CLIMATE CHANGE 2014

SYNTHESIS REPORT

PRE- FIRST ORDER DRAFT – INTERMEDIATE WORK VERSION FOR INTERNAL USE
3 December 2013

PLACEHOLDERS:

FOREWORD
PREFACE

SUMMARY FOR POLICY MAKERS

Contents

[Placeholder for Annexes

I. User guide and access to more detailed information
II. Glossary
III. Acronyms, chemical symbols, scientific units, country groupings
IV. List of Authors
V. List of Reviewers and Review Editors
VI. Index
VII. List of all publications of the IPCC]

Introduction

[PLACEHOLDER: TEXT IN DEVELOPMENT].

Risk and Uncertainty Box

This box introduces the concepts of uncertainty and risk and explains the use of these terms in the Synthesis Report and AR5 in general. 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].

Climate change exposes humans, societies, economic sectors, and ecosystems to risk. Risk is also created by policies that are intended to mitigate climate change or adapt to it. In presenting the state of knowledge about climate change, it is therefore essential to characterize the associated uncertainty and risk. *Uncertainty* refers to a state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. *Risk* refers to the potential, when the outcome is uncertain, for adverse effects on lives, livelihoods, health status, economic, social and cultural assets, environmental and other services, infrastructure and ecosystems. Both risk and uncertainty may be understood qualitatively or quantitatively [WGII: 19.3].

Uncertainty about past and future changes in climate arises from imperfections in measurements (of atmospheric and ocean temperatures, for example) and in understanding and modelling the climate system. Several types of uncertainty discussed in this report are important in evaluating model projections of climate responses and associated impacts arising from emissions of greenhouse gas and other forcing agents. Among these, s*cenario uncertainty* is uncertainty about future emissions, caused by our limited ability to predict factors that underlie those emissions, such as the growth of population and economic output, and the development of technology. *Parameter uncertainty* is associated with uncertainty about the magnitude of particular physical, chemical, and biological processes that are represented in models. *Structural uncertainty* is created by the possibility that models may capture some of the key physical, chemical or biological processes incompletely or not at all – different models may make different choices about what is a key process [WGI:1.4].

Some uncertainties are directly related to climate policy choices and are reflected in scenario uncertainty. These include uncertainties related to the deployment of technologies, uncertainties regarding the likelihood with which regulations will be enacted and enforced over the lifetime of firms' investments, and the impact of uncertainties on the choice of mitigation and adaptation measures made by key decision makers [WGIII:2.1.3].

One quantitative definition of the risk from an event is the probability of the event's occurring multiplied by 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. Uncertainties associated with the probability of an event's occurring and/or the resulting outcome also may be specified. For instance, the risk from a future with more intense hurricanes is the probability that hurricanes will become more intense multiplied by the value of the increased harm that will result if they do. This value would take account of the effects on human life and wellbeing, economic costs, and damage to nature and other harms. 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 [WGII:19.1; WGIII:2.2].

The risk (defined as above) from a low-probability event may be greater than the risk from a high-probability event, if the former event is much more harmful. For example, *unlikely* events may be more important to decision-making than *likely* events, if their consequences are extremely harmful. Concentrating solely on the *likely* events may miss events that are critical in designing policy. Risk management therefore takes into account the full range of events and outcomes that can occur including *extremely 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]

Many aspects of the climate system are not yet well understood and quantified, such as the likelihood of a large, rapid release of methane from hydrates in the seabed. Furthermore, many variable factors determine the relationship between radiative forcing and climate changes, between climate changes and socioeconomic outcomes, and between policies and socioeconomic outcomes. These introduce complex interacting sources of uncertainty, many of which may never be quantified. Differing and even contradictory evaluations of risk can result, leading to a range of assessments by policy makers. [WGI:6.4; WGIII:2.4]

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. 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 [WGIII:2.4, 2.5].

Topic 1: Observed Changes and their Causes

1.1 Introduction

Topic 1 focuses on evidence for a changing climate in observations, the impacts caused by it and the human contributors to it. It discusses observed changes in climate (1.2) and external influences on climate (forcings), differentiating those that are of anthropogenic origin, and their regional contributions (1.3). Section 1.4 attributes causes to observed changes in climate, and to impacts where such a link is possible, and attributes impacts to changes in climate. Vulnerability and exposure in the context of extreme events as well as 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 (see Figure 1.1, WGI 2.2, 2.4, 3.2, 3.7, 4.2-4.7, 5.2, 5.5-5.6, 13.2]

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[1], based on the single longest dataset available4 (see Figure 1.1). {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 (WGI Figure WG1 SPM.2; TS TFE.1, Figure 2; 2.5}
There continues to be insufficient evidence and thus *low confidence* regarding the sign of trend in the magnitude and/or frequency of floods on a global scale. [*WG I 2.6.2, Figure 2.33b, c*].
Observed changes in extremes are discussed in Section 1.5.

[1] Square brackets indicate a 90% uncertainty interval unless otherwise stated.

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}

The estimated net increase in Earth's energy storage between 1971 and 2010 is 274 [196 to 351] ZJ (1 ZJ = 1021 Joules), equivalent to 0.42 W m^{-2} heating applied continuously over Earth's entire surface. [WGI 3.2, Figure 3.2, Box 3.1]

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}

There is very high confidence that oceanic uptake of anthropogenic CO_2 has resulted in gradual acidification of seawater and decreasing pH (i.e., anthropogenic ocean acidification) in surface waters (Figure 1.1). The pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era (*high confidence*). In the ocean interior, pH can also be modified by natural physical and biological processes over decadal time scales [*WG1 3.8.2*].

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*) (see Figure 1.1). {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. {4.4}. 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. {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 km2 per decade), and very likely in the range 9.4 to 13.6% per

decade (range of 0.73 to 1.07 million km2 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 km2 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 4.6.2*].

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 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 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 (1.1 [0.8 to 1.4] mm yr^{-1}), from changes in glaciers (0.76 [0.39 to 1.13] mm yr^{-1}), Greenland ice sheet (0.33 [0.25 to 0.41] mm yr^{-1}), Antarctic ice sheet (0.27 [0.16 to 0.38] mm yr^{-1}), and land water storage (0.38 [0.26 to 0.49] mm yr^{-1}). The sum of these contributions is 2.8 [2.3 to 3.4] mm yr^{-1}. [WGI 13.3]

Rates of sea level rise over broad regions can be several times larger or smaller than the global mean for periods of several decades due to fluctuations in ocean circulation. The regional rates are known globally to high precision using satellite altimetry since 1993, 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. [WG1 3.7, FAQ 13.1]

During warm periods in the last 3 million years, global mean sea level exceeded 5 m above present *(very high confidence)* when global mean surface temperature was up to 2 °C higher than pre-industrial *(medium confidence)*. 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 5.3, 5.6, 13.2].

1.3 Past and recent drivers of climate change

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 change in energy fluxes caused by changes in these drivers. All RF values are for the industrial era, defined here as 1750 to 2011, unless otherwise indicated. Positive RF leads to a near-surface warming, negative RF 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. RF of anthropogenic substances can be reported based on emissions or atmospheric concentration changes of these substances. The RF of an emitted substance includes contributions from additional substances resulting from that emission and thus provides a more direct link to human activities. For a more complete assessment of rapid adjustments to clouds this report quantifies drivers, where possible, as an effective radiative forcing (see Figure 1.2). This improves the representation of RF as a surface temperature change metric.

Atmospheric concentrations of the main well mixed greenhouse gas (CO_2, CH_4 and N_2O) have all shown large increases since preindustrial (40%, 150% and 20% respectively). CO_2 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 current rate of about 0.75 ppb yr^{-1}. [*WG1 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. In addition, carbon monoxide emissions have a clear positive RF, while nitrogen oxide emissions appear to cause a net negative forcing but uncertainties are large. Emissions of ozone-depleting halocarbons *likely* cause a net positive forcing as their warming effect is larger than any cooling effect associated with their induced stratospheric ozone loss. [WGI 8.3]

The total anthropogenic RF since 1750 is 2.29 [1.13 to 3.33] W m^{-2} (see 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. [WG-1 8.5]

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 7.5, 8.3, 8.5]

Changes in solar irradiance and volcanoes can cause natural forcings. 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]

1.3.2 Human activities affecting climate drivers

Anthropogenic CO_2 emissions were 555 ± 85 GtC (2035 ± 310 $GtCO_2$) to the atmosphere between 1750 and 2011. Of this amount, fossil fuel combustion and cement production contributed 375 ± 30 GtC (1375 ± 110 $GtCO_2$) and land use activities (e.g. deforestation and afforestation) contributed 180 ± 80 GtC (660 ± 290 $GtCO_2$). Comparing 2011 to 1970, total cumulative CO_2 emissions since 1750 have doubled (*high confidence*)**.** For fossil fuel sources alone, cumulative CO_2 emissions have increased by more than a factor 3 from about 115 GtC (425 GtCO2) in 1970 to 375 GtC (1370 GtCO2) in 2011 (Figure.1.3).[WGI 6.3, WGIII 5.2]

About half of these anthropogenic CO_2 emissions remained in the atmosphere (240 ± 10 GtC) 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 the pre-industrial times. Estimates range are 93–137 GtC from 1750 to 1994, and 155 [125 to 185] GtC from 1750 to 2011 [WG1 3.8.1, 6.3]. Vegetation biomass and soils stored 160 ± 90 GtC over the 1750-2011 period. [WG1 6.3]

Despite existing mitigation policies coming into effect, including the UNFCCC and the Kyoto Protocol, GHG emissions have grown more rapidly between 2000-2010 than in the preceding decade. Since the AR4, global anthropogenic greenhouse gas (GHG) emissions have continued to grow and reached an all-time high of 50 $GtCO_2eq$ in 2010 (Figure 1.4, weighted with 100-year Global Warming Potentials). In 2010, CO_2 emissions exceeded 75% of the total of GHG CO2eq emissions. Emission growth has been most rapid in the energy and transport sectors, mostly related to increasing fossil fuel use. [WG1-6.3 WGIII-1.3, WGIII-5.1]

Regional patterns of GHG emissions are shifting along with changes in the world economy *(high confidence)***.** Almost 80% of the 9.7 Gt CO_2eq global increase in annual GHG emissions between 2000 and 2010 was emitted in the energy supply (4.8 GtCO2eq) and industry (2.7 GtCO2eq) sectors. 5.9 $GtCO_2eq$

of this sectoral increase comes from upper-middle income countries, where economic growth and infrastructure build-up has been highest. [WGIII 5.3, Figure SPM.3]

Per-capita emissions are highly unequal *(high confidence)***.** In 2010, median per capita emissions (1.4 tCO_2e/cap) for the group of low-income countries are around 10 times lower than median per capita emissions ([12.4] tCO_2e/cap) of high income countries. For high-income countries, the largest source of emissions is typically from the industry and energy sectors; for most low-income countries, the largest source of emissions is from AFOLU. There are substantial variations in per capita emissions within income groups. [WGIII 5.2; Figure SPM 3]

Regardless of the perspective taken, a small number of countries account for a large share of global CO_2 emissions *(high confidence)*. In 2010 ten countries comprising slightly more than half of the world's population accounted for [70]% of CO_2 emissions, if the 27 members of the EU are treated as a single entity. [WGIII-1.3]

Economic and population growth continue to be the two main drivers for increases in global fossil fuel CO2 emissions over 2000-2010, outpacing the decline in energy intensity (*high confidence*). Worldwide economic growth as measured through per capita production and/or consumption robustly grew by 25% over the period 2000-2010 (WGIII Figure SPM.5). The energy intensity decreased by 20%. Increased use of coal has reversed a long-standing pattern of gradual decarbonisation of the world's energy supply. Population increased by 13%; urbanization, associated with economic and emissions growth, increased from 47 to 51% over 2000-2010 (medium confidence). [WGIII 5.3, 12.x] [WGIII-1.3, WGIII-5.3]

The upward trend in global fossil fuel related CO2 emissions is robust across databases and despite uncertainties in measurements (*high confidence***).** Global CO_2 emissions from fossil fuel combustion are known within 10% uncertainty (95% confidence interval). CO_2 emissions related to agriculture and forestry and other land uses (AFOLU) have very large uncertainties attached in the order of ±50%. For global emissions of CH_4, N_2O and the F-gases uncertainty estimates are 25%, 30% and 20% respectively. Uncertainties associated with estimates of historic anthropogenic GHG emissions vary by type of gas and decrease with the level of aggregation. Attributing emissions to the country of final consumption increases uncertainties on the country and region level, but not on the global level. GHG emission estimates in the AR4 were 0-10%, mainly because of new estimates for land-use change CO2 emissions and N2O emissions.. [WGIII 5.2]

1.4. Attribution of climate changes and impacts

Causes of observed changes in the climate system are established following methods for detection and attribution that have been developed across working groups (see GPGP, 2010). Detection addresses the question of whether climate or a system 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 statistical confidence (GPGP, 2010). The assessment accounts very carefully for the extent to which 'confounding' factors have been considered

On a local scale, such as local precipitation or temperature change, attribution to human drivers is *much* more difficult. This is why attribution results that directly link impacts of climate change to human drivers are not easy to achieve. In order to address this, WGII has been very careful in distinguishing between attribution to local climate change disregarding the cause of that change from attribution to global human drivers of global climate change more generally.

Thus, 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, in global mean sea level rise, and in changes in some climate extremes (see Figure 1.6). 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]

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 the contributions from other anthropogenic forcings, including the cooling effect of aerosols, *likely* to be in the range of −0.6°C to 0.1°C. The contribution from natural forcings is *likely* to be in the range of −0.1°C to 0.1°C, and from internal variability is *likely* to be 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. [WGI 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 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 (see 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. Detection and attribution at regional scales is complicated by the greater role played by dynamical factors (circulation changes), a greater range of forcings that may be regionally important, and the greater difficulty of modelling relevant processes at regional scales. Nevertheless, human influence has *likely* contributed to temperature increases in many sub-continental regions. [*WG1 10.3, TS4.8*}

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 (see Figure 1.1). There is evidence for human influence in some individual ocean basins [WGI 3.2, 10.4]**.** 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. [WGI 10.4, 10.5, 13.3] It is *very likely* that oceanic uptake of anthropogenic carbon dioxide has resulted in the acidification of surface waters. [*WG1 3.8,, 10.4, Box 3.2, TS 4.4*].

Anthropogenic influences have *very likely* contributed to Arctic sea ice loss since 1979. 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, see 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

Observed impacts of climate change are widespread and consequential. Recent changes in climate have caused impacts on natural and human systems on all continents and across the oceans.[2] This conclusion is strengthened by more numerous and improved observations and analyses since the AR4. For many natural systems on land and in the ocean, new or stronger evidence exists for substantial and wide-ranging climate change impacts. For human systems, effects of changing social and economic factors have often been larger than climate-change-related impacts, but despite this, some impacts in human systems have also been attributed to climate change. In many regions, impacts on natural and human systems are now detected even in the presence of strong confounding factors such as pollution or land use change. See Table 1-1 and Figure 1-7 for a summary of observed impacts and indicators of a changing climate, illustrating broader trends presented in this section. Most reported impacts of climate change are attributed to warming and/or to shifts in precipitation patterns. There is also emerging evidence of impacts of ocean acidification, although in many places these responses are not yet outside their natural variability and may be influenced by confounding local or regional factors. [WGII 18.1, 18.3-6]. Still, a risk-based framing of climate change impacts supports including these results because consequences could be very large (SYN,SPM,AR4, see Box on risk/uncertainty).

In response to ongoing climate change, terrestrial and marine species have shifted their ranges, seasonal activities, and migration patterns. As a result abundance and species interactions have been altered in many places (*high confidence*). Increased tree mortality, observed in many places worldwide, has been attributed to climate change in some regions. While recent warming contributed to the extinction of many species of Central American amphibians (*medium confidence*), most recent observed terrestrial-species extinctions have not been attributed to recent climate change, despite some speculative efforts (*high confidence*). During Earth history in the past millions of years, natural climate change at rates much slower than current anthropogenic change has led to significant ecosystem shifts, including species emergences and extinctions. [WGII 4.2-4, 5.3-5, 6.1, 6.3-5, 18.3, 18.5, 22.3, 24.4, 25.6, 28.2, 30.4-5, Boxes 4-2, 4-3, 25-3, CC-CR, and CC-MB]

[2] Attribution of observed impacts presented in this section links responses of natural and human systems to climate change, not to anthropogenic climate change, unless explicitly indicated.

In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources and quality (*medium confidence*). Glaciers continue to shrink in many regions due to climate change (*high confidence; see also section 1.4.1*). Climate change has caused permafrost warming and thawing in high-latitude and high-elevation mountain regions. [previous section; WGII 3.2, 4.3, 18.3, 18.5, 24.4, 26.2, 28.2, Tables 3-1 and 25-1, Figures 18-2 and 26-1]

Negative impacts of climate change on crop and terrestrial food production have been more common than positive impacts that have been evident in some high-latitude regions (*high confidence*). Recent periods of rapid food and cereal price increases have indicated that current markets in key producing regions are sensitive to climate extremes. [WGII 7.3, 18.4, 22.3, 24.4, 26.5, Figures 7-2, 7-3, and 7-7]

In recent decades, climate change has *likely* contributed to human ill-health although the present world-wide burden of ill-health from climate change is relatively small compared with effects of other stressors and is not well quantified. There has been increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming (*medium confidence*). [WGII 11.4-6, 18.4, 22.3, 24.4, 25.8, 26.6, 28.2]

"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 1-8). [WGII 18.6.3]

Table 1-1 Examples of observed impacts attributed to climate change with *medium* (M) or *high* (H) confidence, indicating the relative contribution of climate change (major [C] or minor [c]) to the observed change, for natural and human systems across eight major world regions over the past several decades. [WGII Tables 18-5, 18-6, 18-7, 18-8, 18-9, and TS.1]

REGION	Snow & Ice, Rivers & Lakes, Floods & Drought	Terrestrial Ecosystems	Coastal Erosion & Marine Ecosystems	Food Production & Livelihoods
Africa	Retreat of tropical highland glaciers in East Africa (H,C) Lake surface warming and water column stratification increases in the Great Lakes and Lake Kariba (H,C) Increased soil moisture drought in the Sahel since 1970, partially wetter conditions since 1990 (M,C) [22.2.2-3, 22.3.2, Tables 18-5, 18-6, and 22-3]	Tree density decreases in Sahel & semi-arid Morocco, beyond changes due to land use (M,C) Range shifts of several southern plants & animals, beyond changes due to land use (M,C) [22.3.2, Tables 18-7 and 22-3]		
Europe	Retreat of Alpine, Scandinavian, and Icelandic glaciers (H,C) Increase in rock slope failures in Western Alps (M,C) [18.3.1, 23.3.1, Table 18-5; WGI AR5 4.3.3]	Earlier greening, leaf emergence, & fruiting in temperate & boreal trees (H,C) Increased colonization of alien plant species in Europe, beyond a baseline of some invasion (M,C) Earlier arrival of migratory birds in Europe since 1970 (M,C) Increasing burnt forest areas during recent decades in Portugal and Greece, beyond some increase due to land use (H,C) [4.3.2-3, Tables 18-7 and 23-6]	Northward distributional shifts of zooplankton, fishes, seabirds, & benthic invertebrates in Northeast Atlantic (H,C) Northward and depth shift in distribution of many fish species across European seas (M,C) Plankton phenology changes in Northeast Atlantic (M,C) Spread of warm water species into the Mediterranean, beyond changes due to invasive species and human impacts (M,C) [6.3.1, 23.6.4-5, 30.5.1, 30.5.3, Tables 6-2 and 18-8, Boxes 6-1 and CC-MB]	Impacts on livelihoods of Sámi people in northern Europe, beyond effects of economic and sociopolitical changes (M,C) Stagnation of wheat yields in some countries in recent decades, despite improved technology (M,c) Positive yield impacts for some crops mainly in northern Europe, beyond increase due to improved technology (M,c) Spread of bluetongue virus in sheep, and of ticks across parts of Europe (M,c) [23.4.1, 23.4.2, Table 18-9, Figure 7-2]
Asia	Permafrost degradation in Siberia, Central Asia, & Tibetan Plateau (H,C) Shrinking mountain glaciers across Asia (M,C) Increased flow in many rivers due to shrinking glaciers in the Himalayas & Central Asia (H,C) Earlier timing of maximum spring flood in Russian rivers (M,C) Reduced soil moisture in North Central and Northeast China (1950-2006) (M,C) Surface water degradation in parts of Asia beyond changes due to land use (M,c) [24.4.1-2, 28.2.1, Tables 18-5 and 18-6, Boxes 3-1 and 3-2; WGI AR5 4.3.2-3, 10.5.3]	Changes in plant phenology & growth in many parts of Asia (earlier greening), particularly in the north & east (M,C) Distribution shifts of many plant & animal species upwards in elevation or polewards, particularly in the north of Asia (M,C) Advance of shrubs into the Siberian tundra (H,C) [4.3.2-3, 24.4.2, 28.2.3, Table 18-7, Figure 4-4]	Decline in coral reefs & large seaweeds in tropical Asian waters & coastal waters of western Japan, beyond decline due to human impacts (H,C) Northward range extension of coral reefs and predatory fish in Sea of Japan (M,C) [24.4.3, 30.5.1, Table 18-8]	Negative impacts on aggregate wheat yields in South Asia, against a baseline of increase due to improved technology (M,c) [7.2.1, Table 18-9, Figure 7-2]

REGION	Snow & Ice, Rivers & Lakes, Floods & Drought	Terrestrial Ecosystems	Coastal Erosion & Marine Ecosystems	Food Production & Livelihoods
Australasia	Significant decline in late-season snow depth at 3 of 4 alpine sites in Australia (1957-2002) (M,C) Substantial reduction in ice and glacier ice volume in New Zealand (M,C) Reduced inflow in river systems in southwestern Australia (since the mid-1970s) (H,C) [25.5.1, Tables 18-5, 18-6, and 25-1; WGI AR5 4.3.3]	Changes in genetics, growth, distribution, & phenology of many species, in particular birds, butterflies, & plants in Australia, beyond fluctuations due to variable local climates, land use, pollution, & invasive species (H,C) Expansion of monsoon rainforest at expense of savannah and grasslands in northern Australia (M,C) [Tables 18-7 and 25-3]	Southward shifts in the distribution of marine species near Australia, beyond changes due to short-term environmental fluctuations, fishing, and pollution (M,C) Increased coral bleaching in Great Barrier Reef and Western Australian Reefs, beyond effects from pollution & physical disturbance (H,C) Changed coral disease patterns at Great Barrier Reef, beyond effects from pollution (M,C) [6.3.1, 25.6.2, Tables 18-8 and 25-3]	Advanced timing of wine-grape maturation in recent decades, beyond advance due to improved management (M,C) [Tables 18-9 and 25-3]
North America	Shrinkage of glaciers across western and northern North America (H,C) Decreasing amount of water in spring snowpack in western North America (1960-2002) (H,C) Shift to earlier peak flow in snow dominated rivers in western North America (H,C) [Tables 18-5 and 18-6; WGI AR5 2.6.2, 4.3.3]	Phenology changes & species distribution shifts upward in elevation & northward across multiple taxa (M,C) Increased wildfire frequency in subarctic conifer forests and tundra (M,C) Increase in wildfire activity, fire frequency & duration, & burnt area in boreal forest of North America, beyond changes due to land use & fire management (M,c) [26.4.1, 28.2.3, Table 18-7, Box 26-2]	Northward distributional shifts of Northwest Atlantic fish species (H,C) Changes in musselbeds along the west coast of US (H,C) Changed migration and survival of salmon in northeast Pacific (H,C) Increased coastal erosion in Alaska and Canada (M,C) [18.3.1, 18.3.3, 30.5.1, Tables 6-2 and 18-8]	Impacts on livelihoods of indigenous groups in the Canadian Arctic, beyond effects of economic and sociopolitical changes (M,C) [18.4.6, Tables 18-4 and 18-9, 28.2.4]
Central & South America	Shrinkage of Andean glaciers (H,C) Changes in extreme flows in Amazon River (M,C) Changing discharge patterns in rivers in the Western Andes (M,c) Increased streamflow in sub-basins of the La Plata River, beyond increase due to land use change (H,C) [27.3.1, Tables 18-5, 18-6, and 27-3; WGI AR5 4.3.3]		Increased coral bleaching in western Caribbean, beyond effects from pollution & physical disturbance (H,C) [27.3.3, Table 18-8]	More vulnerable livelihood trajectories for indigenous Aymara farmers in Bolivia due to water shortage, beyond effects of increasing social and economic stress (M,C) Increase in agricultural yields and expansion of agricultural areas in southeastern South America, beyond increase due to improved technology (M,C) [13.1.4, 27.3.4, Table 18-9]

Polar Regions	Decreasing Arctic sea ice cover in summer (H,C) Reduction in ice volume in Arctic glaciers (H,C) Decreasing snow cover extent across the Arctic (M,C) Widespread permafrost degradation, especially in the southern Arctic (H,C) Ice mass loss along coastal Antarctica (M,C) Increased winter minimum river flow in most sectors of the Arctic (M,C) Increased lake water temperatures 1985–2009 and prolonged ice-free seasons (M,C) Disappearance of thermokarst lakes due to permafrost degradation in the low Arctic. New lakes created in areas of formerly frozen peat (H,C) [28.2.1, 28.2.3, Tables 18-5 and 18-6; WGI AR5 4.2.2-3, 4.3.3, 4.4, 4.6, 10.5.2-3]	Increased shrub cover in tundra in North America & Eurasia (H,C). Advance of Arctic tree-line in latitude & altitude (M,C). Changed breeding area & population size of subarctic birds, due to snowbed reduction &/or tundra shrub encroachment (M,C) Loss of snow-bed ecosystems & tussock tundra (H,C). Impacts on tundra animals from increased ice layers in snow pack, following rain-on-snow events (M,C) Increased plant species ranges in the West Antarctic Peninsula & nearby islands over the past 50 years (H,C) [28.2.3, Table 18-7]	Increased coastal erosion across Arctic (M,C) Negative effects on non-migratory Arctic species (H,C) Decreased reproductive success in Arctic seabirds (M,C) Decline in Southern Ocean seals & seabirds (M,C) Reduced thickness of foraminiferal shells in southern oceans (M,C) Reduced krill density in Scotia Sea (M,C) [6.3.2, 18.3.1, 18.3.3, 24.4.3, 28.2.2, 28.2.4, 28.3.4, Table 18-8]	Impact on livelihoods of Arctic indigenous peoples, beyond effects of economic and sociopolitical changes (M,C) Increased shipping traffic across the Bering Strait (M,C) [18.4.6, 28.2.4, 28.2.6, Tables 18-4 and 18-9, Figure 28-4]
Small Islands		Tropical bird population changes in Mauritius (M,C) Decline of an endemic plant in Hawai'i (M,C) [29.3.2, Table 18-7]	Increased coral bleaching near many tropical small islands, beyond effects of degradation due to fishing and pollution (H,C) [29.3.1, Table 18-8]	

1.5 Vulnerability, exposure and extreme events

The character and severity of impacts from climate extremes depend not only on these extremes but also on exposure and vulnerability and consequently does their associated risks (see introduction, Fig. 1). Exposure and vulnerability are influenced by a wide range of social factors [SREX SPM], which make difficult to make quantitative assessments of their trends.

Differences in vulnerability and exposure arise from non-climatic stressors and multidimensional inequalities, which shape differential risks from climate change (*very high confidence*). People who are socially, economically, culturally, politically, institutionally, or otherwise marginalized are often highly vulnerable to climate change and climate change 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, income, and exposure, including, for example, discrimination on the basis of gender, class, ethnicity, age, and (dis)ability. The full spectrum of these processes and their context-specific interactions shape multidimensional vulnerability and differential capacities and opportunities of individuals, households, and communities.[3]

Violent conflict strongly influences vulnerability to climate change impacts for people living in affected places (*medium evidence, high agreement*). Large-scale violent conflict harms assets that facilitate adaptation, including infrastructure, institutions, natural capital, social capital, and livelihood opportunities.[4]

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 in social and economic factors. Therefore is more frequent that they could be identified locally or regionally than at global scale.

Impacts from recent extreme climatic events, such as heat waves, droughts, floods, and wildfires, demonstrate significant vulnerability and exposure of some ecosystems and many human systems to climate variability (*very high confidence*). These experiences are consistent with a significant adaptation deficit in developing and developed countries for some sectors and regions.[5]

Changes in many extreme weather and climate events have been observed since about 1950 (see Table **SPM.1 for details). 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 FAQ 2.2, 2.6; 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*) [26.6.1.2]. In Europe, the summer 2003, which was the hottest summer in the last 500 years, caused 35,000 excess deaths [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 Table 23.1].

North American ecosystems are under increasing stress from rising temperatures, CO2 concentrations, and sea-levels, and are particularly vulnerable to climate extremes (*very high confidence*). [WGII Exec Sum 26**]** Since the mid-1980s large wildfire activity in North America has been marked by increased frequency and duration, and longer wildfire seasons. Recent wildfires in

[3] WGII 8.1-2, 8.5, 9.3-4, 10.9, 11.1, 11.3-5, 12.2-5, 13.1-3, 14.1-3, 14.6, 18.4, 19.6, 23.5, 25.8, 26.6, 26.8, 28.4, Box CC-GC
[4] WGII 12.5, 19.4, 19.6
[5] Boxes 4-3, 4-4, 25-5, 25-6, 25-8, and CC-CR

western Canada, the US and Mexico relate to long and warm spring and summer droughts, particularly when they are accompanied by winds [WGII Box 26-2]. In Southern Europe, especially in the Mediterranean Basin, fire incidence has increased dramatically since the 1970s compared with previous decades, especially during extended droughts [WGII 23.4.4]. **Fire weather has increased in Australia since 1973 *(high confidence)*,** with 24 of 38 stations showing significant increases in the McArthur Forest Fire Danger Index [WGII Table 25.1].

It is *likely* that extreme sea levels have increased since 1970, being mainly a result of rising mean sea level [WG1 3.7.4, 3.7.5, Figure 3-14].

There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased. 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, SREX Table 3-2, FAQ 2.2].

There is *low confidence*, due to *limited evidence*, 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, in the attribution of detected changes it is difficult to distinguish the roles of climate and human activities [WGII 3.2.3]. **However, recent detection of trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale (*medium confidence*) [WGII 3.2.3].** Flood damage costs worldwide have been increasing since the 1970s, although this is partly due to increasing exposure of people and assets [WGII 3.2.3].

There is *low confidence* in observed large-scale trends in drought, due to lack of direct observations, dependencies of inferred trends on the index choice and geographical inconsistencies in the trends; and low confidence in attributing changes in drought over global land areas since the mid-20th century due to these 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, over the satellite era (since 1979)**,** increases in the intensity of the strongest storms in the Atlantic appear robust [WG1: SPM, 2.6.3, 10.6].

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 SPM b].

Climate-related hazards constitute an additional burden to people living in poverty, acting as a threat multiplier often with negative outcomes for livelihoods (*high confidence*). Climate-related hazards affect poor people's lives directly through impacts on livelihoods, such as reductions in crop yields or destruction of homes, and indirectly through increased food prices and food insecurity. Limited positive observed impacts on poor people include isolated cases of social asset accumulation, agricultural diversification, disaster preparedness, and collective action.[6]

The adverse climate trends are augmenting the pressure over poor and vulnerable. Fatality rates and economic losses expressed as a proportion of gross domestic product are higher in developing countries (*high confidence*) [SREX SPM b].

[6] WGII 8.2-3, 9.3, 11.3, 13.1-3, 22.3, 24.4, 26.8

1.6. Adaptation experience

Adaptive human responses can be motivated by observed and projected climate change impacts and by broader vulnerability-reduction and development objectives.

Adaptation is already occurring and is becoming embedded in some planning processes (*high confidence*). Engineered and technological adaptation options are the most commonly implemented adaptive responses. There is increasing recognition of the value of ecosystem-based, institutional, and social measures, including provision of social protection measures, and of linkages with disaster risk reduction. Selection of adaptation options continues to emphasize incremental adjustments and co-benefits and is starting to emphasize flexibility and learning (*medium evidence, medium agreement*). Most evaluations of adaptation have been restricted to impacts, vulnerability, and adaptation planning, with very few assessing the processes of implementation or actual adaptation actions (*medium evidence, high agreement*) [[1] WGII 4.4, 5.5, 6.4, 8.3, 9.4, 11.7, 14.1, 14.3-4, 15.2-4, 17.2-3, 21.3, 21.5, 22.3-5, 23.7, 25.4, 26.8-9, 30.6, Boxes 25-1, 25-2, 25-9, and CC-EA].

