Topic 3: Transformations and Changes in Systems

3.1 Human responses: An integrated approach

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

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

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

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

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

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

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

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

Predicting the effects of climate change and climate policy is beset with uncertainty. *{WG II 2.3, 17.3; WG III 2}* However, adaptation and mitigation choices in the near-term will affect the risks of climate change throughout the 21st century, and prospects for climate-resilient pathways for sustainable development are related to what the world accomplishes with climate-change mitigation. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if the limits to adaptation are exceeded. *{WGII 2.5, 16.4, 20.2, SPM}*

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

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

3.2 Characteristics and risks of (evolving) mitigation pathways

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

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

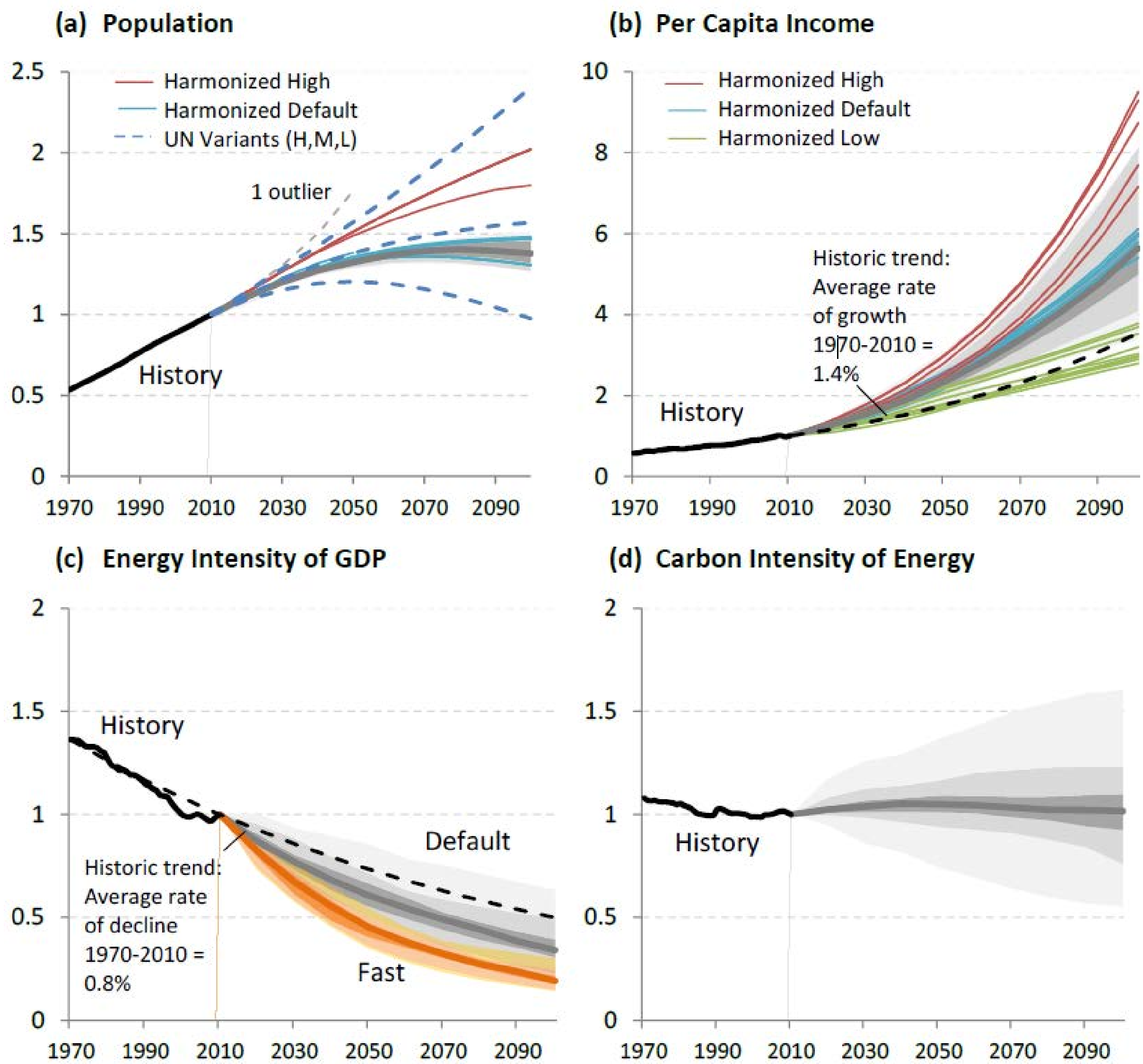


Figure 3.1: Global Baseline Projection Ranges from Integrated Models for Kaya Factors. Scenarios from the Scenario Database for AR5. Scenarios harmonized with respect to a particular factor are depicted with individual lines. Other scenarios depicted as a range with median emboldened; shading reflects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

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

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

Mitigation scenarios in which it is *likely* that the temperature change can be kept to less than 2°C are characterized by atmospheric concentrations in 2100 of about 450 ppm CO_2eq (*high confidence*)**.** Mitigation scenarios reaching concentration levels of about 500 ppm CO_2eq by 2100 are *more likely than not* to limit temperature change to less than 2°C, unless they temporarily 'overshoot' concentration levels of roughly 530 ppm CO_2eq before 2100. In this case, they are *about as likely as not* to achieve that goal. Scenarios that exceed about 650 ppm CO_2eq by 2100 are *unlikely* to limit temperature change to below 2°C. Mitigation scenarios in which temperature increase is *more likely than not* to be less than 1.5°C by 2100 are characterized by concentrations in 2100 of below 430 ppm CO_2eq. Temperature peaks during the century and then declines in these scenarios. *{WGIII 6.3, Box TS.6, Table SPM.1}*

