and accommodation *{WGII 25.6, 25.10, Box 25-1}*; appropriate building codes and settlement patterns; maintenance and restoration of coastal landforms and ecosystems including through community based actions; and improved management of soils and freshwater resources.

Marine systems and oceans: **Marine forecasting and early warning systems as well as reducing non-climatic stressors can help 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. 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, institutional and mangrove buffers that take advantage of beneficial changes, alternative livelihoods, and occupational flexibility are important strategies for reducing the vulnerability of ocean-dependent human communities.

Expansion of aquaculture can also increase flexibility and resilience. Human adaptation options for coral reef systems are 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 increases. *{WGII 6.3, 6.4, 7.3-4, 29.4, 30.6-7, Box CC-MB, 5.4, 25.6.2; 30.3, 30.5, Box CC-CR}*

Food production system/Rural areas: **Adaptation options for agriculture include technological responses (e.g., stress-tolerant crop varieties, irrigation), enhancing smallholder access to credit and other critical production resources, and strengthening institutions at local to regional levels to support gender-oriented measures (*high confidence*)**. Responses to decreased food production and quality include development of new crop varieties including more effective adaptation to changes in CO_2, temperature, and drought; offsetting human and animal health impacts of reduced food quality, and offsetting of economic impacts of land use change. Options exist for adaptation via international agricultural trade (*medium confidence*). Deepening agricultural markets and improving the predictability and the reliability of the world trading system through trade reform could result in reduced market volatility and manage food supply shortages caused by climate change. Investing in the production of small-scale farms in developing countries also provides benefits.*{WGII 9.3, 22.3-4, 22.6, 25.9, 27.3}*

Urban areas, key economic sectors and services: **Urban adaptation benefits from effective multi-level urban risk 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*)** (section 3.3). 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 of the non-diversifiable portion of risk. In some locations, especially at the upper end of projected changes, responses could also require transformational changes such as managed retreat. *{WGII 8.3-4, 24.4, 24.5, 26.8, Table 11-3, Box 25-1, 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 offer the best examples for securing health, security and livelihoods in the near term (*high confidence*).** The most effective adaptation measures for health in the near-term may be programs that implement and improve basic public health measures. Examples include provision of clean water and sanitation, secure essential health care including vaccination and child health services, increased capacity for disaster preparedness and response, and poverty alleviation (*very high confidence*). Health warning systems linked to response strategies, urban planning to reduce heat systems and improvements to the built environment are options to address heat related mortality. Robust institutions can manage many transboundary impacts of climate change to reduce conflict risks. Insurance programs, social protection measures, and disaster risk management may enhance long-term livelihood resilience among poor and marginalized people if policies address multidimensional poverty. *{WGII Figure TS 10, 8.2, 10.8, 11.3-8, 19.3, 22.3, 25.8, 26.6, Box CC-HS}*

Table 4.3: 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. Examples are presented in no specific order and can be relevant to more than one category. Mitigation is considered essential for managing the risks of climate change; it is not addressed in this table as it is considered in other sections of this report. *{WGII Table SPM.2}*

Overlapping Approaches	Category	Examples
Vulnerability and 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 and 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.
Transformation		***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.
	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 and actions consistent with reducing vulnerability & risk and supporting adaptation, mitigation, & sustainable development.
		Personal: Individual & collective assumptions, beliefs, values, & worldviews influencing climate-change responses.

Table 4.4: 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	Ultimate success of assisted migration is difficult to predict; introduction of species into new ecological regions could have adverse impacts on indigenous flora and fauna
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; increases 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

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

Adaptation and mitigation can be promoted by and depend on policies and measures across a range of scales (*very high confidence*).

Climate change has the characteristics of a collective action problem at the global scale, because most GHGs accumulate over time and mix globally, and emissions by any agent (e.g. individual, community, company, country) affect other agents.[18] Therefore, effective mitigation will not be achieved if individual agents advance their own interests independently. While climate change mitigation can also have local co-benefits, climate change adaptation focuses primarily on local to national scale outcomes. However, the effectiveness of adaptation can still depend on links with other sectors and vertical coordination across governance scales, including international cooperation. *{SREX.SPM; WGII.2.2, 15.2; WGIII.13.ES, 14.3, 15.8}*

[18] In the social sciences this is referred to as a 'global commons problem.' As this expression is used in the social sciences, it has no specific implications for legal arrangements or for particular criteria regarding effort-sharing.

4.5.1 Mitigation Policies

A variety of climate policy instruments have been employed and an even wider variety of instruments could be employed at the international, regional, national, and sub-national levels.

4.5.1.1 International and Regional Cooperation

As a global commons problem, effective climate change mitigation requires international cooperation. The UNFCCC has provided a platform for coordinating efforts across nations; and other, increasingly diverse forms of international cooperation have developed over the past decade. These include linkages among regional, national and sub-national policies, and the inclusion of climate change issues in other policy arenas. *{WGIII 13}*

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 (Figure 4.4). *{WGIII 13.4}*