Governments at various scales are starting to develop adaptation plans and policies, and adaptation experience is accumulating across regions (*high confidence*).

- In Africa, most national governments are initiating governance systems for adaptation, and in predominantly isolated efforts, disaster risk management, adjustments in technologies and infrastructure, ecosystem-based approaches, conservation agriculture, and livelihood diversification are reducing vulnerability [WGII 11.7, 22.4, Box CC-EA].
- In Europe, adaptation policy has been developed across scales, with some adaptation planning integrated into coastal and water management and into disaster risk management [WGII 11.7, 23.7, Box 23-3].
- In Asia, adaptation practices have sometimes provided livelihood benefits, and adaptation has been facilitated through integrated water resource management [WGII 11.7, 24.4].
- In Australasia, planning for sea-level rise and, in southern Australia, for reduced water availability is becoming widely adopted, although implementation faces major constraints, especially for transformational responses at local and community levels [WGII 25.4, 25.10, Table 25-2, Boxes 25-1, 25-2, and 25-9]
- In North America, governments are engaging in incremental adaptation assessment and planning, particularly at the municipal level, with some proactive adaptation anticipating future impacts for longer-term investments in energy and public infrastructure [WGII 26.7-9]
- In Central and South America, ecosystem-based adaptation including protected areas, conservation agreements, and community management of natural areas is increasingly common, with benefits for improvements in livelihoods and preservation of traditional cultures [WGII 27.3]
- In the Arctic, residents have a history of adapting to change, but the rate of climate change and complex inter-linkages with societal, economic, and political factors represent unprecedented challenges for northern communities. [1] WGII 28.2, 28.4 [WGII 28.2, 28.4]
- In small islands, diverse physical and human attributes and their sensitivity to climate-related drivers have been inconsistently integrated into adaptation planning [[1] WGII Table 29-3, Figure 29-1]

Box SYR.1: Recent temperature trends and their implications

There is *very high confidence* that 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 decrease in the rate of recent surface warming is attributable in roughly equal measure to a cooling contribution from internal variability and a reduced trend in external forcing (expert judgment, *medium confidence*). {Box SYR.1 Figure 1; *WG1 2.4, 3.2, 3.7, 8.5, 9.4; Table 2.7; Box 9.2, Box 12.2, Box 13.2*}

The long-term surface-warming trend observed over 1951–2012 (Figure SYR.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)[7].

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 (Figure SYR.1a; Box SYR.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).

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 negative 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 surface-warming hiatus, because of uncertainty in the magnitude of the 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 SYR.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 (Figure Box SYR.1). Internal variability thus diminishes the relevance of short trends for long-term climate change. There are also possible 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}*

In summary, the observed recent surface-warming hiatus is attributable in roughly equal measure to a cooling contribution from internal variability and a reduced trend in external forcing (expert judgment, *medium confidence*). {WG1 8.5, Box 9.2}

[7] 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.

Topic 1 Figures

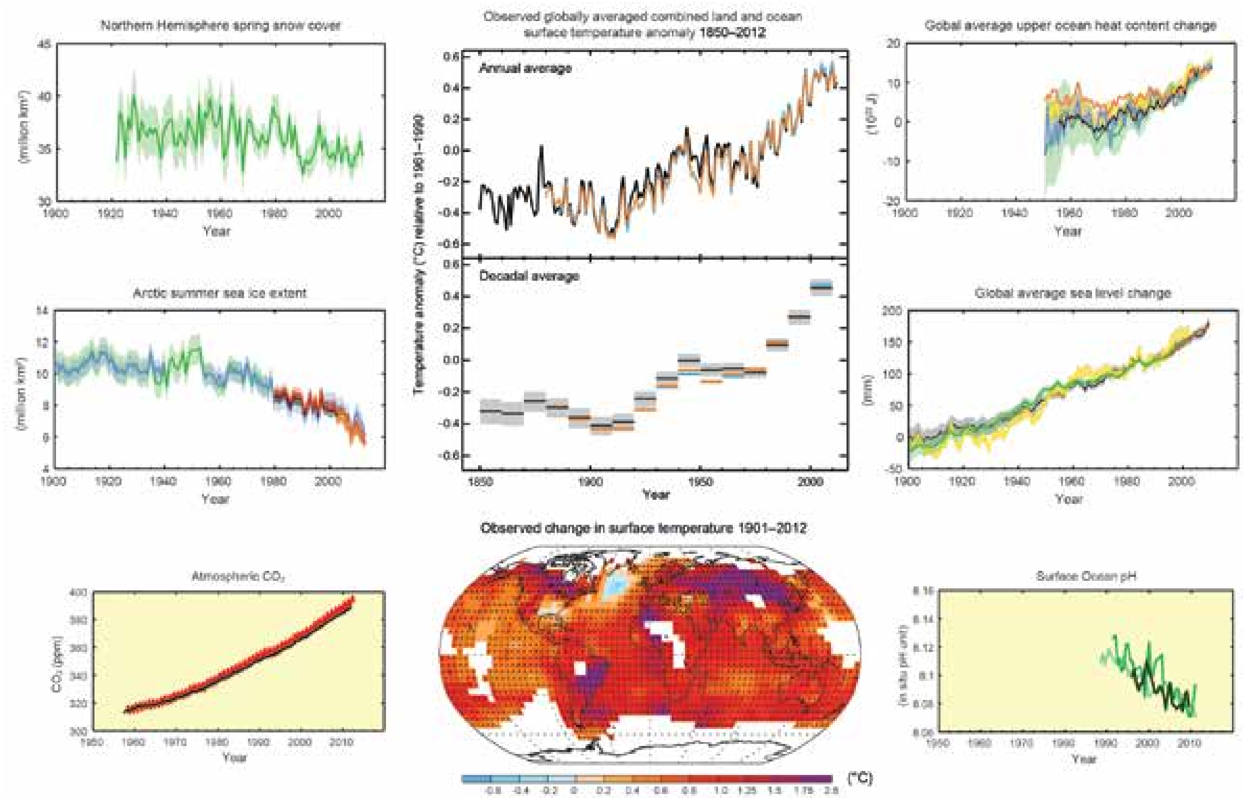


Figure 1.1: Multiple observed indicators of a changing global climate system. For all time series, coloured lines indicate different datasets, and uncertainties (where assessed in the underlying chapters) are indicated by coloured shading. Left column: top, extent of Northern Hemisphere March-April average snow cover; middle, extent of Arctic July-September average sea ice; bottom, atmospheric concentrations of carbon dioxide (CO_2) from Mauna Loa and South Pole.
Middle Column top two panels: Observed globally averaged combined land and ocean surface temperature anomaly (top: annual mean values, middle: decadal mean values); bottom, map of the observed surface temperature change from 1901 to 2012 from one dataset (orange line in panel a; linear trends). Right: top, change in global mean upper ocean (0–700 m) heat content; middle, global mean sea level change; bottom, in situ pH, which is a measure of the acidity of ocean water.
For global mean surface temperature anomalies, annual and decadal mean values relative to the mean of 1961−1990 are provided, with an estimate of decadal mean uncertainty included for one dataset (grey shading). The map of the observed surface temperature change is derived from temperature trends from one dataset. Trends 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. For full technical details, and a listing of the datasets shown, refer to the underlying WGI SPM and the Technical Summary Supplementary Material. [WGI SPM Figures 1, 3, 4; TS Figures 1, 3, 5]

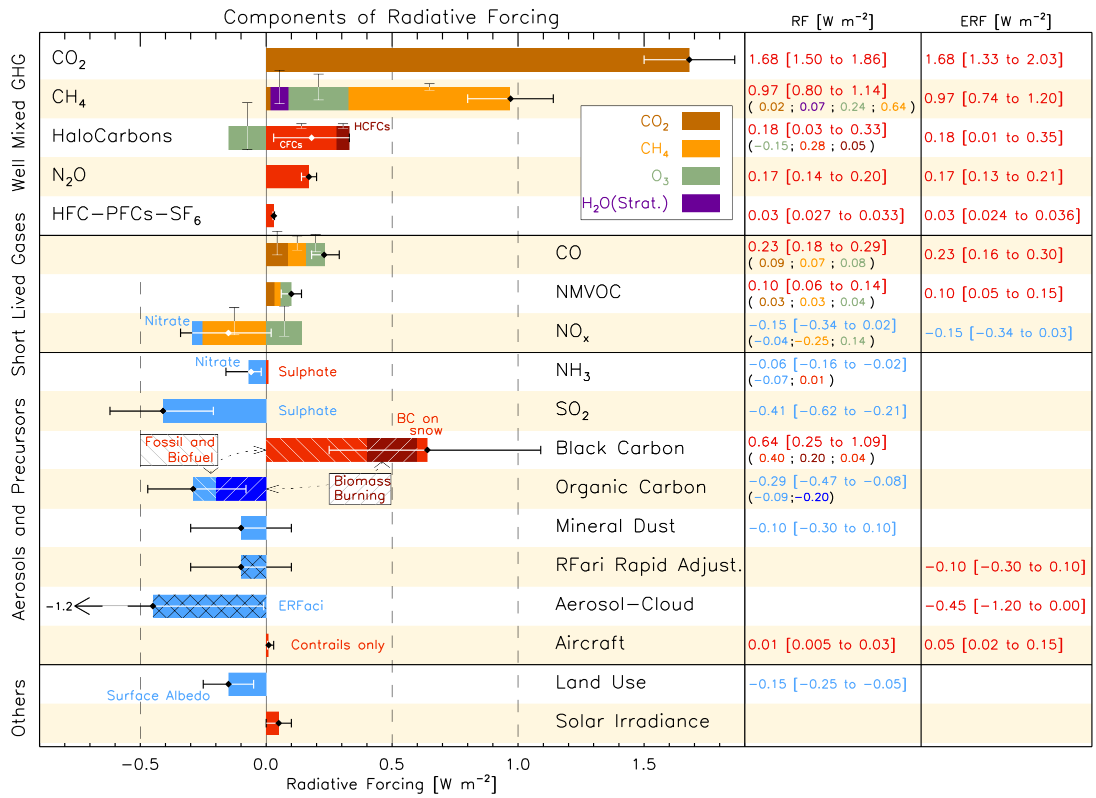


Figure 1.2. Radiative forcing (RF) of climate change during the industrial era shown by emitted components from 1750 to 2010. The horizontal bars indicate the overall uncertainty, while the vertical bars are for the individual components. CFCs: Chlorofluorcarbons, HCFCs; Hydrochlorofluorocarbons, HFCs: Hydrofluorocarbons, PFCs: Perfluorocarbons; NMVOC: Non Methane Volatile Organic Compounds; BC: Black Carbon; RFaci: Aerosol Radiative Forcing through effects on Clouds [WG I TS.7]

Figure 1.3 Change in global anthropogenic GHG emissions by major economic regions 1970-2010. GHG emissions are measured in gigatonnes per year (Gt/yr) of CO_2 equivalent. Non CO_2 greenhouse gases are converted to CO_2 equivalents using 100-year global warming potentials. First panel shows total emissions per region, second panel shows per capita emissions per region; the third panel shows the variation within regions in per capita emissions, in 2010. [Figure WG III 1.x, WG III SPM.3]

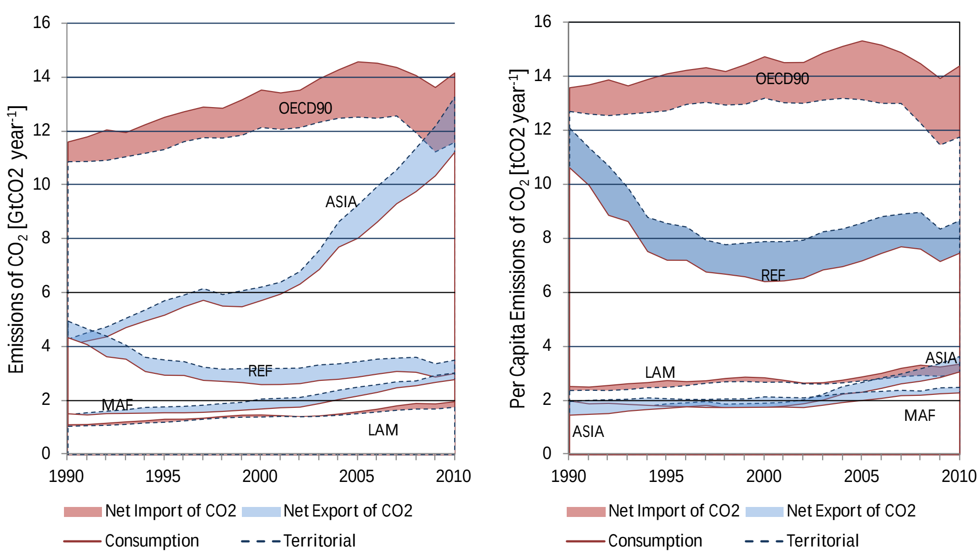


Figure 1.4 . Territorial (blue lines) versus consumption-based (red dotted lines) emissions in five world regions, from 1990 to 2010. The left panel presents total emissions, while the right panel presents per capita emissions. The red areas indicate that a region is a net importer of embedded GHG emissions. The blue area indicates a region is a net exporter of embedded GHG. Regions include: OECD90 (OECD1990 countries), EiT (Economies in

Transition), LAM (Latin America and Caribbean), MAF (Middle East and Africa), ASIA (Asia). [*WG III Figure 5.5.1*]

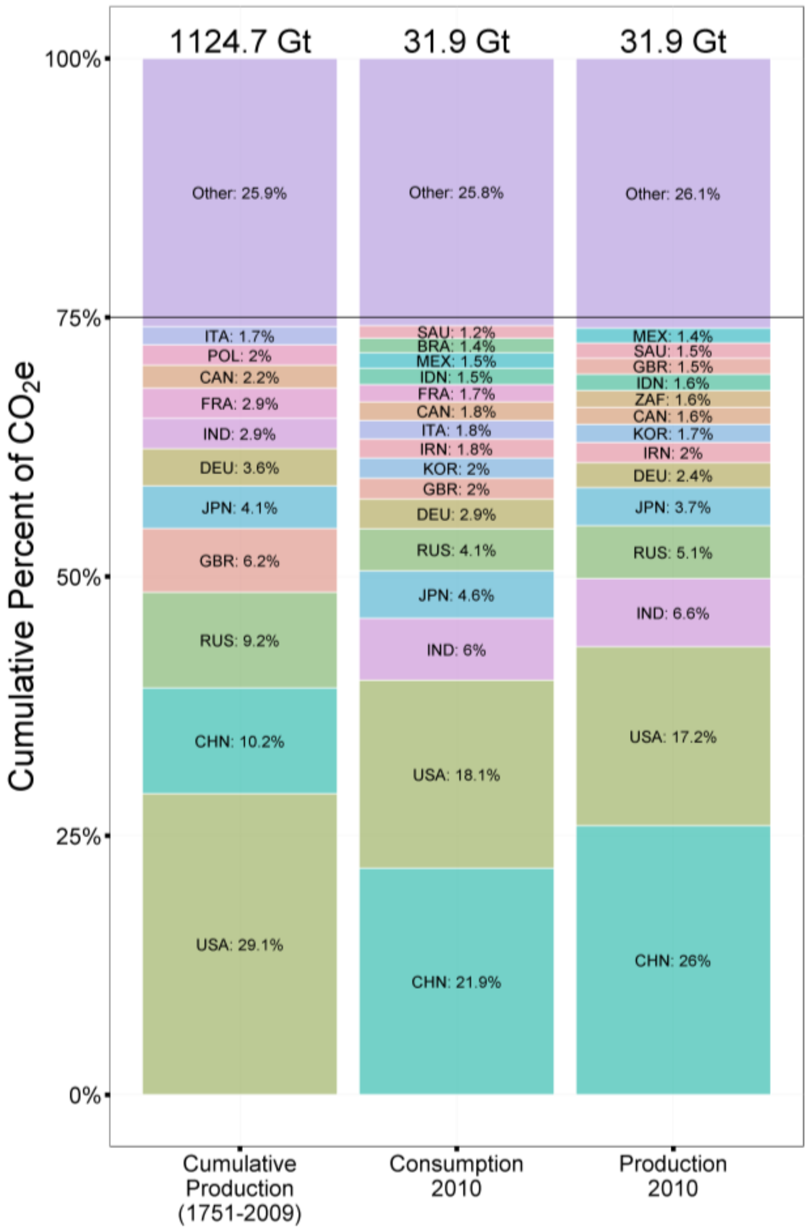


Figure 1. 5 Shares of largest country contributors to 75% of global anthropogenic CO_2 emissions from fossil fuel combustion. Stacked bar on the left shows cumulative territorial emissions for the period 1751-2009, stacked bar in the middle shows consumption based emissions in 2010 and the stacked bar on the right shows production/territorial based emissions in 2010. [*WG III SPM.4, WGIII 1.7*].

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) which 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]. Modeled 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]

2.1. Drivers of future change in climate

Changes in the concentrations of greenhouse gases and air pollutants and land-use have all contributed to the observed changes in climate, (*very high certainty*) [WG-I 8.5]. Emission scenarios and various types of models are used to explore how future changes in these factors may influence the future climate [WGI 8.5, 12.4; WGIII 6.1]. The effect of emissions on the future climate can be approximated by multiplying the emissions, per component, by weighting metrics that take into account the lifetime of the component and its effect on the global climate, which can be warming or cooling (see Figure 2.1 and Box 3.X on emission metrics) [WGI 8.7; WGIII 3.9.6]. The effects of CO_2 emissions persist for centuries; after 1000 years 15-40% of the increase in concentration remains in the atmosphere [WGI Box 6-1; 8.7]. Nitrous oxide has a lifetime of about a century; methane a decade, while ozone and aerosols and their precursors have lifetimes of the order of days and weeks. The global mean surface warming by the late 21st century and beyond is largely determined by the cumulative emissions of CO_2 [WGI 12].

Anthropogenic greenhouse gas emissions are mainly determined by population size, economic activity, energy use, technology used and climate policy [WGIII 5]. Scenarios range from the simple (eg. a 1% yr^{-1} compound increase of atmospheric CO_2 concentration) to comprehensive, internally consistent sets of assumptions on emissions and socio-economic drivers scenarios produced by IAMs. The TAR and the AR4 used the SRES scenarios. In order to cover the full range of possibilities present in the literature and relevant to policy, the AR5 adopted RCPs, described below.

[INSERT FIGURE 2.1 HERE]

2.2. The scenarios used for projections

The RCPs prescribe time series for the 21st century of changes in land cover, the atmospheric concentration of greenhouse gases and the emissions of air pollutants. They are used as input to many runs, by a wide range of models, in order to project the consequences for the climate system (WGI 12). The climate projections are used to assess impacts and adaptation (WG2 19). Finally, the RCPs are used in mitigation analyses to assess the costs associated with different emission combinations which could be consistent with those pathways [WG3 6.3.2; 6.3.6]. The RCP causing greatest warming (RCP8.5) is representative of high non-mitigation scenarios, in which CO_2 emissions reach levels above 25 GtC/yr (100 $GtCO_2$/yr). In contrast, emissions under the RCP6.0 scenario reach nearly 15 GtC/yr (50 $GtCO_2$/yr) by 2100; corresponding to many middle-of-the-road scenarios with modest climate policies. RCP4.5 represents a medium-high range mitigation scenario, with 4 GtC/yr (15 GtCO2/yr) by 2100. Finally, RCP2.6 represents more aggressive mitigation scenarios, aiming to stay below 2°C global warming relative to pre-industrial temperatures. This scenario requires net negative emissions of about -0.5 GtC/yr (-2 $GtCO_2$/yr) in 2100 (Figure 2.2). [WGIII 6.3.2]. The RCPs also cover a wide range of possible land use developments, ranging from strong reforestation to further deforestation. Each of the RCPs also specifies a trajectory for air pollutant emissions, assuming tightening of air quality policies (Figure 2.2).

The RCPs forcings are broadly consistent with ESMs. The RCPs were originally developed using integrated assessment models (IAMs). Using the RCPs in CMIP5 experiments with ESMs allows the sensitivity of the pathways to uncertainties in physical parameters (such as the carbon cycle, atmospheric chemistry and climate change) to be quantified. The CO_2 emission trajectories estimated by the ESMs are consistent with the emissions originally estimated by the IAMs, but as a set show a wider range in terms of carbon budgets. For the RCP2.6, about half the models find that CO_2 emissions need to be negative by the end of the century [WGI 12].

There is considerable uncertainty in present and future total radiative forcing estimates, largely due to uncertainty in aerosol effects [WGI 7, 12]. RCPs are implemented in ESMs by prescribing emissions or forcing levels of aerosol precursors. As a result, aerosol concentration differs across ESMs, leading to differences between the expected RCP radiative forcing scenario and its implementation in a given ESM. ESMs exhibit rapid adjustments to the initial forcing, leading to an additional cloud forcing effect, which also varies across models. The combination of these two effects leads to the range of effective radiative forcing simulated by the CMIP5 ESMs (Figure 2.2)[WGI, 8.5.3, 12.3.3].

Compared to the SRES scenarios, the RCPs cover a wider range of possible outcomes. The emission and land-use variables reported by the RCPs represent a richer set of parameters than the SRES, but comparisons between the two sets can be made. The RCP8.5 is broadly comparable to the A2 scenario, RCP6.0 to B2 and RCP4.5 to B1. For RCP2.6, there is no equivalent scenario in the SRES set.

[INSERT FIGURE 2.2 HERE]

Climate-related risks arise from the interaction of the evolving exposure and vulnerability of human, socioeconomic, and biological systems with the changing physical characteristics of the climate system. [WGII 19.2] 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]

Future outcomes are determined both by development choices and climate change, with their relative importance varying by sector, region, and time period. Development of socio-economic scenarios has started recently, in the form of five Shared Socio-economic Pathways (SSPs), possibly combined with Shared Policy Assumptions (SPAs) that describe adaptation and mitigation actions. Few analyses using SSPs and SPAs were available at the time of this Assessment Report. [WGII 1.1, Box 21-1]

2.3. The methods used to make projections

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

Climate models (atmospheric ocean general circulation models, AOGCMs) 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, ocean currents, and sea-ice extent. When combined with future climate forcings, they are used to make projections of future climate. [WGI, 1]

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, 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, 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 Antarctic ice sheet. *Confidence* in the representation of processes involving clouds and aerosols remains *low* [WGI, 7.3, 7.6, 9.1, 9.2, 9.4, 9.6, 9.8]

Most ESMs simulate global land and carbon sinks over the latter part of the 20th century that are within the range of observational estimates. ESMs reproduce the observed global pattern of ocean-atmosphere CO_2 fluxes, with outgassing in the tropics and uptake in the mid and high latitudes. [WGI 9.4]

2.3.2 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 reveal the effects of rising CO_2 and O_3 on ecosystems and 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 are used in earth system projections: *spatial analogies* identify another part of the world currently experiencing similar conditions to those to anticipated be experienced in the future - for instance, niche envelop models project future distributions of species based on their current distribution; and *temporal analogies* where changes in the past are used to make inferences about changes in the future, such as the use of paleo-ecological data. **Models** 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. Especially when they include socio-economic components, models are not independent of the value judgments, world views, and preferences of the modeller (see Box SYR-x). The impacts are modeled for water resources, biodiversity and ecosystem services on land, 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]

2.4 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 IPCC authors have in climate change projections and associated impacts varies, depending on which aspect of the future is considered. Some of 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* in projected increases in the incidence of extremely high sea-level [WGI SPM] or in the assessment that local warming of above 3.5^{o}C poses very significant risks and challenges to food security [WGII Chapter7 ES]; but there is only *low confidence* in projected changes in the frequency of tropical cyclones at the regional scale [WGI Ch. 14] or in the assessment that risks associated with global aggregate economic impacts become high around 3°C [WGII SPM]. All of the assessments of confidence are based on the opinions of the expert authors, informed by the best available information. [WG 1 SPM, Chapter 1]

Uncertainty regarding future changes arises from an inability of Earth System scientists to perfectly predict, simulate, represent or understand factors that include:
(i) processes that can influence future concentrations of greenhouse gases such as socioeconomic development, population growth, future technologies and future policies limiting emissions of greenhouse gases; [WGIII 1.3]
(ii) Earth system processes and forcings that can alter the climate system [WGI 8.6], as well as the response of the climate system to the forcings imposed [WGI 11-12];
(iii) future vulnerability and exposure in human and natural systems, resulting from factors such as the quality of adaptive responses, socioeconomic and demographic patterns, non-climatic stressors affecting ecosystems, and cross-regional interactions [WGII 11.3, 19.6, 21.3-5, 25.3-4, 25.11, 26.2]

A wide range of potential future impacts is assessed in the AR5, including low-probability outcomes with large consequences which are associated with higher levels of uncertainty.

2.5 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. Many of these changes will persist for centuries.

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]

Air Temperature

Global-mean surface air temperatures are projected to rise over the 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 of 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 scenario. Global-mean surface air temperatures for 2081–2100 for the CO_2 concentration driven RCPs will *likely* be 0.3°C–1.7°C (RCP2.6), 1.1°C–2.6°C (RCP4.5), 1.4°C–3.1°C (RCP6.0), 2.6°C–4.8°C (RCP8.5) (Figure 2.3, Table 2.1). [WGI, 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, and *more likely than not* to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. The Arctic region will warm more rapidly than the mean and warming will be larger over the land than over the ocean (very high confidence) (Figure 2.4)[WGI, 11.3, 12.3, 12.4, 14.8]

[INSERT TABLE 2.1 HERE]

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 increase. It is *very likely* that heat waves will occur with a higher frequency and duration. Occasional cold winter extremes will continue to occur. [WGI, 12.4]

[INSERT FIGURE 2.3 HERE]

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 by the end of this century under the RCP8.5 scenario (Figure 2.4). [WGI, 7.6, 12.4, 14.3]

Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will *very likely* become more intense and more frequent by the end of this century, as global mean surface temperature increases. [WGI, 7.6, 12.4]

Globally, it is *likely* that the area encompassed by monsoon systems will increase over the 21st century and monsoon precipitation is *likely* to intensify due to the increase in atmospheric moisture. [WGI, 14.2] There is *high confidence* that the El Niño-Southern Oscillation (ENSO) will remain the dominant mode of interannual variability in the tropical Pacific. Due to the increase in moisture availability, 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. When tropical cyclones do occur they will *likely* cause stronger winds and heavier precipitation. There is low confidence in projected regional changes in tropical cyclones. [WGI, 14.6, 14.8]

[INSERT FIGURE 2.4 HERE]

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]

Reductions in Arctic sea ice are projected for all scenarios and year-round. Based on an assessment of the subset of models that most closely reproduce the climatological mean state and 1979-2012 trend of the Arctic sea ice extent, a nearly ice-free Arctic Ocean in September before mid-century is *likely* for RCP8.5 (*medium confidence*) (Figure 2.3). In the Antarctic, a decrease in sea ice extent and volume is projected with *low confidence* for the end of the 21st century as global mean surface temperature rises. [WGI, 12.4]

The area of Northern Hemisphere spring snow cover is projected to decrease by 7% for RCP2.6 and by 25% in RCP8.5 by the end of the 21st century for the model average (*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. By the end of the 21st century, the area of permafrost near the surface (upper 3.5 m) is projected to decrease by between 37% (RCP2.6) to 81% (RCP8.5) for the model average (*medium confidence*). [WGI, 12.4]

By the end of the 21st century, 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 for 2081-2100 will *likely* be in the ranges of 0.26 to 0.55 m for RCP2.6, 0.32 to 0.63 m for RCP4.5, 0.33 to 0.63 m for RCP6.0, and 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 2.3, Table 2.1) [WGI, 13.5]

There is currently insufficient evidence to evaluate the probability of specific sea levels above the assessed *likely* range. 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. [WG1, 13.4,13.5]

Many semi-empirical model projections of global mean sea level rise are higher than process-based model projections, but there is no consensus in the scientific community about their reliability and there is thus *low confidence* in their projections. [WGI, 13.5]

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. The corresponding decrease in surface ocean pH by the end of 21st century is in the range of 0.06 to 0.07 for RCP2.6, 0.14 to 0.15 for RCP4.5, 0.20 to 0.21 for RCP6.0 and 0.30 to 0.32 for RCP8.5 (Figure 2.3). [WGI, 6.4]

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) is defined as the equilibrium global average surface warming following a doubling of CO_2 concentration (relative to pre-industrial). ECS is *likely* in the range 1.5°C–4.5°C, and *extremely unlikely* less than 1 °C and very unlikely greater than 6°C. [WGI, Box 12.2]

The transient climate response to cumulative carbon emissions (TCRE) is defined as the global mean surface temperature change per 1000 GtC of carbon dioxide emitted to the atmosphere. TCRE is *likely* in the range of 0.8°C to 2.5° and applies for cumulative emissions up to about 2000 GtC until the time temperatures peak. [WGI, 12.5, Box 12.2]

Limiting the warming caused by anthropogenic CO_2 emissions alone with a probability of at least 66% to less than 2°C since the period 1861–1880, will require cumulative CO_2 emissions from all anthropogenic sources to stay below about 1000 GtC (3665 $GtCO_2$) since that period respectively. These amounts are reduced to about 790 GtC (2895 $GtCO_2$) when accounting for non-CO_2 forcings as in RCP2.6. An amount of 515 [445 to 585] GtC (1890 [1630 to 2145] $GtCO_2$) has already been emitted by 2011. (Table 2.2) [WGI, 12.5]

[INSERT TABLE 2.2 HERE]

2.6 Future risks and impacts caused by a changing climate

Climate change will amplify existing risks to natural and human systems. To a lesser extent, climate change will reduce some risks and generate benefits. Larger magnitudes of warming increase the risk of severe and pervasive impacts (Table 2-3). Some risks are limited to particular sectors or regions, while others will have cascading effects.The precise levels of climate change which breach critical thresholds in the earth system, including its coupled human and natural subsystems, remain uncertain.

2.6.1 Ecosystems and their services in the oceans, coasts, freshwater and land

Carbon in the terrestrial biosphere is vulnerable to loss to the atmosphere due to climate change, deforestation, and ecosystem degradation (*high confidence*). Tree mortality and associated forest dieback will occur in many regions in the next one to three decades (*medium confidence*), posing risks for carbon storage, biodiversity, wood production, water quality, amenity, and economic activity. [WGII 4.2-3, 25.6, Figure 4-8, Boxes 4-2, 4-3, and 4-4]

Large fractions of terrestrial, freshwater and marine species face increasing extinction risks during and beyond the 21st century, due to the interaction among several climate associated drivers (warming, reduced flows in rivers, ocean acidification and hypoxia) and the interaction of climate with habitat modification, over-exploitation of stocks, pollution, eutrophication and invasive species (*high confidence*). Extinction risk is increased under all RCP scenarios, with risk increasing with both magnitude and rate of climate change, *likely* reducing biodiversity and ecosystem services (*high confidence*). Many species will be unable to adapt 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*)[WGII 4.3-4, 6.1, 6.3, 6.5, 25.6, 26.4, Box CC-RF, Box CC-MB].

