3

Future Pathways for Adaptation, Mitigation and Sustainable Development

Topic 3: Future Pathways for Adaption, Mitigation and Sustainable Development

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

Adaptation and mitigation are two complementary strategies for responding to climate change. Adaptation is the process of adjustment to actual or expected climate and its effects in order to either lessen or avoid harm or exploit beneficial opportunities. Mitigation is the process of reducing emissions or enhancing sinks of greenhouse gases (GHGs), so as to limit future climate change. Both adaptation and mitigation can reduce and manage the risks of climate change impacts. Yet adaptation and mitigation can also create other risks, as well as benefits. Strategic responses to climate change involve consideration of climate-related risks along with the risks and co-benefits of adaptation and mitigation actions. *{WGII SPM A-3, SPM C, Glossary, WGIII SPM.2, 4.1, 5.1, Glossary}*

Mitigation, adaptation and climate impacts can all result in transformations to and changes in systems. Depending on the rate and magnitude of change and the vulnerability and exposure of human and natural systems, climate change will alter ecosystems, food systems, infrastructure, coastal, urban and rural areas, human health and livelihoods. Adaptive responses to a changing climate require actions that range from incremental changes to more fundamental, transformational changes[34]. Mitigation can involve fundamental changes in the way that human societies produce and use energy services and land. *{WGII B, C, TS C, Box TS.8, Glossary, WGIII SPM.4}*

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

3.1 Foundations of decision-making about climate change

Effective decision-making to limit climate change and its effects can be informed by a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of governance, ethical dimensions, equity, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty.

Sustainable development and equity provide a basis for assessing climate policies. Limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication. Countries' past and future contributions to the accumulation of GHGs in the atmosphere are different, and countries also face varying challenges and circumstances and have different capacities to address mitigation and adaptation. Mitigation and adaptation raise issues of equity, justice and fairness and are necessary to achieve sustainable development and poverty eradication. Many of those most vulnerable to climate change have contributed and contribute little to GHG emissions. Delaying mitigation shifts burdens from the present to the future, and insufficient adaptation responses to emerging impacts are already eroding the basis for sustainable development. Both adaptation and mitigation can have distributional effects locally, nationally and internationally, depending on who pays and who benefits. The process of decision-making about climate change, and the degree to which it respects the rights and views of all those affected, is also a concern of justice. *{WGII 2.2, 2.3, 13.3, 13.4, 17.3, 20.2, 20.5, WGIII SPM.2, 3.3, 3.10, 4.1.2, 4.2, 4.3, 4.5, 4.6, 4.8}*

Effective mitigation will not be achieved if individual agents advance their own interests independently. Climate change has the characteristics of a collective action problem at the global scale, because most GHGs accumulate over time and mix globally, and emissions by any agent (e.g., individual, community, company, country) affect other agents. Cooperative responses, including international cooperation, are therefore required to effectively mitigate GHG emissions and address other climate change issues. The effectiveness of adaptation can be enhanced through complementary actions across levels, including international cooperation. The evidence suggests that outcomes seen as equitable can lead to more effective cooperation. *{WGII 20.3.1, WGIII SPM.2, TS.1, 1.2, 2.6, 3.2, 4.2, 13.2, 13.3}*

Decision-making about climate change involves valuation and mediation among diverse values and may be aided by the analytic methods of several normative disciplines. Ethics analyses the different values involved and the relations between them. Recent political philosophy has investigated the question of responsibility for the effects of emissions. Economics and decision analysis provide

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

quantitative methods of valuation which can be used for estimating the social cost of carbon (see Box 3.1), in cost–benefit and cost-effectiveness analyses, for optimization in integrated models and elsewhere. Economic methods can reflect ethical principles, and take account of non-marketed goods, equity, behavioural biases, ancillary benefits and costs and the differing values of money to different people. They are, however, subject to well-documented limitations. *{WGII 2.2, 2.3, WGIII SPM.2, Box TS.2, 2.4, 2.5, 2.6, 3.2–3.6, 3.9.4}*

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

Effective decision-making and risk management in the complex environment of climate change may be iterative: strategies can often be adjusted as new information and understanding develops during implementation. However, adaptation and mitigation choices in the near term will affect the risks of climate change throughout the 21st century and beyond, and prospects for climate-resilient pathways for sustainable development depend on what is achieved through mitigation. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if mitigation is delayed too long. Decision-making about climate change is influenced by how individuals and organizations perceive risks and uncertainties and take them into account. They sometimes use simplified decision rules, overestimate or underestimate risks and are biased towards the status quo. They differ in their degree of risk aversion and the relative importance placed on near-term versus long-term ramifications of specific actions. Formalized analytical methods for decision-making under uncertainty can account accurately for risk, and focus attention on both short- and long-term consequences. *{WGII SPM A-3, SPM C-2, 2.1–2.4, 3.6, 14.1–14.3, 15.2–15.4, 17.1–17.3, 17.5, 20.2, 20.3, 20.6, WGIII SPM.2, 2.4, 2.5, 5.5, 16.4}*

3.2 Climate change risks reduced by adaptation and mitigation

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*). Mitigation involves some level of co-benefits and of risks due to adverse side effects, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation efforts.

The risks of climate change, adaptation and mitigation differ in nature, timescale, magnitude and persistence (*high confidence*). Risks from adaptation include maladaptation and negative ancillary impacts. Risks from mitigation include possible adverse side effects of large-scale deployment of low-carbon technology options and economic costs. Climate change risks may persist for millennia and can involve very high risk of severe impacts and the presence of significant irreversibilities combined with limited adaptive capacity. In contrast, the stringency of climate policies can be adjusted much more quickly in response to observed consequences and costs and create lower risks of irreversible consequences (3.3, 3.4, 4.3). *{WGI SPM E.8, 12.4, 12.5.2, 13.5, WGII 4.2, 17.2, 19.6, WGIII TS.3.1.4, Table TS.4, Table TS.5, Table TS.6, Table TS.7, Table TS.8, 2.5, 6.6}*

Mitigation and adaptation are complementary approaches for reducing risks of climate change impacts. They interact with one another and reduce risks over different timescales (*high confidence*). Benefits from adaptation can already be realized in addressing current risks and can be realized in the future for addressing emerging risks. Adaptation has the potential to reduce climate change impacts over the next few decades, while mitigation has relatively little influence on climate outcomes over this timescale. Near-term and longer-term mitigation and adaptation, as well as development pathways, will determine the risks of climate change beyond mid-century. The potential for adaptation differs across sectors and will be limited by institutional and capacity constraints, increasing the long-term benefits of mitigation (*high confidence*). The level of mitigation will influence the rate and magnitude of climate change, and greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*) (3.3). *{WGI 11.3, 12.4, WGII SPM A-3, SPM B-2, SPM C-2, 1.1.4.4, 2.5, 16.3–16.6, 17.3, 19.2, 20.2.3, 20.3, 20.6}*

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*) (Topic 2 and Figure 3.1a). Estimates of warming in 2100 without additional climate mitigation efforts are from 3.7°C to 4.8°C compared with pre-industrial levels (median climate response); the range is 2.5°C to 7.8°C when using the 5th to 95th percentile range of the median climate response (Figure 3.1). The risks associated with temperatures at or above 4°C include severe and widespread impacts on unique and threatened systems, substantial species extinction, large risks to global and regional food security, consequential constraints on common human activities, increased likelihood of triggering tipping points (critical thresholds) and limited potential for adaptation in some cases (*high confidence*). Some risks of climate change, such as risks to unique and threatened systems and risks associated with extreme weather events, are moderate to high at temperatures 1°C to 2°C above pre-industrial levels. *{WGII SPM B-1, SPM C-2, WGIII SPM.3}*

Substantial cuts in GHG emissions over the next few decades can substantially reduce risks of climate change by limiting warming in the second half of the 21st century and beyond (*high confidence*). Global mean surface warming is largely determined by cumulative emissions, which are, in turn, linked to emissions over different timescales (Figure 3.1). Limiting risks across Reasons For Concern would imply a limit for cumulative emissions of CO_2.