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

Reaching 450 ppm CO_2eq by 2100 will involve substantial cuts in anthropogenic GHG emissions by mid-century through large-scale changes in energy systems and potentially land use. Scenarios reaching higher (lower) concentrations include these same changes on a slower (faster) timescale. (*high confidence*)**.** Scenarios reaching these concentrations by 2100 include 40% to 70% reductions in GHG emissions by 2050 relative to 2010, and those with more modest reductions are characterized by higher overshoot (>0.4 Wm2) and substantial reliance on CDR technologies (Table 3.1). Scenarios reaching these concentrations are also characterized a tripling to nearly a quadrupling of the share of zero- and low-carbon energy supply from renewables, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS), or bioenergy with CCS (BECCS) by the year 2050 (Figure 3.2, lower panel). They describe a wide range of changes in land use, reflecting different assumptions about the scale of bioenergy production, afforestation, and reduced deforestation. *{WGIII, 6.3, 7.11}*

Table 3.1: Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters, the 10th to 90th percentile of the scenarios is shown[1,2]. *{WG3 SPM Table SPM1, Table 6.3}*

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

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

[2] Baseline scenarios (see SPM.3) are categorized in the >1000 and 750–1000 ppm CO2eq categories. The latter category includes also mitigation scenarios. The baseline scenarios in the latter category reach a temperature change of 2.5–5.8°C above preindustrial in 2100. Together with the baseline scenarios in the >1000 ppm CO_2eq category, this leads to an overall 2100 temperature range of 2.5–7.8°C (median: 3.7–4.8°C) for baseline scenarios across both concentration categories.

[3] The global 2010 emissions are 31% above the 1990 emissions (consistent with the historic GHG emission estimates presented in this report). CO_2eq emissions include the basket of Kyoto gases (CO_2, CH4, N2O as well as F- gases).
[4] The vast majority of scenarios in this category overshoot the category boundary of 480 ppm CO_2eq concentration.

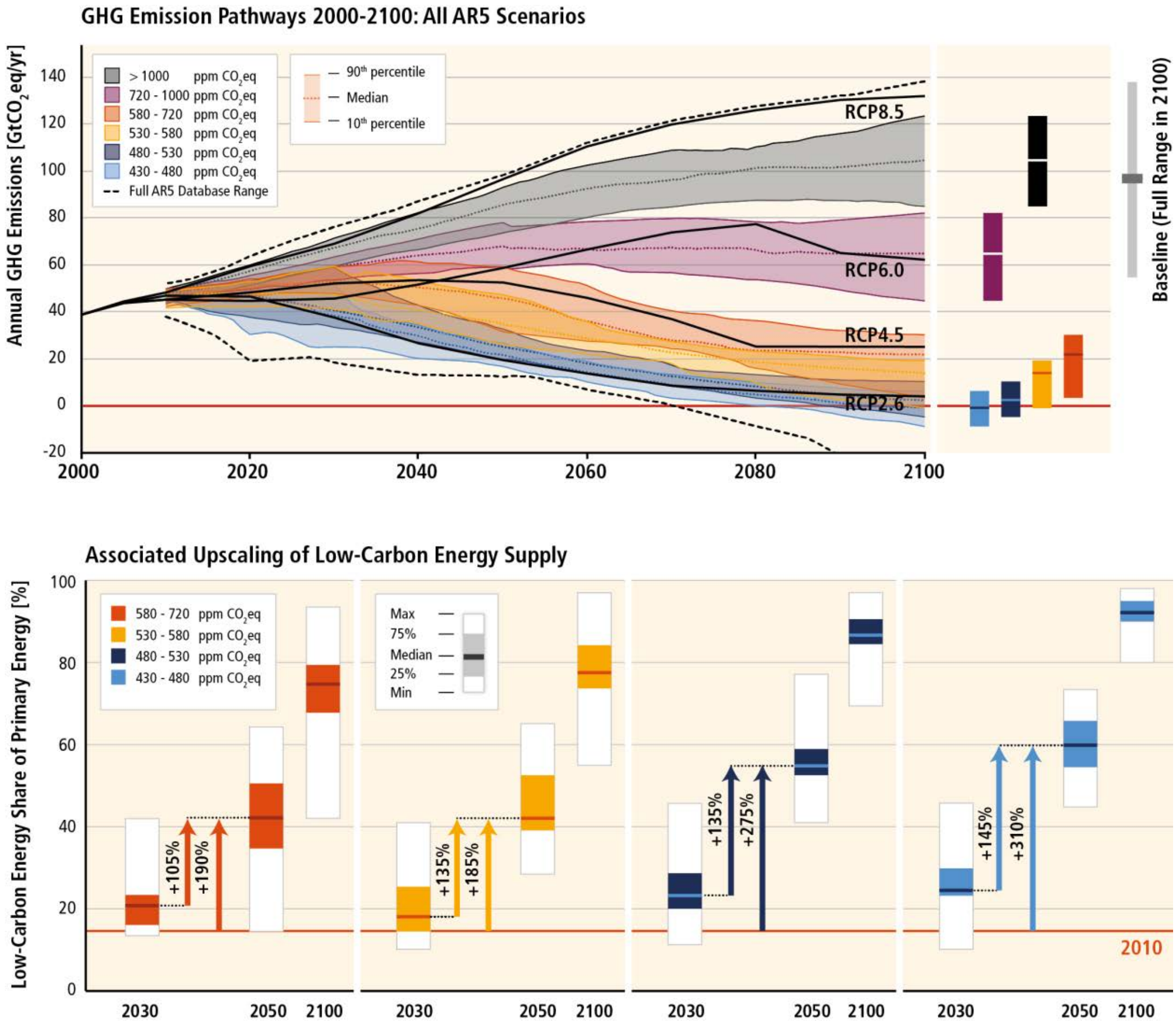


Figure 3.2: Pathways of global GHG emissions ($GtCO_2eq/yr$) in baseline and mitigation scenarios for different long-term concentration levels (upper panel) and associated upscaling requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100 compared to 2010 levels in mitigation scenarios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