By mid-21st century, shifts in the spatial distribution of marine species will cause species richness to increase at mid and high latitudes (*high confidence*) and decrease in the tropics (*medium confidence*), resulting in global redistribution of catch potential for fish and invertebrates, with regional implications for food security (*medium confidence*). Animal displacements are projected to lead to high-latitude invasions and high local extinction rates in the tropics and semi-enclosed seas. Open-ocean net primary production is projected to redistribute and to fall globally by 2100 under RCP8.5. [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 increases 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 occurs in combination with other global environmental changes, (e.g., warming, decreasing oxygen levels) and local changes (e.g., pollution, eutrophication) (*high confidence*), amplifying the impacts for species (figure 2.5). [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]

[INSERT FIGURE 2.5 HERE]

Most dry subtropical regions will face declining renewable surface and groundwater resources, exacerbating competition for water among sectors (*very high confidence*). Freshwater-related risks increase with increasing greenhouse gas emissions (*very high confidence*). Each degree of warming will decrease renewable water resources by at least 20% for an additional 7% of the global population. By 2100 for RCP8.5, drought frequency will *likely* increase in presently dry regions. The number of people exposed annually to a 20th-century 100-year river flood is projected to be three times greater than for RCP2.6. Risks to drinking water quality result from warming and increased sediment, nutrient, and pollutant loadings and disruption of treatment facilities during floods (*high confidence*). [WGII 3.4-5, 26.3, Tables 3-2 and 25-1, Box 25-8; WGI AR5 12.4, WGII 3.2, 3.4-6, 22.3, 25.5, 26.3, Table 3-2, Boxes 25-2 and CC-WE]

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*). Development patterns without adaptation will cause hundreds of millions of people to be affected and displaced due to land loss (*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. The annual damage and adaptation costs amount to several percentage points of GDP [WGII 5.3-5, 22.3, 24.4, 25.6, 26.3, 26.8, Table 26-1, Boxes 25-1 and CC-CR]

2.6.2. Food and urban systems, human health, security and livelihoods

Without adaptation, local temperature increases of 1°C or more above preindustrial levels will negatively impact crop yields (wheat, rice, and maize) in tropical and temperate regions, although cool locations may benefit (*medium confidence*). On average, adaptation improves yields by ~15-18%, but its effectiveness is highly variable (*medium confidence*). While adaptation of crop production to local 2°C increases is possible (*high confidence*), 4°C or more will pose significant risks to food security (figure 2.6). [WGII 7.5, 22.3, 25.7, 26.5, Tables 7-2 and 11-3, Figures 7-4, 7-5, 7-7, and 7-8]

[INSERT FIGURE 2-6 HERE]

Rural areas will experience impacts through water supply, food security, and agricultural incomes, including shifts in production of food and non-food crops in many areas of the world (*high confidence*). Food price rises, induced by climate shocks and other stressors, have a disproportionate impact on the welfare of the poor in rural areas, such as female-headed households and those with limited access to modern agricultural inputs, infrastructure, and education.[WGII 9.3, 25.9, 26.8, Box 25-5]

Heat stress, extreme precipitation, inland and coastal flooding, and drought and water scarcity pose risks in urban areas for people, assets, and economies, and ecosystems, with risks amplified for those lacking essential infrastructure and services or living in exposed areas (*very high confidence*). These impacts are much lower in socio-economic scenarios where basic service deficit are reduced. They could be reduced further by adaptation actions to make infrastructure more resilient and increase basic service provision. [WGII 3.5, 8.2-4, 22.3, 24.4-5, 26.8, Boxes 25-9 and CC-HS]

For most economic sectors, the impacts on productivity, employment and profit of non-climate factors such as changes in population, age structure, income, technology, relative prices, lifestyle, regulation, and governance will be large relative to the impacts of climate change (*medium evidence, high agreement*). Climate change will reduce residential and commercial energy demand for heating and increase it for cooling (*robust evidence, high agreement*). Changes in weather hazards will affect disaster losses and loss variability, possibly posing challenges for affordable insurance, particularly in low- and middle-income countries. Small- and large-scale public-private risk prevention initiatives can facilitate adaptation. [WGII 3.5, 10.2, 10.7, 10.10, 25.7, 26.7, Box 25-7]

Climate change during the 21st century will lead to increases in ill-health in many regions (*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, disease, mal-nutrition, and death; and risks from lost work capacity, reduced labor productivity; and food- and water-borne diseases. Fewer cold extremes and reduced capacity of disease-carrying vectors will result in modestly lower cold-related mortality and morbidity in some areas (*medium confidence*). Globally, positive impacts will 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 over the 21st century will have significant impacts on forms of migration that compromise human security (*medium evidence, high agreement*). Populations that lack the resources for mobility and migration often experience higher exposure to weather-related extremes, in both rural and urban areas, particularly in low-income countries. 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 indirectly increases risks from violent conflict in the form of civil war, inter-group violence, and violent protests by exacerbating well-established drivers of these conflicts such as poverty and economic shocks (medium confidence). Statistical studies show that climate variability is significantly related to these forms of conflict. Poorly designed adaptation and mitigation strategies can increase risks from violent conflict.[WGII SPM, 12.5, 13.2, 19.4]

Climate change impacts will threaten economic growth and poverty reduction, throughout the 21st century, particularly in urban areas and emerging hotspots of hunger (*medium confidence*). Climate change will exacerbate poverty in low and lower-middle income countries and may create new poverty pockets in upper-middle- to high-income countries with increasing inequality. [WGII 8.1, 8.4, 9.3, 10.9, 13.2-4, 22.3, 26.8]

[INSERT FIGURE 2.7 HERE]

[INSERT TABLE 2.3 HERE]

2.7 Long-term, effectively irreversible and abrupt changes

Many aspects of climate change will persist for centuries even if concentrations of greenhouse gases are stabilized. This represents a substantial multi-century commitment created by human activities today, effectively irreversible over a period of many human generations. [WGI, 12.5.2]

'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. The only way to accelerate the return to past temperature regimes would be to extract a large fraction of the anthropogenic greenhouse gasses from the atmosphere, over a sustained period. [WGI, 12.5.2]

Stabilization of global average 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 temperature is stabilized.

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 organismal physiology, behaviour and population dynamics (*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 a best estimate decrease in 2100 of about 0–5% for the RCP2.6 scenario, 20–30% for the RCP4.5 scenario and 36–44% for the RCP8.5 scenario. 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, 12.5.5]

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]

Irreversible mass loss from the Greenland Ice Sheet appears *very unlikely* in the 21st century but *likely* on multi-centennial to millennial time scales in the strongest forcing scenarios. [WGI, 12.5.5]. Surface melting is projected to exceed accumulation for global mean surface air temperature over 3.1 [1.9–4.6] °C above preindustrial, leading to ongoing mass loss. [WGI, 13.4.3]

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 due to thermal expansion of the oceans to be less than 1 m above the pre-industrial level by 2300 for a radiative forcing corresponding to the RCP2.6. For a radiative forcing corresponding to RCP8.5, the projected rise is 1 m to more than 3 m (*medium confidence*). [WGI, 13.5]

Sustained mass loss by ice sheets will eventually cause irreversible sea level rise greater than projected above. There is *high confidence* that sustained (ie. beyond 2100) 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. [WGI, 5.8, 13.4, 13.5]

There is *medium confidence* that warming equal or greater than that projected by RCP4.5 lead to a high risk of abrupt and irreversible regional-scale change in the Amazonian and boreal forests. Crossing such thresholds would substantially increase net carbon emissions to the atmosphere and increase the risk of biodiversity loss [WGI, 12.5.5, 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]

It is *very likely* that warming will increase methane emissions from oceanic clathrates. [WGI, 12.5.5]

BOX SYR.2: Valuation: Ethics and Economics

Although climate change is a physical process, assessing its consequences for the natural and human worlds requires judgements of value. Many of the concepts involved are implicitly evaluative. For example, *risk* is defined as a chance of an event that has negative value (2: 19.1), and the concept of *CO2 equivalent* implicitly compares the values of the different distributions of harm that are caused by different gases (3: TS Box 5, 3: 3.9.6). More explicit valuations appear in estimating the social cost of carbon (3: 3.9.4), in cost-benefit and cost-effectiveness analysis, in optimization using IAMs and in many other instruments that contribute to policy-making (3: 3.6.1).

All judgements of value rest ultimately on ethical principles that specify what values there are and their relative importance. Many of these principles are subject to controversy and disagreement within and between communities. There may be serious ethical disagreements about the values that are implicit in different approaches to decision making. (3: 3.5)

Climate change affects many values. Among them are natural values such as the existence of species and ecosystems, and the beauty of nature. Also among them are human values, which include cultural and social values such as cultural artefacts, ways of life, and equity within and between societies. A major human value is the wellbeing of individual people. It is sometimes argued that all values derive ultimately from the wellbeing of individual people. A consequence of this controversial view would be that nature has no value in its own right. It is also controversial what the wellbeing of individual people consists in: is it the satisfaction of their preferences, their functionings and capabilities, or something else? (3: 3.4)

Setting a value on an event or a policy requires first measuring each of the values that is affected and then aggregating those values together. Both create difficulties. Many particular values are not easily measured because they are too imprecise or too debatable; many natural and cultural values are examples. And different value often cannot be precisely weighed against each other; it seems impossible to weigh the way of life of Arctic peoples against the material costs of carbon dioxide reduction, for example. Since climate change affects both the very rich and the very poor, it is essential in aggregating values to take account of the distribution of harms and benefits across different people, generations and countries. (3: 3.4)

Despite the difficulties, measures have been assigned to many particular values. For example, there are measures of particular aspects of human wellbeing. Dalys and qalys measure human health, taking longevity into account (3: 3.4.5). The Human Development Index is a measure of functionings and capabilities (3: 3.4.3).

Monetary measures of value are convenient because market processes assign a monetary value to many different things. Economics has methods of extending monetary valuation to goods, such as preserving human life, that are not marketed. Since monetary values are all in terms of the same unit B money B they offer a way of aggregating values of different sorts. Moreover, monetary valuation in economics can be given a foundation in ethical principles. (3: 3.6.1)

However, monetary valuation has limits. It measures other values less well than it measures individual wellbeing. It depends on simplifying assumptions that are often questionable. The ethical principles that underlie it are debatable. (3: 3.5) Moreover, they require valuations to take account of the different values that money has to different people B a dollar is generally more valuable to a poor person more than to a rich one B by applying >distributional weights= to crude monetary values. Distributional weighting is rarely applied in practice for aggregating contemporaneous goods. (3: 3.6.1, TS Box 2) In the form of a discount rate, it is much more commonly applied in aggregating goods that are received by different generations. (3: 3.6.2).

[Box 2.1 ends]

Topic 2 Tables

Table 2.1 Projected change in global mean surface air temperature and global mean sea level rise for mid and late 21st century relative to the reference period (1986-2005) [WG1, 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 (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

Table 2.2 Cumulative CO2 emissions to limit the warming to less than 2°C. Emissions are cumulated since 1870 [WG1, 12.5]

		Cumulative CO_2 emissions	
	Probability	**GtC**	**$GtCO_2$**
Accounting for CO_2 forcing only	33%	1560	5720
	50%	1210	4435
	66%	1000	3665
		Cumulative CO_2 emissions	
	Probability	**GtC**	**$GtCO_2$**
Accounting for CO2 and non-CO2 forcing	33%	900	3300
	50%	820	3005
	66%	790	2895

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. For the near-term era of committed climate change, projected levels of global mean temperature increase do not diverge substantially across emission scenarios. For the longer-term era of climate options, 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]]

Table TS.4.

Climate-related drivers of impacts: Warming trend; Extreme temperature; Drying trend; Extreme precipitation; Damaging cyclone; Flooding; Storm surge; Ocean acidification; Carbon dioxide concentration

Risk & potential for adaptation: 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.	Warming trend; Extreme temperature; Drying trend	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.	Warming trend; Extreme temperature	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.	Warming trend; Extreme temperature; Drying trend	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.	Warming trend; Extreme temperature; Drying trend	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.	Ocean acidification	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.	Warming trend; Extreme temperature; Ocean acidification	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.	Warming trend; Drying trend; Carbon dioxide concentration; Extreme temperature; Extreme precipitation	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.		8.3	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

Topic 2 Figures

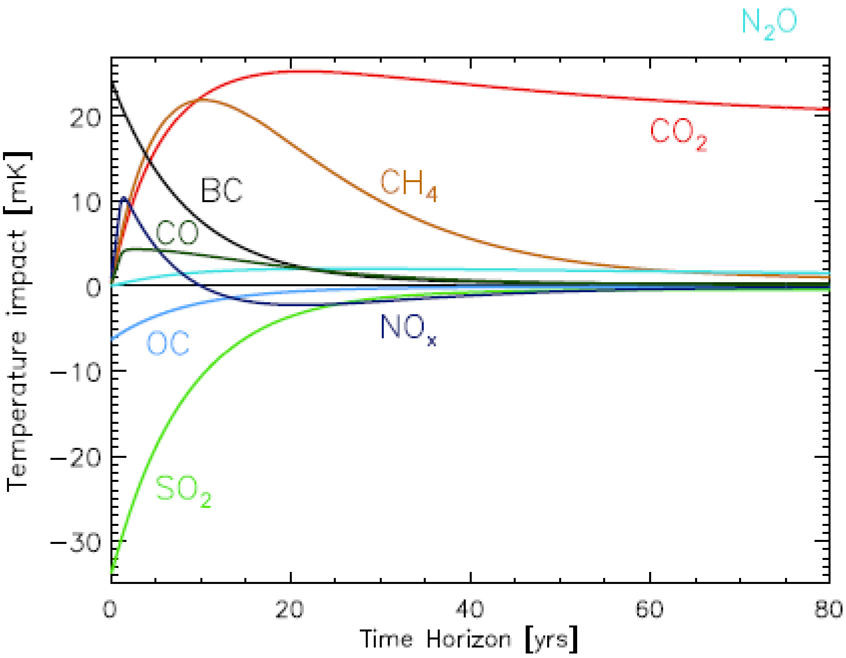


Figure 2.1: The time-course of the global mean surface temperature response resulting from a hypothetical one-year pulse of anthropogenic emissions in 2008, by component. Emission data are from the EDGAR database, except for BC and OC which are for 2005, from Shindell et al. (2012a). There are large uncertainties in the calculated temperature responses (WG1 Figure 8.33) but there is *high confidence* in the relative lifetimes of the responses.

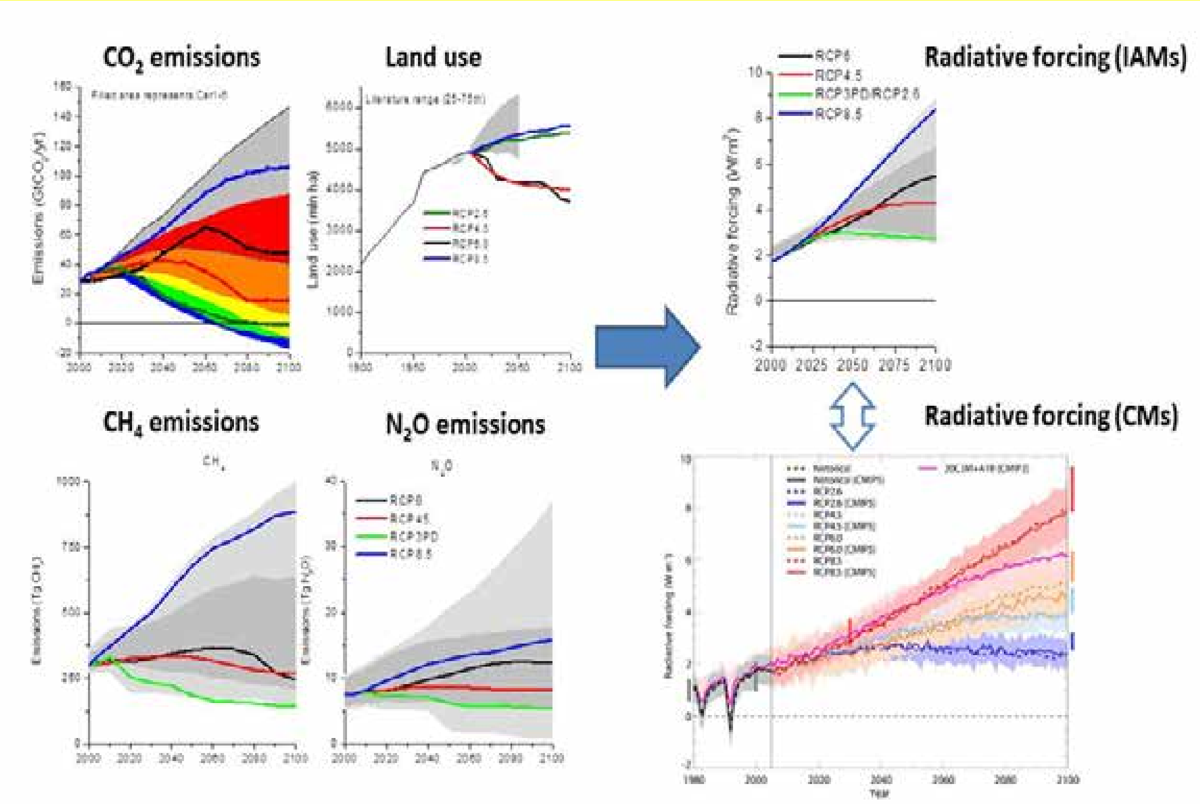


Figure 2.2: Emission scenarios included in the RCPs, and the associated radiative forcing in integrated assessment (IAM) and Climate Models (CM). In most panels literature ranges (grey) are added for comparison,. For CO_2 emissions, the RCPs are compared to the different scenario categories [WG-III 6.3.2] also used in Section 3 of this report. For other drivers, comparison is made with the full scenario range (light grey indicates 10-90th percentile range, dark grey 25-75th percentile). The bottom right panel shows the radiative forcing values

from the runs with climate models described in WG-1 Chapter 12. The coloured zones, which correspond to different RCPs, indicate the range of model outcomes.

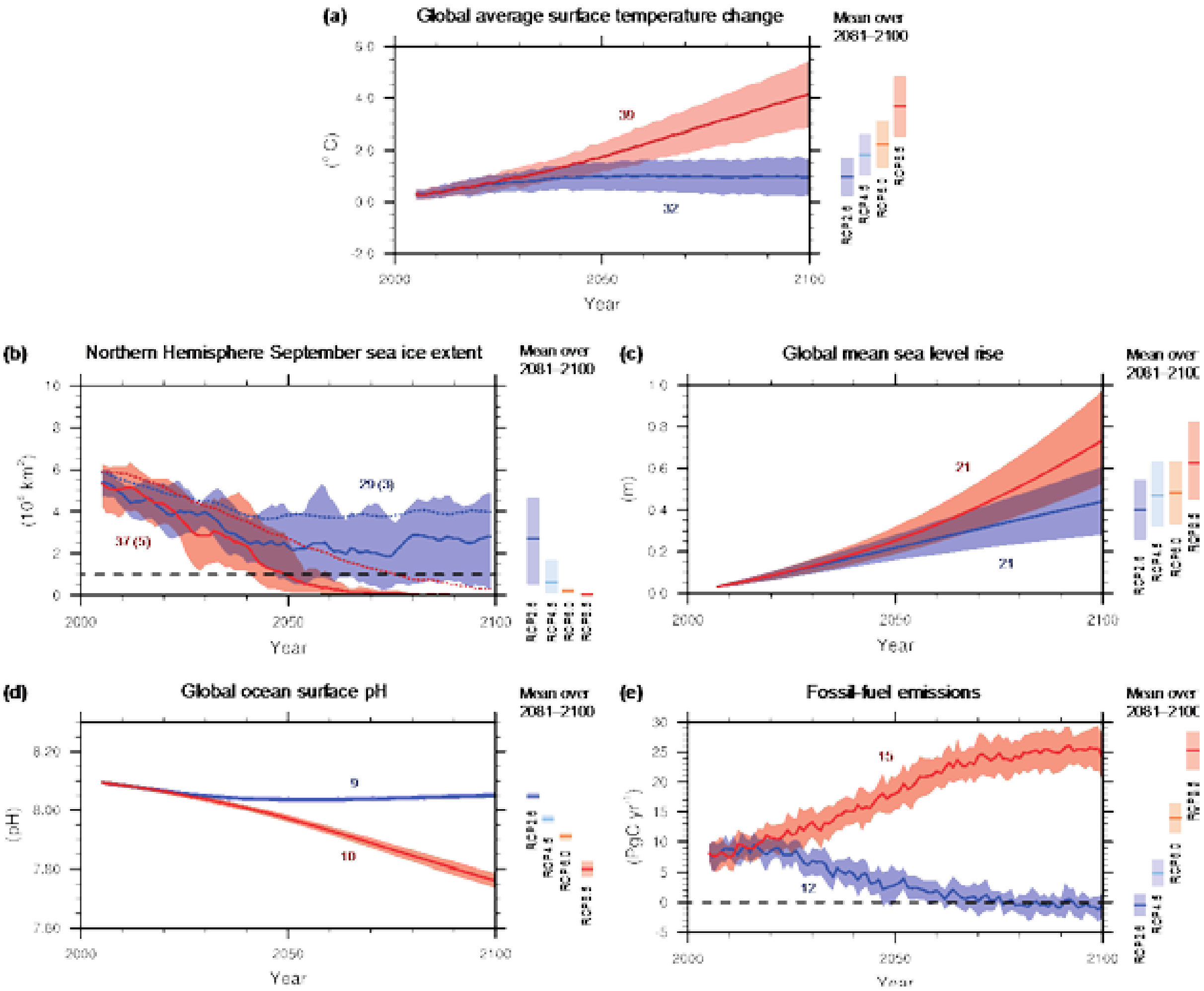


Figure 2.3: CMIP5 multi-model simulated time series from 2005 to 2100 for (a) change in global annual mean surface temperature relative to 1986–2005, (b) Northern Hemisphere September sea ice extent (5 year running mean), (c) global mean sea level rise, (d) ocean surface pH and (e) compatible CO_2 fossil fuel emissions. 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. The numbers of CMIP5 models used to calculate the multi-model mean is indicated. For sea ice extent (b), 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. [WG1 Figure SPM.7]

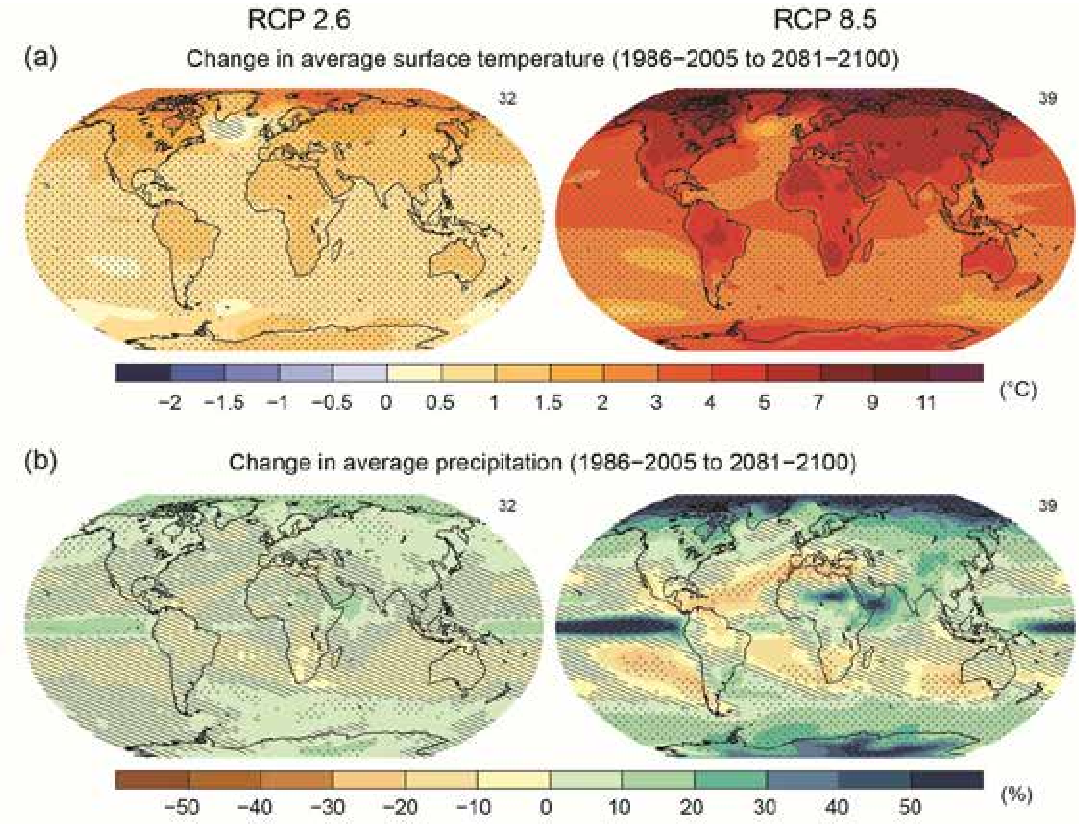


Figure 2.4: CMIP5 multi-model mean projections 2081– 2100 under the RCP2.6 (left) and RCP8.5 (right) scenarios for (a) annual mean surface temperature change and (b) average percent change in annual mean precipitation. Changes are shown relative to 1986–2005. The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Hatching 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 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 WG1, Box 12.1).

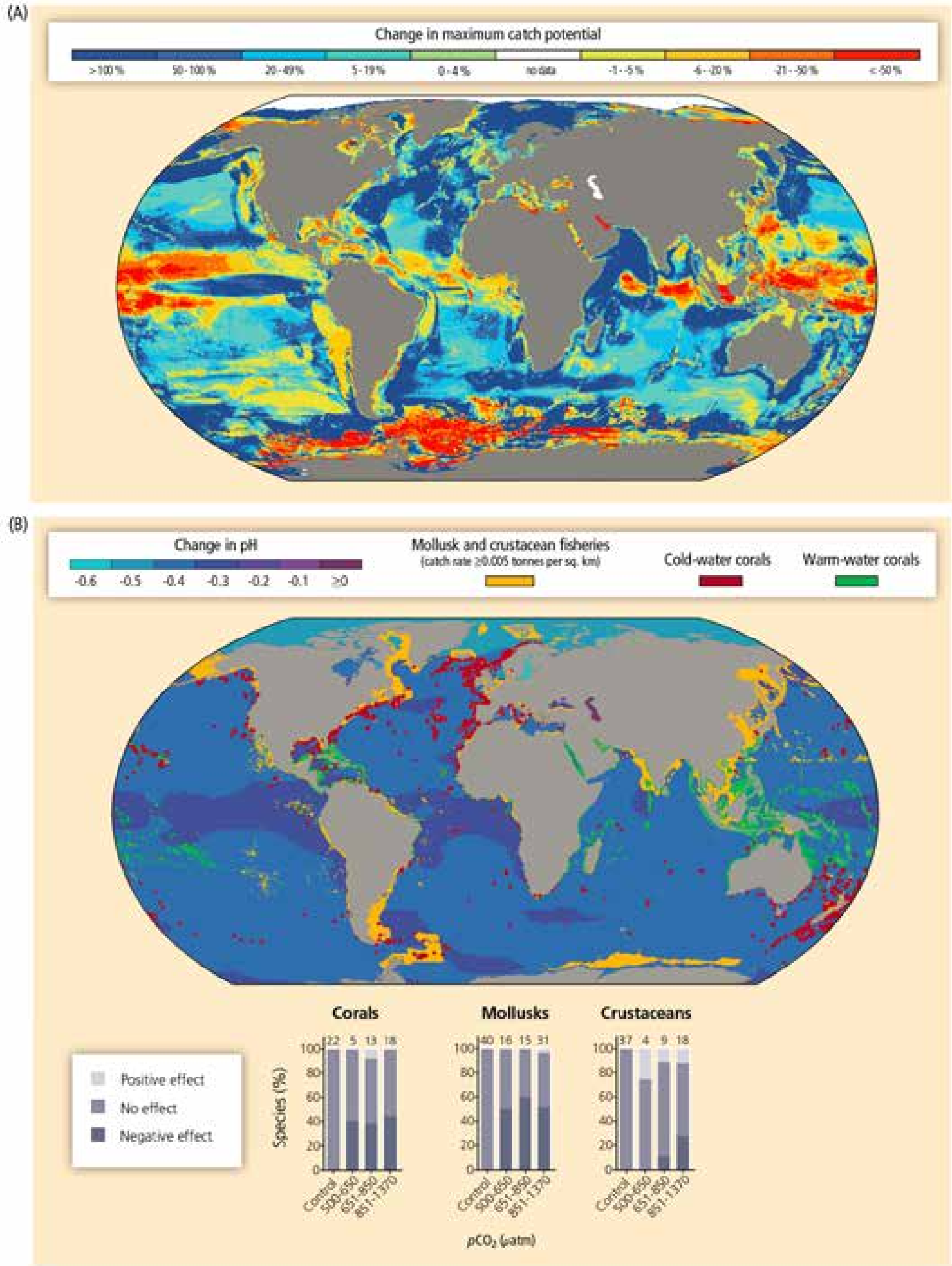


Figure **2.5**: Climate change risks for fisheries. (A) For 2°C increase from preindustrial levels using SRES A1B (≈RCP6.0), projected global redistribution of maximum catch potential of 1000 species of exploited fishes and invertebrates, comparing the 10-year averages 2001-2010 and 2051-2060, without analysis of potential impacts of overfishing. (B) Marine mollusk 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, mollusks, 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 (WGII, Figure SPM.6). [6.1, 6.3, 30.5, Figures 6-10 and 6-14; WGI AR5 Box SPM.1]

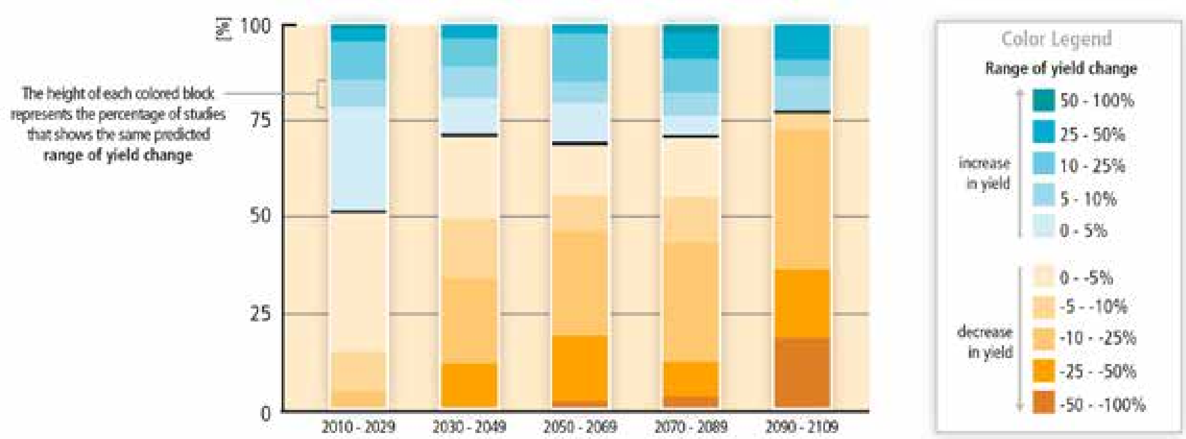


Figure 2.6: Summary of projected changes in crop yield as a function of time with and without adaptation, across studies for all regions. Data (n=1090) are plotted in the 20-year period on the horizontal axis that includes the midpoint of each future projection period (WGII, Figure SPM.7). [Figure 7-5]]

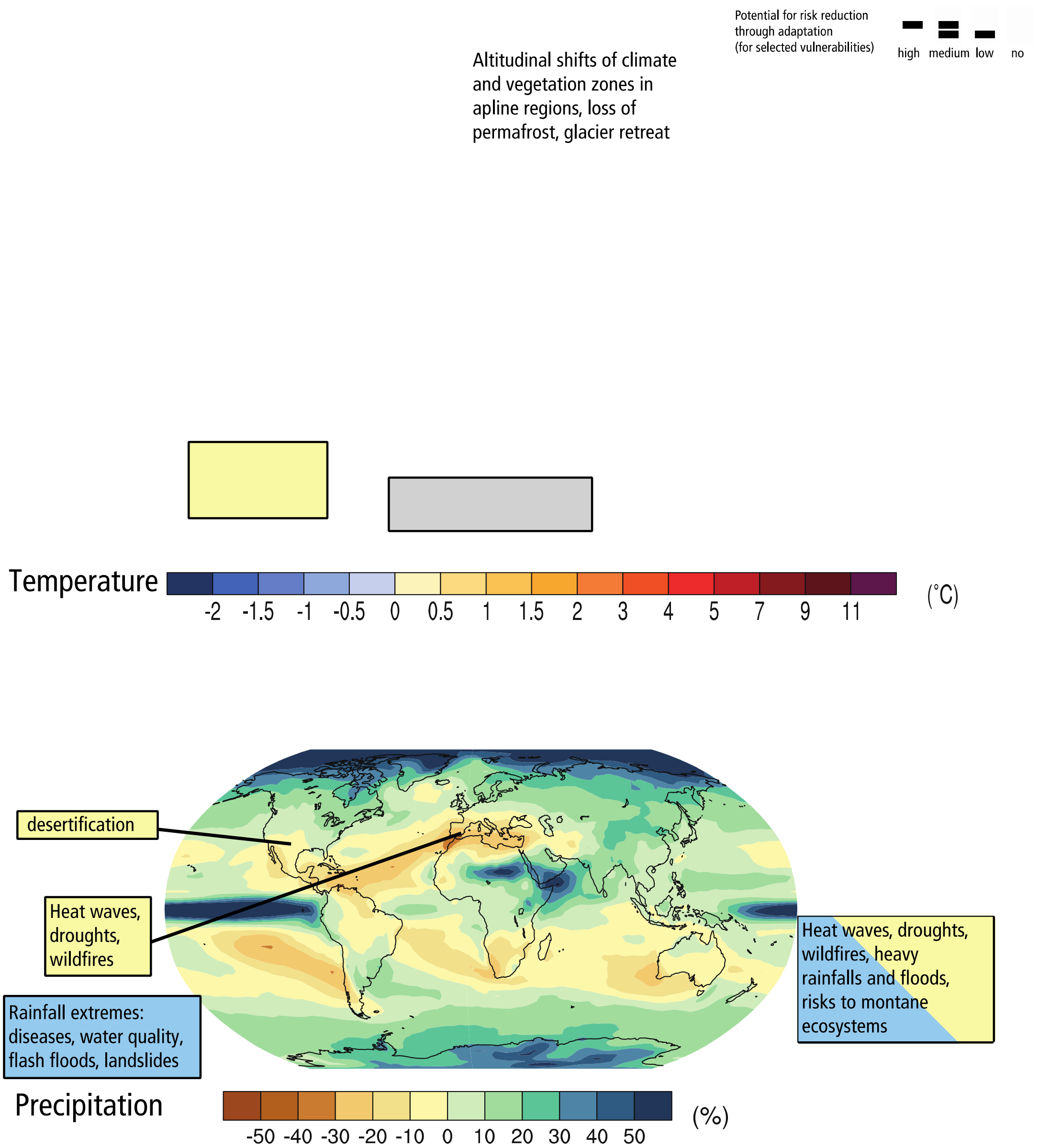


Figure 2.7: Examples of vulnerabilities and impacts on natural systems indicated on maps of multi-model results in 2081–2100 (relative to 1986–2005) of surface air temperature change and of average percent change in mean precipitation under emission scenario RCP 8.5. Scope of adaptation to reduce risk is shown for some categories and regions [Figures WGI SPM.7, 12.11, 12.22, 12.41. See Tables 2-2 and 2-3 for more detailed analyses.]