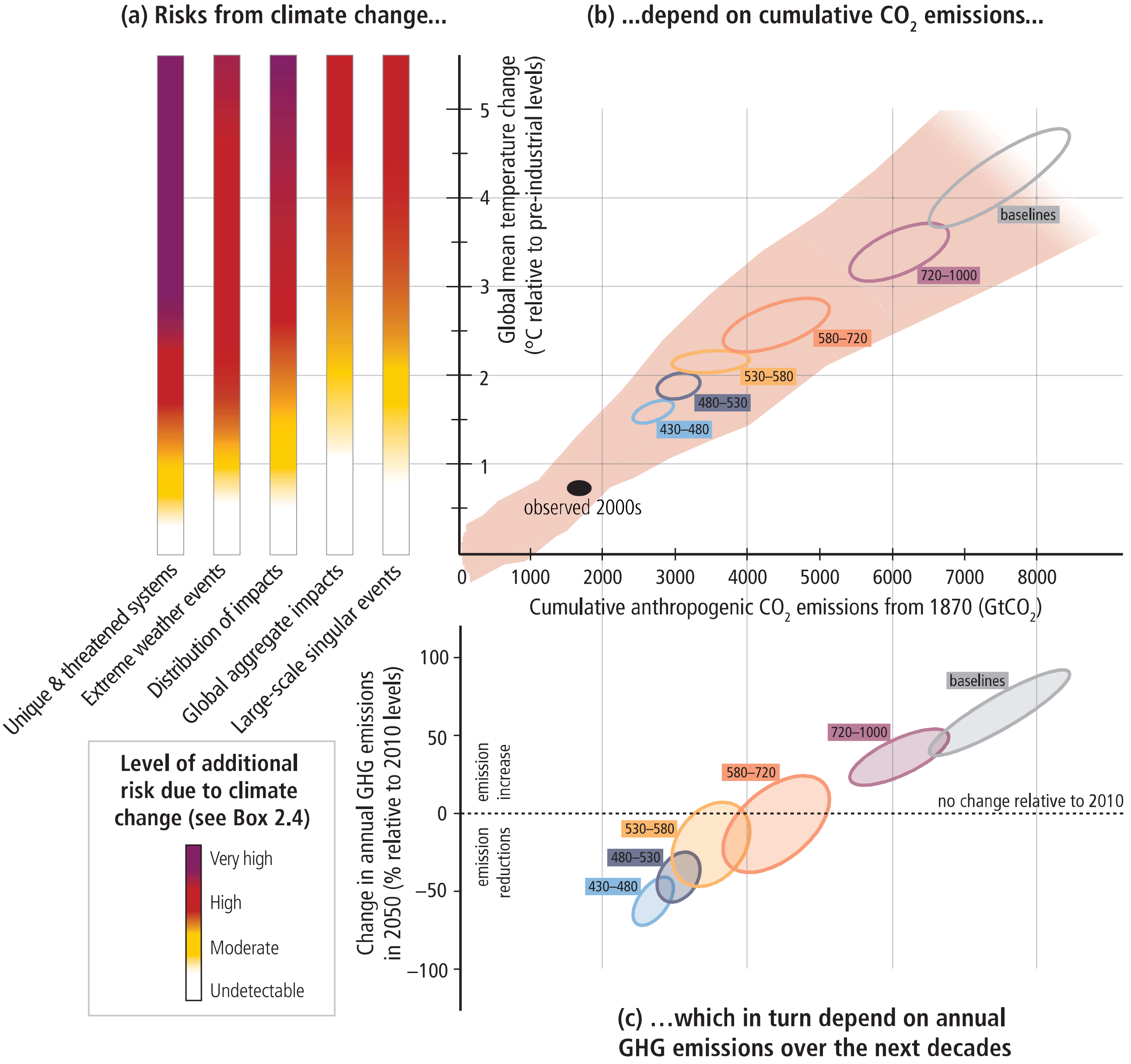

Figure 3.1 | The relationship between risks from climate change, temperature change, cumulative carbon dioxide (CO_2) emissions and changes in annual greenhouse gas (GHG) emissions by 2050. Limiting risks across Reasons For Concern **(a)** would imply a limit for cumulative emissions of CO_2 **(b)**, which would constrain annual emissions over the next few decades **(c)**. **Panel a** reproduces the five Reasons For Concern (Box 2.4). **Panel b** links temperature changes to cumulative CO_2 emissions (in $GtCO_2$), from 1870. They are based on Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations (pink plume) and on a simple climate model (median climate response in 2100) for the baselines and five mitigation scenario categories (six ellipses). Details are provided in Figure 2.3. **Panel c** shows the relationship between the cumulative CO_2 emissions (in $GtCO_2$) of the scenario categories and their associated change in annual GHG emissions by 2050, expressed in percentage change (in percent $GtCO_2$-eq per year) relative to 2010. The ellipses correspond to the same scenario categories as in Panel b, and are built with a similar method (see details in Figure 2.3).

Such a limit would require that global net emissions of CO_2 eventually decrease to zero (Figure 3.1a,b) (*high confidence*). Reducing risks of climate change through mitigation would involve substantial cuts in GHG emissions over the next few decades (Figure 3.1c). But some risks from residual damages are unavoidable, even with mitigation and adaptation (*very high confidence*). A subset of relevant climate change risks has been estimated using aggregate economic indicators. Such economic estimates have important limitations and are therefore a useful but insufficient basis for decision-making on long-term mitigation targets (see Box 3.1). *{WGII 19.7.1, WGIII SPM.3, Figure 3.1}*

Mitigation involves some level of co-benefits and risks, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change (*high confidence*). Scenarios that are *likely* to limit warming to below 2°C or even 3°C compared with pre-industrial temperatures involve large-scale changes in energy systems and potentially land use over the coming decades (3.4). Associated risks include those linked to large-scale deployment of technology options for producing low-carbon energy, the potential for high aggregate economic costs of mitigation and impacts on vulnerable countries and industries. Other risks and co-benefits are associated with human health, food security, energy security, poverty reduction, biodiversity conservation, water availability, income distribution, efficiency of taxation systems, labour supply and employment, urban sprawl, fossil fuel export revenues and the economic growth of developing countries (Table 4.5). *{WGIII SPM.4.1, SPM.4.2, TS.3.1.4, Table TS.4, Table TS.5, Table TS.6, Table TS.7, Table TS.8, 6.6}*

Inertia in the economic and climate systems and the possibility of irreversible impacts from climate change increase the benefits of near-term mitigation efforts (*high confidence*). The actions taken today affect the options available in the future to reduce emissions, limit temperature change and adapt to climate change. Near-term choices can create, amplify or limit significant elements of lock-in that are important for decision-making. Lock-ins and irreversibilities occur in the climate system due to large inertia in some of its components such as heat transfer from the ocean surface to depth leading to continued ocean warming for centuries regardless of emission scenario and the irreversibility of a large fraction of anthropogenic climate change resulting from CO_2 emissions on a multi-century to millennial timescale unless CO_2 were to be removed from the atmosphere through large-scale human interventions over a sustained period (see also Box 3.3). Irreversibilities in socio-economic and biological systems also result from infrastructure development and long-lived products and from climate change impacts, such as species extinction. The larger potential for irreversibility and pervasive impacts from climate change risks than from mitigation risks increases the benefit of short-term mitigation efforts. Delays in additional mitigation or constraints on technological options limit the mitigation options and increase the long-term mitigation costs as well as other risks that would be incurred in the medium to long term to hold climate change impacts at a given level (Table WGIII SPM.2, blue segment). *{WGI SPM E-8, WGII SPM B-2, 2.1, 19.7, 20.3, Box 20-4, WGIII SPM.4.1, SPM.4.2.1, 3.6, 6.4, 6.6, 6.9}*

3.3 Characteristics of adaptation pathways

Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, especially with greater magnitudes and rates of climate change. Taking a longer-term perspective, in the context of sustainable development, increases the likelihood that more immediate adaptation actions will also enhance future options and preparedness.

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

Box 3.1 | The Limits of the Economic Assessment of Climate Change Risks

A subset of climate change risks and impacts are often measured using aggregate economic indicators, such as gross domestic product (GDP) or aggregate income. Estimates, however, are partial and affected by important conceptual and empirical limitations. These incomplete estimates of global annual economic losses for temperature increases of ~2.5°C above pre-industrial levels are between 0.2 and 2.0% of income (*medium evidence, medium agreement*). Losses are *more likely than not* to be greater, rather than smaller, than this range (*limited evidence, high agreement*). Estimates of the incremental aggregate economic impact of emitting one more tonne of carbon dioxide (the social cost of carbon) are derived from these studies and lie between a few dollars and several hundreds of dollars per tonne of carbon in 2000 to 2015 (*robust evidence, medium agreement*). These impact estimates are incomplete and depend on a large number of assumptions, many of which are disputable. Many estimates do not account for the possibility of large-scale singular events and irreversibility, tipping points and other important factors, especially those that are difficult to monetize, such as loss of biodiversity. Estimates of aggregate costs mask significant differences in impacts across sectors, regions, countries and communities, and they therefore depend on ethical considerations, especially on the aggregation of losses across and within countries (*high confidence*). Estimates of global aggregate economic losses exist only for limited warming levels. These levels are exceeded in scenarios for the 21st century unless additional mitigation action is implemented, leading to additional economic costs. The total economic effects at different temperature levels would include mitigation costs, co-benefits of mitigation, adverse side effects of mitigation, adaptation costs and climate damages. As a result, mitigation cost and climate damage estimates at any given temperature level cannot be compared to evaluate the costs and benefits of mitigation. Very little is known about the economic cost of warming above 3°C relative to the current temperature level. Accurately estimating climate change risks (and thus the benefits of mitigation) takes into account the full range of possible impacts of climate change, including those with high consequences but a low probability of occurrence. The benefits of mitigation may otherwise be underestimated (*high confidence*). Some limitations of current estimates may be unavoidable, even with more knowledge, such as issues with aggregating impacts over time and across individuals when values are heterogeneous. In view of these limitations, it is outside the scope of science to identify a single best climate change target and climate policy (3.1, 3.4). *{WGII SPM B-2, 10.9.2, 10.9.4, 13.2, 17.2–17.3, 18.4, 19.6, WGIII 3.6}* in their results. *{WGII SPM C-1, Table SPM.1, 14.1, 14.ES, 15.2, 15.5, 17.2, 17.ES}*

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

Adaptation planning and implementation can be enhanced through complementary actions across levels, from individuals to governments (*high confidence*). National governments can coordinate adaptation efforts of local and sub-national governments, for example by protecting vulnerable groups, by supporting economic diversification and by providing information, policy and legal frameworks and financial support (*robust evidence, high agreement*). Local government and the private sector are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence, high agreement*). *{WGII SPM C-1}*