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

Table 3.2: Global mitigation costs in cost-effective scenarios and estimated cost increases due to assumed limited availability of specific technologies and delayed additional mitigation. Cost estimates shown in this table do not consider the benefits of reduced climate change as well as co-benefits and adverse side-effects of mitigation. The green columns show consumption losses in the years 2030, 2050, and 2100 (green) and annualized consumption growth reductions (bright green) over the century in cost-effective scenarios relative to a baseline development without climate policy.[1] The orange columns show the percentage increase in discounted costs[2] over the century, relative to cost-effective scenarios, in scenarios in which technology is constrained relative to default technology assumptions.[3] The blue columns show the increase in mitigation costs over the periods 2030–2050 and 2050–2100, relative to scenarios with immediate mitigation, due to delayed additional mitigation through 2020 or 2030.[4] These scenarios with delayed additional mitigation are grouped by emission levels of less or more than 55 $GtCO_2eq$ in 2030, and two concentration ranges in 2100 (430–530 ppm CO_2eq and 530–650 CO_2eq). In all figures, the median of the scenario set is shown without parentheses, the range between the 16th and 84th percentile of the scenario set is shown in the parentheses, and the number of scenarios in the set is shown in square brackets.[5] *{WGIII Figures TS.12, TS.13, 6.21, 6.24, 6.25, Annex II.10}*

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

Notes: [1] Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions. [2] Percentage increase of net present value of consumption losses in percent of baseline consumption (for scenarios from general equilibrium models) and abatement costs in percent of baseline GDP (for scenarios from partial equilibrium models) for the period 2015–2100, discounted at 5% per year. [3] No CCS: CCS is not included in these scenarios. Nuclear phase out: No addition of nuclear power plants beyond those under construction, and operation of existing plants until the end of their lifetime. Limited Solar/Wind: a maximum of 20% global electricity generation from solar and wind power in any year of these scenarios. Limited Bioenergy: a maximum of 100 EJ/yr modern bioenergy supply globally (modern bioenergy used for heat, power, combinations, and industry was around 18 EJ/yr in 2008 *{WGIII 11.13.5}*).

[4] Percentage increase of total undiscounted mitigation costs for the periods 2030–2050 and 2050–2100. [5] The range is determined by the central scenarios encompassing the 16th and 84th percentile of the scenario set. Only scenarios with a time horizon until 2100 are included. Some models that are included in the cost ranges for concentration levels above 530 ppm CO_2eq in 2100 could not produce associated scenarios for concentration levels below 530 ppm CO_2eq in 2100 with assumptions about limited availability of technologies or delayed additional mitigation.

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

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

Allowing emission to rise above 50 GtCO_2eq in 2030 while still bringing concentrations to about 450 to 500 ppmv CO_2eq by 2100 will call for a rapid increase in emissions reductions in the following two decades, with an associated increase in costs, technological challenges, and institutional challenges. The majority of mitigation scenarios leading to atmospheric concentrations between 430 ppm CO_2eq and 530 ppm CO_2eq at the end of the 21st century are characterized by 2030 emissions roughly between 30 GtCO_2eq and 50 GtCO_2eq (Figure 3.3). *{WG III, 6}* Scenarios with emissions above 55 GtCO_2e are characterized by substantially higher rates of emissions reductions from 2030 to 2050 (on average 6%/yr as compared to 3%/yr); much more rapid scale-up of low-carbon energy over this period (a quadrupling compared to a doubling of the low-carbon energy share); a larger reliance on CDR technologies in the long term; and higher transitional and long-term economic impacts. *{WG III 6, 7}*