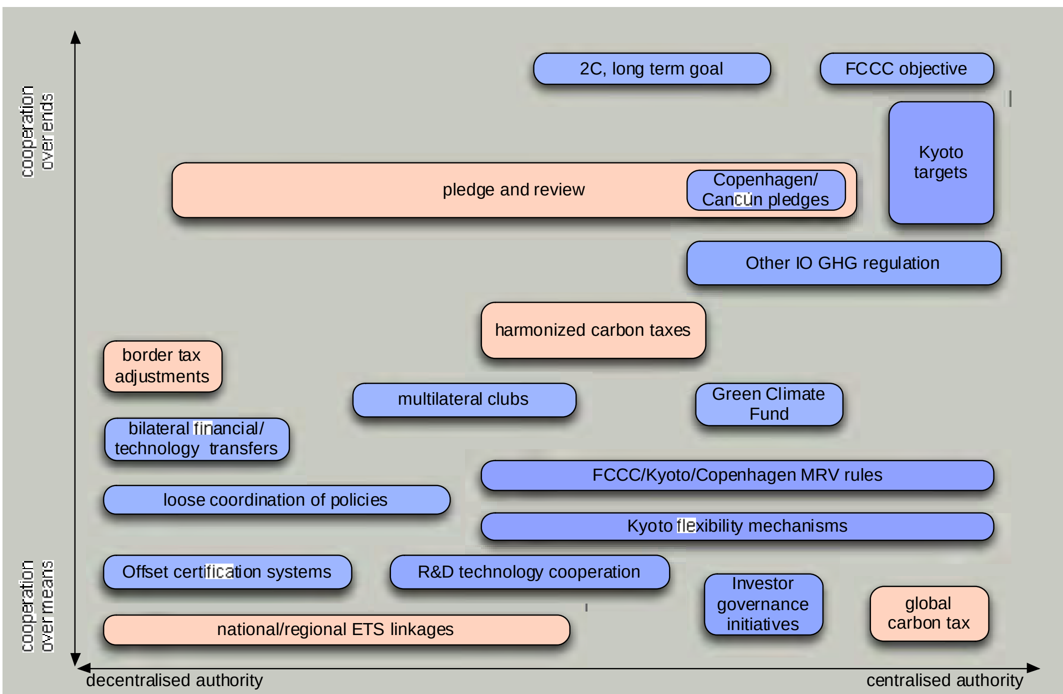


Figure 4.4: International cooperation over ends and means and degrees of centralized authority. Examples in blue are existing agreements. Examples in pale pink are proposed structures for agreements. The width of individual boxes indicates the range of possible degrees of centralization for a particular agreement. The degree of centralization indicates the degree conferred by the agreement, not the process by which is was agreed. *{WGIII Figure 13.2}*

The United Nations Framework Convention on Climate Change (UNFCCC) is the main multilateral forum focused on addressing climate change, with nearly universal participation, but activities since 2007 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, 13.3, 13.4, 13.5, 13.8, 16.2}*

The Kyoto Protocol offers lessons towards achieving the ultimate objective of the UNFCCC, particularly with respect to participation, implementation, flexibility mechanism, and environmental effectiveness (*medium evidence, low agreement*). The Parties collectively surpassed their collective emission reduction target in the first commitment period, but the Protocol credited emissions reductions that would have occurred even in its absence. The Kyoto Protocol does not directly influence the emissions of non-Annex I countries, which have grown rapidly over the past decade. The Kyoto Protocol's Clean Development Mechanism (CDM), which created a market for emissions offsets from developing countries, had generated credits equivalent to over 1.3 $GtCO_2eq$ by July 2013. Its environmental effectiveness has been mixed due to concerns about the additionality of projects, the validity of baselines, the possibility of emissions leakage, and recent credit price decreases *(medium evidence; medium agreement)*. CDM projects were concentrated in a limited number of countries. *{WGIII SPM, 5.2, 13.13.1.1, 13.7, 13.13, 14.3, Table TS.9}*

UNFCCC negotiations since 2007 have led to an increasing number of institutions and other arrangements for international climate change cooperation. Under the 2010 Cancún Agreement, developed countries formalized voluntary pledges of quantified, economy-wide emission reduction targets and some developing countries formalized voluntary pledges to mitigation actions. The distributional impact of the agreement will depend in part on the magnitude and sources of financing, although the scientific literature on this point is limited, because financing mechanisms are evolving more rapidly than respective scientific assessments (*low evidence; low agreement)*. Under the 2011 Durban Platform for Enhanced Action, delegates agreed to craft a future legal regime that would be 'applicable to all Parties … under the Convention' and would include substantial new financial support and technology arrangements to benefit developing countries, but the delegates did not specify means for achieving those ends. *{WG III 13.5.1.1, 13.13.1.3, 16.2.1.1}*

Several models for equitable 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 operationalise equity, and the manner in which developing countries' emissions plans are financed. *{WG III 4.6, 13.4}*

The Montreal Protocol, aimed at protecting the stratospheric ozone layer, has achieved significant reductions in global greenhouse gas emissions *(robust evidence, high agreement)*. The Montreal Protocol set limits on emissions of ozone-depleting gases that are also potent GHGs, such as CFCs and HCFCs, but substitutes for those ozone-depleting gases (such as HFCs, which are not ozone-depleting) may also be potent GHGs. *{WGI 8; WG III 13.3.3, 13.3.4, 13.13.1.4}*

Policy linkages among regional, national, and sub-national climate policies offer potential climate change mitigation and adaptation benefits *(medium evidence, medium agreement).* Linkages can be established between carbon markets and through regional cooperation, such as embodying mitigation objectives in trade agreements or the joint construction of infrastructures that facilitate reduction in carbon emissions. These include lower mitigation costs, decreased emission leakage, and increased market liquidity. *{WGIII SPM, 13.3.1, 13.5 13.6, 13.7, 14.5}*

Various regional initiatives between national and global scales are either being developed or implemented, but their impact on global mitigation has been limited to date *(medium confidence).* Many climate policies can be more effective if implemented across geographical regions. *{WGIII Table TS.9, 13.13, 14.4, 14.5}*