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

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

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

Transformations in economic, social, technological and political decisions and actions can enhance adaptation and promote sustainable development (*high confidence*). Restricting adaptation responses to incremental changes to existing systems and structures without considering transformational change may increase costs and losses and miss opportunities. For example, enhancing infrastructure to protect other built assets can be expensive and ultimately not defray increasing costs and risks, whereas options such as relocation or using ecosystem services to adapt may provide a range of benefits now and in the future. Transformational adaptation can include introduction of new technologies or practices, formation of new financial structures or systems of governance, adaptation at greater scales or magnitudes and shifts in the location of activities. Planning and implementation of transformational adaptation could reflect strengthened, altered or aligned paradigms and consequently may place new and increased demands on governance structures to reconcile different goals and visions for the future and to address possible equity and ethical implications: transformational adaptation pathways are enhanced by iterative learning, deliberative processes, and innovation. At the national level, transformation is considered most effective when it reflects a country's own visions and approaches to achieving sustainable development in accordance with its national circumstances and priorities. *{WGII SPM C-2, 1.1, 2.5, 5.5, 8.4, 14.1, 14.3, 16.2-7, 20.3.3, 20.5, 25.10, Table 14-4, Table 16-3, Box 16.1, Box 16.4, Box 25.1}*

Building adaptive capacity is crucial for effective selection and implementation of adaptation options (*robust evidence, high agreement*). Successful adaptation requires not only identifying adaptation options and assessing their costs and benefits, but also increasing the adaptive capacity of human and natural systems (*medium evidence, high agreement*). This can involve complex governance challenges and new institutions and institutional arrangements. (4.2) *{WGII 8.1, 12.3, 14.1-3, 16.2, 16.3, 16.5, 16.8}*

Significant co-benefits, synergies and trade-offs exist between mitigation and adaptation and among different adaptation responses; interactions occur both within and across regions (*very high confidence*). 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. Examples of actions with co-benefits include (i) improved energy efficiency and cleaner energy sources, leading to reduced emissions of health-damaging, climate-altering air pollutants; (ii) reduced energy and water consumption in urban areas through greening cities and recycling water; (iii) sustainable agriculture and forestry; and (iv) protection of ecosystems for carbon storage and other ecosystem services. *{WGII SPM C-1}*

3.4 Characteristics of mitigation pathways

There are multiple mitigation pathways that are *likely* to limit warming to below 2°C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO_2 and other long-lived greenhouse gases by the end of the century. Implementing such reductions poses substantial technological, economic, social and institutional challenges, which increase with delays in additional mitigation and if key technologies are not available. Limiting warming to lower or higher levels involves similar challenges but on different timescales.

Without additional efforts to reduce GHG emissions beyond those in place today, global emission growth is expected to persist driven by growth in global population and economic activities (*high confidence*) (Figure 3.2). Global GHG emissions under most scenarios without additional mitigation (baseline scenarios) are between about 75 $GtCO_2$-eq/yr and almost 140 $GtCO_2$-eq/yr in 2100[35] which is approximately between the 2100 emission levels in the RCP6.0 and RCP8.5 pathways (Figure 3.2)[36]. Baseline scenarios exceed 450 ppm CO_2-eq by 2030 and reach CO_2-eq concentration levels between about 750 ppm CO_2-eq and more than 1300 ppm CO_2-eq by 2100. Global mean surface temperature increases in 2100 range from about 3.7°C to 4.8°C above the average for 1850–1900 for a median climate response. They range from 2.5°C to 7.8°C when including climate uncertainty (5th to 95th percentile range)[37]. The future scenarios do not account for possible changes in natural forcings in the climate system (see Box 1.1). *{WGIII SPM.3, SPM.4.1, TS.2.2, TS.3.1, 6.3, Box TS.6}*

Many different combinations of technological, behavioural and policy options can be used to reduce emissions and limit temperature change (*high confidence*). To evaluate possible pathways to long-term climate goals, about 900 mitigation scenarios were collected for this assessment, each of which describes different technological, socio-economic and institutional changes. Emission reductions under these scenarios lead to concentrations in 2100 from 430 ppm CO_2-eq to above 720 ppm CO_2-eq which is comparable to the 2100 forcing levels between RCP2.6 and RCP6.0. Scenarios with concentration levels of below 430 ppm CO_2-eq by 2100 were also assessed. *{WGIII SPM.4.1, TS3.1, 6.1, 6.2, 6.3, Annex II}*

Scenarios leading to CO_2-eq concentrations in 2100 of about 450 ppm or lower are *likely* to maintain warming below 2°C over the 21st century relative to pre-industrial levels (*high confidence*). Mitigation scenarios reaching concentration levels of about 500 ppm CO_2-eq by 2100 are *more likely than not* to limit warming to less than 2°C relative to pre-industrial levels, unless concentration levels temporarily exceed roughly 530 ppm CO_2-eq before 2100. In this case, warming is *about as likely as not* to remain below 2°C relative to pre-industrial levels. Scenarios that exceed about 650 ppm CO_2-eq by 2100 are *unlikely* to limit warming to below 2°C relative to pre-industrial levels. Mitigation scenarios in which warming is *more likely than not* to be less than 1.5°C relative to pre-industrial levels by 2100 are characterized by concentration levels by 2100 of below 430 ppm CO_2-eq. In these scenarios, temperature peaks during the century and subsequently declines (Table 3.1). *{WGIII SPM.4.1, Table SPM.1, TS.3.1, Box TS.6, 6.3}*

Mitigation scenarios reaching about 450 ppm CO_2-eq in 2100 (consistent with a *likely* chance to keep warming below 2°C relative to pre-industrial level) typically involve temporary overshoot[38] of atmospheric concentrations, as do many scenarios reaching about 500 ppm CO_2-eq to about 550 ppm CO_2-eq by 2100 (Table 3.1). Depending on the level of overshoot, overshoot scenarios typically rely on the availability and widespread deployment of bioenergy with carbon dioxide capture and storage (BECCS) and afforestation in the second half of the century (*high confidence*). The availability and scale of these and other Carbon Dioxide Removal (CDR) technologies and methods are uncertain, and CDR technologies and methods are, to varying degrees, associated with challenges and risks (see Box 3.3)[39]. CDR is also prevalent in many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive. *{WGIII SPM.4.1, Table SPM.1, TS.3.1, 6.3, 6.9.1, Figure 6.7, 7.11, 11.13}*

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[35] Unless otherwise noted, scenario ranges cited in Topic 3 and Topic 4 refer to the 10th to 90th percentile ranges (see Table 3.1).

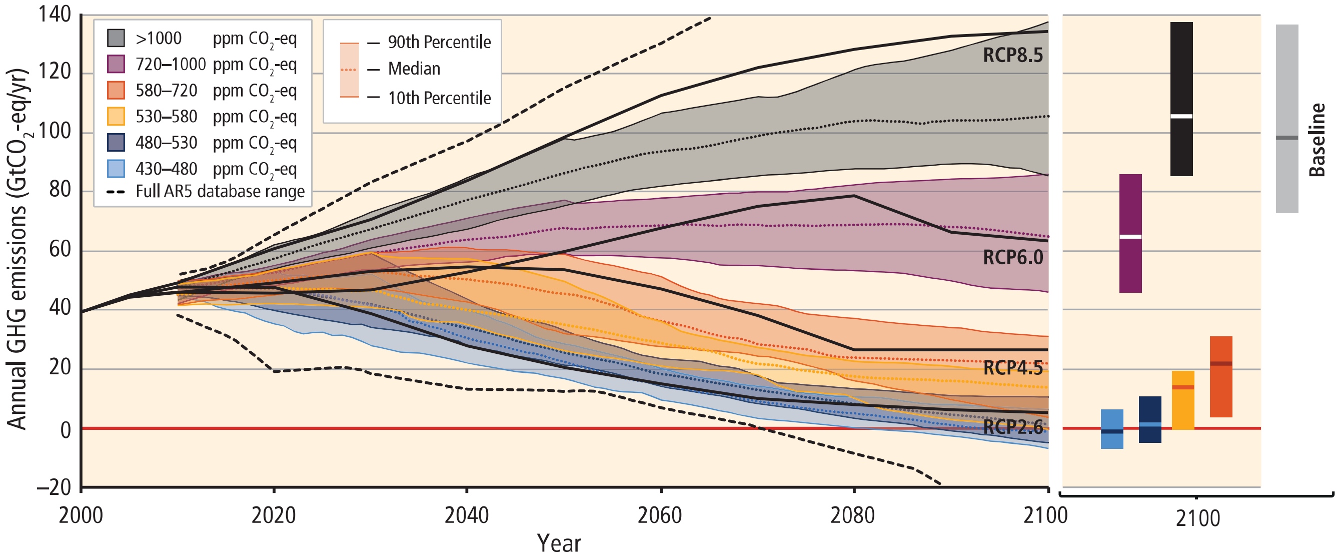
[36] For a discussion on CO2-equivalent (CO2-eq) emissions and concentrations, see Box 3.2 on GHG metrics and mitigation pathways and the Glossary.