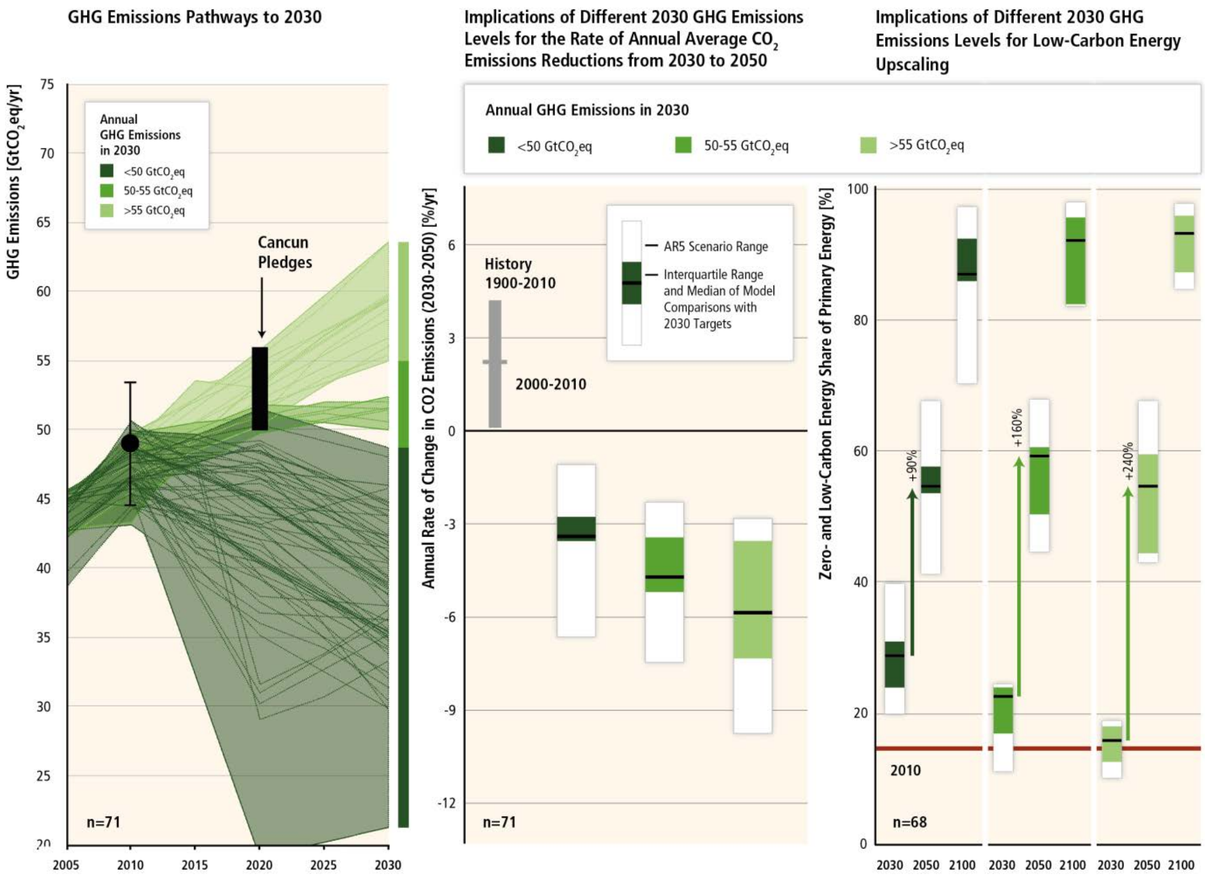


Figure 3.3: The implications of different 2030 GHG emissions levels for the rate of CO_2 emissions reductions and low-carbon energy upscaling from 2030 to 2050 in mitigation scenarios reaching about 450 to 500 (430–530) ppm CO_2eq concentrations by 2100. The scenarios are grouped according to different emissions levels by 2030 (coloured in different shades of green). The left panel shows the pathways of GHG emissions (GtCO_2eq/yr) leading to these 2030 levels. The black bar shows the estimated uncertainty range of GHG emissions implied by the Cancún Pledges. The middle panel denotes the average annual CO_2 emissions reduction rates for the period 2030–2050. It compares the median and interquartile range across scenarios from recent intermodel comparisons with explicit 2030 interim goals to the range of scenarios in the Scenario Database for WGIII AR5. Annual rates of historical emissions change (sustained over a period of 20 years) are shown in grey. The arrows in the right panel show the magnitude of zero and low-carbon energy supply up-scaling from 2030 to 2050 subject to different 2030 GHG emissions levels. Zero- and low-carbon

energy supply includes renewables, nuclear energy, and fossil energy with carbon dioxide capture and storage (CCS), or bioenergy with CCS (BECCS). Note: Only scenarios that apply the full, unconstrained mitigation technology portfolio of the underlying models (default technology assumption) are shown. Scenarios with large net negative global emissions (>20 $GtCO_2eq$/yr), scenarios with exogenous carbon price assumptions, and scenarios with 2010 emissions significantly outside the historical range are excluded. *{WGIII, Figure 6.32, 7.16}*

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

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

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

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

3.3 Characteristics and risks of (evolving) adaptation pathways

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

Adaptation can contribute to the wellbeing of current and future populations, the security of assets and the maintenance of ecosystem services now and in the future as the climate changes. Research since the AR4 has broadened from a dominant consideration of engineering and technological options to include more ecosystem-based, institutional, and social measures, and from cost-benefit analysis, optimisation and efficiency approaches to the development of multi-metric evaluations, including risk and uncertainty dimensions integrated within wider policy and ethical frameworks to assess trade-offs and constraints**.** *{WGII.14.1, 14.3, 15.2, 15.5, 17.2, 17.3, SPM Table 1}*

Adaptation planning and implementation at all levels of governance are contingent on societal values, objectives, and risk perceptions (*high confidence*). Recognition of diverse interests, circumstances, social-cultural contexts, risk perceptions and expectations can benefit decision-making processes. Desired adaptation outcomes and pathways to these usually require effective engagement with the range of affected stakeholders, operating in a decision environment with policy support to overcome constraints at various levels (Topic 4.5). Adaptation decision support is most effective when it is sensitive to context and the diversity of decision types, decision processes, and constituencies (*robust evidence, high agreement*). Adaptation planning and implementation can be enhanced through complementary actions across levels, from individuals to governments, for example through improved coordination, increasing awareness of climate change risks and the uncertainties in these, learning from experience with climate variability, and achieving synergies with disaster risk reduction. *{WGII SPM, 2.2, 15.2, 15.3, 15.5, 16.3, 16.4, 17.3, 19.6, 20.3}*

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

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

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

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

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

Building adaptive capacity is crucial for effective selection and implementation of adaptation options (*high agreement, robust evidence*). Successful adaptation requires not only identifying adaptation options and assessing their costs and benefits, but also building the adaptive capacity of human and natural systems (*Topic 4.2)* (*high agreement, medium evidence*). This can involve complex governance challenges and new institutions and institutional arrangements. The convergence between building adaptive capacity and disaster risk management has been further strengthened since AR4. Indigenous, local and traditional knowledge systems can be a major resource for adapting to climate change, except when the type, patterns and magnitude of changes exceed the knowledge repertoire. *{WGII 12.3,14.1, 14.2, 14.3, 16.2, 16.3, 16.5, 16.8}*