Topic 3: Transformations and Changes in Systems

3.1 Human responses – an integrated approach

Sections 3 and 4 examine the decision-making context for responding to climate change, identifying mitigation and adaptation options, their interactions and the implications for sustainable development. The objective is to present the existing knowledge base for successfully pursuing climate resilient pathways. (Expand chapeau to be consistent with topic 4)

The concept of transformation is intrinsic to understandings of climate change. Transformations involve changes in the fundamental attributes of a system, often based on altered paradigms, goals, or values. Transformations can occur in technological or biological systems, financial structures, and regulatory, legislative, or administrative regimes [II, glossary]. In the context of human responses to climate change, the concept of transformation draws attention to the need to move beyond business-as-usual, recognizing that transformations are an integral part of responses that seek to stabilize emissions pathways, reduce vulnerability, manage risk, and adapt to changing conditions (II:20.5.2.1; III:1.3.4].

The prospects for pursuing climate resilient pathways for sustainable development and human security will be progressively threatened as the climate changes (II: 12.1.2; II: 20.2.3). Climate change interacts with non-climatic stressors and entrenched structural inequalities to shape vulnerabilities (II: 13.1.3). It is a global scale problem that will influence terrestrial and freshwater ecosystems, coastal systems, urban systems, human livelihoods and food security (II:4.2.4; …). The consequences associated with climate change are related to both the mitigation and adaptation efforts, with risks varying substantially across plausible alternative development pathways (II:19.6.2.2; II:20.3.2).

There is increasing evidence that transformative changes may be necessary to prepare for climate impacts. Transformations in political, economic and socio-technical systems can contribute to enhanced climate responses, both for mitigation and adaptation (II:20.5.2). Transformational adaptation may be required if incremental adaptation proves sufficient (II: 2.1.2; II: 2.5.3). However, there are limits to adaptation that can emerge as a result of the interactions among climate change and biophysical and socioeconomic constraints (II: 16.2). Many see the need for more transformative changes to perceptions and paradigms about the nature of climate change and adaptation of human and natural systems (II:14.1; II:14.3).

Stabilizing greenhouse gas concentrations will require transformations in human systems and societies, ranging from the production and consumption of energy to land use patterns (II:20.3.1; III:6.1]. For climate change mitigation, transformation pathways define the set of economic, technological, and social changes that constitute lower emission trajectories that may result in achieving long-term climate 30 stabilization targets [WGIII, Annex 1]. Transformation pathways towards climate stabilization will involve both technological and social change. Both societal support and institutional capacity can mediate distributional conflicts related to climate policies [WGIII, 6.7].

3.2 Decision making in a complex environment

The range and number of interested parties that are involved in choosing climate policy have increased substantially in recent years. Climate policies and international agreements are negotiated at the global and national level in a widening range of forums. They engage many networks within national governments, and at the local, regional and interest-group level. Firms, households and individuals are all involved. (3:2.3.1).

Distributional equity and procedural justice have a crucial role to play in climate change policy. They are important in themselves, and they contribute to achieving cooperation and effective governance (3.10). Yet it is difficult to make decisions in a way that respects the rights and views of all those affected, when some are very poor, some lack information and understanding, some lack political standing, and some belong to generations yet unborn. (WGII 2.2, 2.3?, III.3.3, III.4.2, III.4.3, III.4.6)

Efficient adaptation and mitigation calls for coordination and cooperation between individuals, groups, and countries. Climate change is global commons problem, involving strategic interaction among players who are each affected by the others' actions (3:2.4.5). The emissions of each agent (individual, company or country) affect many other agents. Moreover, while the costs of mitigation are often tangible and immediate, the benefits are uncertain and distant, and many of them will come to people who are not yet born. An efficient outcome will not be achieved if individual agents pursue their interests independently. International cooperation can define and allocate rights and responsibilities over the atmosphere, which make efficient responses possible. (3:3.2)

Decision makers often use simple heuristics and rules of thumb for choosing between options, because they have information-processing limitations as well as attention and time constraints. Their choices are guided not only by external data, such as potential outcomes and their likelihood, but also by their own needs and goals, which are often shaped by previous experience. Empirical studies reveal that interested parties often do not undertake systematic analyses when making decisions. They may misperceive the likelihood and consequences of climate change, focus on the short term, adopt inappropriate decision processes and exhibit a status quo bias. (3:2.4)

Intuitive thinking does not work well for low-probability high-consequence events for which the decision maker has little past experience. It may work well when decision makers have extensive data on the outcomes of different decisions, and when recent experience is a good guide for the future. But disasters are rare, and decision-makers have little experience of them. Intuitive thinking may therefore not be good at dealing with climate change risks, such as flooding and storm surge. (3:2.4.2)

Several formal methods and decision aids are available for making choices in a systematic manner. These tools focus attention on both short and long-term consequences and evaluate the options under consideration evenly, without favoring the status quo. Some can deal with situations where probabilities are difficult to characterize or outcomes are uncertain. They include decision analysis, cost-benefit and cost-effectiveness analysis, use of expert judgment and robust decision-making. Their success in making more informed choices depends on how the problem is formulated and framed, the nature of the institutional arrangements and the participation of the stakeholders. (3:2.5)

Effective risk management strategies take into account how the relevant stakeholders perceive risk and their behavioural responses to uncertain information and data. They also deploy more formal methodologies and decision aids to address risk and uncertainty. Decision-making and risk management in the complex environment of climate change is iterative. Strategies must be adjusted to new information from scientific observations, to progress in our understanding of climate mechanisms and of social and economic responses to policy instruments. These responses will affect the level of uncertainty and risk in the future. Education can therefore play a key role in managing climate change. (3:2.6)

3.3 Characteristics and risks of (evolving) mitigation pathways

Many alternative mitigation scenarios have been constructed that are consistent with limiting GHG concentrations and long-term increases in temperature to particular levels. The AR5 has assessed more than 1200 scenarios, including both baseline and mitigation scenarios. Mitigation scenarios from the literature span the full range of RCP emissions pathways and 2100 concentration levels (Figure SPM.6). Scenarios have been constructed to reach similar 2100 concentrations goals under very different assumptions about energy demands, international cooperation, technology, the contributions of CO2 and other forcing agents, and concentration overshoot. [WGIII, 6.1- 6.9]

Without explicit efforts to reduce GHG emissions, the fundamental drivers of growth are expected to persist despite major improvements in energy supply and end-use technologies *(high confidence)***.** Baseline scenarios in the literature – those without explicit climate policy – have not systematically explored the full distribution of possibilities. Acknowledging that limitation, under a broad range of assumed growth in incomes and decline in energy intensity, as well as alternative assumptions about fossil resources and the cost of low-carbon energy, all scenarios examined here result in forcing that exceeds 450 ppmv CO2-e by 2030 and approach 1000 ppmv CO2-e by the end of the century (Figure 1). [WGIII, 6.2]

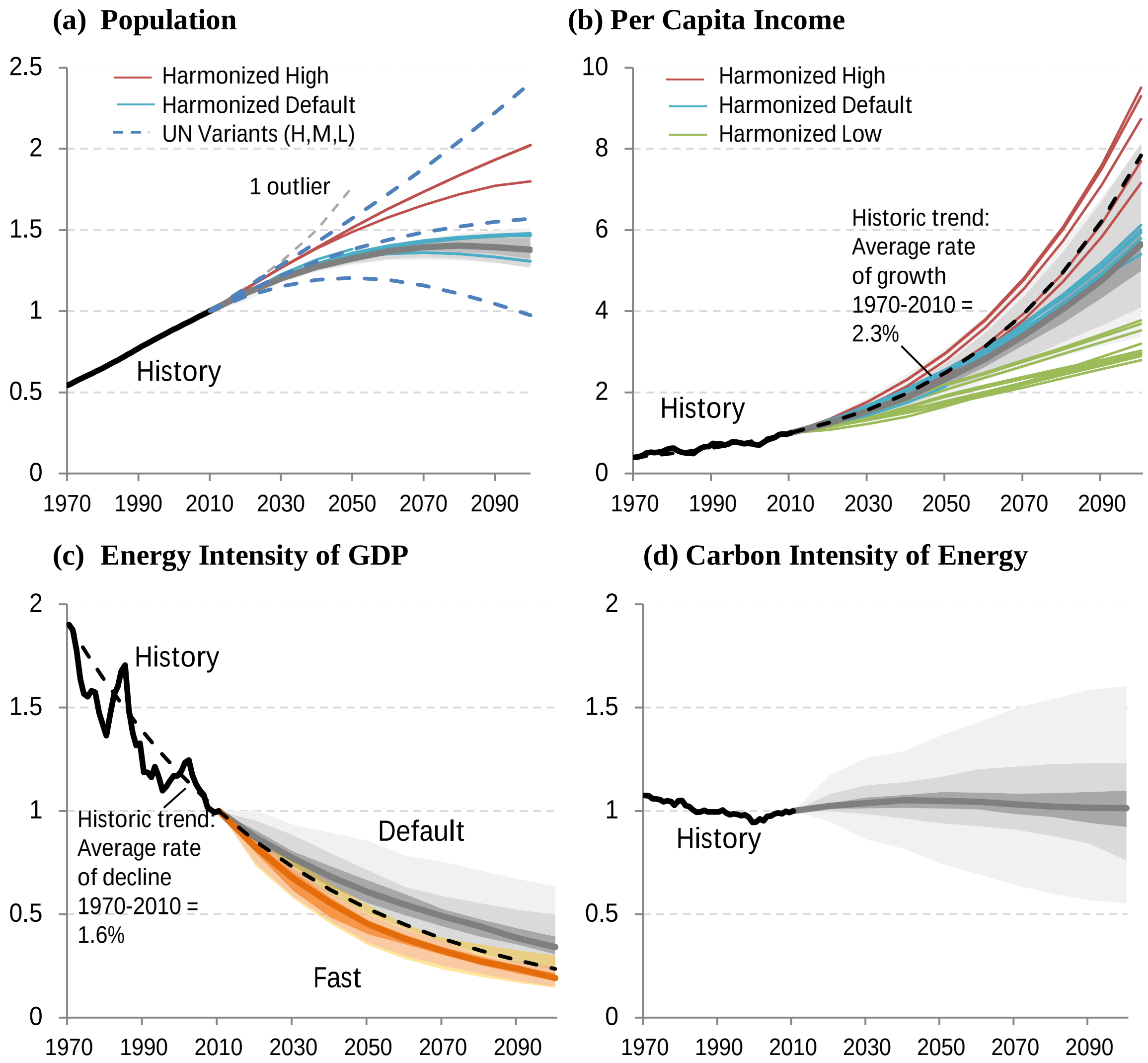


Figure 1. Global Baseline Projection Ranges for Kaya Factors. Scenarios harmonized with respect to a particular factor are depicted with individual lines. Other scenarios depicted as a range with median emboldened; shading reflects interquartile range (darkest), 5th – 95th percentile range (lighter), 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. [WGIII, Figure 6.1]

The temperature response associated with any emissions pathway depends on the long-term concentration goal as well as the degree to which atmospheric GHG concentrations exceed (overshoot) that goal prior to meeting it *(high confidence)*. An analysis of the temperature response that scenarios with atmospheric GHG concentration levels cantered on 450 ppmv CO2eq (430 to 480 ppmv CO2-e) in 2100 are associated with a *likely* chance to limit temperature change to below 2C (*likely* range of 1.2 to 2.3 C in 2100) and a carbon budget below 1000 GtCO2 this century. Scenarios in which concentrations do not exceed this range prior to 2100 are associated with a *very likely* chance to limit temperature change to below 2C (Table 1). A comprehensive assessment of the full range of temperatures outcomes, including the tails of the distribution, is important for assessing the risks of climate change. [WGIII, 6.3]

Carbon dioxide removal (CDR) technologies could make it possible to undertake less mitigation today, but would lead to greater concentration overshoot and would rely on future decision makers to deploy CDR technologies at large scale *(high confidence)*. A variety of CDR technologies could generate negative emissions, for example through large scale afforestation or bioenergy coupled with CCS (BECCS) (Figure 2). Negative emissions are an important feature in scenarios to shift emissions in time and compensate for emissions that cannot be easily removed in the economic system. Higher emission levels in the short term tend to increase the requirements for applying CDR technologies in scenarios. This can increasingly constrain the ability of policymakers to determine technology portfolio choices freely and manage the associated risks. The availability and scale of CDR technologies is uncertain.[WGIII 6.3, WGIII 6.9, WGIII 11.X]

A limited number of studies have explored scenarios reaching concentrations below 430 ppm *(high confidence)*. These studies include scenarios in which temperature change reaches 1.5C with a *likely* chance by the end of the century. Such scenarios are associated with immediate mitigation action, rapid up-scaling of the full portfolio of mitigation technologies, development along a low energy demand trajectory, large-scale application of CDR technologies in the long-term, and substantial overshoot. [WGIII 6.3]

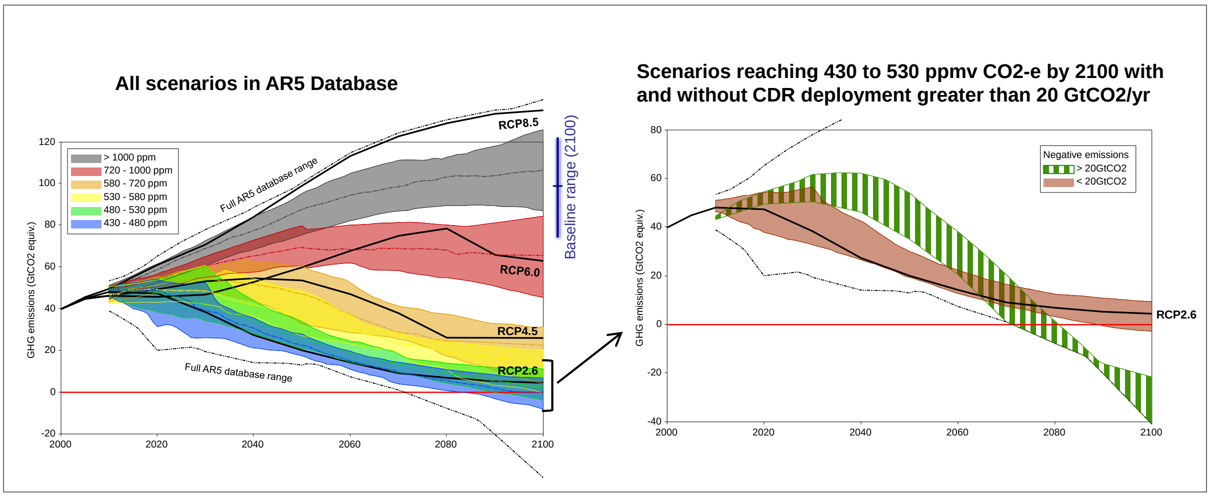


Figure 2. Development of global GHG emission for different long-term concentration levels (left-hand panel) and for low stabilization scenarios (430-530 ppm) with high and low negative emissions (right-hand panel). Ranges are given for the 10-90th percentile of scenarios [WGIII, 6.3]

Table 1: Key characteristics of AR5 scenarios (red: scenarios overshooting the 2100 concentration range indicated in column one; black: scenarios without overshooting the concentration range) [WGIII, 6.3]

	CO_2-eq Conc in 2100[1]	*RCPs*	*2050 CO_2 emissions*[2]	*Cumulative CO_2 emission budgets*[2]		*Indicative 2100 temperature above 1750*[2,,3,5]	*Likelihood to stay below different temperature levels (compared to 1750)*[4,5]		
	ppm CO_2-e	-	*% of 2005 emissions*	*(2011-2050)*	*(2011-2100)*	*°C above 1750*	*1.5°C*	*2°C*	*2.5°C*
	<430	*Only limited amount of studies from individual research groups*							
Cat 1.	450 (430 – 480)	RCP2.6	28 (13-42) 37 (20-53)	540-1050 900-1270	620-1180 670-1180	1.5-1.7 (1.2-2.1) 1.6-1.8 (1.3-2.3)		Very likely Likely	
Cat 2.	500 (480 – 530)		43 (26-53) 47 (32-78)	860-1210 1060-1580	950-1490 1050-1490	1.8-2.1 (1.4-2.6) 1.8-2.1 (1.4-2.7)		More likely than not As likely as not	
Cat 3.	550 (530 – 580)	RCP4.5	71 (41-95) 110 (100-116)	1090-1490 1530-1770	1270-2140 1160-2080	2.1-2.3 (1.7-2.9) 2.1-2.2 (1.7-2.9)		Less likely Unlikely	
Cat 4a	615 (580 – 650)	RCP6.0	91 (59-124)	1250-1630	1860-2450	2.3-2.7 (1.8-3.4)		Unlikely	
Cat 4b	685 (650 – 720)		119 (98-136)	1330-1720	2590-3310	2.6-2.9 (2.1-3.6)		Very Unlikely	
Cat 6.	860 (720–1000)		159 (137-183)	1570-1930	3620-4980	3.1-3.7 (2.5-4.7)		Extremely Unlikely	
Cat. 7	>1000	RCP8.5	214 (185-238)	1830-2230	5340-6900	4.1-4.8 (3.3-6.3)		Extremely Unlikely	

Notes: All ranges correspond to the 10-90th percentile of the scenarios from the AR5 database. Temperature change in 2100 is provided for a central estimate across the scenarios, and including climate system uncertainties (in parenthesis). For further details see table 6.xx.

Scenarios stabilizing atmospheric GHG concentrations at levels below 530 ppm CO_2eq by 2100 require an unprecedented expansion of low-carbon energy sources by mid-century *(robust evidence, high agreement)*. Scenarios centred on 450 (430-480) and 500 ppm (530-580) CO2eq involve tripling to nearly quadrupling the share of zero- and low-carbon energy supply by the year 2050, from today's levels of about [17%], and an increase in total low-carbon energy supply from three-fold to seven-fold over this same period (Figure 4). Many models cannot reach these end-of-century goals if a full suite of low-energy technologies is not available or if supplies are limited. [WGIII 6.3, WGIII 7.X]

If concentrations are to be maintained at or below 530 ppmv CO2-e over the course of the century, then insufficient mitigation through 2030 will require a rapid increase in mitigation and a rapid acceleration in the deployment of low-carbon energy technologies in the decades that follow *(high confidence)*. Scenarios that minimize the overall costs of mitigation are associated with emissions below 50 GtCO2-e in 2030 with annual global emission reductions of roughly 3% (2-7%) per year and roughly a doubling of low-carbon energy supply from 2030 to 2050 (Figure 3). In contrast, in scenarios in which mitigation is insufficient to bring emissions to below 55 GtCO2eq by 2030, then reduction rates roughly double (6% with a range of 3-9%) over this period and global low-carbon energy supplied quadruple. In recent model intercomparison studies, many models could not produce scenarios with these characteristics. [WGIII 6.3, WGIII 7.X]

The Cancun agreements for 2020 are consistent with scenarios that reach 450 or 500 ppmv CO2-e by 2100 only under the assumption that near-term emissions are above what would be required to limit overall mitigation costs. *[High Agreement]* The Cancun agreements for 2020 are broadly consistent with scenarios stabilizing atmospheric GHG concentration levels at 550 ppmv CO2-e to 650 ppmv CO2-e by 2100**.** Scenario studies confirm that 2030 emissions have a larger influence on the subsequent challenges of mitigation than do 2020 emissions. [WGIII 6.4]

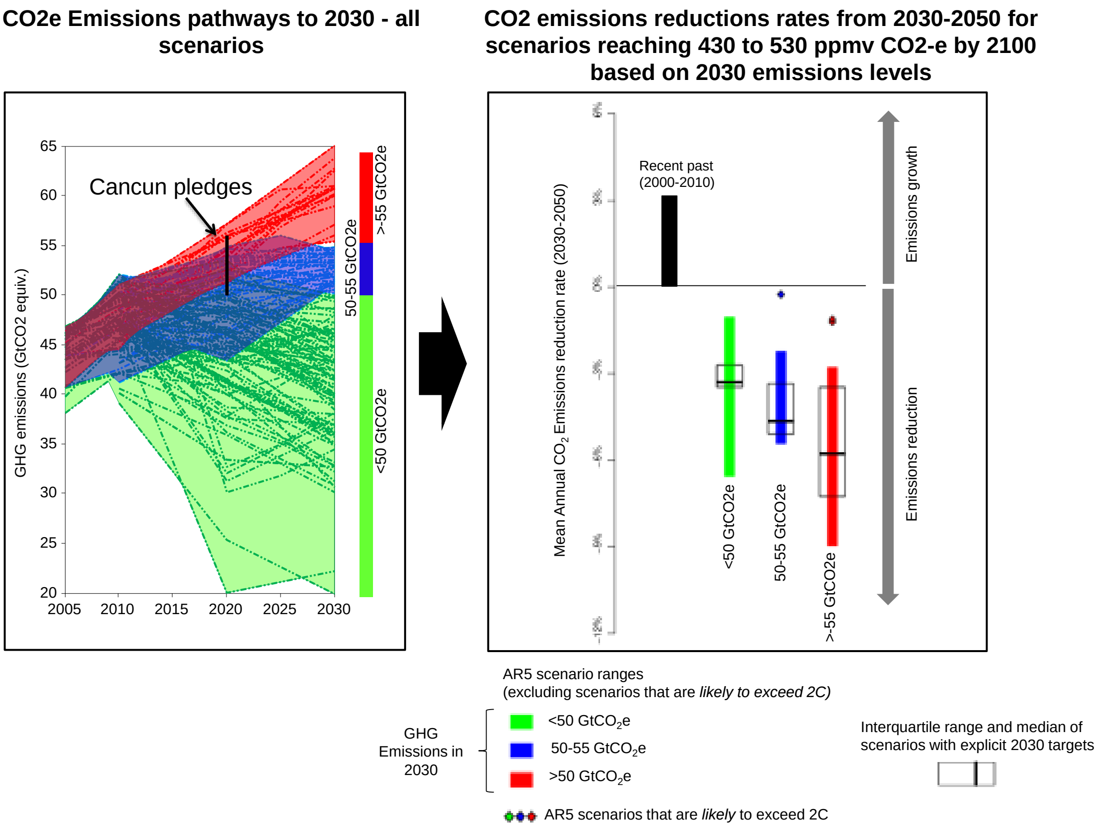


Figure 3. Implications of GHG emissions levels by 2030 for the pace of CO2 emissions reductions by 2050 in mitigation scenarios. Left-hand panel shows the development of GHG emissions to 2030. Right-hand panel denotes corresponding reduction rates for the period 2030-2050 and for long-term concentration levels of between 430-530 ppm CO2e. The median and interquatile range from scenarios from recent intermodeling comparisons with explicit interim targets by 2030 (black whiskers) are compared to the range of scenarios in the AR5 database (colored bars).[WGIII, 6.3]

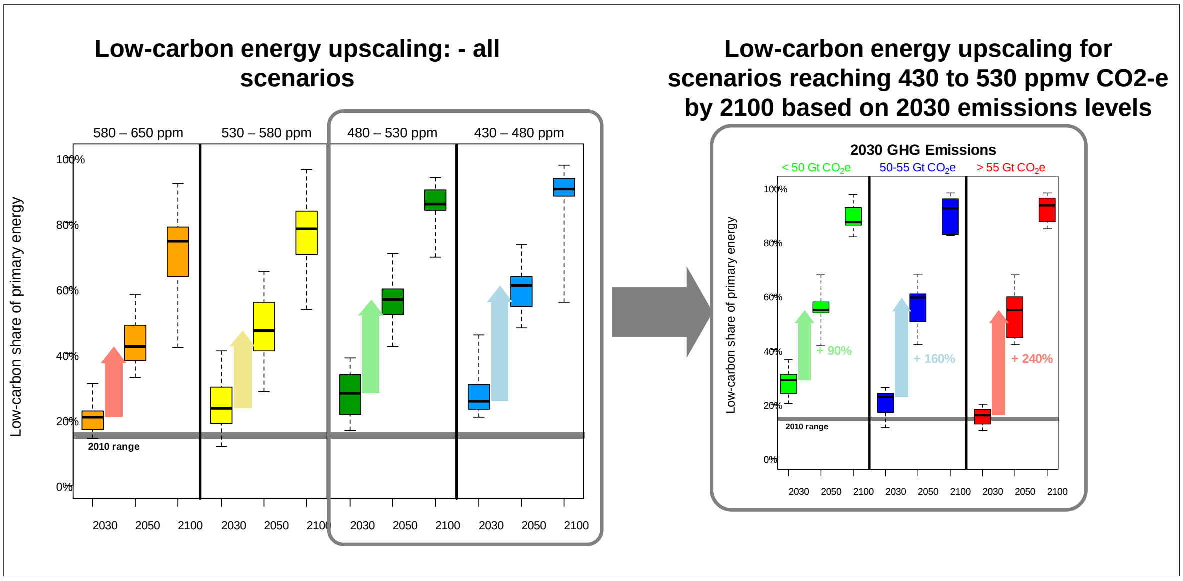


Figure 4 The up-scaling of low-carbon energy in scenarios meeting different 2100 GHG concentration levels (left-hand panel). The right panel shows the rate of up-scaling for different levels of emissions in 2030. Low-carbon technologies include renewables, nuclear energy and fossil fuels with CCS. Sources: AR5 scenario database (left-hand panel) and scenarios from multimodel comparisons with explicit 2030 emissions targets (right-hand panel) (WGIII, Figure 7.X).

Estimates of the aggregate economic costs of mitigation vary widely, but increase with stringency of mitigation *(high confidence)*. Under largely idealised conditions about the efficiency of existing markets, most scenarios indicate that stabilization at atmospheric GHG concentrations centred on 450 ppm CO_2eq might be achieved at global consumption losses of 0% to 2% in 2020, 2% to 6% in 2050, and 2.5% to 12% in 2100, with considerable variation across regions. Estimated costs for maintaining concentrations below 550 ppm CO_2eq are estimated to be roughly 1/3 to 2/3 lower.[WGIII 6.3]

Delays in mitigation through 2030 can have substantial impacts on mitigation costs for the entire century *(high confidence)***.** Although delays by any major emitter will reduce near-term mitigation costs, they will also result in more investment in carbon-intensive infrastructure and then rely on future decision-makers to undertake a more rapid and costly future transformation from this infrastructure. Studies have found increases in total century-long costs of meeting 450 ppmv CO2-e (550 ppmv CO2-e) goals by 2100 of several-fold or more (fill in for 550 ppmv CO2-e). The medium-term, transitional costs of mitigation are more affected by delayed mitigation than are century-long, discounted costs. [WGIII 6.3]

Technology cost, performance, and availability have an important influence on the costs of mitigation. These cost effects are felt more quickly for more ambitious stabilization goals *(high confidence)*. In general, scenarios indicate that there is flexibility to focus regional strategies on particular combinations of technologies that best fit local conditions with only modest increases in aggregate economic costs. However, studies show that pessimistic assumptions about important technologies for decarbonising non-electric energy supply, in particular CCS and biomass due to their use in CDR, could increase the global mitigation costs of reaching 450 ppmv CO2-e by the end of the century by up to four times and the costs of reaching 550 ppmv CO2e by up to 2.5 times (Figure 5; *medium confidence)*. Studies also indicate large economic cost savings from energy use reductions [WGIII 6.3].

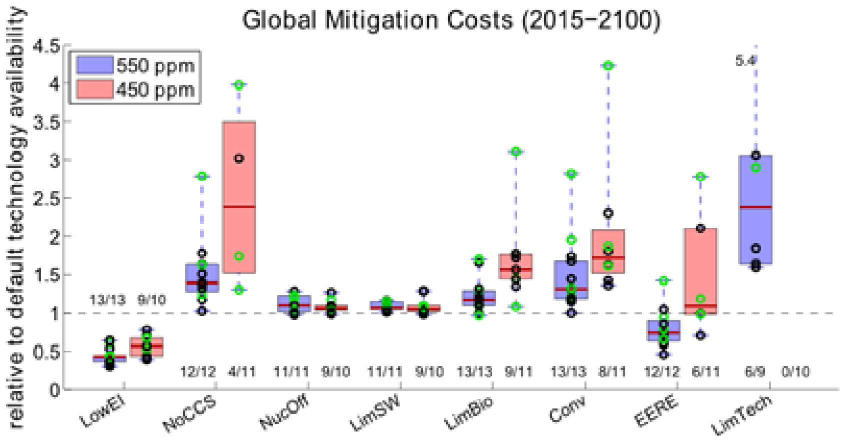


Figure 5. Relative mitigation cost increase in case of technology portfolio variations compared to a scenario with default technology assumptions under a 450 ppm (red) and a 550 ppm (blue) CO2-e 2100 goals from the EMF27 study. Net present value of mitigation costs, discounted at 5%, for the period 2015-2100 is shown. The thick red line corresponds to the median, the coloured box to the inter-quartile range (25th to 75th percentile) and the whiskers to the total range across scenarios. Dots correspond to individual scenarios with partial equilibrium models being shown in green and general equilibrium models in black. The numbers at the bottom indicate the number of models that attempted the reduced technology portfolio scenarios and how many in each sample were feasible. [WGIII, 6.3]

Studies demonstrate that mitigation will influence the costs of meeting other objectives *(high confidence)*. Recent multi-objective studies indicate that stringent climate policies significantly reduce the costs of reaching energy security and/or air pollution objectives. These economic effects are not taken into account in the majority of scenario studies, which typically attribute mitigation costs exclusively to the climate objective. While sectoral studies indicate a number of other potential co-benefits and adverse side-effects, the overall welfare implications of these have not been assessed thoroughly in the literature. [WGIII, 6.6, 7.9, 8.7, 9.7, 10.8, 11.7, 12.8]

Effort-sharing frameworks can ameliorate distributional issues and decouple regional mitigation effort from financial burdens, but would be associated with significant international financial transfers *(high confidence)*. In large part because reductions from baseline in non-OECD will ultimately need to be higher than for OECD countries, the majority of direct mitigation costs will be borne in these countries. Financial transfers to ameliorate this asymmetry are estimated to be on the order of hundred billions of USD before mid-century to meet a goal of 450 ppmv CO2-e by the end of the century. [WGIII 6.3, 13.X]

3.4 Characteristics and risks of (evolving) adaptation pathways

The risks of damages from climate change can be reduced by both (i) mitigation that reduces the likelihood of physical impacts, and (ii) adaptation that reduces the vulnerability and exposure of societies and ecosystems to those impacts (high confidence)**.** The benefits of mitigation and adaptation vary over different timeframes (high confidence). In the near-term, committed temperature changes do not vary much with emission scenario [WGI 11.3] and so societal responses, particularly adaptations, will have relatively more substantial influence. In the second half of the 21st century and beyond, global temperature diverges between emission scenarios [WGI AR5 12.4] and so both mitigation and adaptation options and their interaction with development pathways will increasingly determine the risks of climate change [WGII, 2.5, 21.2, 21.5] Risk associated with the distribution of impacts is generally greatest in low-latitude, less developed areas, but because vulnerability is unevenly distributed within countries, some populations in developed countries are highly vulnerable to warming of less than 2°C, as noted in AR4 (*high confidence*) [WGII, 19.6].