[37] The range quoted here is based on the warming results of a simple climate model for the emissions of around 300 baseline scenarios, expressed compared to the 1850–1900 period. The warming results quoted in Section 2.2 are obtained by prescribing future concentrations of GHG in CMIP5 Earth System Models. This results in a mean warming of 1.0°C (5th to 95th percentile range: 0.3°C to 1.7°C) for RCP2.6, and a mean warming of 3.7°C (2.6°C to 4.8°C) for RCP8.5 relative to the period 1986–2005. For the same concentration-driven experiments, the simple climate model approach gives consistent results. The median warming is 0.9°C (0.5°C to 1.6°C) for RCP2.6 and 3.7°C (2.5°C to 5.9°C) for RCP8.5 relative to the period 1986–2005. However, the high-end of the CMIP5 ESMs range is more constrained. In addition, the baseline temperature increase quoted here is wider than that of the concentration-driven RCP8.5 experiments mentioned above as it is based on a wider set of scenarios, includes carbon cycle response uncertainty, and uses a different base year (2.2, 3.4).

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

[39] CDR methods have biogeochemical and technological limitations to their potential on the global scale. There is insufficient knowledge to quantify how much CO2 emissions could be partially offset by CDR on a century timescale. CDR methods may carry side effects and long-term consequences on a global scale.

(a) GHG emission pathways 2000–2100: All AR5 scenarios



(b) Associated upscaling of low-carbon energy supply

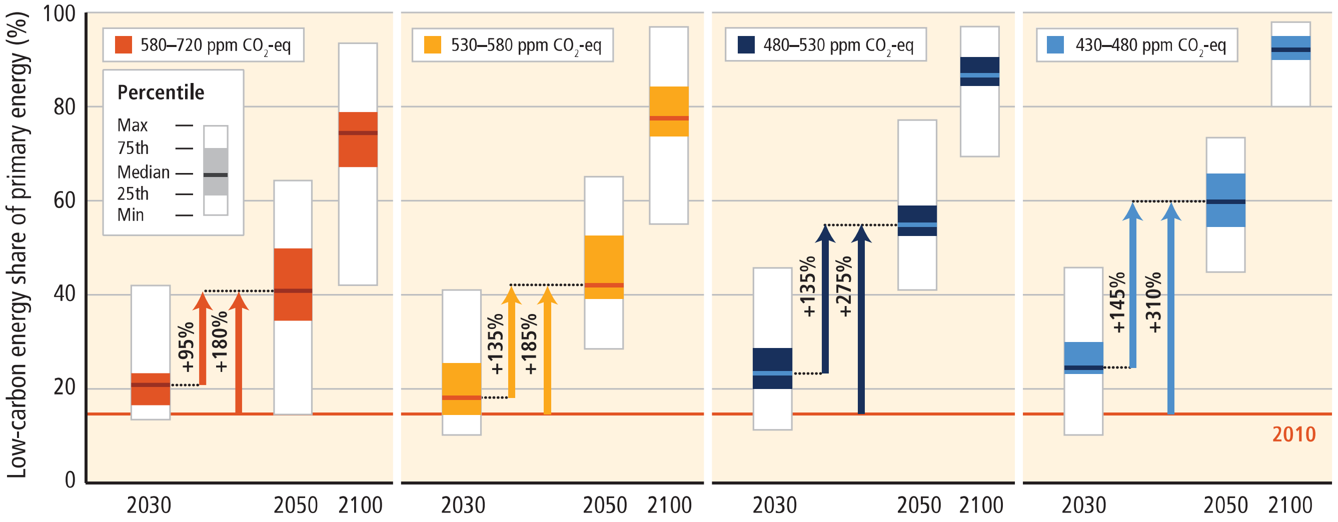


Figure 3.2 | Global greenhouse gas (GHG) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) in baseline and mitigation scenarios for different long-term concentration levels **(a)** and associated scale-up requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100, compared to 2010 levels, in mitigation scenarios **(b)**. *{WGIII SPM.4, Figure 6.7, Figure 7.16}* [Note: CO_2-eq emissions include the basket of Kyoto gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) as well as fluorinated gases) calculated based on 100-year Global Warming Potential (GWP_{100}) values from the IPCC Second Assessment Report.]

Limiting warming with a *likely* chance to less than 2°C relative to pre-industrial levels would require substantial cuts in anthropogenic GHG emissions[40] by mid-century through large-scale changes in energy systems and possibly land use. Limiting warming to higher levels would require similar changes but less quickly. Limiting warming to lower levels would require these changes more quickly (*high confidence*). Scenarios that are *likely* to maintain warming at below 2°C are characterized by a 40 to 70% reduction in GHG emissions by 2050, relative to 2010 levels, and emissions levels near zero or below in 2100 (Figure 3.2, Table 3.1). Scenarios with higher emissions in 2050 are characterized by a greater reliance on CDR technologies beyond mid-century, and vice versa. Scenarios that are *likely* to maintain warming at below 2°C include more rapid improvements in energy efficiency and a tripling to nearly a quadrupling of the share of zero- and low-carbon energy supply from renewable energy, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS) or BECCS by the year 2050 (Figure 3.2b). The scenarios describe a wide range of changes in land use, reflecting

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

Table 3.1 | Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters the 10th to 90th percentile of the scenarios is shown [a].

CO_2-eq Concentrations in 2100 (ppm CO_2-eq) [f] Category label (conc. range)	Subcategories	Relative position of the RCPs [d]	Change in CO_2-eq emissions compared to 2010 (in %) [c]		Likelihood of staying below a specific temperature level over the 21st century (relative to 1850–1900) [d, e]			
			2050	2100	1.5°C	2°C	3°C	4°C
<430	Only a limited number of individual model studies have explored levels below 430 ppm CO_2-eq [j]							
450 (430 to 480)	Total range [a, g]	RCP2.6	–72 to –41	–118 to –78	*More unlikely than likely*	*Likely*	*Likely*	*Likely*
500 (480 to 530)	No overshoot of 530 ppm CO_2-eq		–57 to –42	–107 to –73	*Unlikely*	*More likely than not*		
	Overshoot of 530 ppm CO_2-eq		–55 to –25	–114 to –90		*About as likely as not*		
550 (530 to 580)	No overshoot of 580 ppm CO_2-eq		–47 to –19	–81 to –59		*More unlikely than likely* [i]		
	Overshoot of 580 ppm CO_2-eq		–16 to 7	–183 to –86				
(580 to 650)	Total range	RCP4.5	–38 to 24	–134 to –50				
(650 to 720)	Total range		–11 to 17	–54 to –21		*Unlikely*	*More likely than not*	
(720 to 1000) [b]	Total range	RCP6.0	18 to 54	–7 to 72	*Unlikely* [h]		*More unlikely than likely*	
>1000 [b]	Total range	RCP8.5	52 to 95	74 to 178		*Unlikely* [h]	*Unlikely*	*More unlikely than likely*

Notes:

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

[b] Baseline scenarios fall into the >1000 and 720 to 1000 ppm CO_2-eq categories. The latter category also includes mitigation scenarios. The baseline scenarios in the latter category reach a temperature change of 2.5°C to 5.8°C above the average for 1850–1900 in 2100. Together with the baseline scenarios in the >1000 ppm CO_2-eq category, this leads to an overall 2100 temperature range of 2.5°C to 7.8°C (range based on median climate response: 3.7°C to 4.8°C) for baseline scenarios across both concentration categories.

[c] The global 2010 emissions are 31% above the 1990 emissions (consistent with the historic greenhouse gas emission estimates presented in this report). CO_2-eq emissions include the basket of Kyoto gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) as well as fluorinated gases).

[d] The assessment here involves a large number of scenarios published in the scientific literature and is thus not limited to the Representative Concentration Pathways (RCPs). To evaluate the CO_2-eq concentration and climate implications of these scenarios, the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) was used in a probabilistic mode. For a comparison between MAGICC model results and the outcomes of the models used in WGI, see WGI 12.4.1.2, 12.4.8 and WGIII 6.3.2.6.

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

[f] The CO_2-equivalent concentration (see Glossary) is calculated on the basis of the total forcing from a simple carbon cycle/climate model, MAGICC. The CO_2-equivalent concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 to 520 ppm). This is based on the assessment of total anthropogenic radiative forcing for 2011 relative to 1750 in WGI, i.e., 2.3 W/m^2, uncertainty range 1.1 to 3.3 W/m^2.