3.4 Climate Change Risks Reduced by Mitigation and Adaptation

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

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

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

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

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

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

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

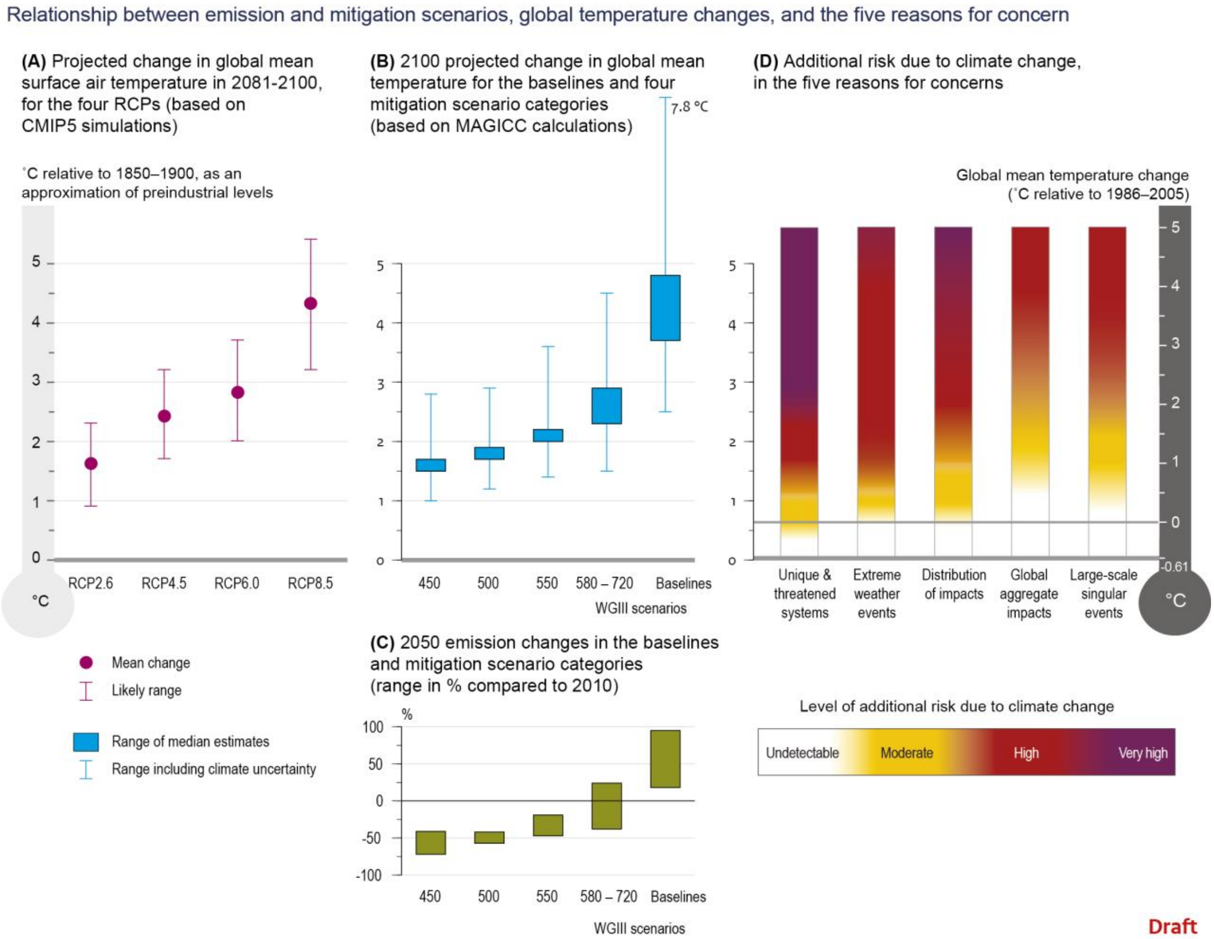


Figure 3.4: Relationship between emission and mitigation scenarios, global temperature changes, and the five Reasons for Concerns (RfC). Temperature changes shown compared with pre-industrial levels. For reference, the extreme right temperature axis shows temperature changes with respect to the 1986-2005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

coral reefs and the Arctic system; RFC2, includes risks associated with extreme heat; RFC3, regionally differentiated risks to food and water; RFC4, aggregate economic damages and biodiversity loss; RFC5, risk associated with a large sea level rise due to loss of mass from polar ice sheets. Undetectable risk (white) indicates no associated impacts are detectable and attributable to climate change. Moderate risk (yellow) indicates that associated impacts are both detectable and attributable to climate change with at least medium confidence, also accounting for the other specific criteria for key risks. High risk (red) indicates severe and widespread impacts, also accounting for the other specific criteria for key risks. Purple, introduced in this assessment, shows that very high risk is indicated by all specific criteria for key risks.*{Ch.19.2}* Note the different temperature baselines used in WGII Assessment Box SPM.1 Figure 1. Beyond 2100, temperature, and therefore risk, decreases in most of the lowest three scenarios and increases further in most of the others.

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

Mitigation also involves risks and uncertainties. These risks are particularly high for the most ambitious mitigation pathways. *{WGIII 2.1, 2.3-2.5}* Risks increased by mitigation include those associated with large-scale deployment of technology options for producing low-carbon energy – including bioenergy, nuclear power, carbon capture with storage, and even wind power – the potential for high aggregate economic costs, large impacts on vulnerable countries and industries, and other risks. This includes linkages to human health, food security, energy security, poverty reduction, biodiversity conservation, water availability, income distribution, efficiency of taxation systems, labour supply and employment, urban sprawl, and the growth of developing countries.