The impacts from climate change tend to increase in most sectors with global average temperature and cumulative emissions of long-lived greenhouse gases [WGII 16.6] hence, cutting these emissions can reduce a large and increasing part of the risk associated with climate change impacts over the 21st century [WGII, 19.7, *high confidence*]. Examples include reduced risk of negative agricultural yield impacts, of water scarcity, of major challenges to urban settlements and infrastructure from sea level rise, and of adverse impacts from heat extremes, floods, and droughts in areas where increased occurrence of these extremes are projected. Benefits from mitigation are most immediate for ocean acidification and least immediate for impacts related to sea level rise due to the inertia in the climate system. Mitigation also delays the need to adapt to a particular level of climate change impacts, potentially by several decades, although this benefit only emerges from the mid-21st century. Under all assessed scenarios for mitigation and adaptation, some risk from residual damages is unavoidable (very high confidence).

The impacts avoided by adaptation vary markedly across regions and sectors. This is due to (a) differing levels of regional climate change, (b) differing numbers of people and levels of resources at risk in different regions (e.g. presence of unique ecosystems or the size of the human population exposed to impacts), and (c) differing sensitivities and adaptive capacities of humans, institutions, species or ecosystems in different regions. Similarly, residual impacts will differ between sectors due to different levels of sensitivity and differing effectiveness of adaptation options and levels of adaptive capacity.

Adaptation research, planning and implementation have progressed since the AR4 with an emphasis on the regionally and context-specific nature of adaptation, with no single approach appropriate across all settings including due to variation in values, objectives, and risk perceptions (*high confidence*) [WGII, 15.2, 15.3]**.** Effective risk reduction and adaptation strategies consider the dynamics of vulnerability and exposure and their linkages with development and climate change (*high confidence*) and can be supported by targeted decision support processes which help address the many uncertainties and institutions which broker knowledge between different actors. Few instances of adaptation have been monitored and evaluated.

There has been an evolution of the adaptation discourse from a focus on incremental adaptations to be more inclusive of systemic and transformative adaptation, from a primary focus on engineering and technological options to more ecosystem-based, institutional, and social measures [WGII 14.1, 14.3, 15.2,15.5] and from a focus on cost-benefit analysis, optimisation and efficiency to the development of multi-metric evaluations including risk and uncertainty dimensions integrated within wider policy and ethical frameworks [WGII 17.2, 17.3]. Thus there has been a marked increase in the range of adaptations explored including a broad range of economic instruments such as risk financing, sharing and transfer mechanisms, payments for environmental services and improved resource pricing that can foster adaptation by providing incentives for anticipating and reducing impacts. There are limits to the effectiveness of these adaptation options and hence residual loss and damage will still occur. Additionally, possible maladaptations have been identified that can arise from poor planning, overemphasizing short-term outcomes, or discounting or failing to consider all consequences [WGII 17.2, 17.3]. Significantly large and/or rapid increases in climate extremes and climate-related extreme weather events are less amenable to incremental adaptations to climate change and will often require more transformational change if development is to be sustained without major disruptions [WGII 20.5]

Global adaptation cost estimates are substantially greater than current adaptation funding and investment, particularly in developing countries, suggesting a funding gap and a growing adaptation deficit (limited evidence, *medium confidence*). The most recent global adaptation cost estimates suggest a range from $70 billion to $100 billion per year globally by 2050 (low confidence) which are an order of magnitude greater than current investment levels particularly in developing countries **(***limited evidence***)**. [WGII 17.4].

Successful adaptation requires not only identifying adaptation options and assessing their costs and benefits, but also expanding the adaptive capacity of human and natural systems (*high agreement, medium evidence*). Continued development of knowledge of how to build adaptive capacity through research and practice could accelerate more widespread and successful adaptation outcomes. However, this can involve complex governance challenges and may necessitate new institutions and institutional arrangements [WGII 16.2; 16.3; 16.5; 16.8]. The convergence between building adaptive capacity and disaster risk management has been further strengthened since AR4 [WGII 14.1, 14.2, 14.3] (*High agreement, robust evidence*). Traditional and indigenous forms of knowledge are a major resource for adapting to climate change except when the changes exceed the knowledge repertoire (high agreement, robust evidence). Unmitigated climate change will increasingly constrain the efficacy of indigenous and traditional knowledge in adaptive responses [WGII 12.3]. For sectors where adaptive capacity is limited, such as range- and temperature-limited ecosystems, mitigation is a key part of reducing risks, but this will only become effective beyond about 2050 when climate trajectories materially diverge under different emission pathways [WGI.12.4; WGII.4.4, 19.6].

Is there an optimum amount of mitigation to reduce climate change risks?

Determining optimal adaptation and mitigation strategies through cost-benefit analyses face difficult methodological, technical and ethical issues which currently result in high uncertainties in estimates (WG2.2, WG3.2, WG3.3, WG3.4). In particular, estimates of aggregate costs of climate change cannot be directly compared with mitigation costs, and estimates of the social cost of carbon cannot be directly compared with estimates of the carbon price required to reach a given amount of emission reductions (WG3.2).

Current estimates of globally aggregated costs of impacts may be underestimated because they not include many non-monetized impacts, such as biodiversity loss, and because they omit many known impacts that have only recently been quantified, such as reduced labour productivity [II.19.6.3.5, *high confidence*]. In addition, aggregated estimates of costs mask significant differences in impacts across sectors, regions, countries and populations [II.19.6.3.5, *very high confidence*].

The probability of reaching adaptation limits and suffering from large damages increases with temperature change although there appears to be no temperature threshold where the risk of this increases markedly [16.6]. In particular, current knowledge suggests that the risk from climate change does not exhibit a step or an inflexion around 2^{o}C (low confidence). Costs of adaptation increase with the magnitude of impacts.

Mitigating emissions can reduce a large and increasing part of the risks associated with climate change impacts over the 21st century (WG2.19.7.1, high confidence). For example, there is limited evidence that stringent mitigation scenarios, consistent with a 50% chance of limiting warming to 2°C above pre-industrial, can avoid one half of the aggregate economic impacts that would otherwise accrue by 2100, and between 20-60% of the physical impacts, depending on sector and region (WG2.19.7.1).

Impacts depend on both the rate and magnitude of warming and fewer impacts can be avoided if emissions peak later and are then reduced very rapidly, than if emissions peak earlier and are reduced at a lesser but sustained rate. (WG2.19.7.2). In particular this arises where impacts are sensitive to peak warming that may occur as part of emission overshoot trajectories (WG2.19.7.2)

The cost of mitigation increases highly non-linearly over time for a given temperature objective such as maintaining the temperature increase below 2^{o}C ( ). When combined with the above results, this indicates that earlier and more significant emission reduction can reduce mitigation costs, adaptation costs and impact costs although no optimum strategy can be precisely determined at this point

3.5 Climate-change risks reduced by mitigation and adaptation

[Note to reviewers: This section is key for synthesizing material from Working Groups II and III. Due to the high coordination requirements, this will be jointly developed during the next meeting of the Core Writing Team after this review round.]

- Risks and impacts can be reduced by adaptation (climate change impacts = cost of adaptation + residual impacts)
- The presence of adaptation has an impact on the magnitude and timing of desirable mitigation actions. Adaptation and mitigation are complementary.

- Risks avoided thanks to mitigation – and therefore mitigation benefits – can be measured using estimates of aggregated impacts for different levels of warming: econometric analyses, IAM estimates of GDP losses, IAM estimates of social cost of carbon. (summary of existing studies)
- Reasons why these aggregated monetary estimates are partial and imperfect. Measuring mitigation benefits can also be done using additional metrics.
- What we know about avoided impacts: mitigation can avoid a significant fraction of damages, avoided damages vary across regions, there is no threshold or inflexion point around 2C.
- Determining an optimal adaptation and mitigation strategies through a cost-benefit analysis face difficult methodological, technical and ethical issues, and is currently out of reach due to the high uncertainty
- Iterative risk management is a decision-making approach designed to deal with contexts of large uncertainty, disagreement on values and worldviews, and learning over time.

3.6 Interactions among mitigation, adaptation, and sustainable development

Climate change is closely interconnected with sustainable development in a number of ways.

Sustainable development trajectories that combine adaptation and mitigation to reduce climate change and its impacts lead to climate resilient pathways (WG II 2.5, 13.4, 20.2-4) Climate change is likely to be a threat multiplier that will affect social and natural systems in ways that place additional burdens on the poor and constrain possible development paths (WGII, 20.1, 13.13, 19). Some climate policy responses can impose other environmental costs, have adverse distributional effects, and draw resources away from other developmental priorities (WGIII 4.8.2, 6.6, WG II 30.1, 13.13). At the same time, development along existing trends contributes to climate pressures (WGIII 4.2.1.2) while current failures to address emerging impacts erode the basis for sustainable development (WGII 1.1, 11.8, 13.4, 16, 25.10, 26.5, .9)

Given these extensive linkages, climate change policies need to be embedded within a larger strategy of sustainable development that allows consideration of a broad range of social and economic objectives. These include economic development, the elimination of poverty, and the convergence of living standards across and within countries (WGIII 4.2). This close relationship between climate change and sustainable development suggests the need to frame climate policy in the context of sustainable development as an exercise of seeking multiple objectives, across which there are both synergies and trade-offs (WGIII 3.6.3, 4.8, WGII 17.2, 15.xx), that occur both within and across regions (WGII 8.4, 9.3, 13.3, 21.4, 25.x, 26.8). This framing has several implications for the formulation of climate policy.

Since synergies and trade-offs are likely to be place-specific, policy choices aimed at mitigation and at addressing vulnerability and risk will vary in different regions and countries in response to particular contextual factors (WGIII 6.6; WG II 20.3.2). Policy design choices will also vary across time as contexts change (WGIII 3.5, 4.8, 4.6). Consequently, the process through which decisions are made needs to be robust, adequately analyzed for trade-offs and be sensitive to local context (WGIII, 3.2, 3.10, 14.1, 15.8). Cost-benefit analysis and multi-criteria analysis provide tools for this purpose (WGIII, 3.5, 3.7, 6.6).

In many contexts, the approach to climate policy may start with consideration of local priorities to create appropriate incentives for action. There is evidence from national climate action plans that foregrounding local incentives is increasingly used as a basis for formulating climate policy in a range of countries (WGII 15.x; WGIII 15.2).

Changes in paradigms and goals lead to transformations in political, economic and technological systems that can facilitate adaptation and mitigation and promote sustainable development, while at the same time may place new demands on governance structures to

reconcile conflicting goals and visions for the future (WG II 1.1, 2.5, 14.3, 22.4, 25.4, WGIII 4.3).

Evidence taking into account multiple objectives suggests that climate mitigation policy could provide an entry point to achieve a broader set of non-climate objectives. In many cases, if stringent climate policies are in place, synergistic relationships between societal objectives tend to be stronger and the added costs of any supplementary policies to reach other objectives (energy security/air pollution) at stringent levels can be significantly reduced - particularly in the near term (Figure 6). The extent of the synergies will depend on the ambition level for the different objectives [WGIII 3.6.3, 6.6]. For example, the literature documents a large number of co-benefits and a small number of adverse side-effects for energy efficiency options compared to supply side mitigation options. [WGIII 6.6, 7.9, 10.8, 9.8, 10.8, 11.8] Conversely, bioenergy deployment offers both significant potential for climate change mitigation, but also considerable risks [WGIII 11.A]. In adaptation, there are a number of approaches that address sustainable development and climate adaptation, such as extension of public health measures and essential health services (WGII 11.6) and addressing gender based vulnerabilities (WGII, Box 9-2).

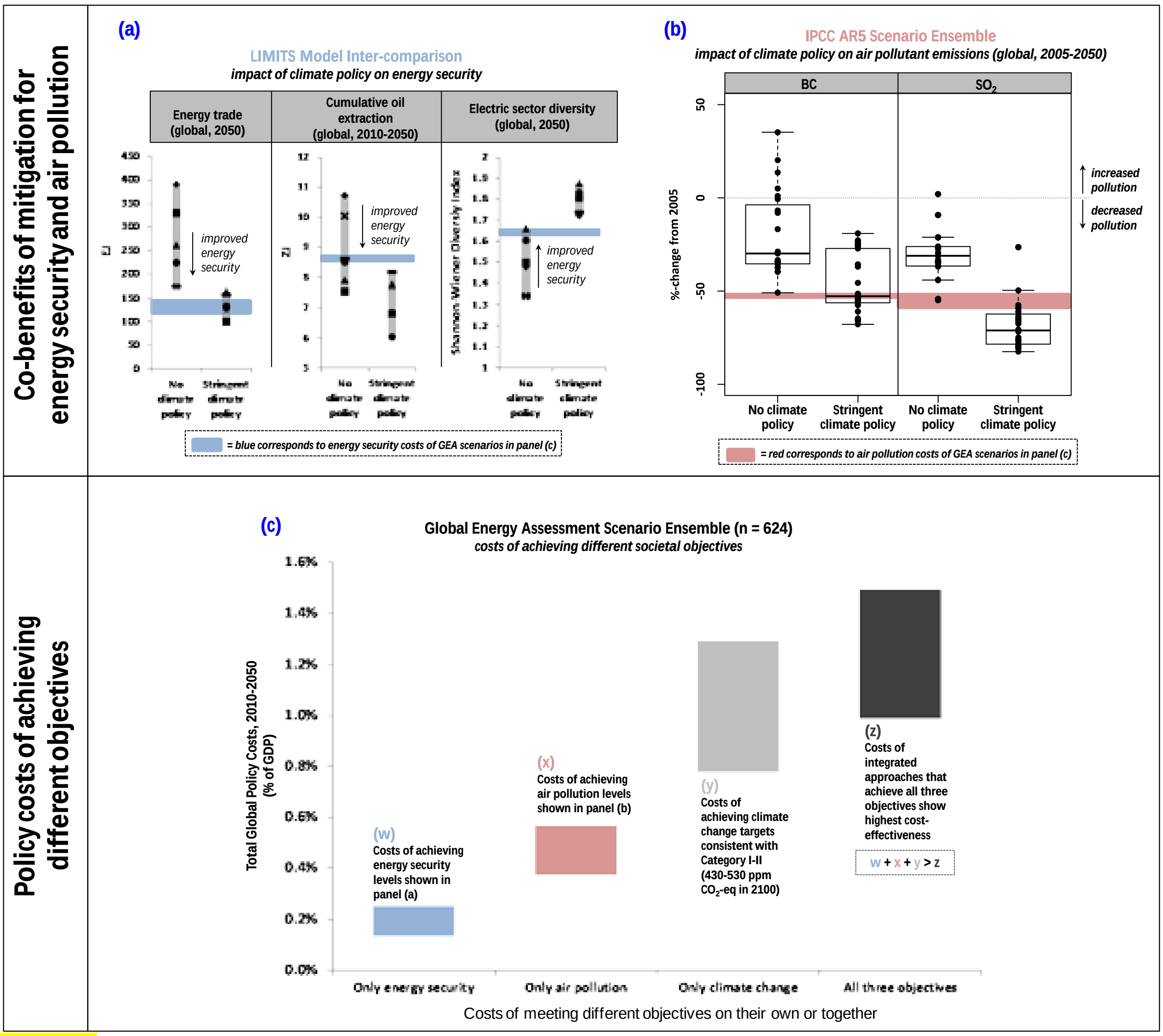


Figure 6 - Co-benefits of mitigation for energy security and air pollution in scenarios with stringent climate policies (concentration 430-530 ppm CO_2-eq in 2100). Upper panels show co-benefits for different security indicators and air pollutant emissions. Lower panel shows related global policy costs of achieving the energy security, air quality and mitigation objectives, either alone (w, x, y) or simultaneously (z). Integrated approaches which achieve these objectives simultaneously show the highest cost-effectiveness due to

synergies (w+x+y>z). Policy costs are given as the increase in total energy system costs relative to a no-policy baseline. Costs are indicative and do not represent full uncertainty ranges. [Figure 6.32]

BOX SYR.3: Geo-engineering

Box : Geo-engineering – possible role, options, risks and status [600 words: currently 637]
[**Piers Forster**, **Jan Fuglestvedt**, Leon Clarke, Hans Portner, John Broome, Rob Stavins]

Geoengineering refers to a broad set of methods and technologies that aim to alter the climate system in order to alleviate the impacts of climate change. Carbon Dioxide Reduction (CDR) aims to slow or reverse increases in atmospheric CO_2 concentrations. Solar Radiation Management (SRM) aims to counter the warming associated with increasing GHG concentrations by reducing the amount of sunlight absorbed by the climate system {WGI-6.5, WGI-7.7}.

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. CDR would need to be deployed at large scale and over at least one century to have a significant effect on CO_2 concentrations. There are biogeochemical, and currently technical, limitations that make it difficult to provide quantitative estimates of the potential for CDR. Some of its side-effects arise from altered surface albedo from afforestation, ocean acidification from ocean disposal or leakage of CO_2 from underground storage sites, ocean de-oxygenation and acidification from ocean fertilization and deep storage of biomass, and increased N_2O emissions {WGII-6.4.2; Table 6-5; Box CC-OA}. Land-based CDR methods, like Bioenergy with Carbon Capture and Storage (BECCS) and afforestation, would probably face competing demands for land. The level of confidence in the effectiveness of CDR methods and their side-effects on carbon and other biogeochemical cycles is *low* {WGI-6.5}. The possible shortage of land implies that the potential for BECCS as a late-century, large-scale mitigation strategy is still unknown [see Section X].

Solar Radiation Management (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 the radiative forcing (RF) and some of the climate effects expected from 560 ppm CO_2eq. 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 {WGI-7.7}.

Numerous side-effects, risks and shortcomings from SRM have been identified. SRM would produce an inexact 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 ocean acidification from CO_2. There could also be other unanticipated consequences {WGI-7.6, 7.7, WGIII-6.9, WGII-6.4.2, 19.5.4}.

Some studies have shown that SRM strategies would create benefits to some regions and costs to others. 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 {WGIII-13.2, 13.4}. 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 {WGI-7.7.3, 7.7.4; WGII-4.4.1, 6.1.2, 6.3.1}

The availability of CDR technologies, in general, may allow emission reductions to be delayed, but at a risk of further overshoot. Assessments of SRM are still few. Even research on SRM, as well as its eventual deployment, is subject to ethical objections (WGIII-3.3.7). An attractive feature of SRM is that it can be applied relatively quickly. Still, one finding is that despite the low costs of some SRM techniques, they will not necessarily pass a cost-benefit test that takes account of the risks of termination and costly side-effects {WGIII-6.9}.

Box SYR.4: Co-benefits

Box: Co-benefits [400 words: currently 407]
[**Navroz Dubash**, **Purnamita Dasgupta**, Ottmar Edenhofer; Stephane Hallegatte, Marc Fleurbaey, Joy Pereira]

A government policy or a measure intended to achieve one objective (such as mitigation) will affect also other objectives (such as local air quality). To the extent these side-effects are positive, they can be deemed 'co-benefits'; otherwise they are termed 'adverse side-effects'. In the adaptation domain, they are referred to as "ancillary benefits" and some adaptation measures are labelled "no regret" when their co-benefits are sufficient to justify their implementation, regardless of their adaptation benefits (2.17.2.3, 2.17.3). In this report, co-benefits and adverse side-effects are most of the time measured in non-monetary units. Their effect on overall social welfare has not been yet evaluated with exception of a few recent multi-objective studies. If and how cobenefits or adverse side-effects materialize depends on local circumstances and implementation pace, scale and practices. While climate policy affects non-climate objectives (see Tables TS.3.2.2-30 3.2.6) other policies also affect climate change outcomes. [3.6.3, 4.2, 6.6, 8.7, Annex I]

There are many potential co-benefits and adverse side-effects, which makes comprehensive analysis difficult. The direct benefits of climate policy include, for example, intended effects on mean global temperature, sea level rise, agricultural productivity, biodiversity, and health effects of global warming [WG2]. The co-benefits and adverse side-effects of climate policy could include effects on a partly overlapping set of objectives such as local air pollutant emissions and related health and ecosystem impacts, energy security, income distribution, efficiency of the taxation system, labour supply and employment, urban sprawl, and the sustainability of the growth of developing countries [3.6, 4.8, 6.6, 15.2.4]. For instance, climate policy likely raises the price of carbon-intensive products that constitute a high fraction of spending by low-income families. Adverse side effects on the distribution of income can be offset through support to low-income families [3.6, 7.9, 9.7]. Similarly, adaptation and development policies often overlap, for instance in terms of infrastructure service provision such as sanitation and drainage [2.17.2].

All these effects are important, because a comprehensive evaluation of climate policy needs to account for benefits and costs related to other objectives. Climate policy, in particular, may affect many market and non-market activities of households and businesses, some of which are already the targets of preexisting 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. [3.6.3]

Box SYR.5: GHG metrics and transformation pathways

Box: GHG metrics and transformation pathways [400 words] – currently 499
[**Jan Fuglestvedt, Jan Minx,** Detlef van Vuuren, Andy Reisinger, Piers Foster, Ottmar Edenhofer]

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_2-equivalents"). 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 in AR5 (WGI-8.7; WGIII-3.9.6).

The choice of metric and time horizon depends on application and policy context and no recommendations are given by AR5. All metrics have shortcomings and choices contain value judgments, such as the climate effect considered and the weighting of effects over time, the climate policy goal, and the degree to which metrics incorporate economic or only physical considerations. Metrics can apply to all forcing agents, or to sub-groups based on contributions to short- and long-term climate change (WGI-8.7, WGIII-3.9.6).

The weight assigned to non-CO_2 components relative to CO_2 depends strongly on the choice of metric and time horizon. 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 some metrics, the weighting changes over time as a chosen target year is approached (WGI-8.7; WGIII-3.9.6).

The choice of metric affects the emphasis placed on abating short- and long-lived components and may influence magnitude and timing of peak CO_2 emissions in optimal mitigation strategies. Using time-dependent GTP instead of GWP_{100} leads to less CH_4 mitigation in the near-term but more in the long-term. The impacts on the global CO_2 emission reduction profile and costs in most studies are small and depend on detailed policy goals. Metrics that consistently result in less abatement of short-lived components than GWP_{100} (e.g. constant GTP) would require earlier and more stringent CO_2-abatement to achieve the same climate outcome and would increase net global mitigation costs. 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 (WGI-6/12; WGIII-6).

Under scenarios of global participation and optimal mitigation pathways, global cost differences under alternative metrics are small compared to variations between IAMs and technology assumptions; implications for individual countries and sectors could be more significant. Alternative metrics and time horizons significantly affect the calculated contributions from various components and sources. This could influence abatement technology development, choice of policies and timing of mitigation for sectors with significant non-CO_2 emissions (WGIII-6).

Topic 4: Adaptation and Mitigation Measures

4.1. Introduction: making near-term decisions consistent with long-term and strategic goals

Topic 4 focuses on operational and implementation perspectives for adaptation and mitigation. It assesses response options that can be influenced and implemented in the near term, and that would be consistent with and contribute to achieving long-term strategic goals and follow resilient pathways as characterised in Topic 3.Even though Topic 4 focuses on practical responses and decisions that can be taken now or in the very near future,some of the available response options and policies can be driven by long-term perspectives and have long-lasting effects, such as investments in capital infrastructure and the development of human settlements with long lifetimes. Moreover, achieving some long-term outcomes (such as limiting global average temperature increases to no more than 2 degrees above pre-industrial levels, as indicated in recent decisions by the UNFCCC; see also Box on Article 2) relies on near-term actions being implemented to keep the long-term goal within plausible reach.[SREX; II 15.5, 20.2; III refs]

The nature of low carbon and climate resilient development pathways may vary from one region to another given there are multiple entry points and response options for adaptation and mitigation that are better suited for specific areas and circumstances. To this end, iterative risk management is a useful framework for decision making and to manage the uncertainties and inevitable changes over time in the impacts of climate change, the cost and availability of technologies, and societal preferences that influence decisions.In many cases, a first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate through low-regrets measures and actions emphasizing co-benefits (*high confidence*); similarly, some non-climate policies such as the reduction of fossil fuel subsidies can achieve significant emissions reductions but may not be motivated primarily by climate change concerns but by their net benefits to society (*robust evidence, high agreement*). This implies that there is no single optimal set of adaptation and mitigation responses. [refs]

The presentation and discussion of response options and their trade-offs in Topic 4 reflects these multiple entry points and policy interactions.Topic 4 addresses the following areas: i) response options for adaptation; ii) response options for mitigation; iii) adaptation and mitigation in the context of multiple objectives; iv) constraints, limits and enabling factors in adaptation and mitigation measures; and v) climate and non-climate policies, their interactions and integration at different scales.

4.2. Response Options for Adaptation [Joy, Ben, Purnamita, Andy][1200 words]

Opportunities exist to enable adaptation planning and implementation for actors across all sectors and geographic regions (*very high confidence*). Enhancing the awareness of individuals, organizations, and institutions about climate change vulnerability, impacts and adaptation can help build individual and institutional capacity for adaptation planning and implementation. Opportunities can also arise as actors learn from experience with climate variability and incorporate consideration for long-term climate change into disaster risk reduction efforts. [16.2 16.3.1; 16.5; Table 16-1; Table 16-3; Box 16-1; Box 16-2; Box CC-EA]

Freshwater resources: **Adaptive water management techniques, including scenario planning, learning-based approaches, and flexible and low-regret solutions, can address uncertainty due to climate change (*limited evidence, high agreement*).**[3.6, Box 25-2] Adaptive responses in Asia include integrated water management strategies, such as development of water saving technologies, increased water productivity, and water reuse. [24.4] On-going adaptation strategies in Central and South America include reduced mismatch between water supply and demand, and water-management and coordination reforms (*medium confidence*). [27.2-3]

Terrestrial and freshwater ecosystems: Management actions can reduce, but not eliminate, risks to ecosystems and can increase ecosystem adaptability, for example through reduction of other stresses and habitat fragmentation, maintenance of genetic diversity, assisted translocation, and manipulation of disturbance regimes (*high confidence*). [Figure SPM.5, 4.3-4, 25.6, 26.4, Box CC-RF]

Coastal systems and low-lying areas: **Without adaptation, hundreds of millions of people will be affected by coastal flooding and displaced due to land loss by 2100, due to climate change and development patterns (*high confidence*).** The majority affected will be in East, Southeast, and South Asia. The relative costs of adaptation vary strongly among and within regions and countries for the 21st century (*high confidence*). Some low-lying developing countries and small island states are expected to face very high impacts and associated annual damage and adaptation costs of several percentage points of GDP. [5.3-5, 24.4, 25.6, Box 25-1]

Marine systems: In the short term, strategies including climate forecasting and early warning systems can reduce risks from ocean warming and acidification for some fisheries and aquaculture industries. Fisheries and aquaculture industries with high-technology and/or large investments, as well as marine shipping and oil and gas industries, have high capacities for adaptation due to greater development of environmental monitoring, modelling, and resource assessments. For smaller-scale fisheries and developing nations, building social resilience, alternative livelihoods, and occupational flexibility represent important strategies for reducing the vulnerability of ocean-dependent human communities. [6.4, 7.3-4, 25.6, 29.4, 30.6-7]

Food production systems and food security: **Without adaptation, local temperature increases of 1°C or more above preindustrial levels are projected to negatively impact yields for the major crops (wheat, rice, and maize) in tropical and temperate regions, although individual locations may benefit (*medium confidence*).** In Africa, adaptive agricultural processes such as collaborative, participatory research that includes scientists and farmers, strengthened communication systems for anticipating and responding to climate risks, and increased flexibility in livelihood options provide potential pathways for strengthening adaptive capacities. [22.3-4, 22.6]

Urban areas: Urban adaptation provides opportunities for incremental and transformational adjustments towards resilience and sustainable development via effective multi-level urban risk governance, alignment of policies and incentives, strengthened local government and community adaptation capacity, synergies with the private sector, or appropriate financing and institutional development (*medium confidence*). Enabling the capacity of low-income groups and vulnerable communities and their partnerships with local governments can also be an effective urban adaptation strategy. [8.3-4, 24.4, 24.5, 26.8, Table 11-3, Box 25-9]

Rural areas: **Options exist for adaptations within 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. [9.3, 25.9]

Key economic sectors and services: More frequent and/or severe weather disasters for some regions and/or hazards will increase losses and loss variability in various regions and challenge insurance systems to offer affordable coverage while raising more risk-based capital, particularly in low- and middle-income countries. Large-scale public-private risk prevention initiatives and government insurance of the non-diversifiable portion of risk offer example mechanisms for adaptation.

Human health: The most effective adaptation measures for health in the near-term are programs that implement basic public health measures such as provision of clean water and sanitation, secure essential health care including vaccination and child health services, increase capacity for disaster preparedness and response, and alleviate poverty (*very high confidence*). [Figure TS 10, 8.2, 10.8, 11.3-8, 19.3, 22.3, 25.8, 26.6, Box CC-HS]

*Human security:*The presence of robust institutions can manage many rivalries due to transboundary impacts of climate change, such as changes in sea ice, shared water resources, and migration of fish stocks, to reduce conflict risks.

*Livelihoods and poverty:*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.

Adaptation is highly regionally and context specific, with no single approach for reducing risks appropriate across all settings (medium confidence). [2.1, 8.3-4, 13.1, 13.3-4, 15.2-3, 15.5, 16.2-3, 16.5, 17.2, 17.5, 19.6, 21.3, 22.4, 25.4, 26.8-9, 29.6, 29.8] Adaptation response options have overlapping entry points and approaches, which are often pursued simultaneously [TABLE SPM 2, WG 2]. There is *high confidence* that effective adaptation takes into account the dynamics of vulnerability and exposure and their linkages with development and climate change. Low regret measures are effective adaptation options that focus on human development, poverty alleviation, livelihood security, disaster risk management and ecosystem management.

From individuals to governments, actors across scales and regions have complementary roles in enabling adaptation planning and implementation (*high confidence*), for example through increasing awareness of climate change risks, learning from experience with climate variability, and achieving synergies with disaster risk reduction.Adaptation is constrained by market and coordination failures, lack of resources or information of affected actors, behavioral and cognitive biases of decision-makers, and distorted incentives in government. Adaptation therefore requires appropriate public action and policies, and a supportive policy environment (robust evidence, high agreement) [wg2.17.3].Local government and the private sector are increasingly recognized as critical to progress in adaptation (*medium evidence, high agreement*). National governments can coordinate adaptation by local and subnational governments, creating legal frameworks, protecting vulnerable groups, and providing information, policy frameworks, and financial support (*robust evidence, high agreement*).

Existing and emerging economic instruments can foster adaptation by providing incentives for anticipating and reducing impacts (*medium confidence*). Instruments include risk sharing and transfer mechanisms, loans, public-private finance partnerships, payments for environmental services, improved resource pricing (e.g., water markets), charges and subsidies including taxes, norms and regulations, and behavioral approaches [10.7, 10.9, 13.3, 17.4-5, 22.4, Box 25-7]

Indigenous, local, and traditional forms of knowledge are a major resource for adapting to climate change (*robust evidence, high agreement*). Such forms of knowledge are often neglected in policy and research, and their mutual recognition and integration with scientific knowledge will increase the effectiveness of adaptation. [9.4, 12.3, 15.2, 22.4, 24.4, 24.6, 25.8, Table 15-1]

Significant tradeoffs exist between alternative adaptation options (*very high confidence*). Adaptation options are influenced by cultural characteristics, institutional context and capacity, perception of risks, sense of place and entitlements to resources. Individuals or institutions may have specific management objectives that they seek to achieve or maintain through adaptation (16.2, Table 16-2). However, there may be multiple adaptation options for every objective and each may be associated with a particular set of costs, benefits, and externalities.