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

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

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

[j] In these scenarios, global CO_2-eq emissions in 2050 are between 70 to 95% below 2010 emissions, and they are between 110 to 120% below 2010 emissions in 2100.

different assumptions about the scale of bioenergy production, afforestation and reduced deforestation. Scenarios leading to concentrations of 500 ppm CO_2-eq by 2100 are characterized by a 25 to 55% reduction in GHG emissions by 2050, relative to 2010 levels. Scenarios that are *likely* to limit warming to 3°C relative to pre-industrial levels reduce emissions less rapidly than those limiting warming to 2°C. Only a limited number of studies provide scenarios that are *more likely than not* to limit warming to 1.5°C by 2100; these scenarios are characterized by concentrations below 430 ppm CO_2-eq by 2100 and 2050 emission reduction between 70 and 95% below 2010. For a comprehensive overview of the characteristics of emissions scenarios, their CO_2-equivalent concentrations and their likelihood to keep warming to below a range of temperature levels, see Table 3.1. *{WGIII SPM.4.1, TS.3.1, 6.3, 7.11}*

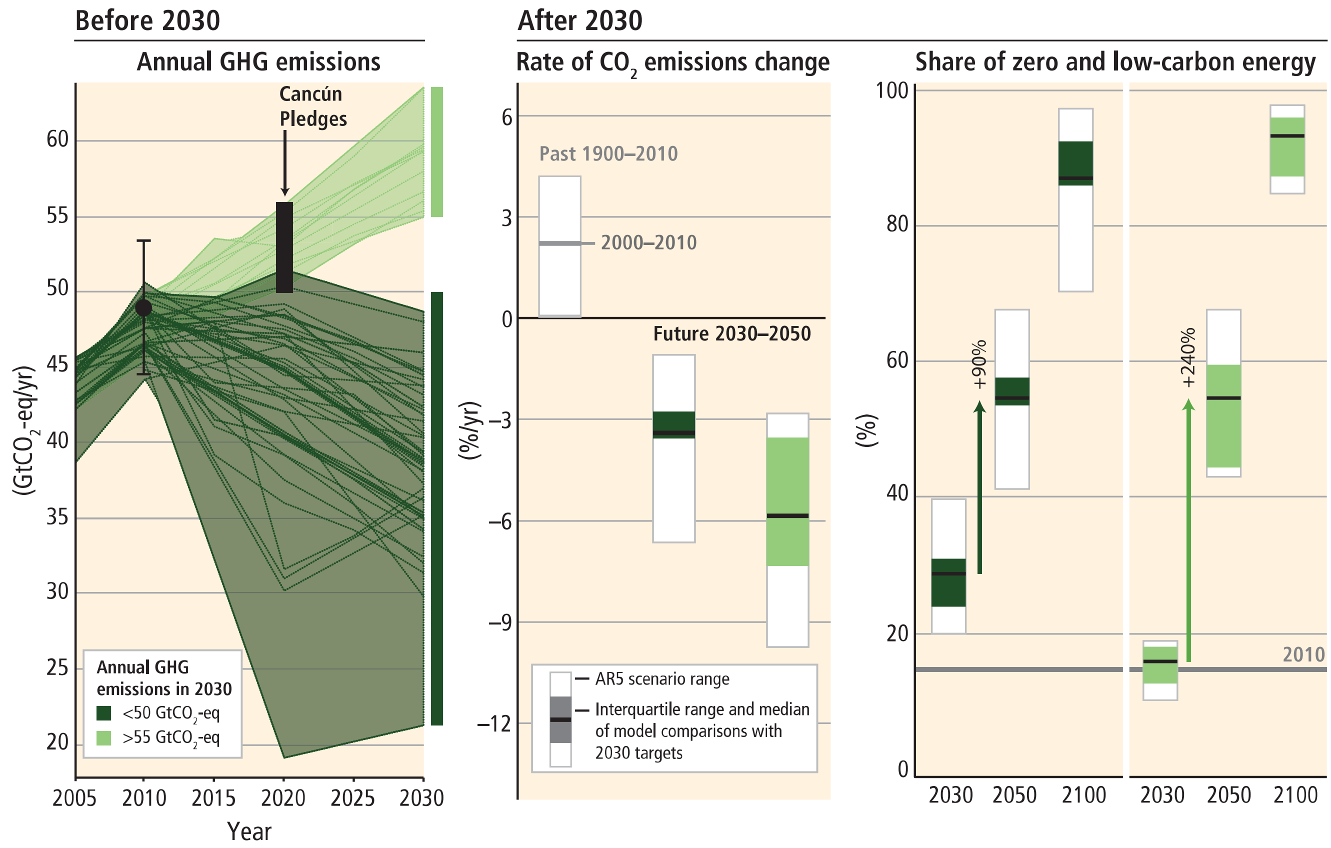

Figure 3.3 | The implications of different 2030 greenhouse gas (GHG) emissions levels for the rate of carbon dioxide (CO_2) emission reductions and low-carbon energy upscaling in mitigation scenarios that are at least *about as likely as not* to keep warming throughout the 21st century below 2°C relative to pre-industrial levels (2100 CO_2-eq concentrations 430 to 530 ppm). The scenarios are grouped according to different emissions levels by 2030 (coloured in different shades of green). The left panel shows the pathways of GHG emissions ($GtCO_2$-eq/yr) leading to these 2030 levels. Black dot with whiskers gives historic GHG emission levels and associated uncertainties in 2010 as reported in Figure 1.6. The black bar shows the estimated uncertainty range of GHG emissions implied by the Cancún Pledges. The middle panel denotes the average annual CO_2 emission reduction rates for the 2030–2050 period. It compares the median and interquartile range across scenarios from recent intermodel comparisons with explicit 2030 interim goals to the range of scenarios in the Scenario Database for WGIII AR5. Annual rates of historical emission changes (sustained over a period of 20 years) are shown as well. The arrows in the right panel show the magnitude of zero and low-carbon energy supply upscaling from between 2030 and 2050, subject to different 2030 GHG emission levels. Zero- and low-carbon energy supply includes renewable energy, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS) or bioenergy with CCS (BECCS). Only scenarios that apply the full, unconstrained mitigation technology portfolio of the underlying models (default technology assumption) are shown. Scenarios with large net negative global emissions (>20 $GtCO_2$-eq/yr), scenarios with exogenous carbon price assumptions, and scenarios with 2010 emission levels that are significantly outside the historical range are excluded. *{WGIII Figure SPM.5, Figure 6.32, Figure 7.16, 13.13.1.3}*

Reducing emissions of non-CO_2 climate forcing agents can be an important element of mitigation strategies. Emissions of non-CO_2 gases (methane (CH_4), nitrous oxide (N_2O), and fluorinated gases) contributed about 27% to the total emissions of Kyoto gases in 2010. For most non-CO_2 gases, near-term, low-cost options are available to reduce their emissions. However, some sources of these non-CO_2 gases are difficult to mitigate, such as N_2O emissions from fertilizer use and CH_4 emissions from livestock. As a result, emissions of most non-CO_2 gases will not be reduced to zero, even under stringent mitigation scenarios (see Figure 4.1). The differences in radiative properties and lifetimes of CO_2 and non-CO_2 climate forcing agents have important implications for mitigation strategies (see also Box 3.2). *{WGIII 6.3.2}*

All current GHG emissions and other climate forcing agents affect the rate and magnitude of climate change over the next few decades. Reducing the emissions of certain short-lived climate forcing agents can reduce the rate of warming in the short term but will have only a limited effect on long-term warming, which is driven mainly by CO_2 emissions. There are large uncertainties related to the climate impacts of some of the short-lived climate forcing agents. Although the effects of CH_4 emissions are well understood, there are large uncertainties related to the effects of black carbon. Co-emitted components with cooling effects may further complicate and reduce the climate impacts of emission reductions. Reducing emissions of sulfur dioxide (SO_2) would cause warming. Near-term reductions in short-lived climate forcing agents can have a relatively fast impact on climate change and possible co-benefits for air pollution. *{WGI 8.2.3, 8.3.2, 8.3.4, 8.5.1, 8.7.2, FAQ 8.2, 12.5, WGIII 6.6.2.1}*

Delaying additional mitigation to 2030 will substantially increase the challenges associated with limiting warming over the 21st century to below 2°C relative to pre-industrial levels (*high confidence*). GHG emissions in 2030 lie between about 30 $GtCO_2$-eq/yr and 50 $GtCO_2$-eq/yr in cost-effective scenarios that are *likely* to *about as likely as not* to limit warming to less than 2°C this century relative to pre-industrial levels (2100 atmospheric concentration