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

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

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

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

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

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

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

3.5 Interactions among mitigation, adaptation, and sustainable development

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

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

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

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

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

Climate resilient pathways for sustainable development can be supported by transformations that facilitate both adaptation and mitigation. Examples of transformations include the introduction of new technologies or practices (e.g., changes in land allocation and farming systems), formation of new structures or systems of governance (e.g., cooperative multilevel governance), or shifts in the types or locations of activities (e.g., harnessing off-shore wind energy). Some transformation processes also involve risks that may have inequitable consequences. Strategies and actions can be pursued now that will move towards climate-resilient pathways for sustainable development, while at the same time helping to improve livelihoods, social and economic well-being, and responsible environmental management. *{WG II 1.1, 2.5, 14.3, 20.5, 22.4, 25.4, SPM; WG III 4.3}*

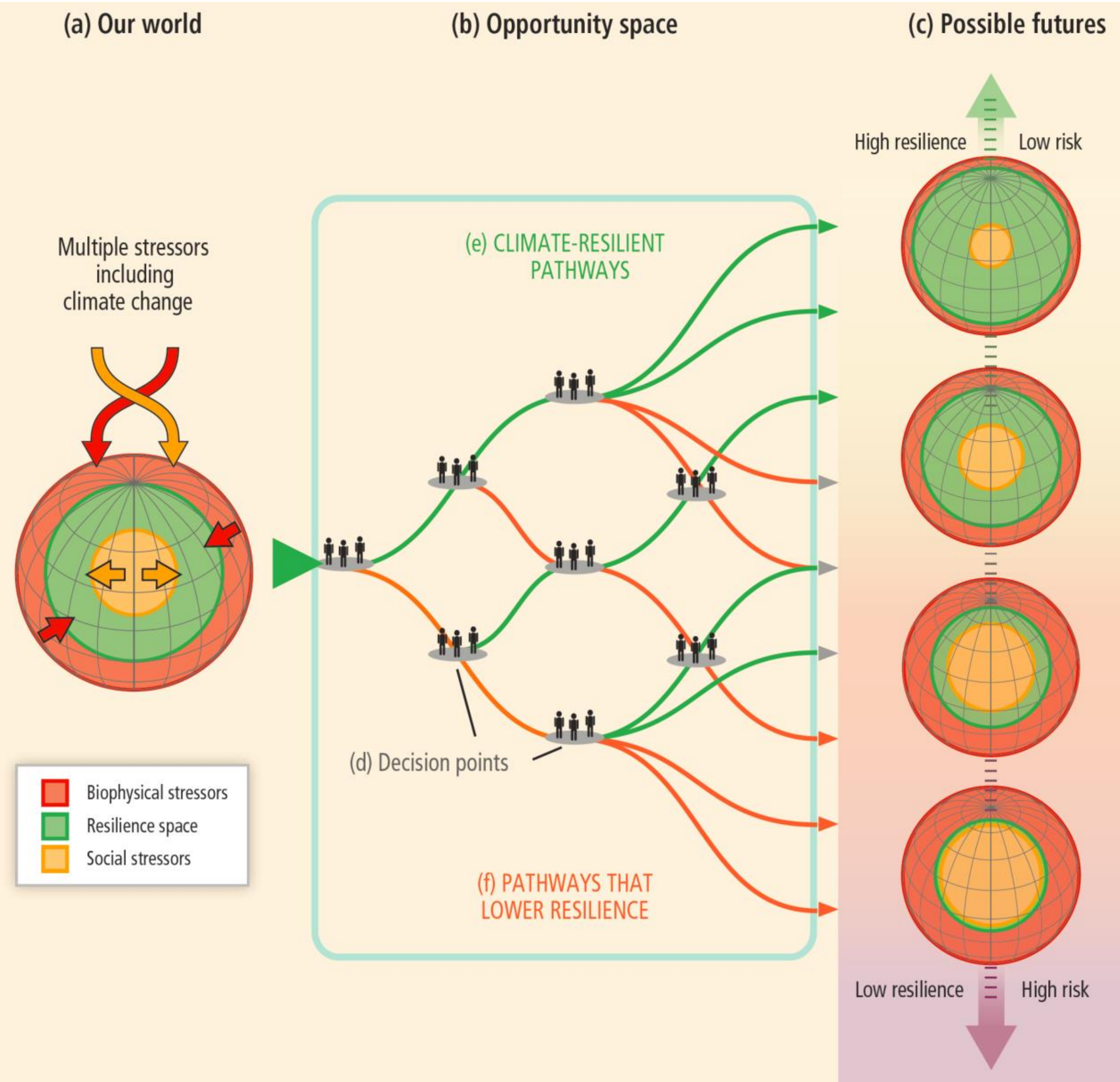


Figure 3.5: Opportunity space and climate-resilient pathways. (a) Our world [A-1, B-1] is threatened by multiple stressors that impinge on resilience from many directions, represented here simply as biophysical and social stressors. Stressors include climate change, climate variability, land-use change,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