4.5.1.2 National and Sub-National Policies

There are increased numbers of national and sub-national plans and strategies to address climate change since AR4 ***(high agreement, medium evidence)*****, but there is inadequate evidence to assess their impacts on emissions.** ***{WGIII 15.1, 15.2}***

Sector-specific policies have been more widely used than economy-wide policy instruments ***(high agreement, medium evidence) See Table 4.5.*** Although most economic theory suggests that economy-wide policies for the singular objective of mitigation would be more cost-effective than sector-specific policies, since AR4 a growing number of studies has demonstrated that administrative and political barriers may make economy-wide policies harder to design and implement than sector-specific policies. *{WG III 8.10, 9.10, 10.10, 15.2, 15.5, 15.8, 15.9}*

Carbon pricing regimes have been implemented in a diverse set of countries. Since AR4 the number of cap and trade systems has increased, but their short-run environmental effects have been limited as a result of loose caps or caps that have not proved to be constraining *(limited evidence, medium agreement)*. **Where implemented, 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, although differentiation across sectors results in heterogenous marginal abatement costs and thus reduces cost-effectiveness. In a large group of countries, fuel taxes have effects that are akin to sectoral carbon taxes**. *(Robust evidence, medium agreement)* Revenues from carbon taxes or auctioned emission allowances can be used to cut distortionary taxes on labor and investment, and thereby to lower net social costs, *{WG III 3.6.3}*. Targeted distribution of revenues and allowances can also be used to render policies more politically acceptable, although potentially at the cost of environmental effectiveness. *{WG III 14.4.2; 15.5.2}*.

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 labeling programs that can help consumers make better-informed decisions. *{WG III 3.9.5, 15.5.5, 15.5.6}*

Sub-national climate policies play important roles, both in countries with national policies and in those without. For example, state and provincial climate policies exist in many European countries, in the United States, in China and elsewhere. Some of these are regional cap-and-trade systems, most prominently the Regional Greenhouse Gas Initiative in nine northeastern U.S. states and California's ambitious and multi-faceted Global Warming Solutions Act (AB 32). Likewise, in China, six local, pilot CO_2 cap-and-trade scheme have been launched. In addition, transnational cooperation has arisen among sub-national actors, commonly referred to as "transnational climate governance initiatives", notably by institutional investors, NGOs seeking to govern carbon offset markets, and among networks of cities seeking to collaborate in generating low-carbon urban development. *{WGIII 13.5.2, 15.2.4, 15.3, 15.8}*

Without coordination, policy instruments may not work as expected. Carbon prices to address the emissions externality can interact positively with an R&D subsidy to address innovation market failures. By contrast, while the emission abatement effects of policies nested under a carbon tax are additive, policies nested under a quantity-averaging instrument, such as cap-and-trade, are not (*medium evidence, high agreement*). *{WGIII 15.7.}*

Table 4.5: 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 taxes	? 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	? 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 (EU ETS) ? CDM credits ? Tradable Green Certificates	-Fuel and vehicle standards	? Tradable certificates for energy efficiency (white certificates)	? Emission trading ? Emission credit under CDM ? Tradable Green Certificates	? CDM credits ? Compliance schemes outside Kyoto protocol Voluntary carbon markets	? Urban-scale Cap-and-Trade
Economic Instruments – Subsidies	? Fossil fuel subsidy removal ? Feed in tariffs ? Capital subsidies and insurance for CCS	? Biofuel subsidies ? Vehicle purchase subsidies ? Feebates	? Subsidies or Tax exemptions for, 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	? Fuel economy standards	? Building codes and	? Energy efficiency standards for	? National policies to	? Mixed use zoning ? Development

	performance standards ? Renewable Portfolio standards for renewable energy ? Equitable access to electricity grid ? Legal status of long term CO_2 storage	? Fuel quality standards ? GHG emission standards ? Regulations to encourage modal shifts (road to rail) ? Restriction on use of vehicles ? Airport capacity constraints	standards ? Equipment and appliance standards ? Mandates for energy retailers to assist customers invest in energy efficiency	equipment ? Energy management systems (also voluntary) ? Voluntary agreements (where bound by regulation) ? Labelling and public procurement regulations	support REDD+ including monitoring, reporting and verification ? Forest law to reduce deforestation ? Air and water pollution control GHG precursors ? Land-use planning and governance	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 ? Information policies to support REDD+	
Government Provision of Public Goods or Services	? Research and development ? Infrastructure expansion	? Investment in transit ? Investment in infrastructure ? Vehicle procurement	? Public procurement of efficient buildings and appliances	? Training and education ? Brokerage for industrial cooperation	? Protection of forests. ? Diffusion of innovative technologies	-Provision of utility infrastructure - Park improvements - Trail improvements -Urban rail,
Voluntary Actions			? Labelling programmes for efficient buildings ? Product eco-labeling	? Voluntary agreements on energy targets or adoption of energy management systems , or resource efficiency	? Promotion of sustainability by developing standards and educational campaigns	

4.5.2 Adaptation Policies

Adaptation to climate change is transitioning from a phase of awareness to the construction of strategies and embedding in planning processes. Integration across scales of governance and the public and private sector through robust institutions and frameworks are considered important to overcome common constraints to adaptation (*medium evidence, high agreement*), but evaluation of implementation and monitoring of outcomes remains limited.