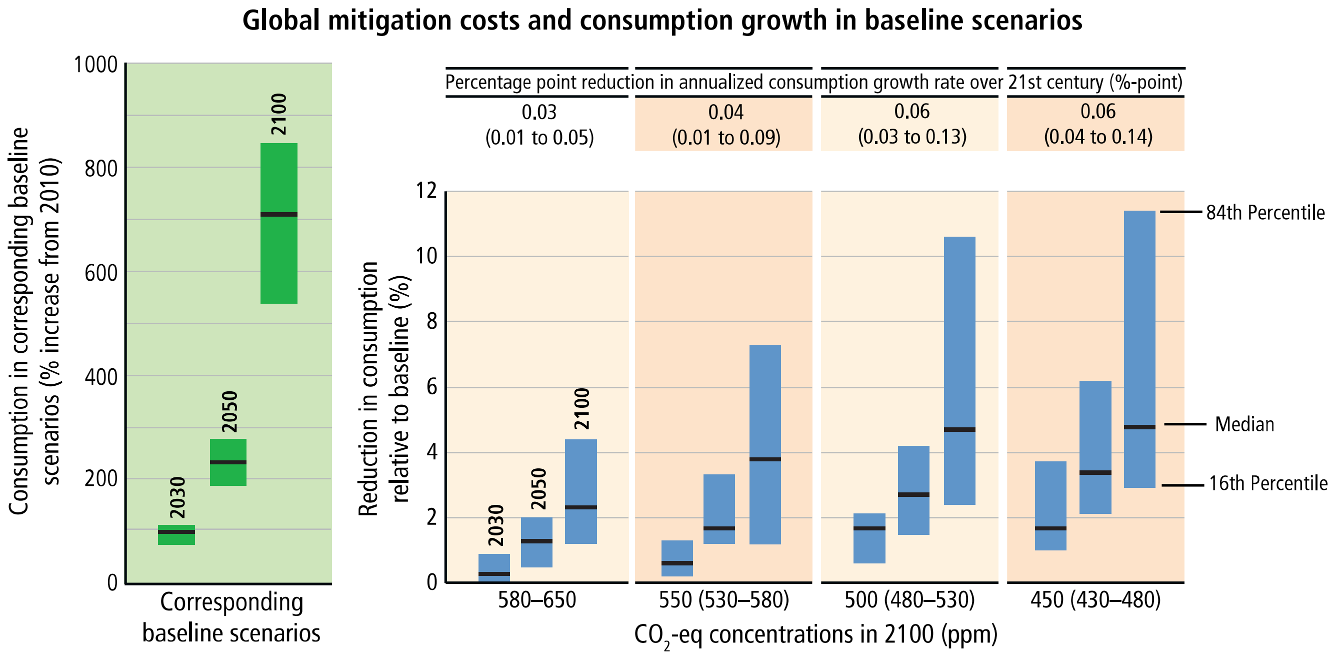

Figure 3.4 | Global mitigation costs in cost-effective scenarios at different atmospheric concentrations levels in 2100 (right panel) and growth in economic consumption in the corresponding baseline scenarios (those without additional mitigation) (left panel). The table at the top shows percentage points of annualized consumption growth reductions relative to consumption growth in the baseline of 1.6 to 3% per year (e.g., if the reduction is 0.06 percentage points per year due to mitigation, and baseline growth is 2.0% per year, then the growth rate with mitigation would be 1.94% per year). Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and they impose no additional limitations on technology relative to the models' default technology assumptions. Consumption losses are shown relative to a baseline development without climate policy. Cost estimates shown in this table do not consider the benefits of reduced climate change nor co-benefits and adverse side effects of mitigation. Estimates at the high end of these cost ranges are from models that are relatively inflexible to achieve the deep emissions reductions that would be required in the long run to meet these goals and/or include assumptions about market imperfections that would raise costs. *{WGIII Table SPM.2, Figure TS.12, 6.3.6, Figure 6.21}*

levels of about 450 ppm CO_2-eq to about 500 ppm CO_2-eq) (Figure 3.3, left panel). Scenarios with GHG emission levels of above 55 $GtCO_2$-eq/yr require substantially higher rates of emissions reductions between 2030 and 2050 (median estimate of 6%/yr as compared to 3%/yr in cost-effective scenarios; Figure 3.3, middle panel); much more rapid scale-up of zero and low-carbon energy over this period (more than a tripling compared to a doubling of the low-carbon energy share relative to 2010; Figure 3.3, right panel); a larger reliance on CDR technologies in the long term; and higher transitional and long-term economic impacts (Table 3.2). (3.5, 4.3) *{WGIII SPM.4.1, TS.3.1, 6.4, 7.11}*

Estimated global emission levels by 2020 based on the Cancún Pledges are not consistent with cost-effective long-term mitigation trajectories that are at least *about as likely as not* to limit warming to below 2°C relative to pre-industrial levels (2100 concentration levels of about 500 ppm CO_2-eq or below), but they do not preclude the option to meet this goal (*high confidence*). The Cancún Pledges are broadly consistent with cost-effective scenarios that are *likely* to limit temperature change to below 3°C relative to pre-industrial levels. *{WGIII SPM.4.1, 6.4, 13.13, Figure TS.11}*

Estimates of the aggregate economic costs of mitigation vary widely depending on methodologies and assumptions but increase with the stringency of mitigation (*high confidence*). Scenarios in which all countries of the world begin mitigation immediately, in which there is a single global carbon price, and in which all key technologies are available have been used as a cost-effective benchmark for estimating macroeconomic mitigation costs (Figure 3.4). Under these assumptions, mitigation scenarios that are *likely* to limit warming to below 2°C through the 21st century relative to pre-industrial levels entail losses in global consumption—not including benefits of reduced climate change (3.2) as well as co-benefits and adverse side effects of mitigation (3.5, 4.3)—of 1 to 4% (median: 1.7%) in 2030, 2 to 6% (median: 3.4%) in 2050, and 3% to 11% (median: 4.8%) in 2100, relative to consumption in baseline scenarios that grows anywhere from 300% to more than 900% over the century[41]. These numbers correspond to an annualized reduction of consumption growth by 0.04 to 0.14 (median: 0.06) percentage points over the century relative to annualized consumption growth in the baseline that is between 1.6% and 3% per year (Figure 3.4). In the absence or under limited availability of mitigation technologies (such as bioenergy, CCS, and their combination BECCS, nuclear, wind and solar), mitigation costs can increase substantially depending on the technology considered (Table 3.2). Delaying additional mitigation reduces near-term costs but increases mitigation costs in the medium- to long-term (Table 3.2). Many models could not limit *likely* warming to below 2°C over the 21st century relative to pre-industrial levels, if additional mitigation is considerably delayed, or if availability of key technologies, such as bioenergy, CCS and their combination (BECCS) are limited (*high confidence*) (Table 3.2). *{WGIII SPM.4.1, Table SPM.2, Table TS.2, TS.3.1, 6.3, 6.6}*

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[41] Mitigation cost ranges cited here refer to the 16th to 84th percentile of the underlying sample (see Figure 3.4).

Mitigation efforts and associated cost are expected to vary across countries. The distribution of costs can differ from the distribution of the actions themselves (*high confidence*). In globally cost-effective scenarios, the majority of mitigation efforts takes place in countries with the highest future GHG emissions in baseline scenarios. Some studies exploring particular effort-sharing frameworks, under the assumption of a global carbon market, have estimated substantial global financial flows associated with mitigation in scenarios that are *likely* to *more unlikely than likely* to limit warming during the 21st century to less than 2°C relative to pre-industrial levels. *{WGIII SPM.4.1, TS.3.1, Box 3.5, 4.6, 6.3.6, Table 6.4, Figure 6.9, Figure 6.27, Figure 6.28, Figure 6.29, 13.4.2.4}*

Table 3.2 | Increase in global mitigation costs due to either limited availability of specific technologies or delays in additional mitigation [a] relative to cost-effective scenarios [b]. The increase in costs is given for the median estimate and the 16th to 84th percentile range of the scenarios (in parentheses). The sample size of each scenario set is provided in the coloured symbols [c]. The colours of the symbols indicate the fraction of models from systematic model comparison exercises that could successfully reach the targeted concentration level. *{WGIII Table SPM.2, Table TS.2, Figure TS.13, Figure 6.24, Figure 6.25}*

	Mitigation cost increases in scenarios with limited availability of technologies [d] *[% increase in total discounted* [e] *mitigation costs (2015–2100) relative to default technology assumptions]*				**Mitigation cost increases due to delayed additional mitigation until 2030** *[% increase in mitigation costs relative to immediate mitigation]*	
2100 concentrations (ppm CO_2-eq)	no CCS	nuclear phase out	limited solar/wind	limited bioenergy	medium term costs (2030–2050)	long term costs (2050–2100)
450 (430 to 480)	138% (29 to 297%) 🟥 4	7% (4 to 18%) 🟫 8	6% (2 to 29%) 🟫 8	64% (44 to 78%) 🟧 8	44% (2 to 78%) 🟧 29	37% (16 to 82%) 🟧 29
500 (480 to 530)	not available (n.a.)	n.a.	n.a.	n.a.		
550 (530 to 580)	39% (18 to 78%) 🟩 11	13% (2 to 23%) 🟩 10	8% (5 to 15%) 🟩 10	18% (4 to 66%) 🟩 12	15% (3 to 32%)	16% (5 to 24%)
580 to 650	n.a.	n.a.	n.a.	n.a.		

Symbol legend—fraction of models successful in producing scenarios (numbers indicate the number of successful models)

🟩: all models successful

🟫: between 80 and 100% of models successful

🟧: between 50 and 80% of models successful

🟥: less than 50% of models successful

Notes:

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

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

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

[d] No CCS: carbon dioxide capture and storage is not included in these scenarios. Nuclear phase out: no addition of nuclear power plants beyond those under construction, and operation of existing plants until the end of their lifetime. Limited Solar/Wind: a maximum of 20% global electricity generation from solar and wind power in any year of these scenarios. Limited Bioenergy: a maximum of 100 EJ/yr modern bioenergy supply globally (modern bioenergy used for heat, power, combinations and industry was around 18 EJ/yr in 2008). EJ = Exajoule = 10^{18} Joule.

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

Box 3.2 | Greenhouse Gas Metrics and Mitigation Pathways

This box focuses on emission-based metrics that are used for calculating CO_2-equivalent emissions for the formulation and evaluation of mitigation strategies. These emission metrics are distinct from the concentration-based metric used in SYR (CO_2-equivalent concentration). For an explanation of CO_2-equivalent emissions and CO_2-equivalent concentrations, see Glossary.