Table SPM.2: Managing the risks of climate change: entry points, strategies, and adaptation options. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Examples given can be relevant to more than one category. [14.2-3, Table 14-1]

Overlapping Entry Points	Category	Examples	Chapter Reference(s)
Vulnerability reduction through development & planning *Including many low-regrets measures*	Human development	Improved access to education, nutrition, health facilities, energy, safe settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.	8.3, 9.3, 13.1-3, 14.2-3, 22.4
	Poverty alleviation	Insurance schemes; Social safety nets & social protection; Disaster risk reduction; Improved access to & control of local resources, land tenure, & storage facilities.	8.3, 9.3, 13.1-3, Box 8-4
	Livelihood security	Income, asset, & livelihood diversification; Improved infrastructure; Access to technology & decision-making fora; Enhanced agency; Changed cropping, livestock, & aquaculture practices; Reliance on social networks.	7.5, 13.1-3, 22.3-4, 23.4, 26.5, 27.3, 29.6, Table 24-7
	Disaster risk management	Early warning systems; Hazard & vulnerability mapping; Improved drainage; Flood & cyclone shelters; Building codes; Storm & wastewater management; Transport & road infrastructure improvements.	8.2-4, 11.7, 14.3, 15.3-4, 22.4, 24.4, 25.4, 26.6, 28.4
	Ecosystem management	Maintaining wetlands & urban green spaces; Coastal afforestation; Dam management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Assisted translocation; Manipulation of disturbance regimes; Community-based natural resource management.	4.3-4, 8.3, 22.4, Table 3-3, Boxes 4-2, 4-3, 8-2, 15-1, 25-8, 25-9, & CC-EA
	Spatial or land-use planning	Provisioning of adequate housing, infrastructure, & services; Managing development in flood prone & other high risk areas; Urban upgrading programs; Land zoning laws; Easements; Protected areas.	4.4, 8.1, 8.3-4, 22.4, 23.7-8, 27.3, Box 25-8
Adaptation *Including incremental & transformational adjustments*	Structural/ physical	*Engineered & built-environment options:* Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.	3.5-6, 5.5, 8.2-3, 10.2, 11.7, 23.3, 24.4, 25.7, 26.3, 26.8, Boxes 15-1, 25-1, 25-2, & 25-8
		Technological options: New crop & animal varieties; Traditional technologies & methods; Efficient irrigation; Water-saving technologies; Conservation agriculture; Food storage & preservation facilities; Hazard mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling.	7.5, 8.3, 9.4, 10.3, 15.3-4, 22.4, 24.4, 26.3, 26.5, 27.3, 28.2, 28.4, 29.6-7, Table 25-2, Boxes 20-5 & 25-2
		Ecosystem-based options: Ecological restoration; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted migration or managed translocation; Ecological corridors; Ex situ conservation & seed banks; Community-based natural resource management.	4.4, 5.5, 8.3, 9.4, 11.7, 15.3-4, 22.4, 23.6-7, 24.4, 25.6, 26.4, 27.3, 28.2, 29.7, 30.6, Boxes 15-1, 22-2, 25-9, 26-2, & CC-EA
		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.	3.5-6, 8.3, 9.3-4, 11.7, 11.9, 22.4, 29.6, Box 13-2
	Institutional	*Economic options:* Financial incentives including taxes & subsidies; Insurance; Catastrophe bonds; Payments for ecosystem services; Water tariffs; Microfinance; Disaster contingency funds; Cash transfers.	8.3-4, 9.4, 10.7, 11.7, 13.3, 15.4, 17.5, 22.4, 26.7, 27.6, 29.6, Box 25-7
		Laws & regulations: Land zoning laws; Building standards; 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.	4.4, 8.3, 9.3, 10.5, 10.7, 15.2, 15.4, 17.5, 22.4, 23.4, 23.7-8, 24.4, 25.4, 26.3, 27.3, Table 25-2, Box CC-CR
		Government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.	2.2-4, 3.6, 4.4, 5.5, 6.4, 7.5, 8.3, 11.7, 15.2-4, 22.4, 23.7, 25.4, 25.8, 26.8-9, 27.3-4, 29.6, 30.6, Boxes 25-1, 25-2, & 25-9
	Social	*Educational options:* Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing local & traditional knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.	8.3-4, 9.4, 11.7, 12.3, 15.2-4, 22.4, 25.4, 28.4, 29.6, Table 25-2
		Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development.	2.4, 5.5, 8.3-4, 9.4, 11.7, 15.2-4, 22.4, 23.5, 24.4, 25.8, 26.6, 26.8, 27.3, 28.2, 28.5, Table 25-2, Box 26-3
		Behavioral options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock, & aquaculture practices; Reliance on social networks.	5.5, 7.5, 9.4, 11.7, 12.4, 22.3-4, 23.4, 23.7, 25.7, 26.5, 27.3, 29.6, Table SM24-7, Box 25-5

Table 16-1: Identification of key adaptation opportunities. Each typ
illustrative examples as well as supporting references.

Opportunity	Examples	
Awareness raising	Positive stakeholder engagement	Ka
	Communication of risk and uncertainty	Be Pi
	Participatory research	Pe (20 Fa
Capacity building	Research, data, education, and training	PC (20
	Extensions services for agriculture	De
	Resource provision	Ay Kl
	Development of human capital	Bo
	Development of social capital	De Le
Tools	Risk analysis	va Ch (20
	Vulnerability assessment	Al Ne (20
	Multi-criteria analysis	de (20
	Cost/benefit analysis	Ha *al.*
	Decision support systems	No
	Early warning systems	Lo (20
Policy	Integrated resource and infrastructure planning	Ro *et*
	Spatial planning	Br
	Design/planning standards	Ha (20 (20
Learning	Experience with climate vulnerability and disaster risk	Fi *et*
	Learning-by-doing	Be an
	Monitoring and evaluation	GI Co
Innovation	Technological change	Ha Ly (20
	Infrastructure efficiencies	Be
	Digital/mobile telecommunications	Os

Table 16-2: Examples of potential trade-offs associated with an illustrative set of adaptation options that could be implemen management objectives.

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

4.3 Response options for mitigation

Multiple sectoral mitigation options exist that could significantly reduce GHG emissions as well as remove carbon from the atmosphere and store it through afforestation, reforestation and in soils. A rapid and near-term decarbonization of electricity generation is technically feasible in many regions including where grid penetration has not yet reached. The three main categories of mitigation measures in the energy end-use sectors are demand reduction, efficiency improvements and fuel switching, but their relative importance varies with the availability of advanced technologies and the level of behavioural and cultural change**.** AFOLU and bioenergy also offer significant mitigation options.

Energy Supply: A fundamental transformation of the heat and electricity supply system is possible, including the long-term substitution of freely emitting fossil fuel conversion technologies by low-GHG alternatives (*robust evidence, high agreement*). The energy supply sector is the largest and fastest growing contributor to global GHG emissions (*robust evidence, high agreement*); in the AR5 baseline scenarios, direct emissions increased from 16 GtCO2/yr in 2010 to

23.7-32.8 GtCO2/yr in 2050. The main mitigation options include improved efficiency of heat and power plants; reduction of fugitive emissions during fuel extraction as well as in energy conversion, transmission, and distribution systems; switching away from high-carbon fuels; greater deployment of low-carbon renewable energy (RE) and nuclear power supply technologies;, and carbon dioxide capture and storage (CCS) for coal- and gas-fired thermal plants.

Renewable energy: RE technologies have substantially advanced in terms of performance and cost and a growing number of RE technologies have achieved technical and economic maturity, making RE the fastest growing energy supply category (*robust evidence, high agreement*). Where good RE resources exist, several technologies are already economically competitive in various settings (Figure TS.3.2.6). Levelized costs of photovoltaic systems have fallen substantially, especially between 2009 and 2012, and a similar trend, though less extreme, has been observed for many other RE technologies. Decentralized RE capacity to meet rural energy demand has also increased, particularly modern and advanced traditional bioenergy systems, small hydropower, PV, and wind.

Nuclear energy: The global primary energy share of this mature technology has declined since 2002 although new plants are being constructed in at least four?? countries (*robust evidence, high agreement*). Barriers nuclear energy include concerns about operational safety, (nuclear weapon) proliferation risks, waste management security as well as financial and regulatory risks (*robust evidence, high agreement*). New fuel cycles and reactor technologies addressing some of these issues are under development. [7.5.4, 7.8, 7.9, 7.12, Figure TS.3.2.6]

NGCC and CHP: Near-term GHG emissions can be reduced by replacing coal-fired plants with highly efficient natural gas combined cycle (NGCC) plants and combined heat and power (CHP) plants (*medium evidence, medium agreement*). However, in most low stabilization scenarios natural gas power generation without CCS is below current levels in 2050, and declines further in the second half of the century. [7.5.1, 7.8, 7.9, 7.11, 7.12].

CCS : This technology could significantly reduce the specific CO2eq life-cycle emissions of fossil fuel power plants (*medium evidence, medium agreement*). Barriers to large-scale deployment include concerns about the operational safety and long-term integrity of CO2 storage, risks during transport, and liability (*limited evidence, medium agreement*) (Table TS.3.2.2). Bioenergy CCS (BECCS) has attracted particular attention since AR4 because linking the combustion of sustainably produced biomass fuels with CCS offers the prospect of negative emissions. Technological challenges and potential risks are as for CCS with the addition of those associated with the land use demand to supply the biomass feedstock. [7.5.5., 7.9, Bioenergy Appendix]**.**

Transport: Behavioural change leading to avoided journeys, modal shifts, uptake of improved vehicle and engine performance technologies, low-carbon fuels, investments in related infrastructure and changes in the built environment, together offer mitigation potential to offset high demand growth for both freight and passengers. There are regional differences in transport mitigation pathways with major opportunities to shape transport systems and infrastructure around low-carbon options, particularly in developing and emerging countries where most future urban growth will occur. Improved energy intensity of vehicles and engine designs play the largest role for emission reductions in the short term. Shifts in transport mode and behaviour, together with new infrastructures and urban (re)development, could also play a key role . Electricity, hydrogen and biofuel technologies could significantly reduce the carbon intensity of fuels if produced from low-carbon sources but their total mitigation potential and costs are very uncertain.

Buildings: Recent proliferation of advanced technologies, know-how and policies in the building sector make it feasible to stabilize or even reduce global total sector energy use by mid-century. Widespread demonstrations of very low, or net zero energy buildings, both in new construction and retrofits, have advanced worldwide. Significant lock-in risks arise from the long lifespans of buildings and infrastructure. New technologies, design practices, increased know-how and behavioural change together can achieve a two to ten-fold reduction in energy requirements of individual new buildings and a two to four-fold reduction for individual existing buildings, usually cost-effectively or even at net negative costs. Retrofits are key mitigation strategies for established building stocks, and a large fraction of 2050 developed country buildings already exist *(robust evidence, high agreement)*. Reductions of energy for heating/cooling by 50-90% have been achieved by many best practices. Historic energy efficient building programmes show that 25-30% improvements have been available at costs substantially lower than marginal supply. In addition , lifestyle, culture and other behavioural changes can lead to further 3-5 times reductions in building and appliance energy requirements.

Industry: Energy efficiency and other measures are available for mitigation in the industrial sector. Options to reduce emissions include fuel and feedstock switching; adoption of CCS technologies; material use efficiency (e.g. less scrap, new product design); recycling and re-use of materials and products; product service efficiency (e.g. more intensive use of products through car sharing, longer life for products); radical product innovations (e.g. alternatives to cement), and demand reductions [10.4, 10.7]. *(limited evidence, high agreement)* (Table TS.3.2.1, Figure TS.3.2.9). The energy intensity of the sector could be reduced by approximately 25% through the wide-scale deployment of best available technologies, particularly in countries where these are not common practice for non-energy intensive industries. In addition to reducing carbon intensity, mitigation opportunities exist for non-CO2 gases. Options exist in cost ranges up to USD 50 /t CO2eq with some even below USD 0 /tCO2eq. However, achieving near-zero emission intensity levels in the industry sector would require realisation of additional long-term step-change options (e.g. CCS) associated with higher levelized costs of conserved carbon in the range of 50-150 USD/tCO2eq.

AFOLU: The most cost-effective forestry options are reducing deforestation and forest management. For agriculture, low carbon prices favour cropland and grazing land management and high carbon prices favour restoration of organic soils. Emissions from AFOLU are projected to remain stable in the short term, but could decline in the long term. According to the AR5 baseline scenarios, AFOLU emissions will decrease to 1.0-1.9 GtCO2/yr in 2050, compared to 5.8 GtCO2/yr in 2010 mainly due to less deforestation. The economic mitigation potential of supply-side measures is estimated to be around 7.2 to 10.6 (full range: 0.5-13.8) GtCO2eq/yr in 2030 at carbon prices up to USD 100/ tCO2eq, about a third of which can be achieved at a USD <20 / tCO2eq (*medium evidence, medium agreement*). Demand-side measures, such as waste reduction and dietary change, could have a significant, but uncertain, impact on GHG emissions from food production (1.5-15.6 GtCO2eq/yr by 2050) (*limited evidence, low agreement*) [11.6]. Demand-side measures include dietary change and waste reduction in the food supply chain. Increasing forestry and agricultural production without a commensurate increase in emissions also reduces emission intensity, i.e. the GHG emissions per unit of product, a mitigation mechanism largely unreported for AFOLU in AR4 [11.3, 11.4]. **REDD+ can be a very cost effective policy option for mitigating climate change** (*limited evidence, medium agreement*). It could supply a large share of global abatement of emissions from the AFOLU sector, especially through reducing deforestation in tropical regions, with potential economic, social and other environmental co-benefits.

Bioenergy: **Bioenergy could play a critical role in stabilizing climate change, if conversion of high carbon density ecosystems (forests, grass- and peat-lands) is avoided and best-practice land management is implemented.** The IPCC's Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN), suggested a sustainable bioenergy potential to be between 100-300EJ, but many studies suggest a lower potential, depending on the assumptions taken. A clear and comprehensive policy framework is required for realizing the sustainable bioenergy potential. The increased deployment of improved cook stoves, biogas and small-scale bio-heat and bio-power plants could improve livelihoods and health whilst also reducing GHG emissions. However, if policy conditions (e.g. price on fossil and terrestrial carbon, land-use planning, etc.) are not met, large scale bioenergy deployment could increase emissions, and compromise livelihoods, biodiversity and ecosystem services [11.X]. Land and livelihood-related dimensions are often effected by bioenergy deployment and need to be addressed.

Human Settlements and Infrastructures: The largest opportunities for future urban GHG emissions reduction might be in rapidly urbanizing countries where infrastructure inertia has not set in; however, the required governance, technical, financial, and institutional capacities can be limited (*high confidence, high evidence)* [12.4, 12.5, 12.6, 12.7].

4.4 Adaptation and mitigation in the context of multiple objectives

Purnamita Dasgupta; **Navroz Dubash**; Yacob Mulugetta; Luis Gomez; Youba Sokona; Karen O'Brien (Marc Fleurbaey has also been involved in discussions on this section, as co-lead on 3.6, which is closely related to 4.4) Target: 1000 words.

For this initial iteration, we have pulled together salient text from the two WG TSs. These will have to be crafted into a conceptually cogent document over the next few weeks. We have erred on the side of too many bullets, with the hope we can craft some integrative text.

From WGII TS

C1. In many cases, a first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate through low-regrets measures and actions emphasizing co-benefits (high confidence). Available strategies and actions can increase resilience across a range of possible future climates while helping to improve human livelihoods, social and economic well-being, and environmental quality. Integration of adaptation into planning and decision-making can promote synergies with development. Adaptation strategies that also strengthen livelihoods, enhance development, and reduce poverty include improved social protection, improved water and land governance, enhanced water storage and services, greater involvement in planning, and elevated attention to urban and peri-urban areas heavily affected by migration of poor people. See 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]

C-2. Significant co-benefits, synergies, and tradeoffs exist between mitigation and adaptation and between alternative adaptation responses; interactions occur both within and across regions (very high confidence).

Illustrative examples include the following.
• Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, particularly at the intersections among water, energy, land use, and biodiversity, but tools to understand and manage these interactions remain limited (very high confidence).
• Climate policies such as increasing energy supply from renewable resources, encouraging bioenergy crop cultivation, or facilitating payments under REDD+ will affect some rural areas both positively (e.g., increasing employment opportunities) and negatively (e.g., land use changes, increasing scarcity of natural capital) (medium confidence).
• Mangrove, sea grass, and salt marsh ecosystems offer important carbon storage and sequestration opportunities (limited evidence, medium agreement), in addition to ecosystem services such as protection against coastal erosion and storm damage and maintenance of habitats for fisheries species.
• Geoengineering approaches involving manipulation of the ocean to ameliorate climate change (such as nutrient fertilization, binding of CO2 by enhanced alkalinity, or direct CO2 injection into the deep ocean) have very large environmental and associated socioeconomic consequences (high confidence).
• Some agricultural practices can reduce emissions and also increase resilience of crops to temperature and rainfall variability (high confidence). [23.8, Table 25-7]
• Many solutions for reducing energy and water consumption in urban areas with co-benefits for climate change adaptation (e.g., greening cities and recycling water) are already being implemented (high confidence). Transport systems promoting active transport and reduced motorized-vehicle use

can improve air quality and increase physical activity (medium confidence). [11.9, 23.8, 24.4, 26.3, 26.8, Boxes 25-2 and 25-9]
• Improved energy efficiency and a shift to cleaner energy sources can reduce local emissions of health-damaging climate-altering air pollutants (very high confidence). [11.9, 23.8]
(Possible addition of Table TS.8 (WGII TS), but 2 pages long)

Box TS.9. The Water-Energy-Food Nexus
Water, energy, and food/feed/fiber are linked through numerous interactive pathways affected by a changing climate(Box TS.9 Figure 1). [Box CC-WE] The depth and intensity of those linkages vary enormously among countries, regions, and production systems. Many energy sources require significant amounts of water and produce a large quantity of waste water that requires energy for treatment. [3.7, 7.3, 10.2-3, 22.3, 25.7, Box CC-WE] Food production, refrigeration, transport, and processing also require both energy and water. A major link between food and energy as related to climate change is the competition of bioenergy and food production for land and water, and the sensitivity of precipitation, temperature, and crop yields to climate change (*robust evidence, high agreement*).[7.3, Boxes 25-10 and CC-WE] Most energy production methods require significant amounts of water, either directly (e.g., crop-based energy sources and hydropower) or indirectly (e.g., cooling for thermal energy sources or other operations) (*robust evidence, high agreement*). [10.2-3, 25.7, Box CC-WE] Water is required for mining, processing, and residue disposal of fossil fuels or their byproducts. [25.7] Water for energy currently ranges from a few percent in most developing countries to more than 50% of freshwater withdrawals in some developed countries, depending on the country. [Box CC-WE] Future water requirements will depend on electric demand growth, the portfolio of generation technologies, and water management options. Future water availability for energy production will change due to climate change (*robust evidence, high agreement*). [3.4-5] Energy is also required to supply and treat water. Water may require significant amounts of energy for lifting (especially as aquifers continue to be depleted), transport, and distribution and for its treatment either to use it or to depollute it. Wastewater and even excess rainfall in cities requires energy to be treated or disposed. Some nonconventional water sources (wastewater or seawater) are often highly energy intensive. [Table 25-7, Box 25-2] Energy intensities per m3 of water vary by about a factor of 10 among different sources, e.g., locally produced potable water from ground/surface water sources vs. desalinated seawater. [Boxes 25-2 and CC-WE] Groundwater is generally more energy intensive than surface water. [Box CC-WE] Linkages among water, energy, food/feed/fiber, and climate are strongly related to land use and management, such as afforestation, which can affect water as well as other ecosystem services, climate, and water cycles (*robust evidence, high agreement*). [4.4, Box 25-10] Land degradation often reduces efficiency of water and energy use (e.g., resulting in higher fertilizer demand and surface runoff), and many of these interactions can compromise food security. [3.7, 4.4] On the other hand, afforestation activities to sequester carbon have important co-benefits of reducing soil erosion and providing additional (even if only temporary) habitat, but may reduce renewable water resources. [Box 25-10]

Consideration of the interlinkages of energy, food/feed/fiber, water, land use, and climate change has implications for security of supplies of energy, food, and water; adaptation and mitigation pathways; air pollution reduction; and health and economic impacts. This nexus is increasingly recognized as critical to effective climate-resilient-pathway decision-making (*medium evidence, high agreement*), although tools to support local- and regional-scale assessments and decision-support remain very limited.
Also consider Box TS.9 Figure 1, WGII TS.

From WGIII TS

51. **Behaviour, lifestyle and culture significantly influence energy use and its emissions, and can have a high mitigation potential when combined with or supplementing technological and structural change.** Emissions can be significantly lowered through changes in consumption patterns (e.g. mobility demand, energy use in households, choice of longer-lasting products), dietary change and reduction in food wastes, and change of life style (e.g. stabilizing/lowering consumption in some

of the most developed countries, sharing economy and other behavioural changes affecting activity) (Table TS.3.2.1). [8.1, 8.9, 9.2, 9.3, Box 10.2, 10.4, 11.4, 12.4, 12.6, 12.7]

Spatial planning can increase cross-sector efficiencies in infrastructure and activities, andtherefore reduce emissions. Spatial and land use planning, such as mixed use zoning, transport oriented development, increasing density, and co-locating jobs and homes can contribute mitigation across sectors by a) reducing emissions from travel demand for both work and leisure, and enabling non-motorized transport, b) reducing floor space for housing, and hence c) reducing overall direct and indirect energy use through efficient infrastructure supply. Compact and in-fill development of urban spaces and intelligent densification can save land for agriculture and bioenergy and preserve land carbon stocks. [7.X, 8.4, 9.X, 10.X, 11.X, 12.2, 12.3] *(add uncertaintystatement)*

At the sectoral level, identified interdependencies between adaptation and mitigation suggest benefits from considering adaptation and mitigation in concert (*medium evidence, high agreement*)**.** Particular mitigation actions can affect sectoral climate vulnerability, both by influencing exposure to impacts and by altering the capacity to adapt to them [8.5, 11.5]. Other interdependencies include effects of climate impacts on the relative merits of alternative mitigation technology pathways [7.7, 8.5, 9.5, 10.6, 11.5], and, *vice versa*, the effects of particular adaptation actions on GHG emissions and radiative forcing [7.7, 11.5]. There is a growing evidence base for such interdependencies in each sector, and yet the presence of substantial knowledge gaps has precluded generating integrated results at the cross-sectoral level.

There are often co-benefits from the use of RE, such as a reduction of air and water pollution, local employment opportunities, few severe accidents compared to some other forms of energy supply, as well as improved energy access and security (*medium evidence, medium agreement*) (Table TS.3.2.2). At the same time, however, some RE technologies can have technology and location-specific adverse side-effects, which can be reduced to a degree through appropriate technology selection, operational adjustments, and siting of facilities. [7.9]

Shifts in transport mode and behaviour, together with new infrastructures and urban (re)development, could play a central role in mitigation of transportation emissions. *(add uncertainty statement)* Over the medium-term (up to 2030) to long-term (to 2050 and beyond), urban redevelopment and new infrastructure, linked with land use policies, could evolve to reduce GHG intensity through more compact urban form, integrated transit, and urban planning oriented 8 support cycling and walking, reducing GHG emissions by 20-50% compared to business-as-usual. Infrastructure investments may appear expensive at the margin, but sustainable urban planning and related policies can gain support when co-benefits, such as improved health, accessibility and resilience, are accounted for (Table TS.3.2.3). Pricing strategies, when supported by public acceptance initiatives and public and non-motorized transport infrastructures, can reduce travel demand, increase the demand for more efficient vehicles (e.g. where fuel economy standards exist) and induce a shift to low-carbon modes. (*medium evidence, medium agreement*) Business initiatives to decarbonize freight transport have begun but need support from fiscal, regulatory and advisory policies to encourage shifting to low-carbon modes such as rail or waterborne options where feasible, as well as improving logistics. [8.4, 8.5, 8.7, 8.8, 8.9, 8.10]

A range of strong and mutually-supportive policy measures will be needed for the transport sector to decarbonise and for the co-benefits to be exploited (*robust evidence, high agreement*).Transport strategies associated with broader non-climate policies at all government levels can usually target several objectives simultaneously to give lower travel costs, improved mobility, better health, greater energy security, improved safety, and time savings. Activity reduction measures have the largest potential to realize co-benefits. Realising the co-benefits depends on the regional context in terms of economic, social and political feasibility as well as having access to appropriate and cost-effective advanced technologies (Table TS.3.2.3). (*medium evidence, high agreement*) Since rebound effects can reduce the CO_2 benefits of efficiency improvements and undermine a particular policy, a balanced package of policies, including pricing initiatives, could help to achieve stable price signals, avoid unintended outcomes, and improve mobility, social welfare, safety and health (*medium evidence, medium agreement*). [8.4, 8.7, 8.10]

In addition to technologies and architecture, lifestyle, culture and other behavioural changes can lead to further large reductions in building and appliance energy requirements (and thusemissions), causing 3-5 times differences in energy use *(low evidence, high agreement).* In developed countries, evidence indicates that behaviours informed by awareness of energy and 1 climate issues can reduce demand by up to 20% in the short term and up to 50% by 2050 (*medium* 2 *evidence, medium agreement).* There is a high risk of emerging countries to follow the same path as developed economies in terms of building-related architecture, lifestyle and behaviour. But the literature suggests that alternative development pathways exist which provide high levels of building services at much lower energy inputs, incorporating strategies like learning from traditional lifestyles, architecture and construction techniques. [9.3]

Most mitigation options in buildings have significant and diverse co-benefits (*robust evidence,high agreement*). They often substantially exceed climate and energy benefits and include improved energy security and decreased need for energy subsidies; health and environmental improvements; productivity, competitiveness and net employment gains; increased social welfare; alleviated energy and fuel poverty. (Table TS.3.2.4)[9.8]

Mitigation measures are often associated with co-benefits in industry (*robust evidence, high agreement*). Co-benefits include enhanced competitiveness, cost reductions, new business opportunities, better environmental compliance, health benefits through better local air and water quality and better work conditions, and reduced waste, all of which provide multiple indirect private and social benefits (Table 3.2.5). [10.8]

Policies governing practices in agriculture as well as forest conservation and management need to account for the needs of both mitigation and adaptation *(medium evidence, high agreement).* Economic incentives (e.g. special credit lines for low carbon agriculture, sustainable agriculture and forestry practices, tradable credits, payment for ecosystem services) and regulatory approaches (e.g. enforcement of environmental law to protect forest carbon stocks by reducing deforestation, set-aside policies, air and water pollution control reducing nitrate load and N_2O emissions) have been effective in different cases. Investments in research, development and diffusion (e.g. increase of resource use-efficiency (fertilizers), livestock improvement, better forestry management practices) could result in synergies between adaptation and mitigation. Successful cases of deforestation reduction in different regions were found to combine different policies such as land planning, regulatory approaches and economic incentives *(limited evidence, high agreement)*. [11.10]

Bioenergy deployment offers significant potential for climate change mitigation, but also carries considerable risks*(medium confidence)*. **Land- and livelihood-related dimensions are often effected by bioenergy deployment** *(high confidence)*. Land demand for bioenergy depends on (1) the share of bioenergy derived from wastes and residues; (2) the extent to which bioenergy production can be integrated with food and fibre production, and conservation to minimize land-use competition; (3) the extent to which bioenergy can be grown on areas with little current production; and (4) the quantity of dedicated energy crops and their yields. Considerations of trade-offs with water, land and biodiversity are crucial to avoid adverse effects. A notable shortcoming of integrated assessment studies exists with regard to the treatment of livelihoods, in particular the incorporation of insights from finer scale studies (such as from human geography). The total impact on livelihood and distributional consequences depends on global market factors, impacting income and income-related food-security, and site-specific factors such as land tenure and social dimensions. Further research is needed to evaluate the schemes that sustainably improve rather than harm livelihoods. [11.9]

Infrastructure and urban form are strongly interlinked, and lock-in patterns of land use, transport choice, housing, and behaviour *(high agreement, medium evidence).* Infrastructure development shapes urban form, structures long-term land use management, and influences individual transport choice, housing, and behaviour that are difficult to change. Urban form and infrastructure are strongly linked to the system-wide efficiency of a city, including throughput of materials and energy, and generation of waste. [12.2, 12.3, 12.4]

The successful implementation of urban climate change mitigation strategies can provide co-benefits (*high agreement, medium evidence)*.Co-benefits of local climate change mitigation can include public savings, pollution and health benefits, and productivity increases in urban centres, providing additional motivation for undertaking GHG mitigation activities. [12.5, 12.6, 12.7]

Since AR4, there is growing political and analytical attention to co-benefits and adverse side effects of climate policy on other objectives and vice versa that has resulted in an increased focus on policies designed to integrate multiple objectives, maximize synergies and minimize trade-offs Working version Technical Summary *(high confidence).* Co-benefits are often explicitly referenced in climate and sectoral plans and strategies and often enable enhanced political support [15.X]. However, the analytical and empirical underpinnings for many of these interactive effects, and particularly for the associated welfare impacts, are under-developed [1.2, 3.6.3, 4.2, 4.8, 6.6]. The scope for co-benefits is greater in low-income countries, where complementary policies for other objectives, such as air pollution, are 5 often weak. [5.7, 6.6, 15.X]

Also can consider some composite of sector tables showing co-benefits eg, Table 3.2.2 for energy supply. (See next page for example)

Table 6.5: Overview of potential co-benefits (green arrows) and adverse side-effects (orange arrows) of the main mitigation measures in the XXX sector; arrows pointing up/down denote increased/decreased effect on respective the objective. Co-benefits and adverse side-effects depend on local circumstances as well as on the implementation practice, pace and scale (see Tables 7.3, 8.7.1, 9.6, 10.5, 11.9, 11.A.1).