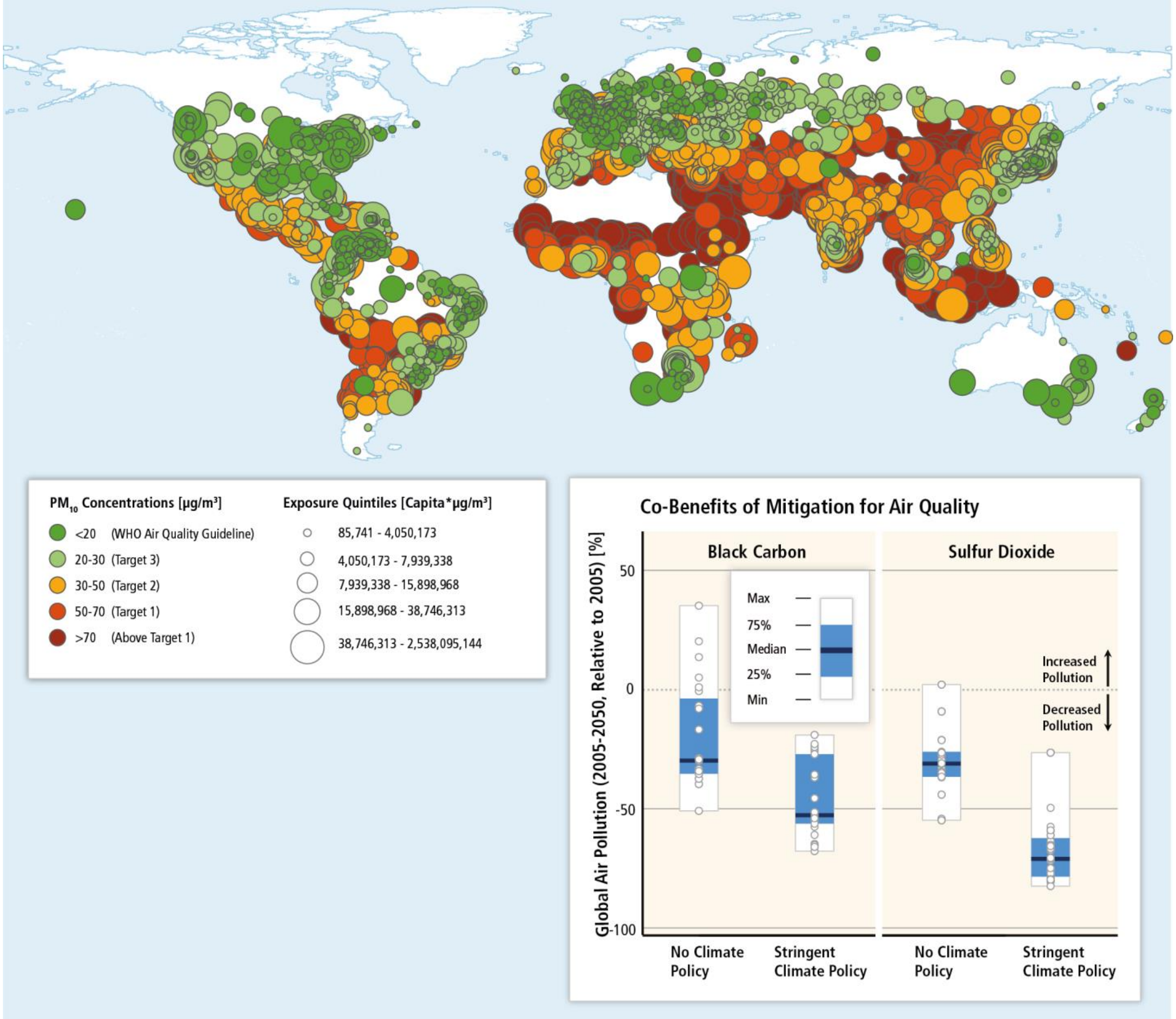
insufficient mitigation, maladaptation, failure to learn and use knowledge, and other actions that lower resilience; and they can be irreversible in terms of possible futures. *{WGII Figure SPM.9}*

Box 3.1: Co-benefits

A government policy or a measure intended to achieve one objective often affects other objectives (for example, mitigation policies can influence local air quality; Box 3.1, Figure 1 for urban air pollution levels). When the effects are positive they are called 'co-benefits', also referred to as 'ancillary benefits'. Negative effects are referred to as 'adverse side-effects', and the lack of capacity to better manage the impacts of current climate variability is often referred to as the "adaptation deficit". Some measures are labelled 'no regret' when their co-benefits are sufficient to justify their implementation, even in the absence of immediate direct benefits. *{WG II 17.2, 17.3}* Co-benefits and adverse side-effects are most often measured in non-monetary units. Their effect on overall social welfare has not yet been quantitatively examined, with exception of a few recent multi-objective studies. It has been shown that both co-benefits or adverse side-effects depend on local circumstances and implementation rate, scale and practices.

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

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



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

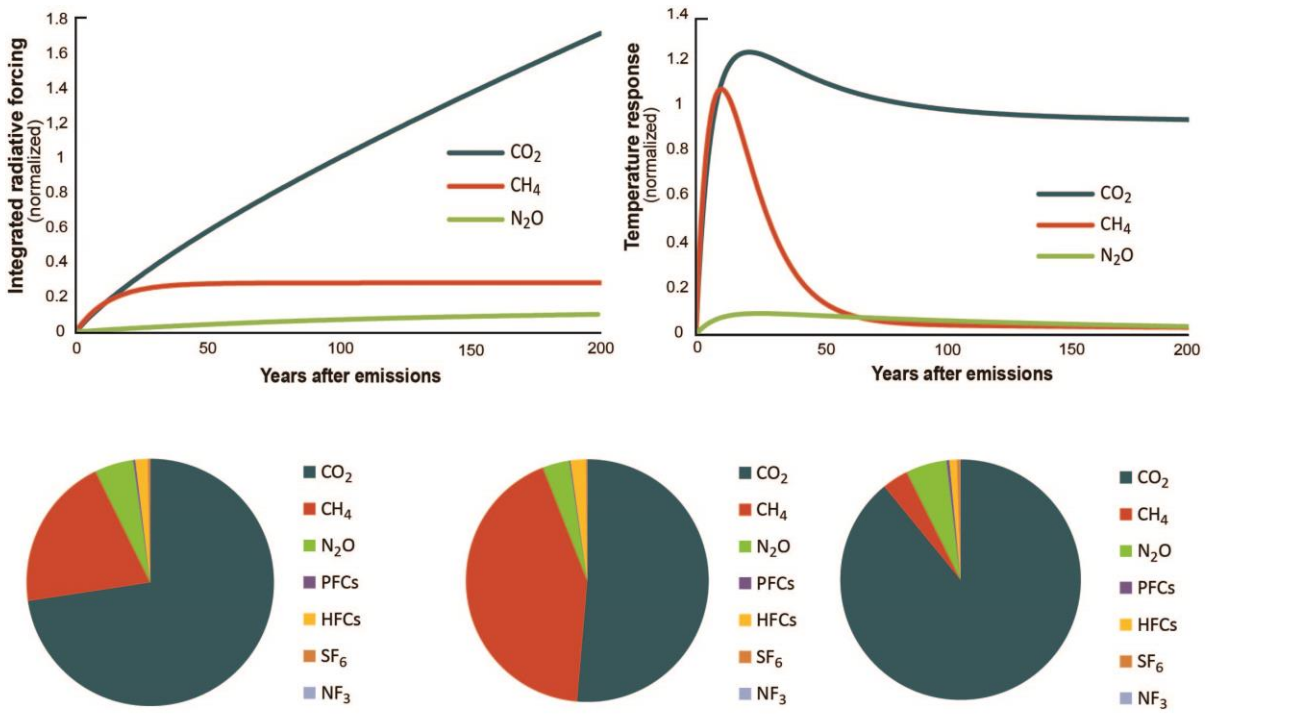
Box 3.2: GHG metrics and transformation pathways