Emission metrics facilitate multi-component climate policies by allowing emissions of different greenhouse gases (GHGs) and other climate forcing agents to be expressed in a common unit (so-called 'CO_2-equivalent emissions'). The Global Warming Potential (GWP) was introduced in the IPCC First Assessment Report, where it was also used to illustrate the difficulties in comparing components with differing physical properties using a single metric. The 100-year GWP (GWP_{100}) was adopted by the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol and is now used widely as the default metric. It is only one of several possible emission metrics and time horizons. *{WGI 8.7, WGIII 3.9}*

The choice of emission metric and time horizon depends on type of application and policy context; hence, no single metric is optimal for all policy goals. All metrics have shortcomings, and choices contain value judgments, such as the climate effect considered and the weighting of effects over time (which explicitly or implicitly discounts impacts over time), the climate policy goal and the degree to which metrics incorporate economic or only physical considerations. There are significant uncertainties related to metrics, and the magnitudes of the uncertainties differ across metric type and time horizon. In general, the uncertainty increases for metrics along the cause–effect chain from emission to effects. *{WGI 8.7, WGIII 3.9}*

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

Box 3.2, Table 1 | Examples of emission metric values from WGI [a].

		GWP		GTP	
	Lifetime (yr)	Cumulative forcing over 20 years	Cumulative forcing over 100 years	Temperature change after 20 years	Temperature change after 100 years
CO_2	[b]	1	1	1	1
CH_4	12.4	84	28	67	4
N_2O	121.0	264	265	277	234
CF_4	50,000.0	4880	6630	5270	8040
HFC-152a	1.5	506	138	174	19

Notes:

[a] Global Warming Potential (GWP) values have been updated in successive IPCC reports; the AR5 GWP_{100} values are different from those adopted for the Kyoto Protocol's First Commitment Period which are from the IPCC Second Assessment Report (SAR). Note that for consistency, equivalent CO_2 emissions given elsewhere in this Synthesis Report are also based on SAR, not AR5 values. For a comparison of emissions using SAR and AR5 GWP_{100} values for 2010 emissions, see Figure 1.6.

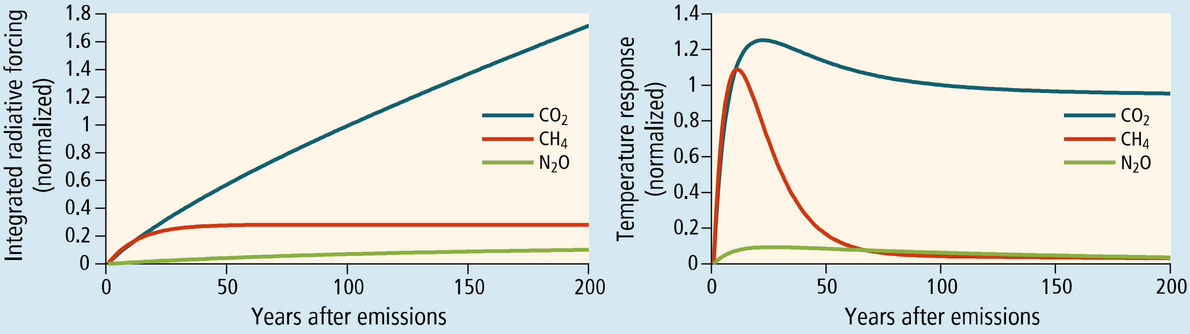
[b] No single lifetime can be given for CO_2. *{WGI Box 6.1, 6.1.1, 8.7}*

The choice of emission metric affects the timing and emphasis placed on abating short- and long-lived climate forcing agents. For most metrics, global cost differences are small under scenarios of global participation and cost-minimizing mitigation pathways, but implications for some individual countries and sectors could be more significant (*medium evidence, high agreement*). Different metrics and time horizons significantly affect the contributions from various sources/sectors and components, particularly short-lived climate forcing agents (Box 3.2, Figure 1b). A fixed time independent metric that gives less weight to short-lived agents such as CH_4 (e.g., using GTP_{100} instead of GWP_{100}) would require earlier and more stringent CO_2 abatement to achieve the same climate outcome for 2100. Using a time-dependent metric, such as a dynamic GTP, leads to less CH_4 mitigation

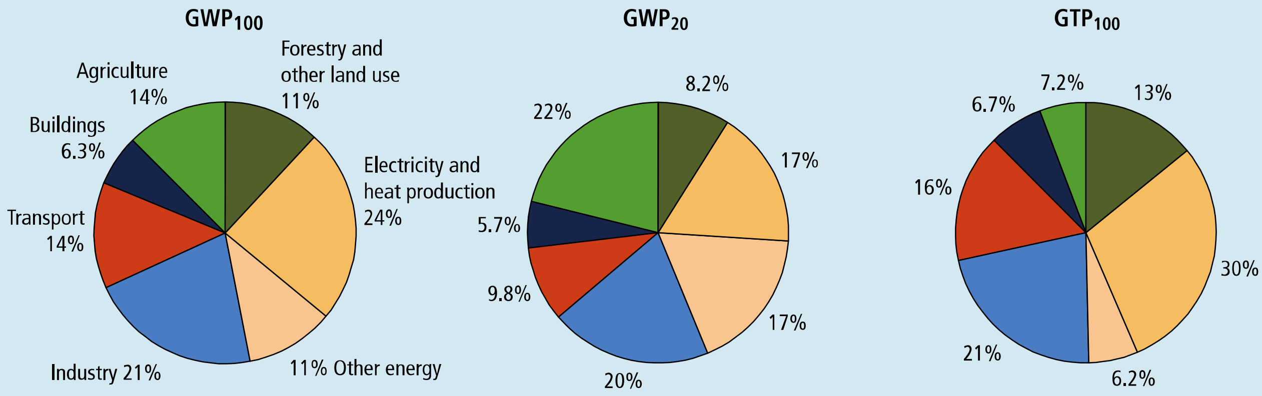
Box 3.2 (continued)

in the near term but to more in the long term as the target date is being approached. This implies that for some (short-lived) agents, the metric choice influences the choice of policies and the timing of mitigation (especially for sectors and countries with high non-CO_2 emission levels). *{WGI 8.7, WGIII 6.3}*

(a) Weighting of current emissions over time



(b) Contributions by sectors to total GHG emissions using different metrics



Box 3.2, Figure 1 | Implications of metric choices on the weighting of greenhouse gas (GHG) emissions and contributions by sectors for illustrative time horizons. Panel **(a)**: integrated radiative forcing (left panel) and warming resulting at a given future point in time (right panel) from global net emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in the year 2010 (and no emissions thereafter), for time horizons of up to 200 years. Integrated radiative forcing is used in the calculation of Global Warming Potentials (GWP), while the warming at a future point in time is used in the calculation of Global Temperature change Potentials (GTP). Radiative forcing and warming were calculated based on global 2010 emission data from WGIII 5.2 and absolute GWPs and absolute GTPs from WGI 8.7, normalized to the integrated radiative forcing and warming, respectively, after 100 years, due to 2010 net CO_2 emissions. Panel **(b)**: Illustrative examples showing contributions from different sectors to total metric-weighted global GHG emissions in the year 2010, calculated using 100-year GWP (GWP_{100}, left), 20-year GWP (GWP_{20}, middle) or 100-year GTP (GTP_{100}, right) and the WGIII 2010 emissions database. *{WGIII 5.2}* Note that percentages differ slightly for the GWP_{100} case if values from the IPCC Second Assessment Report are used; see Topic 1, Figure 1.7. See WGIII for details of activities resulting in emissions in each sector.

Box 3.3 | Carbon Dioxide Removal and Solar Radiation Management Geoengineering Technologies—Possible Roles, Options, Risks and Status

Geoengineering refers to a broad set of methods and technologies operating on a large scale that aim to deliberately alter the climate system in order to alleviate the impacts of climate change. Most methods seek to either reduce the amount of absorbed solar energy in the climate system (Solar Radiation Management, SRM) or increase the removal of carbon dioxide (CO_2) from the atmosphere by sinks to alter climate (Carbon Dioxide Removal, CDR, see Glossary). Limited evidence precludes a comprehensive assessment of feasibility, cost, side effects and environmental impacts of either CDR or SRM. *{WGI SPM E.8, 6.5, 7.7, WGII 6.4, Table 6-5, Box 20-4, WGIII TS.3.1.3, 6.9}*

CDR plays a major role in many mitigation scenarios. Bioenergy with carbon dioxide capture and storage (BECCS) and afforestation are the only CDR methods included in these scenarios. CDR technologies are particularly important in scenarios that temporarily overshoot atmospheric concentrations, but they are also prevalent in many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive. Similar to mitigation, CDR would need to be deployed on a large scale and over a long time period to be able to significantly reduce CO_2 concentrations (see Section 3.1). *{WGII 6.4, WGIII SPM 4.1, TS.3.1.2, TS 3.1.3, 6.3, 6.9}*

Several CDR techniques could potentially reduce atmospheric greenhouse gas (GHG) levels. However, there are biogeochemical, technical and societal limitations that, to varying degrees, make it difficult to provide quantitative estimates of the potential for CDR. The emission mitigation from CDR is less than the removed CO_2, as some CO_2 is released from that previously stored in oceans and terrestrial carbon reservoirs. Sub-sea geologic storage has been implemented on a regional scale, with no evidence to date of ocean impact from leakage. The climatic and environmental side effects of CDR depend on technology and scale. Examples are associated with altered surface reflectance from afforestation and ocean de-oxygenation from ocean fertilization. Most terrestrial CDR techniques would involve competing demands for land and could involve local and regional risks, while maritime CDR techniques may involve significant risks for ocean ecosystems, so that their deployment could pose additional challenges for cooperation between countries. *{WGI 6.5, FAQ 7.3, WGII 6.4, Table 6.5, WGIII 6.9}*