Mitigation measures	Effect on additional objectives			
	Economic	Social	Environmental	Other
Energy Supply	*For possible upstream effects of biomass supply for bioenergy, see AFOLU.*			
Nuclear replacing coal power	? Energy security ? Employment impact ↑ Legacy cost of waste and abandoned reactors	Health impact via ↓ Air pollution and coal mining accidents ↑ Nuclear accidents/waste treatment and U mining ↑ Fear or radiation	Ecosystem impact via ↓ Air pollution and coal mining ↑ Nuclear accidents/waste treatment and U mining	Proliferation risk
RE (Wind, PV, CSP, hydro, geothermal, bioenergy) replacing coal	↑ Energy security (resource sufficiency, diversity in the near/medium term) ? Employment impact ↑ Hydro: irrigation, flood control, navigation, and water supply via regulated rivers ↑ Additional options for rural electrification ↑ Extra measures to match demand (for PV, wind and some CSP)	Health impact via ↓ Air pollution (except bioenergy) ↓ Coal mining accidents ↑ Education benefits and income generation opportunities via increased energy access ↑ Local conflicts (siting of plants, threat of displacement for, e.g., large hydro)	Ecosystem impact via ↓ Air pollution (except bioenergy) ↓ Coal mining ↑ Habitat impact (for some hydro) ↑ Landscape and wildlife impact (for wind) ↓ Water use by wind and PV ↑ Water use by CSP, geothermal, and reservoir hydro	Higher material use of critical metals for PV and direct drive wind Climate impacts have variable local effects on potential (except geothermal)
Fossil CCS replacing coal	↑ ↓ Preservation vs lock-in of human and physical capital in the fossil industry ↓ Avoidance of transaction costs in the reallocation to other options	Health impact via ↑ Risk of CO_2 leakage ↑ Upstream supply-chain activities ↑ Local conflicts (siting of CO_2 storage and transport)	Ecosystem impact via ↑ Risk of CO_2 leakage ↑ Upstream supply-chain activities ↑ Water use	Long-term monitoring of CO_2 storage
BECCS replacing coal	*See fossil CCS. For possible upstream effect of biomass supply, see AFOLU*			
Fugitive methane capture and use or treatment	↑ Energy security (potential to use gas in some cases)	↑ Health impact via reduced air pollution ↑ Occupational safety at coal mines	↓ Ecosystem impact via reduced air pollution	

4.5. Enabling factors, constraints and limits to adaptation and mitigation

4.5.1. Mitigative and Adaptive Capacity

Mitigative and adaptive capacity are key factors influencing the future rate and magnitude of climate change and the extent to which the associated risks can be successfully managed by human and natural systems (*very high confidence*). Mitigative and adaptive capacity, which can be collectively referred to as response capacity, vary significantly among global regions, institutions, sectors, communities, and ecological systems as well as among different time periods**.** Differential response capacity is a function of available opportunities that enable the planning and implementation of mitigation and adaptation policies and measures as well as factors that act to constrain the range of options, increase the costs of their implementation, or reduce their effectiveness. [*WGII 1.1, 16.3, 15.1, 16.8, Box 20-, SPM, TS; WGIII 4.6*]

Response capacity at the global, regional, and local level and across different sectors is closely linked to socioeconomic development pathways (*very high confidence*). The new set of shared socio-economic pathways (SSPs) in the AR5 highlight a range of possible future greenhouse gas emission trajectories, costs and benefits of mitigation, and people's and ecosystems' vulnerability to climate change. Development pathways characterized by high population growth and rapid, fossil fuel intensive economic development may pose greater challenges for mitigation efforts than those characterized by lower population growth and economic development based on sustainability principles including low carbon intensive energy technologies. Meanwhile, rapid economic development may enhance entitlements to resources that increase adaptive capacity, whereas slower, regionally fragmented, and inequitable development may pose greater challenges to adaptation and climate risk management. [*WGII 1.1, 16.4, 20.4; WGIII 4.5, Box TS.6*]

4.5.2. Enabling Factors for Mitigation and Adaption

The success of climate policy depends on how people perceive and respond to climate and other risks in their choice context *(high agreement, medium evidence)*. The risk management paradigm frames the potential consequences of climate change and potential policy responses in the context of national, institutional, and individual actors' values, objectives, and planning horizons as they make decisions under uncertainty. Some risks posed by climate change may be accepted, some may be tolerated, and some may be judged intolerable because they pose fundamental threats to actors' objectives and/or the sustainability of valued natural systems (Figure 4-X). Risks may be perceived differently among experts, decision-makers, and civil society at-large. Therefore, the assessment of risk, the communication of uncertainty, and the identification of response options are critical components of climate risk management.[WGII 2.2, 16.2, 19.6, SPM, TS; WGIII 2.2, SPM, TS]

The response capacity of human and natural systems can be enabled through economic, institutional, technological, infrastructure, and behavioral choices that facilitate the implementation of climate policies (*very high confidence*). Building the capacity of individuals, institutions, and nations to implement policies and measures for mitigation and adaptation is an important aspect of long-term climate risk management. Research, education, and actions that increase awareness regarding climate risk and the costs and benefits of different response options can help develop the societal knowledge base that supports effective climate policy development. Technological innovation and change drives overall economic growth, the energy intensity of growth, the carbon intensity of energy, the costs of mitigation, and the resilience of human and natural systems to climate variability and change. Effective institutions and institutional arrangements can increase policy effectiveness, facilitate technology transfer and learning, and share the burden of mitigation and adaptation implementation costs. Learning from experiences with disaster risk management and the implementation of mitigation and adaptation options can contribute to the development of best practices for climate change responses. [WGII 14.2, 14.3, Table 14-1, 15.5, 16.3, Table 16-1, Box 16-2, SPM, TS; WGIII 2.1, 2.2, 2.3, 5.3, 16.3, 16.4, 16.5, SPM, TS.]

The implementation of policies for mitigation and adaptation can generate co-benefits for other societal objectives (*high agreement, medium evidence*). Managing climate risk is one of many economic, social, and environmental policy objectives. Therefore, climate policy objectives and options need to be assessed within a multi-objective framework in order to maximize synergistic effects and to avoid trade-offs with other policy objectives. Including co-benefits in the evaluation of potential mitigation and adaptation options can increase the incentives associated with their implementation and may help facilitate the mainstreaming of climate policy into decision-making processes oriented toward other societal objectives. [WGII 16.3, 17.2, 20.3, 20.4 SPM, TS; WGIII 4.2, Box 4.2.2, 4.8, 6.6, Table 6.5, 10.8, SPM, TS]

4.5.3. Constraints and Limits Associated with Mitigation and Adaptation (350 words)

Rapid rates of anthropogenic change in human and natural systems is a significant driving force contributing to climate risk and constraining choices regarding response options and their effectiveness in managing risk (*high agreement, medium evidence*). The global annual extraction and use of material resources including fossil fuels increased eightfold during the 20th century, and emission growth from consumption continues to outpace emission savings from efficiency improvements. More rapid rates of emissions and climate change increase the costs of adaptation and constrain the effectiveness of adaptation options in avoiding or reducing adverse consequences of climate change. Material resource extraction and use also contribute to land use change and ecosystem degradation that can reduce the resilience of natural systems. Increasing concentration of vulnerable populations in landscapes exposed to climate hazards may increase the economic losses associated with climate variability and change, although such losses may decline relative to the size of the overall economy. [WGII Box 16-3, 19.5, SPM, TS; WGIII 4.4, SPM, TS]

A range of institutional, financial, technological, social, and cultural factors constrain the availability and effectiveness of response options to manage climate risk (*very high confidence)*. The implementation of climate policy may have significant resource demands including expert and local knowledge as well as financial, social, natural, and physical capital. Public and private institutions influence entitlements to such resources as well as the development of policies, legal instruments, and other measures that support the implementation of climate policy. Therefore, institutional weaknesses, lack of coordinated governance, immature markets, and conflicting objectives among different actors can constrain policy implementation. Social values and cultural characteristics such as age, gender, and sense of place also influence risk perception, entitlements to resources, and preferences for mitigation and adaptation options. [WGII 15.5, 16.3, 16.4, 16.5, 16.6, Table 16-2; Table 16-3; Box 16-3; WGIII 5.3, 5.4, 5.5, 5.6, 7.10, 13.10, 14.2, SPM, TS]

Limits to mitigation and adaptation can emerge as a result of the interactions among climate change and biophysical and socioeconomic constraints that reduce response capacity (*high agreement, medium evidence*). Limits to action can manifest as limits to the capacity of mitigation efforts to reduce greenhouse gas emissions and/or in the capacity of adaptation to ensure the preservation of the objectives and values of actors. A key limit from the perspective of international climate negotiations is whether mitigation policies will be sufficient to prevent global mean temperature from exceeding 2°C increase above pre-industrial levels (cross-reference to Box on Article II). Path dependence in global and regional economic development, energy technologies, future emissions, the vulnerability of human and natural systems, and institutional behavior determine whether limits to mitigation and/or adaptation will be exceeded. Significant uncertainties remain regarding the climatalogical limits associated with natural and human systems and the capacity of actors to effectively respond to meet mitigation and adaptation objectives. Therefore, meaningful interpretation of limits the articulation of the objectives and values sought by actors , their tolerance for risk, and robust assessment of climate and policy uncertainty. [WGII 16.2, 16.4, 16.5, 16.6, Box 16-4; WGIII 7.10, 13.10, 14.2, SPM, TS]

Table 4.X. *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 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, 3.6, 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 14.3, 16.3]
Social attitudes and behaviors	Influences societal perceptions of the utility of mitigation policies and technologies and willingness to pursue sustainable behaviors and technologies [WGIII 3.7, 3.9, TS]	Influences framing of adaptation, perceptions of acceptable vs. intolerable risks, as well as preferences for specific adaptation policies and measures [WGII 16.3, 17.3, 17.5, SPM, TS]
Governance, institutions and policy	Influence policies, incentives, and cooperation for the development of 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]	Influence ability to coordinate adaptation policies and measures and to deliver capacity to actors to plan and implement adaptation [WGII 15.5, 16.3, 17.5, SPM, TS]
Finance	Influences the capacity of developed and, particularly, developing nations to pursue policies and technologies that reduce emissions. [WGIII 13.12, 15.2, 15.12, 16.2, SPM, TS]	Influences the scale of investment in adaptation policies and measures and therefore their effectiveness [WGII 16.3, 17.5, SPM, TS]
Technology	Influences the rate at which society can reduce the carbon intensity of energy production and use and transition toward renewable technologies [WGIII 2.4, 6.3, 6.5, 6.6, 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]
Natural resources	Influence the relative long-term sustainability of different energy technologies [WGIII 4.5, 11.6, TS]	Influence the coping range of actors, vulnerability to non-climatic factors, and potential competition for resources that enhances vulnerability [WGII 16.3]
Adaptation and development deficits	Impede negotiation efforts regarding mitigation due to unmet expectations of development assistance for developing nations [WGIII 4.3]	Increase vulnerability to current climate vulnerability as well as future climate change [WGII 2.4, 14.7, 17.2, TS]

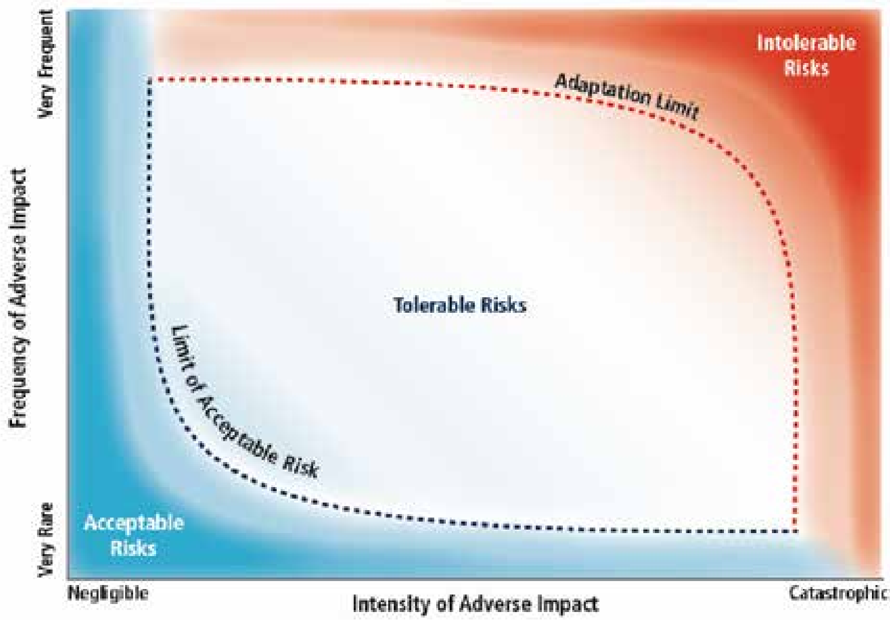


Figure 4-X: Conceptual model of the determinants of acceptable, tolerable and intolerable risks and their implications for limits to adaptation [WGII 16.2].

4.6. Policy approaches at different scales, including technology development and transfer, and finance

[note: this section is far too long, but it contains (all of?) the relevant material, which we will use to shorten to meet word limits in January, after reviewing overlaps and duplication with other sections/topics. We are also still considering whether to re-structure this topic by "international/regional cooperation, and national/sub-national policies" as primary split, rather than "mitigation/adaptation" as primary split as at present.]

Adaptation and mitigation can be promoted by and depend on policies and measures across a range of scales (*high agreement, robust evidence*). Even though mitigation is primarily a global commons problem requiring collective action, it can have potentially strong local co-benefits; conversely, adaptation focuses primarily on local to national scale outcomes, but its effectiveness can depend on links with other sectors and vertical coordination across governance scales. Consequently, international cooperation and agreements, and policy mechanisms across sectors and all governance scales play a key role in fostering action, managing trade-offs and allowing responses to be tailored to local, national and regional contexts and development goals. [SREX.SPM, II.2.2, II.15.2, III.13.ES, III.14.3, III.15.8]

4.6.1. Mitigation Policies

4.6.1.1. International and Regional Cooperation

Various approaches to international cooperation could facilitate progress on climate change mitigation. These vary along several dimensions, including the degree to which they are centrally organized and managed(Figure 4.2). At one end of the spectrum is strong multilateralism, whereby countries and regions agree to a high degree of mutually binding rules or standards to guide their actions--for example, fixed targets and timetables for emission reductions. The Kyoto Protocol is an example of such an approach. A less-centralized approach would structure international cooperation around harmonized national policies, where national or regional policies are made compatible through, for example, harmonized carbon taxes, cap and trade schemes, or standards. Finally, at the other end of the spectrum, decentralized architectures may arise out of homogeneous or heterogeneous regional, national, and sub-national policies, which may vary in the extent to which they are internationally linked. [WG3, 13.4]

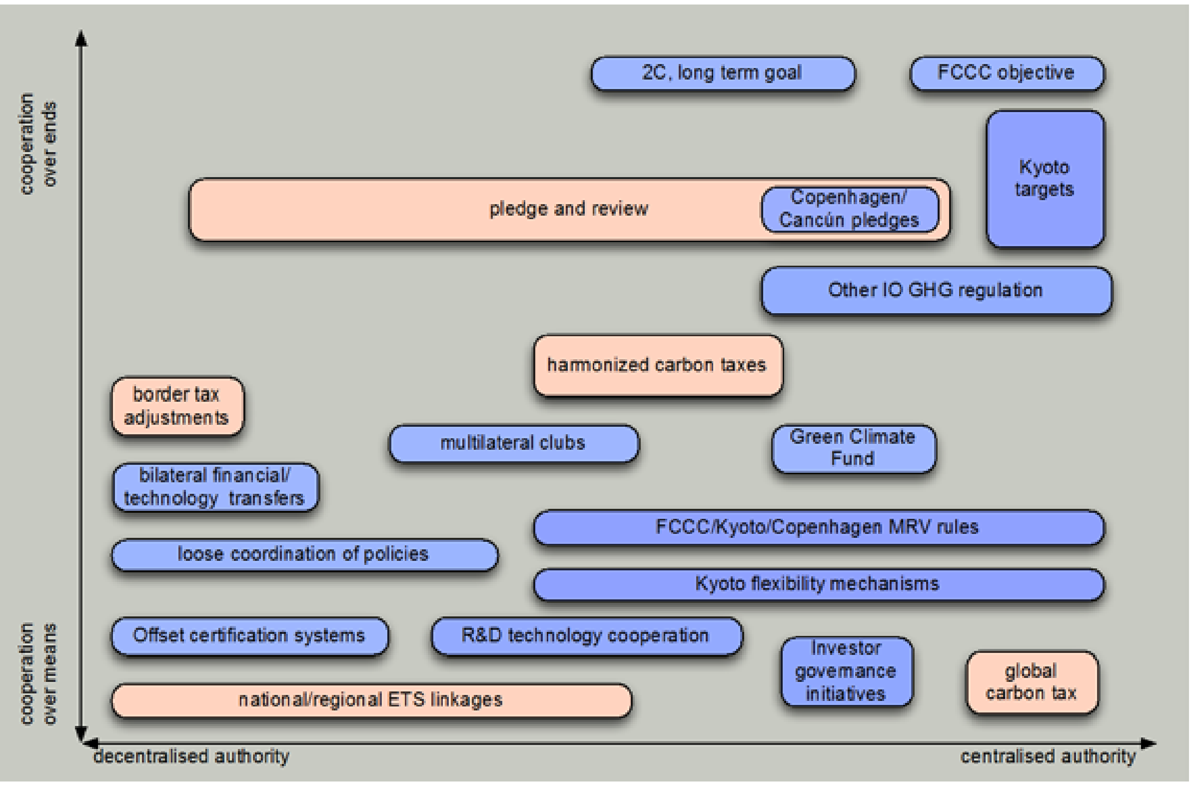


Figure 4.2. International cooperation over ends and means and degrees of centralized authority. Examples in blue are existing agreements. Examples in pale pink are proposed structures for agreements. The width of individual boxes indicates the range of possible degrees of centralization for a particular agreement. The degree of centralization indicates the degree conferred by the agreement, not the process by which is was agreed. [WG3 Figure 13.2]

International cooperation on climate change has become more institutionally diverse over the past decade *(robust evidence, high agreement)*.The UNFCCC remains a primary international forum for climate negotiations. (13.3.1, 13.12) Institutional diversity at multiple scales of climate policy arises in part from the growing inclusion of climate change issues in other policy arenas. (13.3, 13.4, 13.5) For example, the Montreal Protocol, aimed at protecting the stratospheric ozone layer, has also achieved significant reductions in global greenhouse gas emissions (13.3.3, 13.3.4, 13.13.1.4). Also, international trade can offer a range of positive and negative incentives to promote international cooperation on climate change (13.8).

The performance of the Kyoto Protocol has been mixed. In terms of *environmental effectiveness*, emission reductions have exceeded the Kyoto Protocol's goals, but most cuts have been due to the scaling-back of GHG-intensive industries in the transition economies subsequent to the collapse of the former Soviet Union and its satellite regimes. In terms of *cost-effectiveness*, the Kyoto Protocol established three flexible mechanisms. International emissions trading (IET) and Joint Implementation have not improved cost-effectiveness significantly, because trading has been very limited under these provisions. The Clean Development Mechanism (CDM) has stimulated over five thousand registered projects with a total of 1.15 billion emission credits issued between 2003 and 2012, but its environmental effectiveness depends on three key factors: whether project developers are indeed motivated primarily by expected revenue from the sale of the emission credits (so-called "additionality"), the validity of the baseline from which emission reductions are calculated, and indirect emissions impacts ("leakage") caused by projects. In terms of *distributional impacts*, the Kyoto Protocol places emissions mitigation requirements on the Annex I countries, largely the wealthiest countries and those responsible for the majority of the current stock of anthropogenic GHGs in the atmosphere, consistent with the UNFCCC goal of "common but differentiated responsibilities and respective capabilities." However, by 2011, approximately fifty non-Annex I countries had higher per capita income than the poorest of the Annex I countries. (WG3, 13.7, 13.13)

More recent UNFCCC negotiations have sought to include more ambitious commitments from countries listed in Annex B of the Kyoto Protocol, mitigation commitments from a broader set of countries than those covered under Annex B, and substantial new funding mechanisms *(medium evidence, low agreement)*. Voluntary pledges of quantified, economy-wide emission reductions targets by developed countries and voluntary pledges to mitigation actions by many developing countries were formalized in the 2010 Cancun Agreement. The distributional impact of the agreement will depend in part on sources of financing, including the successful fulfilment by developed countries of their expressed joint commitment to mobilize $100b/yr by 2020 for climate action in developing countries. (13.5.1.1, 13.13.1.3, 16.2.1.1).

International cooperation may play a role in stimulating public investment, financial incentives, and regulations to promote technological innovation *(medium evidence, medium agreement)***.** Technology policy may be able to lower mitigation costs, address equity issues, create incentives for countries to participate in agreements, and more actively engage the private sector with the climate regime. (13.9, 13.12) International cooperation may play a role in facilitating public investment in R&D (13.9.3). The intellectual property rights regime in a country can affect both technology transfer and the development of new technologies. (13.9.2)

In the absence of — or as a complement to — a binding, international agreement on climate change, policy linkages among existing and nascent regional, national, and sub-national climate policies offer potential climate benefits*(medium evidence, medium agreement)*. [13.3.1, 13.6, 13.7] While policy linkage can take several forms, linkage through carbon markets has been the primary means of regional policy linkage. Such linkage could form building blocs for greater global cooperation. The benefits of policy linkage may include lower mitigation costs, decreased emission leakage, increased credibility of market signals, and increased liquidity due to expanded market size. [WG3, 13.6, 13.7, 14.4]

4.6.1.2. National and Sub-National Policies

There has been a considerable increase in national and sub-national plans and strategies to address climate change since AR4 *(high agreement, medium evidence)***.**These plans and strategies are in their early stages in many countries, and there is inadequate evidence to assess their impact on future emissions. There is limited evidence that plans and strategies may stimulate development of new climate institutions. [15.1, 15.2]There is no single, best policy; different policies play different roles. A combination of policies that meets all three roles detailed in Table 4.5 will be most effective. Policies should be designed and adjusted so as to complement rather than substitute for other policies in the same and other jurisdictions. Appropriate designs depend on national and local circumstances and institutional capacity. [WG3, 15.5, 15.6, 15.8]

Table 4.5: Three roles of climate policy instruments. [WG3, Table 15.1]

	Providing a price signal	Removing barriers	Promoting long-term investments
Examples of policy instruments	Economic Instruments ▪ Fuel, energy, or carbon tax ▪ Emission trading systems	Regulatory approaches ▪ Appliance standards ▪ Energy management systems and energy audits Information programs ▪ Appliance labeling Voluntary actions ▪ Voluntary agreements	Technology Policy ▪ Govt grants for R&D and investment ▪ Feed-in tariff for renewable power ▪ Renewable portfolio standards. Governmental Provision ▪ Government Provision of low-emission urban and transport infrastructure
Suitable Context	The entire economy	Behavioral (cognitive and computational) constraints, Asymmetric information, non-competitive markets	Technology development for emission reduction

Sector- specific policies are more widely prevalent than economy-wide policy instruments*(high agreement, medium evidence)*. Although economic theory suggests that market-based policies are generally more cost-effective than sectoral approaches, political economy obstacles often make those policies harder to achieve than sectoral policies. The latter may also be implemented to overcome sectoral-specific market failures, and may be bundled in complementary packages. [8.10, 9.10, 10.10, 15.2, 15.5, 15.8, 15.9]

Regulatory approaches and information measures are widely used, and are often environmentally effective, though debate remains on the extent of their environmental impacts and cost-effectiveness*(medium evidence, medium agreement)*. Examples include energy efficiency standards and labelling programs that can help consumers make better-informed decisions. While such approaches often work at a net social benefit, the scientific literature is divided on whether such policies are implemented with negative private costs to firms and individuals. [3.X, 8.X, 9.X, 10.X, 15.5.5, 15.5.6].

Policies are best thought of in packages; without coordination, policy instruments may not work as expected. A carbon price (tax or cap and trade) to address the emissions externality can interact positively with an R&D subsidy to address the innovation failure and encourage fuel switching in the long term. By contrast, in the presence of cap-and-trade and other quantity-averaging policies, the effects of additional policy instruments – such as energy efficiency standards – can be neutralized within the capped sectors. (*medium evidence , high agreement*) [15.7.4.2, 15.8.3]

Carbon pricing regimes have been implemented in a diverse set of countries. Cap and trade systems for greenhouse gases are being established in a growing number of countries and regions but their short run environmental effect has been limited because tight caps have not yet come into effect *(limited evidence, medium agreement)*. **Carbon taxes have been implemented in some countries and contributed to a decoupling of carbon emissions from GDP. In a large group of countries, fuel taxes (although not designed for the purpose of climate mitigation) act as sectoral carbon taxes and contribute to strong reductions in carbon emissions**. *(Robust evidence, medium agreement)* Revised designs for cap-and-trade systems, such as banking of allowances along with ceilings and floors on prices, are being considered in many jurisdictions and, by reducing uncertainty, could facilitate the adoption of more stringent targets.In some countries the revenues from carbon taxes are explicitly used to reduce other taxes in an environmental fiscal reform illustrating the general principle that climate mitigation policies that raise government revenue (e.g., auctioned emission allowances under a cap and trade system or taxes) generally have lower social costs than approaches which do not, although this depends on how the revenue is used (3.6.3). Targeted distribution of revenues or free allocation of allowances have also been used in some countries to render policies more politically feasible. [14.4.2; 15.5.2].

The private sector plays a central role in mitigation within an appropriate enabling environment *(high agreement, medium evidence)*. In 2010 and 2011, about 75% of global mitigation finance came from the private sector and about 25% from public sources such as development banks, but data are scarce and accounting systems highly imperfect (high agreement, medium evidence) [16.2.1]. A country's broader context—including the efficiency of its institutions, security of property rights, credibility of policies and other factors—have a substantial impact on whether private firms invest in new technologies and infrastructures. Those same broader factors will [likely] have a big impact on whether and where investment occurs in response to mitigation policies. [16.4.2]One of the central roles for policy is to incentivize investment that may otherwise be suboptimal because of market imperfections. The relevant risks include those associated with future market conditions, regulatory actions, public acceptance, and technology cost and performance. Dedicated policy instruments exist to lower these risks for private actors—for example, credit insurance, power purchase agreements and feed-in tariffs, concessional finance or rebates. [16.4]

4.6.2. Adaptation Policies

Adaptation to climate change is transitioning from a phase of awareness to the construction of strategies and plans *(high agreement, robust evidence)***.** It is not clear how effective these responses are or will be in the future. Few plans have been monitored and evaluated, and there is a tendency in the literature to consider adaptation planning a problem-free process capable of delivering positive outcomes, underestimating the complexity of adaptation, creating unrealistic expectations, and perhaps overestimating capacity to deliver intended outcomes. [15.2.1, 15.2.2]

Adaptation is highly regionally and context specific, with no single approach for reducing risk appropriate across all settings *(medium confidence)***.**From individuals to governments, actors across scales and regions have complementary roles in enabling adaptation planning and implementation, such as through increasing awareness of risks, learning from experience with climate variability, and achieving synergies with disaster risk reduction.Local government and the private sector are increasingly recognized as critical to progress in adaptation, given the diverse processes and outcomes at the sub-national and local levels. The national level plays a key role as it commonly maintains financial and organizational authority in planning and implementing public goods related to risk management, and national governments can coordinate adaptation by local and subnational governments, creating legal frameworks, protecting vulnerable groups, and providing information, policy frameworks, and financial support (*robust evidence, high agreement*). Public action can influence the degree to which private parties undertake adaptation actions.[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]

Closer integration at the international level of disaster risk reduction and climate change adaptation, andthe mainstreaming of both into international development assistance, could foster greater efficiency in the use of available and committed resources and capacity *(high confidence)*.[SREX 7.4] The fast growth of international mechanisms for supporting adaptation planning has assisted in the creation of adaptation strategies, plans, and actions at the national, sub-national, and local level. 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. Key funding mechanisms are associated with the Global Environmental Facility adaptation funds (Least Developed Countries Climate Adaptation Fund and Special Climate Change Fund), support for the Pilot Program for Climate Resilience, and special purpose adaptation funds for UN agencies. The Adaptation Fund set up under the Kyoto Protocol has pioneered direct access mechanisms to developing countries, allowing countries to access essential funds without having to work through a multilateral development agency. [II 15.2.1]

Existing and emerging economic instruments can foster adaptation by providing incentives for anticipating and reducing impacts *(medium confidence)***.** Instruments include risk sharing and transfer mechanisms, loans, public-private finance partnerships, payments for environmental services, improved resource pricing (for example, water markets), charges and subsidies including taxes, norms and regulations, and behavioral approaches. Risk financing mechanisms can contribute to increasing resilience to climate extremes and variability, but can also provide disincentives, cause market failure, and decrease equity. Mechanisms include insurance, reinsurance, micro insurance, and national, regional, and global risk pools. The public sector often plays a key role as regulator, provider, or insurer of last resort.[10.7, 10.9, 13.3, 17.4-5, 22.4, Box 25-7; SREX 6.5]

Evidence indicates that disaster risk management and adaptation policy can be integrated, reinforcing,and supportive – but this requires careful coordination that reaches across domains of policy and practice*(high agreement, medium evidence)***.** [SREX 8.2, 8.3, 8.5, 8.7]

Indigenous, local, and traditional forms of knowledge can bea major resource for adapting to climate change (*robust evidence, high agreement*). Such forms of knowledge are often neglected in policy and research, and their mutual recognition and integration with scientific knowledge will increase the effectiveness of adaptation. [9.4, 12.3, 15.2, 22.4, 24.4, 24.6, 25.8, Table 15-1]

Maladaptation is a cause of increasing concern to adaptation planners, where intervention in one location or sector could increase the vulnerability of another location or sector, or increase the vulnerability of the target group to future climate change(*robust evidence, high agreement*).[II 14.7.3]Integration of adaptation into planning and decision-making can promote synergies with development and reduce the possibility of maladaptive actions.[II 8.3, 9.3, 14.2, 14.6, 15.3-4, 17.2, 20.2-3, 22.4, 24.5, 29.6, Box CC-UR]

4.6.3 Technology development and transfer

There can be a distinct role for technology policy in GHG mitigation as a complement to other mitigation policies *(high confidence)***.**Such policies include technology-push (e.g. publicly-funded R&D) and demand-pull (e.g. governmental procurement programs). These policies can address market failures particularly related to innovation. [1.x; 3.11; 15.6] Technology support policies have promoted diffusion of new energy technologies, such as wind turbines and photovoltaic panels, but have also raised questions about economic efficiency, and introduced challenges for grid and market integration. [7.x; TRANSPORT XREF; 15.x]

Worldwide investment in research in support of GHG mitigation is small relative to overall public research spending ***(high confidence)*****.** The effectiveness of research support will likely be greater if it is increased slowly and steadily rather than dramatically or erratically. [15.6.7]

Development and diffusion of technologies and management practices will continue to be critical to many adaptation efforts, but their effective use depends on an appropriate institutional, regulatory and social context ***(confidence)*****.** Unlike mitigation, where low-carbon technologies are often new and protected by patents held in developed countries, in adaptation the technologies are often familiar and applied elsewhere. However, providing information does not mean that users will be able to make effective use of it, as successful technology transfer requires not only exchange of technological solutions, but also strengthening policy and regulatory environments, and capacities to absorb, employ and improve appropriate technologies. [II 15.4]

4.6.4 Investment and Finance [section includes last-minute edits, will require significant condensation]

66. **Substantially different patterns of investment would be needed if goals such as limiting warming to less than 2°C are to be achieved.** A significant number of studies have examined the investment needs to transform the economy to limit warming to 2°C. In scenarios that don't envision over-shooting the warming goal, annual investment in the existing technologies associated with the energy supply sector (e.g. conventional fossil fuelled power plants and fossil fuel extraction) would decline over the next decades (2010 to 2030) while investment in low carbon electricity supply would rise. In addition, energy efficiency investments in transport, buildings and industry are expected to increase by several $100 bln per year (Figure SPM.9). For comparison, global total annual investment in the energy system is presently about $1200 bln and current annual investment in low carbon projects is about $ 350 bln. Of that $350b, about 15-25% of that total takes the form of international flows, including about $40b/yr in flows provided by multilateral and bilateral institutions. [13.x; 16.2.2]

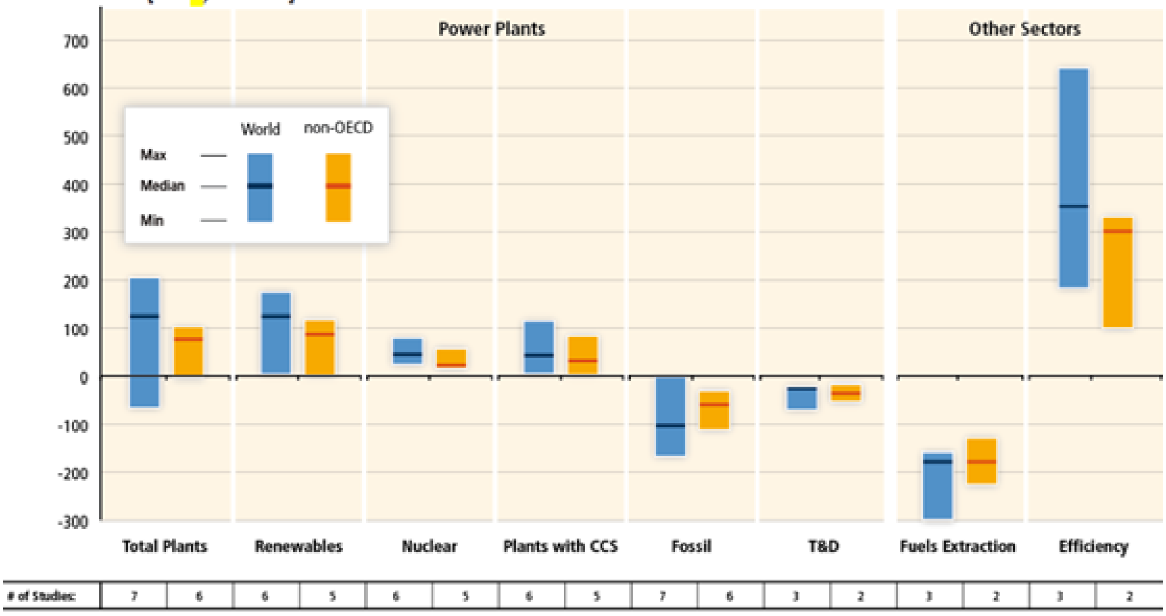


Figure SPM.9. Change of annual investment in energy supply and efficiency from different models for policy scenarios likely to limit temperature increase to below 2°C, compared to the reference investment levels averaged over the period 2010-2029. The vertical bars indicate the range between minimum and maximum estimate of investment changes; the horizontal bar indicates the median of model results. The numbers in the bottom row indicate the number of scenarios available. [Figure 16.3]

160. **Increased financial support by developed countries for mitigation (and adaptation) measures in developing countries will be needed to stimulate the increased investment**. Developed countries have committed to a goal of jointly mobilizing USD 100 billion per year by 2020. The funding could come from a wide variety of sources, public and private, bilateral and multilateral, including alternative sources of finance. Figure TS.4.5 provides an overview of climate finance, outlining sources and managers of capital, financial instruments, project owners and projects. Estimates suggest that current public flows to developing countries were on average at around USD 40 billion per year between 2010 and 2011 coming almost evenly from multilateral and bilateral institutions. Multilateral and bilateral institutions usually provide public climate finance to developing countries as concessional loans and grants. Robust information on levels of respective private sector flows from developed to developing countries is virtually unavailable. The climate finance reported by Annex II Parties averaged nearly USD 10 billion per year from 2005-2010. Between 2010 and 2012, a range of developed countries provided ´fast start finance´ amounting to over USD 10 billion per year. *(medium agreement, medium evidence)* [16.2.1.1]

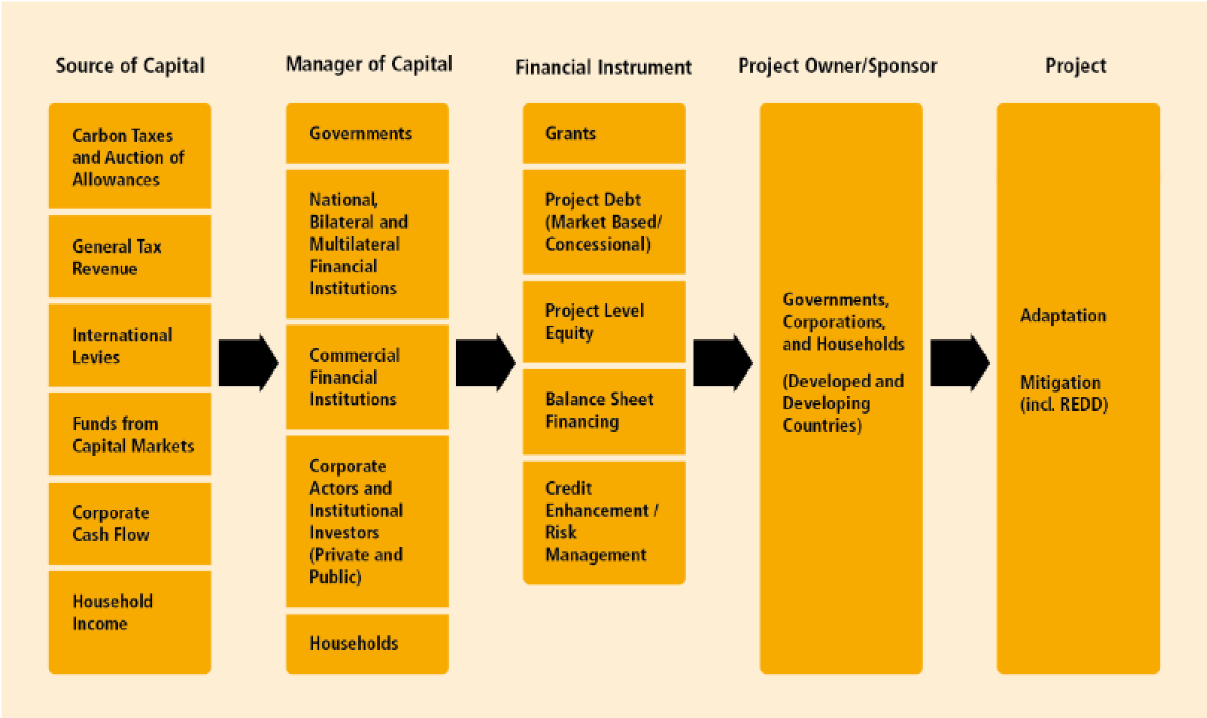


Figure TS.4.5 Overview of climate finance flows. Note: Capital should be understood to include all relevant financial flows. The size of the boxes is not related to the magnitude of the financial flow.