International mechanisms for supporting adaptation planning have assisted in the creation of adaptation strategies, plans, and actions at the national, sub-national, and local level *(high confidence)*. Examples include the Global Environmental Facility adaptation funds, the Pilot Program for Climate Resilience, the Adaptation Fund set up under the Kyoto Protocol, and special purpose adaptation funds by UN agencies. The directives and initiatives of the European Commission (EC) have fostered the creation of a large number of national adaptation strategies and plans in EU member countries since the last IPCC report. Closer integration at the international level of disaster risk reduction and climate change adaptation, and the mainstreaming of both into international development assistance, could foster greater efficiency in the use of available and committed resources and capacity. *{WGII 15.2.1, SREX 7.4, 8.2, 8.3, 8.5, 8.7}*

Current approaches to adaptation are dominated by top-down consideration of future impacts and often focus on the construction of defensive infrastructure, but this does not necessarily lead to the most cost-effective and efficient adaptation policy decisions. Climate change adaptation takes place as a response to multiple stressors, and the importance of adaptation is influenced by how the issue is framed in particular contexts, and the extent that it is viewed as a public safety issue and disaster risk management issue or a development issue. Coupling adaptive improvements in infrastructure with efforts to improve ecosystem resilience, governance, community welfare, and development can improve community resilience and strengthen both adaptation planning and implementation. *{WGII 15.2.1, 15.3.1, 15.3.3, 15.5.1.2, Box 15-1}*

Local government and the private sector are increasingly recognized as critical to progress in adaptation. National governments can coordinate adaptation efforts of local and subnational governments through finance, legal and policy frameworks, information, and protection of vulnerable groups (*medium to high evidence, high agreement)*. Common constraints on implementation arise from limited financial and human resources; limited integration or coordination of governance; uncertainty about projected impacts; different perceptions of risks; competing values; absence of key adaptation leaders and advocates; and limited tools to monitor adaptation effectiveness. Institutional dimensions in adaptation governance play a key role in promoting the transition from planning to implementation of adaptation. Public action can address some of these constraints, and can in turn influence the degree to which private parties undertake adaptation actions. However, most assessments of adaptation have been restricted to impacts, vulnerability, and adaptation planning, with very few assessing the process of implementation or the effectis of adaptation actions (*medium evidence, high agreement*). *{WGII SPM, 2.1-4, 3.6, 8.3-4, 9.3-4, 14.2, 15.2-3, 15.5, 16.2-5, 17.2-3, 22.4, 24.4, 25.4, 26.8-9, 30.7, Tables 21-1, 21-5, and 21-6, Boxes 16-1, 16-2, and 25-7; SREX 6.2, 6.4}*

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 ecosystem 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, 10.7, 10.9, 13.3, 17.4-5, 22.4, Box 25-7; SREX 6.5}*

4.5.3 Technology development and transfer

Technology development, deployment and diffusion can be important components of mitigation and adaptation efforts, but face varying challenges in terms of scale, integration with existing systems, and integration in local context (*high confidence*).

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 the invention of new technologies and practices (the information that flows from R&D efforts) is often a public good, and thus R&D 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. *{WGIII 2.6.5, 3.11; 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)***.** Unlike mitigation, where low-carbon technologies are often new and protected by patents, adaptation technologies are often familiar and already applied. However, successful technology transfer requires not only the provision of finance and information about technological solutions, but also strengthening policy and regulatory environments, and capacities to absorb, employ and improve technologies appropriate to local circumstances. *{WGII 15.4}*

4.5.4 Investment and Finance

Effective mitigation and adaptation efforts can require both changes in patterns of investment in developed and developing countries, and increases in financial support for developing countries (*high confidence*). Appropriate governance arrangements and institutions are essential conditions for efficient, effective, and sustainable financing of mitigation and adaptation measures (*high agreement, robust evidence*).

Substantial reductions in emissions would require large changes in investment patterns (*high agreement, robust evidence*). Over the next two decades (2010-2029) 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 $1200 billion (Figure 4.5). *{WGIII SPM}*