SRM is untested, and is not included in any of the mitigation scenarios, but, if realisable, could to some degree offset global temperature rise and some of its effects. It could possibly provide rapid cooling in comparison to CO_2 mitigation. There is *medium confidence* that SRM through stratospheric aerosol injection is scalable to counter radiative forcing from a twofold increase in CO_2 concentrations and some of the climate responses associated with warming. Due to insufficient understanding there is no consensus on whether a similarly large negative counter radiative forcing could be achieved from cloud brightening. Land albedo change does not appear to be able to produce a large counter radiative forcing. Even if SRM could counter the global mean warming, differences in spatial patterns would remain. The scarcity of literature on other SRM techniques precludes their assessment. *{WGI 7.7, WGIII TS.3.1.3, 6.9}*

If it were deployed, SRM would entail numerous uncertainties, side effects, risks and shortcomings. Several lines of evidence indicate that SRM would itself produce a small but significant decrease in global precipitation (with larger differences on regional scales). Stratospheric aerosol SRM is *likely* to modestly increase ozone losses in the polar stratosphere. SRM would not prevent the CO_2 effects on ecosystems and ocean acidification that are unrelated to warming. There could also be other unanticipated consequences. For all future scenarios considered in AR5, SRM would need to increase commensurately, to counter the global mean warming, which would exacerbate side effects. Additionally, if SRM were increased to substantial levels and then terminated, there is *high confidence* that surface temperatures would rise very rapidly (within a decade or two). This would stress systems that are sensitive to the rate of warming. *{WGI 7.6–7.7, FAQ 7.3, WGII 19.5, WGIII 6.9}*

SRM technologies raise questions about costs, risks, governance and ethical implications of development and deployment. There are special challenges emerging for international institutions and mechanisms that could coordinate research and possibly restrain testing and deployment. Even if SRM would reduce human-made global temperature increase, it would imply spatial and temporal redistributions of risks. SRM thus introduces important questions of intragenerational and intergenerational justice. Research on SRM, as well as its eventual deployment, has been subject to ethical objections. In spite of the estimated low potential costs of some SRM deployment technologies, they will not necessarily pass a benefit–cost test that takes account of the range of risks and side effects. The governance implications of SRM are particularly challenging, especially as unilateral action might lead to significant effects and costs for others. *{WGIII TS.3.1.3, 1.4, 3.3, 6.9, 13.4}*

3.5 Interaction among mitigation, adaptation and sustainable development

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

Climate change poses an increasing threat to equitable and sustainable development (*high confidence*). Some climate-related impacts on development are already being observed. Climate change is a threat multiplier. It exacerbates other threats to social and natural systems, placing additional burdens particularly on the poor and constraining possible development paths for all. Development along current global pathways can contribute to climate risk and vulnerability, further eroding the basis for sustainable development. *{WGII SPM B-2, 2.5, 10.9, 13.1–13.3, 20.1, 20.2, 20.6, WGIII SPM.2, 4.2}*

Aligning climate policy with sustainable development requires attention to both adaptation and mitigation (*high confidence*). Interaction among adaptation, mitigation and sustainable development occurs both within and across regions and scales, often in the context of multiple stressors. Some options for responding to climate change could impose risks of other environmental and social costs, have adverse distributional effects and draw resources away from other development priorities, including poverty eradication. *{WGII 2.5, 8.4, 9.3, 13.3–13.4, 20.2–20.4, 21.4, 25.9, 26.8, WGIII SPM.2, 4.8, 6.6}*

Both adaptation and mitigation can bring substantial co-benefits (*medium confidence*). Examples of actions with co-benefits include (i) improved air quality (see Figure 3.5); (ii) enhanced energy security, (iii) reduced energy and water consumption in urban areas through greening cities and recycling water; (iv) sustainable agriculture and forestry; and (v) protection of ecosystems for carbon storage and other ecosystem services. *{WGII SPM C-1, WGIII SPM.4.1}*

Strategies and actions can be pursued now that will move towards climate-resilient pathways for sustainable development, while at the same time helping to improve livelihoods, social and economic well-being and effective environmental management (*high confidence*). Prospects for climate-resilient pathways are related fundamentally to what the world accomplishes with climate change mitigation (*high confidence*). Since mitigation reduces the rate as well as the magnitude of warming, it also increases the time available for adaptation to a particular level of climate change, potentially by several decades. Delaying mitigation actions may reduce options for climate-resilient pathways in the future. *{WGII SPM C-2, 20.2, 20.6.2}*

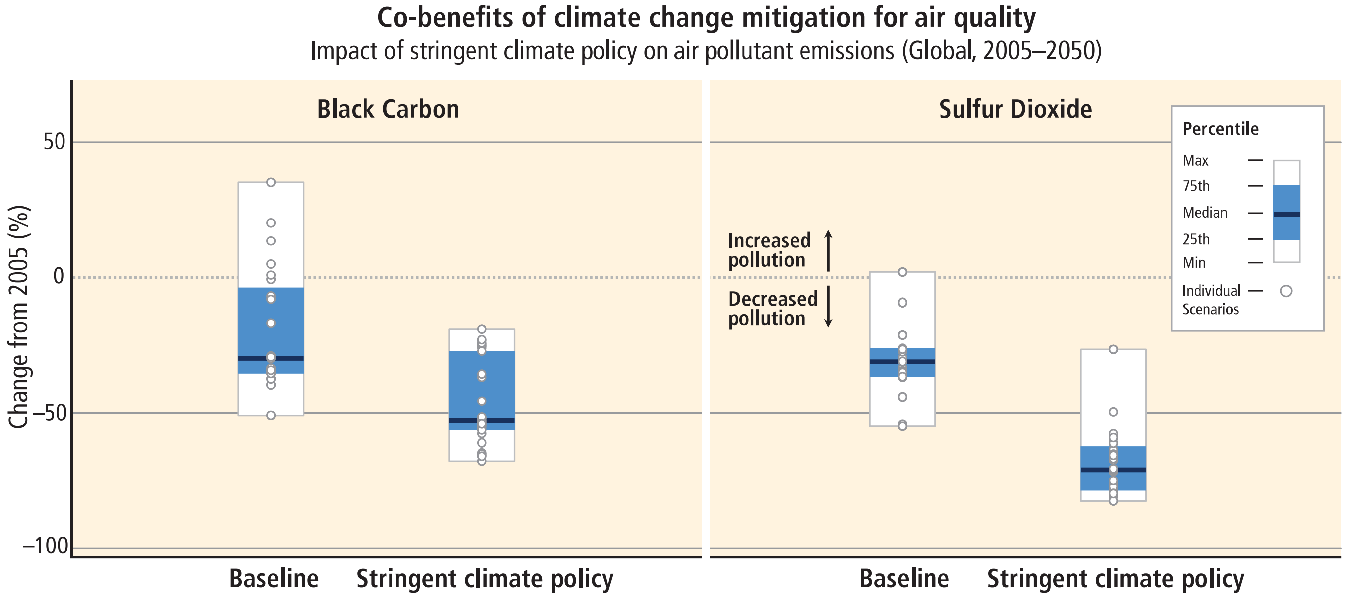


Figure 3.5 | Air pollutant emission levels of black carbon (BC) and sulfur dioxide (SO_2) by 2050, relative to 2005 (0 = 2005 levels). Baseline scenarios without additional efforts to reduce greenhouse gas (GHG) emissions beyond those in place today are compared to scenarios with stringent mitigation policies, which are consistent with reaching about 450 to about 500 (430 to 530) ppm CO_2-eq concentration levels by 2100. *{WGIII SPM.6, TS.14, Figure 6.33}*

Box 3.4 | Co-benefits and Adverse Side effects

A government policy or a measure intended to achieve one objective often affects other objectives, either positively or negatively. For example, mitigation policies can influence local air quality (see Figure 3.5). When the effects are positive they are called 'co-benefits', also referred to as 'ancillary benefits'. Negative effects are referred to as 'adverse side effects'. Some measures are labelled 'no or low regret' when their co-benefits are sufficient to justify their implementation, even in the absence of immediate direct benefits. Co-benefits and adverse side effects can be measured in monetary or non-monetary units. The effect of co-benefits and adverse side effects from climate policies on overall social welfare has not yet been quantitatively examined, with the exception of a few recent multi-objective studies. Many of these have not been well quantified, and effects can be case and site-specific as they will depend on local circumstances. *{WGII 11.9, 16.3.1, 17.2, 20.4.1, WGIII Box TS.11, 3.6, 5.7}*

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

Comprehensive strategies in response to climate change that are consistent with sustainable development take into account the co-benefits, adverse side effects and risks that may arise from both adaptation and mitigation options. The assessment of overall social welfare impacts is complicated by this interaction between climate change response options and pre-existing non-climate policies. For example, in terms of air quality, the value of the extra tonne of sulfur dioxide (SO_2) reduction that occurs with climate change mitigation through reduced fossil fuel combustion depends greatly on the stringency of SO_2 control policies. If SO_2 policy is weak, the value of SO_2 reductions may be large, but if SO_2 policy is stringent, it may be near zero. Similarly, in terms of adaptation and disaster risk management, weak policies can lead to an adaptation deficit that increases human and economic losses from natural climate variability. 'Adaptation deficit' refers to the lack of capacity to manage adverse impacts of current climate variability. An existing adaptation deficit increases the benefits of adaptation policies that improve the management of climate variability and change. *{WGII 20.4.1, WGIII Box TS.11, 6.3}*