Global adaptation cost estimates are substantially greater than current adaptation funding and investment, particularly in developing countries, suggesting a funding gap and a growing adaptation deficit*(medium confidence)*. The most recent global adaptation cost estimates suggest a range from 70 to 100 US$ billion per year in developing countries from 2010 to 2050 (*low confidence*). Important omissions and shortcomings in data and methods render these estimates highly preliminary (*high confidence*). [II 17.4] 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; and much of this funding has been directed towards capacity-building, standalone projects, or pilot programs. [II 14.2, 17.X]

Appropriate governance arrangements and institutions at the national, regional, and international level are essential conditions for efficient, effective, and sustainable financing of mitigation measures, and for promoting the transition from planning to implementation of adaptation. *(high agreement, robust evidence).* These can ensure that financing to mitigate and adapt to climate change is more likely to respond to national needs and priorities and link to national and international activities [II 15.2, 15.5; III 16.5].

4.6.5. Opportunities and Challenges of Integrated Climate and Non-Climate Policies at Different Scales

There is growing political and analytical attention to co-benefits and adverse side effects of climate policy on other objectives and vice versa. This has resulted in an increased focus on policies designed to integrate multiple objectives, maximize synergies, and minimize trade-offs (high confidence). (3.6.3, 4.8, 5.7, 6.6, 7.9, 8.7, 9.7, 10.8, 11.7, 12.8, 15.2, 15.7) Co-benefits are often referenced in climate and sectoral plans and strategies and can enable enhanced political support [15.X]. However, the analytical and empirical underpinnings for many of these interactive effects, and particularly the associated welfare impacts, are not well developed [1.2, 3.6.3, 4.2, 4.8, 6.6]. The scope for co-benefits may be greater in low-income countries, where complementary policies for other objectives, such as air pollution control, are often weak. [5.7, 6.6, 15.X].

Reduction of subsidies to fossil fuels can achieve significant emission reductions at negative social cost(robust evidence, high agreement). Although political economy barriers are substantial, a number of countries have reformed their tax and budget systems to reduce fuel subsidies, which typically accrue to the relatively wealthy in low-income countries, and replaced these with lump-sum cash transfers or other mechanisms that are more targeted to the poor [15.5.2].

Mitigation policy can devalue natural resource endowments of fossil fuel exporting countries, but differences between regions and fuels exist. The effect on coal exporters is expected to be negative, at least in the short term, as policies could reduce the benefits of using coal as an energy source if no cost-competitive CCS technologies become available. Gas exporters could benefit as coal is replaced by gas for electricity generation. The overall impact on oil 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. [14.4]

There are a growing number of countries devising policies for adaptation, as well as mitigation. At the international level there may be benefits to considering the two within a common policy framework (medium evidence, low agreement), although the benefits of mitigation and adaptation occur over different timeframes (high confidence) [II.TS].At the sectoral level, identified interdependencies between adaptation and mitigation suggest benefits from considering adaptation and mitigation in concert, but there are divergent views on whether adding adaptation to mitigation measures in the national policy portfolio encourages or discourages participation. [WGIII refs]

Urbanization is transforming human settlements, societies, and energy use (high agreement, robust evidence), and urban areas already hold more than half the world's population and most of its built assets and economic activities, and account for more than half of global primary energy use and energy-related CO2 emissions (high agreement, medium evidence).A high proportion of the population and economic activities at risk from climate change are in urban areas, and a high proportion of global greenhouse gas emissions are generated by urban-based activities and residents. Urban adaptation provides opportunities for incremental and transformational adjustments towards resilience and sustainable development. The largest opportunities for future urban GHG emissions reduction might be in rapidly urbanizing countries where infrastructure inertia has not set in. However, the feasibility of spatial planning instruments is highly dependent on a city's governance, technical, financial, and institutional capacities, which can be limited. [II.TS; III.TS]

Box relevant to Article 2 of the UNFCCC

1. Providing scientific information relevant to Article 2 of the UN Framework Convention on Climate Change (UNFCCC)

Article 2 of the UNFCCC objective is « to achieve (...) stabilisation of *greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system»*, and prescribes that «*Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change*[8]*, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner*». There is a net energy uptake of the Earth System, and it is *virtually certain* that this is caused by human activities, primarily by the increase in CO_2 concentrations (WGI SPM 3.) Warming of the climate system is unequivocal (WGI SPM 2.) It is *extremely likely* that human activities have caused more than half of the observed increase in global average surface temperature since the 1950s (WGI SPM). Recent changes in climate have caused impacts on natural and human systems on all continents and across the oceans, such as ranges shifts and alteration of species interactions, changing precipitation and snow melt affecting water resources, and impacts on crops more often negative than positive. (WGII SPM A-1). Science can (in many instances) quantify risks, based on probability, magnitude, timing, scope, and other factors of potential consequences of future climate change. However, defining a level of risk as "dangerous", also requires value judgments, made across scales by people and societies with differing goals, vulnerabilities, and worldviews. Judgments about the risks of climate change depend on the relative importance ascribed to, for example, economic vs. ecosystem assets, and the present vs. the future. To inform this, the IPCC AR5 assesses the literature on the ethical aspects of climate change, explains the assumptions required by different methods used to support decision making, but it does not decide what level of anthropogenic interference is dangerous [WGIII, chapters 2 and 3].

In 2010, the Cancun Agreements, under the UNFCCC, formalized a goal of reducing GHG emissions so as to limit global average temperature increases below 2°C above pre-industrial levels and agreed to review this objective with a view to a possible strengthening to 1.5 °C [WGIII 13.13.1.3]. However, the AR5 considers a full range of potential warming.

Some aspects of climate will continue to change even if temperatures are stabilized (WGI 12.5.4). As an example, sustained warming greater than some threshold would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a global mean sea level rise of up to 7 m. Current estimates indicate that the threshold is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) global mean warming with respect to pre-industrial [WGI SPM E.8].

2. Risks, vulnerability, and adaptation

Vulnerabilities of society or social-ecological systems are considered "key" if they have the potential to combine with physical hazards to result in severe impacts and thus are relevant to Article 2. Physical changes may have consequences for several aspects of risk considered in Article 2, as ecosystems, food, and development may all be affected, for example, by floods, drought and sea-level rise. Vulnerabilities and risks are assessed in this report as "key" based on a variety of criteria including degree of exposure, probability of occurrence, magnitude, persistence and irreversibility of hazards related to climate change, and potential for adaption and mitigation to reduce risk and vulnerability. Among other reasons, differences in vulnerability and exposure arise from non-climatic stressors and multidimensional inequalities in socioeconomic status, income, and other factors which may be associated with various types of discrimination (WGII SPM).

[8] Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change, where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

Specific examples of risks related to the three elements mentioned in Article 2 (unless indicated otherwise, all temperature changes are relative to 1986-2005, i.e.,"recent"[9].

- Ecosystems: Some unique and threatened systems are at risk from climate change at recent temperatures, with increasing numbers at risk of severe consequences at global mean warming of 1°C, and many species and systems with limited ability to adapt subject to very high risk at warming of 2°C, particularly Arctic sea ice and coral reef systems (high confidence) [WGII Chapter 19 ES]. The Arctic Ocean will likely become nearly ice-free in September before mid-century for RCP8.5 (medium confidence, WGI SPM). Many species will be unable to move fast enough during the 21st century to track suitable climates under mid and high-range rates of climate change (RCP 4.5 and higher) (medium confidence). There is a high risk that the large magnitudes and high rates of climate change associated with those scenarios will result within this century in abrupt and irreversible regional-scale change in the composition, structure and function of terrestrial and freshwater ecosystems, especially in the Amazon and Arctic, leading to substantial additional climate change (medium confidence) [WGII Chapter 4 SPM].

- Food (and water): Studies have documented a large negative sensitivity of crop yields to extreme daytime temperatures around 30°C. Without adaptation, local temperature increases in excess of about 1°C above pre-industrial is projected to have negative effects on yields for the major crops (wheat, rice and maize) in both tropical and temperate regions, although individual locations may benefit (medium confidence). Under scenarios of high levels of warming, leading to local mean temperature increases of 3-4 °C or higher, models based on current agricultural systems suggest large negative impacts on agricultural productivity and substantial risks to global food production and security (medium confidence). Positive and negative yield impacts associated with local temperature increases of about 2°C above pre-industrial maintain possibilities for effective adaptation in crop production [WGII Chapter 7 SPM]. Projected changes to ocean ecosystems as a result of ocean warming and acidification will reduce access to food, and increase poverty and health risks in many countries [was in WGII SPM/TS Hybrid draft, check if still valid]

Climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions (high agreement, robust evidence) [WGII Chapter 3.5]. Overall, based on risks to regional crop production and water resources the risk associated with the distribution of impacts is assessed to become high around 2°C above preindustrial global mean temperature [medium confidence; WGII Chapter 19.6.3.4]].

- Development: Climate change impacts energy demand, energy sources and technologies, transport (and energy transport) infrastructures, water resources, settlements and infrastructures (floods, wildfires...), tourism, health, labour productivity and economic growth in complex ways (see topic 2). Limited evidence suggests that higher temperatures decrease economic growth rates in low-income countries by ~1.3%-2.5%/year per 1°C of warming [WGII 10.9.2.1 and 18.4.2.1; 19.6.3.5]. Effects of climate change will make sustainability more difficult to achieve for many locations, systems, and affected populations unless climate-resilient pathways are pursued [WGII 20.2]. Climate-related hazards constitute an additional burden to people living in poverty, acting as a threat multiplier often with negative outcomes for livelihoods (*high confidence*) [WGII SPM].

Vulnerability and exposure to climate risks will differ depending on the development pathway taken [WGII 19.6.3.1]. A global mean average temperature rise of 2.5°C may lead to global aggregated economic losses

[9] Levels of global mean temperature change are variously presented in the literature with respect to "pre-industrial" temperatures in a specified year or period, e.g., 1850-1900. Alternatively, the average temperature within a recent period, e.g., 1986-2005, is used as a baseline. In this chapter, we use both, depending on the literature being assessed. The increase above pre-industrial (1850-1900) levels for the period 1986-2005 is estimated at 0.61°C (AR5 WGI Section 11.3.6.3). For example, using these baselines, a 2°C increase above pre-industrial levels corresponds to a 1.39°C increase above 1986-2005 levels. We use other baselines on occasion depending on the literature cited and explicitly indicate where this is the case. Climate impact studies often report outcomes as a function of regional temperature change, which can differ significantly from changes in global mean temperature. In most land areas, regional warming is larger than global warming (AR5 WGI Section 10.3.1.1.2). However, given the many conventions in the literature for baseline periods, the reader is advised to check carefully and to adjust baseline levels for consistency when comparing outcomes.[WGII Chapter 19]

between 0.2 and 2.0% of income (*medium evidence*, *medium agreement*) and losses increase with greater warming. Little is known about aggregate economics impacts above 3°C. Impact estimates are incomplete and depend on a large number of assumptions, many of which are disputable. Aggregate impacts hide large differences between and within countries [WGII SPM; WGII Chapter 10 SPM]. Risk associated with globally aggregated impacts become high around 3.5°C, reflecting an increase in the *magnitude* and *likelihood* of both aggregate economic risks (*low confidence*) and risk of extensive loss of biodiversity with concomitant loss of ecosystem services (*high confidence*, WGII 19.3.2.1).

As climate changes alters the social, economic, and political conditions within communities, emergent risks include increasing rates of conflicts between individuals, groups, and political organisations [WGII 19.4.2.2]. Furthermore, vulnerability and exposure to such risks will differ depending on the development pathway taken [WGII 19.6.3.1].

There is a very large number of potential interactions among climate changes, vulnerabilities, and impacts to sectors and regions, and many important ones have not yet been quantified, meaning that some key risks have been overlooked [WGII 19.3].

Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits that emerge from the interaction among climate change and biophysical and socioeconomic constraints (*high confidence*). Risks associated with global temperature rise in excess of 4°C relative to pre-industrial levels include potential adverse impacts on agricultural production worldwide, potentially extensive ecosystem impacts, and increasing species extinction risk (*high confidence*), as well as possible crossing of thresholds that lead to disproportionately large earth system responses (*low confidence*).[WGII SPM].

Over the next few decades, societal responses, particularly adaptations, will influence near-term outcomes. In the second half of the 21st and beyond, near-term and longer-term mitigation and adaptation, as well as development pathways, will determine the risk of climate change [WGII SPM].

Figure SYR.X [bottom-right panel] illustrates the variation of risk in five categories (i.e., Reasons for Concern) and examples of impacts at different levels of global average warming above pre-industrial levels [WGII chapter 19.6, 19.7]. [For version FOD_v2 only: Examples are selected to illustrate the relationship between vulnerability, exposure, climate change, and impacts and risks, focusing on aspects that are relevant to Article 2 and for which there is sufficient knowledge to estimate variation of risk or impacts with temperature, taking into account limits to adaptation [WGII Chapter 19.7]].

3. Mitigation and socio-economic aspects of stabilisation pathways

(THIS SECTION WILL NEED TO BE SUBSTANTIALLY UPDATED AFTER THE WGIII FGD DRAFT IS AVAILABLE)

The principal driver of long-term warming is the cumulative emissions of CO_2 and the two quantities are approximately linearly related [WGI Chapter 12].

Stabilising greenhouse gas concentrations at any level will ultimately require deep reductions in greenhouse gas emissions. Stabilisation requires, in particular[10], that net global CO_2 emissions (the balance between emissions and absorptions) are eventually brought to zero, and temporarily below zero for some low stabilisation levels [WGI 6; WGI 12.5; WGIII T.S.].

Deep emission reductions will require large-scale transformations in human societies [SYR topic 3], in the way energy is produced and consumed, in land surface use, and in many industrial processes [WGIII 6.1.1.]. The more ambitious the stabilisation goal, the more rapidly this transformation must occur [WGIII 6.1.1.]. For any given level of CO_2 concentration stabilization, higher emissions early on will require lower emissions by about the same amount later on (WGI Chapter 12).

[10] [Placeholder: Note on difference between stabilizing CO2 or CO2eq concentrations, and reductions in relevant emissions – on the long term this will be CO2-only emissions, but still it would be good to be very clear about this distinction throughout the SYR as information from the WGs might report different quantities.]

Scenarios in the lowest group defined in AR5 (category 1) have cumulative greenhouse gas emissions below 1280 Gt CO_2 equivalent for 2011-2100 (1200 Gt CO_2 if a substantial concentration overshoot is excluded) and CO_2 equivalent concentration in 2100[11] below 480 ppm; with those scenarios, the probability of limiting global warming in 2100 to 1.5°C above pre-industrial is about 25%, and the probability of limiting to 2°C is > 64%. In category 2, cumulative emissions remain below 1720 Gt CO_2 for 2011-2100, and CO_2 equivalent concentrations in 2100 are below 530 ppm ; the corresponding probability of limiting the global warming in 2100 to 2°C is between 33 and 68 % (depending on the scenario), and the probability of limiting to 2.5°C is > 75%. The global warming levels associated with larger emission categories are listed in topic 3, table XX, and represented in figure SYR.art2.

[the above paragraph will need to be updated following the release of the WGIII FGD]

For example, delay by XXX [to be revised from WGIII FD] years in international mitigation efforts aimed at a 450 ppm CO_2 stabilisation level leads to a considerably higher rate of temperature increase in the next decades compared to prompt action and translates into a higher probability (60% instead of 40%) of exceeding the 2°C goal [WGIII 6.3.2]. [Placeholder: clarity about the role of non-CO_2 gases and aerosols will be needed].

Three considerations figure heavily in the emissions profile over time:

- The option to **overshoot**. Overshoot scenarios allow for greenhouse gas concentrations to temporarily exceed a long-term goal, allowing for less mitigation in the near-term. The vast majority of scenarios attaining a concentration lower or equal to 480 ppmv CO_2-eq by the end of the century rely on overshoot pathways [WGI 12, WGIII 6.3.2.2].
- **Technology mitigation portfolios**[12], especially those which include CO_2 removal (CDR) technologies, --that may ultimately achieve net negative emissions, such as BECCS or large-scale afforestation. It is important to note that most CDR technologies are not mature and therefore attended by a large set of risks [WGIII 6.3, 6.4, 6.9].
- **Institutions and policy governance** The transformation that would be commensurate with the lower concentration pathways requires a strengthening of both international cooperation and local governance at a scale, pace, and duration that is unprecedented in human history [WGIII SPM.3]. **[Placeholder:** connection to topics 3 and 4].

Figure SYR.X upper left panel summarises global GHG emissions for different long-term concentration levels, while the **upper right panel** shows global mean surface temperature increase as a function of cumulative total global CO_2 emissions. The **bottom left panel** shows the evolution of global temperature and sea level over the 21st century [and beyond].

[11] Including GHGs and other substances contributing to the radiative forcing, such as aerosols
[12] Geo-engineering is discussed in a Box in Topic 3.

Caption and notes on figure to Box Art.2

Two possible versions are provided on the following pages.

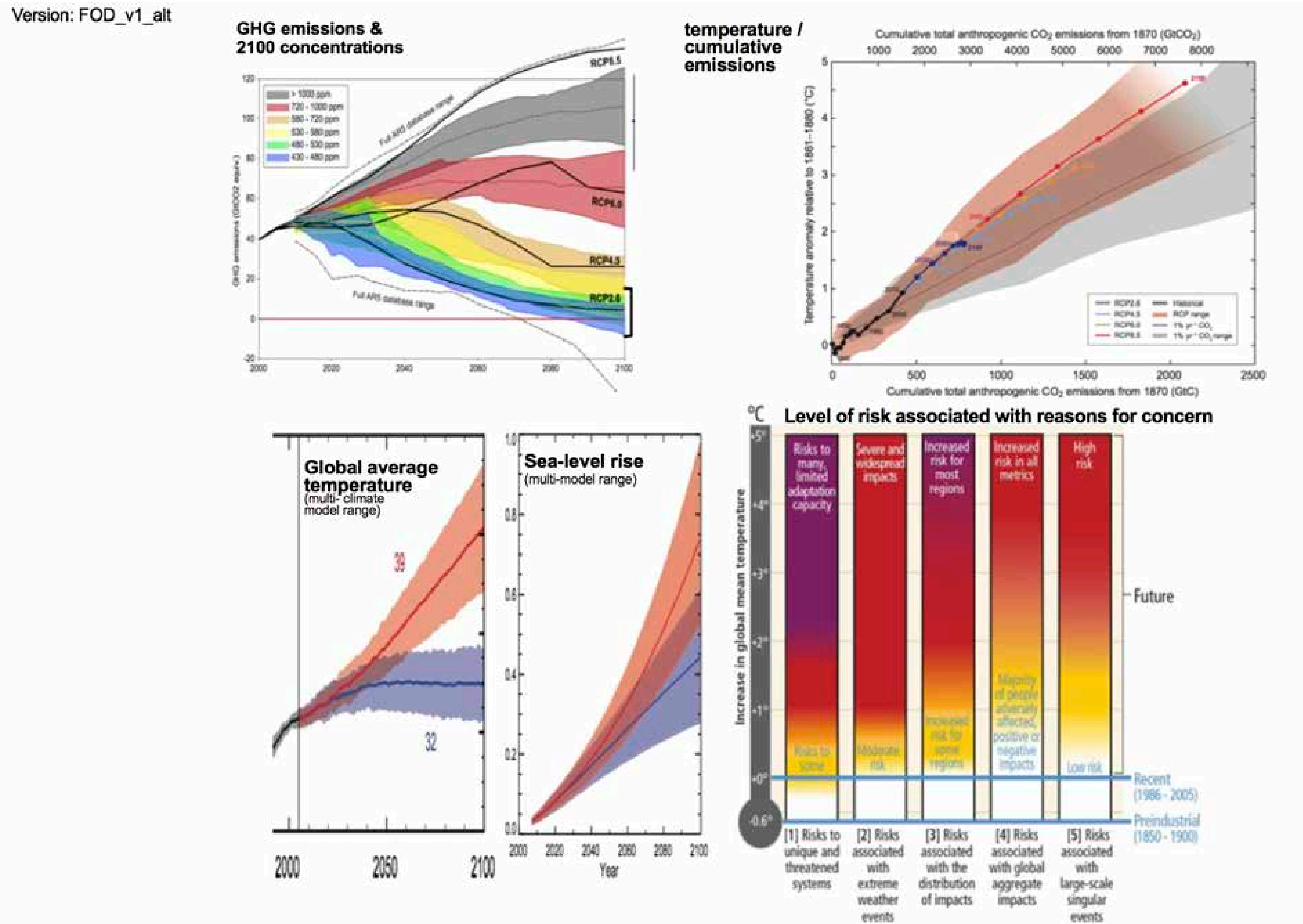
The general principle is to follow the spirit of figure WGII 19-7, but in an expanded form (in particular by adding information from WGI). The differences between the two current versions are:

FOD_v1_alt (first page) only contains exact copies of available WG figures;

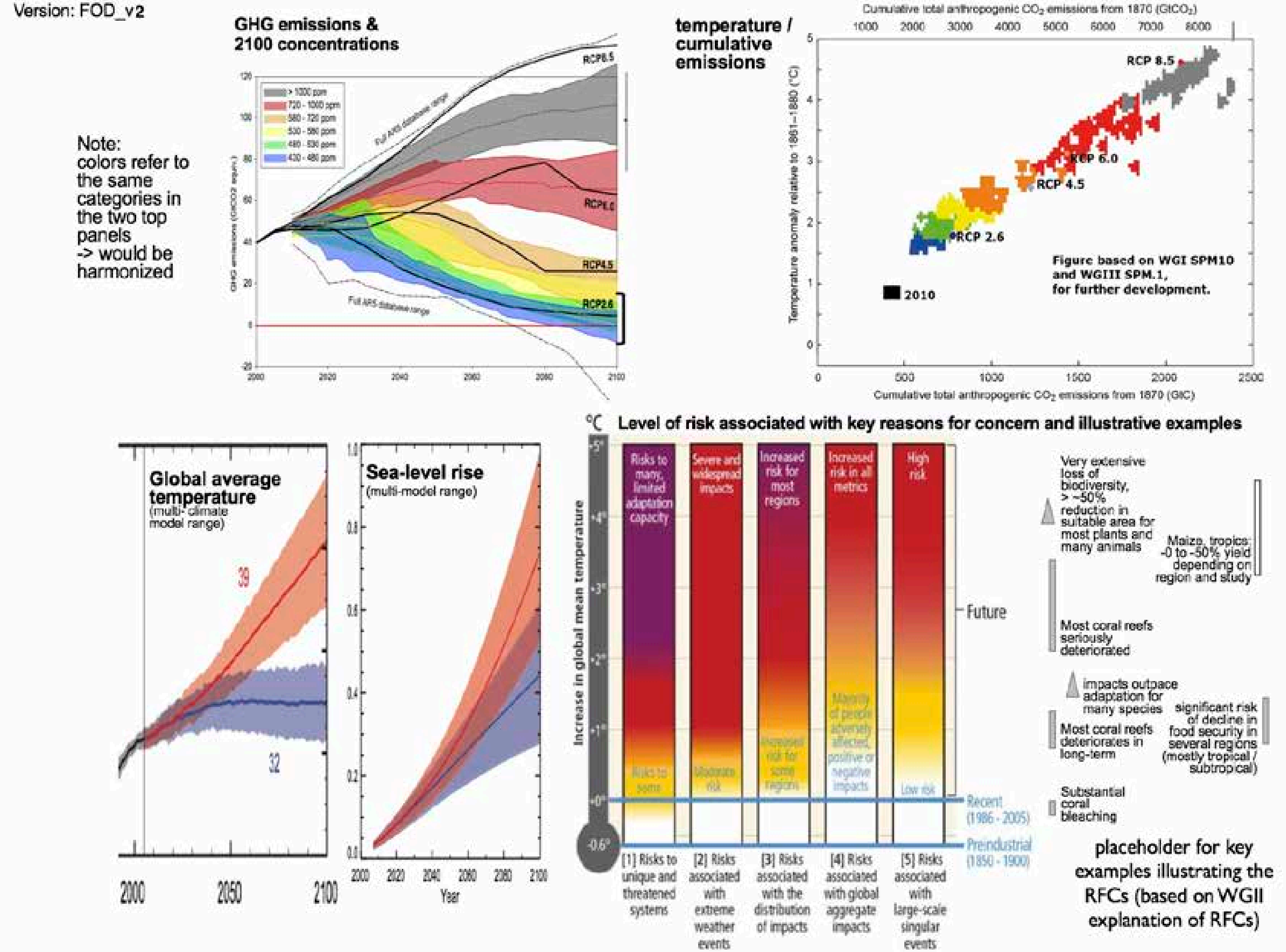
FOD_v2 (second page) adds two potential improvements:
the top-right panel is a preliminary attempt at combining data on cumulative emissions in 2100 from WGI (SPM 10) and WGIII. The principle is to keep WGI data for 2100 only, which facilitates combination with WGIII. The figure will be further discussed with WG I and III authors.
the bottom-right panel includes examples taken from the explanations underlying the RFCs in WGII, in an attempt at making the “concerns” more concrete.

The addition of new “burning embers” will be considered, depending on feasibility/availability, for example
- a possible acidification burning ember
- possible new WG3 burning embers on, e.g., costs of early versus late mitigation or “BECCS allowed versus “BECCS not allowed” attached to the cumulated emissions axis

The presentation will be broadly improved and new data will be imported from WGII and WGIII contributions. The caption will be added (on the basis of the sentences now available at the end of sections 2 and 3 above).



Version: FOD_v1_alt
GHG emissions & 2100 concentrations
Full AR5 database range
RCP8.5
RCP6.0
RCP4.5
RCP2.6
temperature / cumulative emissions
Cumulative total anthropogenic CO2 emissions from 1870 (GtCO2)
Temperature anomaly relative to 1861–1880 (°C)
Cumulative total anthropogenic CO2 emissions from 1870 (GtC)
Global average temperature
(multi- climate model range)
39
32
Sea-level rise
(multi-model range)
Year
°C
Level of risk associated with reasons for concern
Increase in global mean temperature
Risks to many, limited adaptation capacity
Severe and widespread impacts
Increased risk for most regions
Increased risk in all metrics
High risk
Future
Recent (1986 - 2005)
Preindustrial (1850 - 1900)
[1] Risks to unique and threatened systems
[2] Risks associated with extreme weather events
[3] Risks associated with the distribution of impacts
[4] Risks associated with global aggregate impacts
[5] Risks associated with large-scale singular events


Version: FOD_v2
GHG emissions &
2100 concentrations
Note:
colors refer to the same categories in the two top panels
-> would be harmonized
RCP8.5
RCP6.0
RCP4.5
RCP2.6
temperature / cumulative emissions
Cumulative total anthropogenic CO2 emissions from 1870 (GtCO2)
Temperature anomaly relative to 1861–1880 (°C)
RCP 8.5
RCP 6.0
RCP 4.5
RCP 2.6
2010
Figure based on WGI SPM10 and WGIII SPM.1, for further development.
Cumulative total anthropogenic CO2 emissions from 1870 (GtC)
Global average temperature
(multi- climate model range)
39
32
Sea-level rise
(multi-model range)
Year
Level of risk associated with key reasons for concern and illustrative examples
Increase in global mean temperature
Risks to many, limited adaptation capacity
Severe and widespread impacts
Increased risk for most regions
Increased risk in all metrics
High risk
Future
Recent (1986 - 2005)
Preindustrial (1850 - 1900)
[1] Risks to unique and threatened systems
[2] Risks associated with extreme weather events
[3] Risks associated with the distribution of impacts
[4] Risks associated with global aggregate impacts
[5] Risks associated with large-scale singular events
Very extensive loss of biodiversity, > ~50% reduction in suitable area for most plants and many animals
Maize, tropics: -0 to -50% yield depending on region and study
Most coral reefs seriously deteriorated
impacts outpace adaptation for many species
significant risk of decline in food security in several regions (mostly tropical / subtropical)
Most coral reefs deteriorates in long-term
Substantial coral bleaching
placeholder for key examples illustrating the RFCs (based on WGII explanation of RFCs)