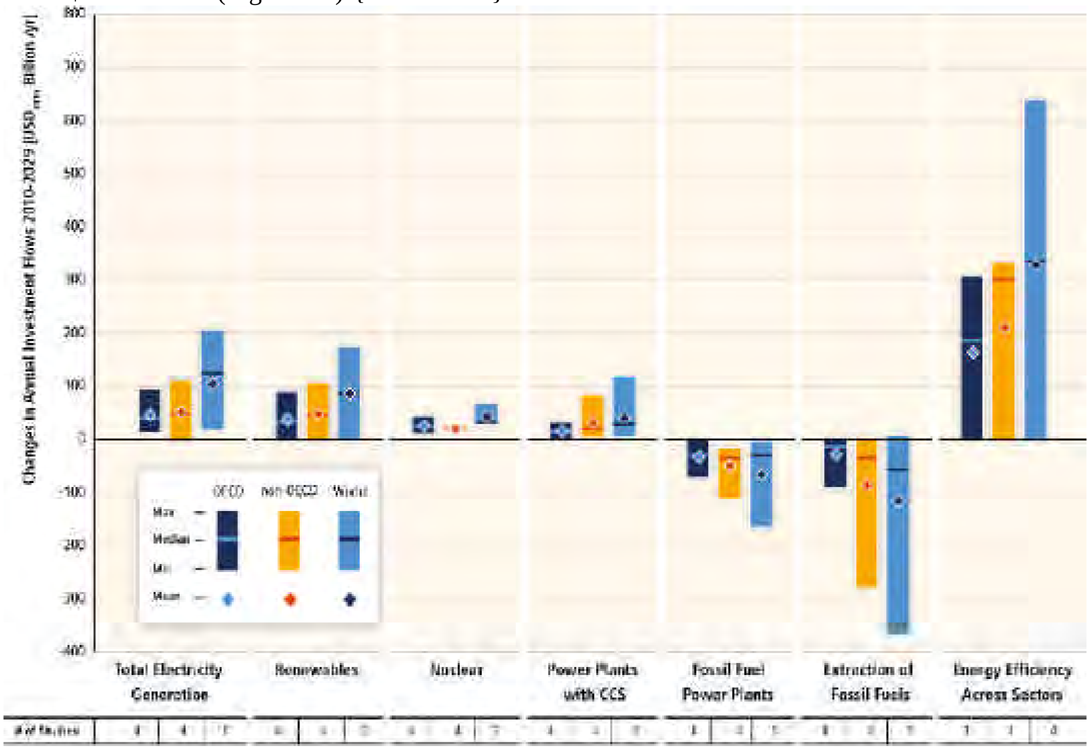


Figure 4.5: Change in annual investment flows from the average baseline level over the next two decades (2010 to 2029) for mitigation scenarios that stabilize concentrations within the range of approximately 430-530 ppm CO_2eq by 2100. The vertical bars indicate the range between minimum and maximum estimate; the horizontal bar indicates the median. The numbers in the bottom row show the total number of studies in the literature used for the assessment. *{WGIII Figure 16.3}*

Increased financial support from developed to developing countries will be needed to stimulate investment in low-carbon energy sources and energy efficiency in developing countries *(high agreement, medium evidence)*. Developed countries have committed to a goal of jointly mobilizing US$ 100 billion per year from various sources by 2020 for adaptation and mitigation in developing countries (see Figure 4.6 for an overview of climate finance). There is lack of agreement on what share of this can be mobilized through the public versus private sectors. Bilateral and multilateral institutions typically provide public climate finance to developing countries as concessional loans and grants. Robust information on private sector flows from developed to developing countries is very limited. *(medium agreement, medium evidence) {WGIII 16.2.1.1, 16.2.1, 16.4}*

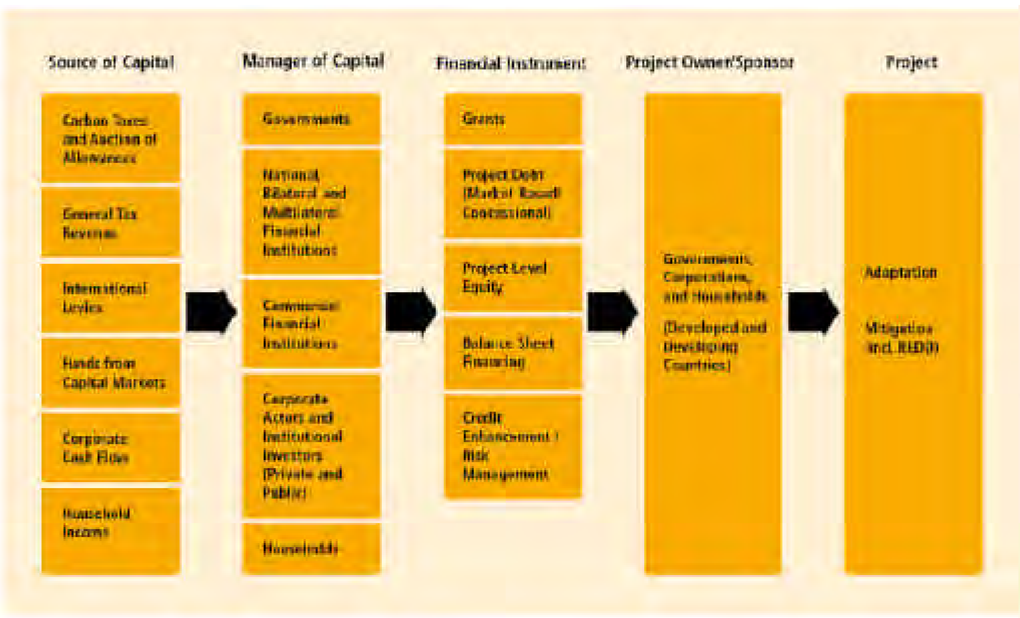


Figure 4.6: Overview of climate finance flows. Note: Capital should be understood to include all relevant financial flows. The size of the boxes is not related to the magnitude of the financial flow. *{WGIII Figure TS.4.5}*

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. 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, for example, credit insurance, power purchase agreements and feed-in tariffs, concessional finance or rebates provide an incentive for mitigation investment by lowering risks for private actors. Large-scale public-private risk reduction initiatives and economic diversification are examples of adaptation actions relying on private sector participation. *{WGII SPM 10.7, 10.10, 15.2-3, 17.2; WGIII SPM, 16.2.1, 16.3, 16.4}*.

Limited evidence indicates a gap between global adaptation needs and the funds available for adaptation (medium confidence). This gap suggests a growing adaptation deficit, particularly in developing countries. Financial resources for adaptation have been slower to become available for adaptation than for mitigation in both developed and developing countries. Adaptation finance made up probably only a fifth of initial allocations of fast-start funding. *{WGII 14.2, 17.X}*

4.6 Trade-offs, synergies, and integrated responses

Climate policy is increasingly driven by an understanding of the close links between climate and development policies and between different aspects of adaptation and mitigation. Recognizing these linkages and developing tools with which to address them is critical to the success of integrated responses to climate change

4.6.1 Trade-offs and Synergies

There is a growing evidence base indicating significant synergies and tradeoffs between mitigation and adaptation, as well as between these and development outcomes, but tools to understand and manage these interactions remain limited. *{WGII 8.5, 11.5}* As an example of synergies across ecosystems and human systems, mangrove, sea grass, and salt marsh ecosystems offer important carbon storage and sequestration opportunities, while also providing ecosystem services such as protection against coastal erosion and storm damage and maintenance of habitats for fisheries. In some cases both synergies and tradeoffs can exist: or facilitating payments under REDD+ can affect rural areas by increasing income and employment opportunities, but may also lead to the expropriation of land, the loss of livelihoods, or food insecurity. *{WGII 23.8, Table 25-7}*