Emission metrics underpin multi-component climate policies by allowing emissions of different GHGs and other forcing agents to be expressed in a common unit ("CO_2equivalents"). The Global Warming Potential (GWP) was introduced in the FAR to illustrate difficulties in comparing components with differing physical properties using a single metric. The 100-year GWP was adopted by the UNFCCC and its Kyoto Protocol and is now used widely as default metric, including in successive IPCC reports, to compare climate effects of different emissions and allow substitution among gases. Alternative metrics have been proposed and a suite of metrics is assessed. *{WG I 8.7; WG III 3.9}*

The choice of metric and time horizon depends on application and policy context and no recommendations are given here. All metrics have shortcomings, and choices contain value judgments, such as the climate effect considered and the weighting of effects over time (which explicitly or implicitly discounts impacts over time), the climate policy goal, and the degree to which metrics incorporate economic or only physical considerations. Metrics can be applied to emissions as a single basket, or separate metrics could be applied based on contributions of different gases and aerosols to short- and long-term climate change. *{WG I 8.7; WG III 3.9}*

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

The choice of metric affects the timing and emphasis placed on abating short- and long-lived components. For most metrics, global cost differences are small under scenarios of global participation and optimal mitigation pathways, but implications for individual countries and sectors could be more significant (*high agreement, medium evidence*). Alternative metrics and time horizons significantly affect the calculated contributions from various components and sources (Box 3.2, Figure 1, Panel B). Metrics that consistently result in less abatement of short-lived components than GWP_{100} (e.g. GTP_{100}) would require earlier and more stringent CO_2-abatement to achieve the same climate outcome and would increase net global mitigation costs. By contrast, using a time-dependent metric such as a dynamic GTP instead of GWP_{100} leads to less CH_4 mitigation in the near-term but more in the long-term. This implies that for some (short-lived) gases, the metric choice influences abatement technology development, the choice of policies, and the timing of mitigation (especially for sectors with high non-CO_2 emissions). The impacts of metric choice on the global CO_2 emission reduction profile and global mitigation costs in most studies are small and depend on policy goals and model assumptions. Given the long response time of CO_2, its emissions must fall to very low levels, regardless of the choice of metric, for any stabilization scenario. *{WG I 6.1, 12.5; WG III 6.3}*



Box 3.2, Figure 1: Implications of metric choices on the weighting of greenhouse gas emissions and contributions by gases. Upper panel (A): integrated radiative forcing (left panel) and warming resulting at a given future point in time (right panel), from global emissions of CO_2, CH_4 and N_2O in the year 2010, for time horizons up to 200 years. Integrated radiative forcing is used in the calculation of Global Warming Potentials (GWP), while the warming at a future point in time is used in the calculation of Global Temperature change Potentials (GTP). Radiative forcing and warming were calculated based on global 2010 emissions data from WGIII-5.2 and absolute Global Warming Potentials and absolute Global Temperature change Potentials from WGI-8.7, normalized to the integrated radiative forcing and warming, respectively, after 100 years due to 2010 CO_2 emissions. Lower panel (B): contributions of different gases (regulated by the Kyoto Protocol) to total CO_2eqquivalent global greenhouse gas emissions in the year 2010, calculated using 100-year GWP (left), 20-year GWP (middle) or 100-year GTP (right).

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

Geoengineering refers to a broad set of methods that aim to alter the climate system in order to reduce climate change and some impacts. There are two clusters of technologies: Carbon Dioxide Reduction (CDR) aims to slow or reverse increases in atmospheric CO_2 concentrations. Solar Radiation Management (SRM) aims to counter the warming by reducing the amount of sunlight absorbed by the climate system. *{WG I 6.5, 7.7, WG II Box 20-4, WGIII 6.9}*

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

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

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

Numerous side-effects, risks and shortcomings from SRM have been identified. SRM would produce an inexact spatial compensation for the RF by GHGs. Several lines of evidence indicate that SRM would itself decrease global precipitation. Another side-effect is that stratospheric aerosol SRM is likely to deplete ozone in the polar stratosphere. SRM would not prevent the negative effects of CO_2 on ecosystems and ocean acidification. There could also be other unanticipated consequences. *{WG I 7.6, 7.7; WG II 6.4, 19.5; WG III 6.9}* As long as GHG concentrations continue to increase, SRM would need to increase commensurately, which would exacerbate side-effects. Additionally, there is *high confidence* that if SRM were increased to substantial levels and then stopped, surface temperatures would rise rapidly (within a decade or two). This would stress systems that are sensitive to the rate of warming. *{WG I 7.7; WG II 4.4, 6.1, 6.3}*