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) (Table 4.6).* Governments explicitly reference co-benefits in climate and sectoral plans and strategies *{WGII 15.2}*. Despite the growing attention in policymaking and the scientific literature, since AR4 the analytical and empirical underpinnings for understanding many of these interactive effects are under-developed *{WGII 1.2, 3.6.3, 4.2, 4.8, 6.6} {Box X}*. The scope for co-benefits may be greater in low-income countries, where complementary policies for other objectives, such as air pollution, are often weak. *{WGIII 5.7, 6.6, 15.2}*

Managing trade-offs, synergies and other interactions (Figure 4.X) is challenging due to their complexity and to the limited availability of tools to support decision-making at local and regional scales. *{WGII Box CC-WE}* However, the benefits of addressing climate change using integrated approaches and multiple metrics have been shown to be consistent with the achievement of multiple goals associated with climate resilient pathways for sustainability *{WGII.20.5}*.

Adaptations that do not consider the full range of consequences arising from actions may be maladaptive *{WGII 14.6.1}.* This may result from poor planning, an overemphasis on short-term outcomes, or discounting future consequences. For example, increased use of air conditioning increases energy demand, whereas adaptations focused on energy efficiency and building design can reduce heat exposure as well as energy demand. *{WGII.25.7.4, Box 25-9}* Maladaptation can increase the vulnerability or exposure of the target group in the future, or the vulnerability of other locations or sectors. *{WGII 14.6, 15.5, 17.2-3, 22.4, 25.9}*

Integration of adaptation into planning and decision-making can create synergies with development. *{II 20.3}* Adaptation strategies that strengthen livelihoods, enhance well-being and human security, and reduce poverty include increased access to information and resources, improved health services and social protection, and more effective water and land management and governance. *{WGII 3.6, 9.4, 11.2,14.2, 15.2-3, 15.5, 17.2, 20.4, 20.6, 22.4, 24.4, 25.10, 27.3-5, Boxes 25-2, 25-6, 25-8, and 25-9}* Adaptation can generate larger benefits when linked to development activities and disaster risk reduction. *{WGII 8.3, 9.3, 14.2, 14.6, 15.3, 15.4, 20.2, 20.3, 22.4, 24.5 29.6, Box CC-UR}*

Table 4.6: This is an abridged version of Table III.6.7. Potential co-benefits (blue text) and adverse side-effects (red text) of the main sectoral mitigation measures. Co-benefits and adverse side-effects 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 Sections XXX *{WGIII.3.9, 6.3.6, 14.4.2}*. The uncertainty qualifiers in 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.

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	Energy security (reduced exposure to fuel price volatility) (m/m); local employment impact (but uncertain net effect) (l/m); legacy 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)
RE (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) (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) (m/h)	Mixed ecosystem impact via reduced air pollution (except bioenergy) (m/h) and coal mining (l/h), habitat impact (for some hydro) (m/m), landscape and wildlife impact (for wind) (m/m); lower/higher water use (for wind, PV (m/m); bioenergy CSP, geothermal and reservoir hydro (m/h))
Fossil 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 fuel carbon intensity	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 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, RES incorporation, green roofs)	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 time for women/children (for replaced traditional cookstoves) (m/h)	Reduced health impact in residential buildings and ecosystem impact (via reduced fuel poverty (r/h), indoor/ 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); lower need for energy subsidies (l/l); asset values of buildings (l/m); disaster resilience (l/m)	Fuel poverty alleviation via reduced energy demand (for retrofits, efficient equipment) (m/h); energy access (higher cost for housing) (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)
Behavioral changes reducing energy demand	Energy security (m/h); lower 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 work 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).*		
<u>Supply side</u>: forestry, land-based agriculture, livestock, integrated systems and **bioenergy** <u>Demand side:</u> 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 labor-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 pesticides, reduced burning practices and practices like agroforestry & silvo-pastoral systems** (m/h); **human health when using 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)

4.6.2 Interactions between energy and mitigation through prices

Changes in energy production and supply through mitigation policies often directly or indirectly lead to changes in relative energy prices, with significant implications for economic, social and environmental outcomes. These synergies or trade-offs can be managed by deliberate attention to the feedbacks and consequences.

The reduction of subsidies for GHG-related activities in various sectors can achieve emission reductions, depending on the social and economic context (high agreement). While subsidies can affect emissions in many sectors, most of the recent literature has focused on subsidies in 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. Although political barriers are substantial, some countries have reformed their tax and budget systems to reduce fuel subsidies. To help reduce possible adverse effects on lower income groups, who often spend a large fraction of their income on energy services, many governments have utilized lump-sum cash transfers or other mechanisms targeted on the poor. *{WGIII 7.12, 13.13, 14.32, 15.5.2}*

Mitigation policy could devalue fossil fuel assets and reduce revenues for fossil fuel exporters, but differences between regions and fuels exist. Most mitigation scenarios are associated with reduced revenues from coal and oil trade for major exporters. . The effect of mitigation on natural gas export revenues is more uncertain, with some studies showing possible benefits for export revenues in the medium term until about 2050. The availability of CCS would reduce the adverse effect of mitigation on the value of fossil fuel assets. The overall impact on oil exports is more complex. Mitigation policies could reduce export revenues from oil, but those same policies could increase the relative competitiveness of conventional oil vis-à-vis more carbon-intensive unconventional oil and coal-to-liquids. *{WGIII.14.4 6.3.6, 6.6}*

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 ***(medium confidence).*** Whether transformation pathways will have adverse distributional effects and thus impede achieving energy access objectives will depend on the climate policy design and the extent to which complementary policies are in place to support the poor, through either income tax rebates or other benefit transfer mechanisms. *{WGIII.chapter}*

The contribution of renewable energy to energy access can be substantial. About 1.3 billion people worldwide do not have access to electricity and about 3 billion are dependent on traditional solid fuels for cooking and heating, with severe health effects and adverse implications for development. Scenario studies show that the costs for achieving nearly universal access are between US$ 65-86 billion per year until 2030. *{WGIII 4.3, 6.6, 7.9, 9.7, 11.13.6, 16.8}*

4.6.3 Integrated Responses

Integrated responses focused on discrete policy arenas are a productive approach to successful climate policy in the context of sustainable development. Policymaking relevant to climate change is increasingly occurring in the context of sectoral decision-making, particularly with reference to managing synergies and trade-offs across multiple objectives (see also 4.5.1.2, 3.5).

An integrated response to urbanization, which is transforming human settlements, societies and energy use, provides substantial opportunities for enhanced resilience, reduced emissions and more sustainable development. 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 lock-in of high emission patterns. *{WGIII.5.6.3, 9.4, 12.3,12.4}* Mixed use zoning, transport oriented development, increasing density, and co-locating jobs and homes can reduce direct and indirect energy use across sectors. Compact and in-fill development of urban spaces and intelligent densification can save land for agriculture and bioenergy and preserve land carbon stocks. *{WGIII.7.X, 8.4, 9.X, 10.X, 11.X, 12.2, 12.3}*

- Urban adaptation provides opportunities for incremental and transformational adjustments towards resilience and sustainable development. Reduced energy and water consumption in urban areas through greening cities and recycling water are examples of mitigation action with adaptation benefits. Building resilient infrastructure systems can reduce vulnerability of urban settlements and cities from coastal flooding, sea level rise and other climate induced stresses. *{WGII.TS; WGIII.TS}*

Explicit consideration of interactions between water use, food and fibre production, energy generation, and carbon sequestration, is increasingly recognised as critical to making 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. Conversely, irrigation can increase the climate resilience of food and fibre production but reduces water availability for other uses. *{WGII Box CC-WE}*

Box: Information relevant to Article 2 of the UNFCCC

Article 2 states the objective of the Convention: « stabilisation of *greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (...) 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 Cancun (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). They also agreed to review this long-term global target on the basis of the best available scientific knowledge with a view to possibly strengthening the target to 1.5°C. Nonetheless, global GHG emissions continue to grow at an increasing rate (Topic 1).

While human influence on the climate system is clear, defining a level of risk as "dangerous" involves both risk assessment and value judgments. This report documents the magnitude of current and future projected climate change and provides a basis for judgment about the level of climate change at which risks become dangerous. This is done by assessing them across contexts and through time, including considerations of extreme vulnerability, potential for severe impacts in specific locations, and for low-probability events with high and irreversible consequences, and also by assessing approaches to valuing these risks. The determination of which level of anthropogenic interference is considered dangerous is not done here, as it would require value judgments (Topic 3.1). However, the assessment provide below may assist in the exercise of such value judgements on an informed basis.

Key vulnerabilities and risks related to ecosystems, food and water, development and other socioeconomic factors are integrated into five complementary and overarching Reasons for Concern (see Figure 3.4; all references to "RFC" below relate to this figure). Risks differ due to the nature of the climate change, vulnerability, and exposure op people, society, and ecosystems, which vary by location, setting, and degree of inequality and marginalization, particularly for the least developed countries and vulnerable communities, given their limited ability to cope. Risks from extreme weather and climate events (RFC 2) and low probability/high-impact events or from exceeding critical global thresholds (RFC 5) may affect the potential for "development to proceed in a sustainable manner" because they are associated with a wide range of impacts, including on infrastructures, services, food systems, and livelihoods.*{1.5, WGII SPM}*

Impacts from current changes in the climate system

- Some unique and threatened ecosystems are already affected, e.g., tropical coral reefs and Arctic systems, which are showing early warning signs of approaching critical thresholds due to climate change (RFC1,3).
- Climate change has already negatively affected wheat and maize yields for many regions and in the global aggregate. In many regions, water resources are already being altered in terms of quantity and quality by changing precipitation or melting snow and ice (Topic 1.4.2; RFC 3).

Risks for warming between about 1°C and 2°C above pre-industrial[19]

Risks increase as temperature and CO_2 concentrations increase, and become high for unique and threatened systems between about 1 and 2°C of warming as do risks associated with extreme events (Figure 3.4).

- Food insecurity linked to warming, drought, and precipitation variability is a key risk particularly in poorer regions (RFC 1, 2, 3, 4).Without adaptation, local temperature increases of 2°C or more above late-20th-century levels are projected to negatively impact yields for the major crops in tropical and temperate regions. Adaptation is potentially effective up to about 2°C, with greater benefits for crops in temperate than in tropical regions (RFC 3*).{WGII 7.5 WGII SPM B.2}*

[19] In this box, except specified otherwise, all global temperature increases are expressed relative to pre-industrial level (the average temperature over the period 1850-1900 can be used as approximations for this level). "Additional warming" refers to a temperature increase above late-20th-century levels.

- Many impacts are difficult to value and monetize; estimates of global annual economic losses for additional temperature increases of ~2°C are between 0.2 and 2.0% of income. Aggregate economic damages accelerate with increasing temperature, with large differences between and within countries(RFC 4*).{WGII 10.9, 13.2.2.1, 19.6}*
- Risks associated with large-scale singular events (e.g. possibility of a near-complete loss of the Greenland ice sheet over a millennium or more for sustained global mean warming above a threshold which is greater than about 1°C but less than about 4°C, causing global mean sea level rise of up to 7 m.*{WGI SPM}*) become moderate for a warming above ~1°C (RFC 5).

Scenarios reaching atmospheric concentration levels of about 450 ppm CO_2eq by 2100 require substantial cuts in anthropogenic GHG emissions by mid-century. Such scenarios are consistent with a *likely* chance to keep temperature increase below 2°C relative to pre-industrial levels (Topic 3.2). Global surface temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6, for which it is *likely* to remain below 2°C (Topic 2.4).Limiting the warming to less than 2°C above pre-industrial with a probability of 50% or >66% require cumulative CO_2 emissions since 1870 to stay below about 3000 and about 2900 $GtCO_2$, respectively, when accounting for non-CO_2forcings. An amount of 1890 $GtCO_2$ (1630-2150) was emitted by 2011. Meeting the 2°C goal with a >66% probability will require GHG emissions reductions of roughly 40% to 70% in 2050 relative to 2010 through fundamental changes in energy systems and potentially land use and agriculture, and emission levels near zero $GtCO_2$eq or below in 2100*. {WG I SPM, WGIII SPM}*

Reducing emissions so that it is *likely* that temperature change will remain below 2°C compared to preindustrial levels will entail its own set of risks. These include the potential for reductions in aggregate economic growth (between 0.04 to 0.14% per year over the century, not including benefits from reduced climate change) and larger economic impacts on specific countries and industries (Topic 3.4).Some mitigation efforts could undermine action to promote sustainable development and equity. Achieving a *likely* chance of remaining below 2°C will bring on these risks more rapidly than higher temperature goals. Delaying mitigation narrows the range of options consistent with maintaining temperature change below 2°C relative to pre-industrial levels, and therefore further increases mitigation costs in the medium to long term (Topic 3.2). All energy technologies – including bioenergy, nuclear power, carbon capture with storage, hydropower, and even wind power – are associated with both risks and possible co-benefits when deployed at large-scale (Topic 3.4).

Risks for warming between about 2°C and 4°C above pre-industrial

Risks increase with temperature and become high for all Reasons for Concern by 4°C warming above preindustrial levels (Figure 3.4).

- Many species and systems with limited adaptive capacity are subject to very high risks with additional warming of 2°C, particularly Arctic sea-ice and coral-reef systems (RFC 1).
- Many species will be unable to track suitable climates under mid- and high-range rates of change (RCP 4.5 and higher) and those that cannot adapt sufficiently fast will decrease in abundance or go extinct in part or all of their ranges. For medium- to high-emission scenarios (RCP 4.5 and higher), ocean acidification, together with decreasing oxygen levels and other drivers, poses substantial risks to marine ecosystems. A large fraction of terrestrial, freshwater, and marine species face increasing extinctions risk under projected climate change during and beyond the 21st century (RFC 1, 4). *{WGII SPM.B1}* Extensive biodiversity loss with associated loss of ecosystem goods and services results in aggregate risks becoming high by 4°C warming (RFC 1, 4)
- Climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions (Topic 2.5.2).
- Aggregate economic damages accelerate with increasing temperature but few quantitative estimates have been completed for additional warming around 3°C or above (RFC 4).
- Risks from large-scale singular events increase disproportionately around ~2°C and become high above 3°C, due to the potential for a large and irreversible sea-level rise from ice sheet loss. *{RFC 5, WGII SPM B-1}*

Global surface temperature change for the end of the 21st century is *more likely than not* to exceed 2°C for RCP4.5, and *likely* to exceed 2°C for RCP6.0 and RCP8.5. It is *about as likely as not* to exceed 4°C for

RCP8.5. Such scenarios require slower emission cuts than the scenarios *likely* to avoid a warming above 2°C, but all scenarios that limit climate change require substantial and sustained reductions in greenhouse gas emissions (Topic 3.2). *{WGI SPM}*

Risks from warming above 4°C compared to pre-industrial

Above 4°C warming compared to preindustrial levels, as projected by RCP8.5, risks from climate change are high to very high in all reasons for concerns and include substantial species extinction, large risks to global and regional food security, and the combination of high temperature and humidity compromising normal human activities in some areas for parts of the year (Figure 3.4) All aspects of food security are potentially affected by climate change including food access, utilization, and price stability (RFC 3). *{WGII SPM B2}*

Interaction with sustainable development

Limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication.
Throughout the 21st century, climate-change impacts, especially without additional mitigation, are projected to slow economic growth, make poverty reduction more difficult, and prolong existing and create new poverty traps, the latter particularly in urban areas and emerging hotspots of hunger. Climate-related hazards exacerbate other stressors, often with negative outcomes for livelihoods, especially for people living in poverty. *{WGII SPM B-2}* Climate change is projected to increase displacement of people, and can indirectly increase risks of violent conflicts by amplifying drivers of conflict such as poverty and economic shocks (Topic 2.5).

Societal responses, particularly adaptation, will influence outcomes over the next few decades.
Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits and delaying mitigation actions may reduce options for climate-resilient pathways in the future (Topic 4.2).

International cooperation is required to effectively mitigate GHG emissions and address other climate change issues. *{WGIII SPM}* Because emissions by any agent (e.g., individual, community, company, country) affect other agents, the risk of climate change in the second half of the 21st century and beyond will be determined by the cumulative amount of near-term and longer-term mitigation, as well as development pathways and resulting adaptation (Topic 4.5).