参考資料３－６

Summary for Policymakers

SPM

Summary for Policymakers

Drafting Authors:

Ottmar Edenhofer (Germany), Ramón Pichs-Madruga (Cuba), Youba Sokona (Mali), Shardul Agrawala (France), Igor Alexeyevich Bashmakov (Russia), Gabriel Blanco (Argentina), John Broome (UK), Thomas Bruckner (Germany), Steffen Brunner (Germany), Mercedes Bustamante (Brazil), Leon Clarke (USA), Felix Creutzig (Germany), Shobhakar Dhakal (Nepal/Thailand), Navroz K. Dubash (India), Patrick Eickemeier (Germany), Ellie Farahani (Canada), Manfred Fischedick (Germany), Marc Fleurbaey (France), Reyer Gerlagh (Netherlands), Luis Gómez-Echeverri (Colombia/Austria), Sujata Gupta (India/Philippines), Jochen Harnisch (Germany), Kejun Jiang (China), Susanne Kadner (Germany), Sivan Kartha (USA), Stephan Klasen (Germany), Charles Kolstad (USA), Volker Krey (Austria/Germany), Howard Kunreuther (USA), Oswaldo Lucon (Brazil), Omar Masera (México), Jan Minx (Germany), Yacob Mulugetta (UK/Ethiopia), Anthony Patt (Austria/Switzerland), Nijavalli H. Ravindranath (India), Keywan Riahi (Austria), Joyashree Roy (India), Roberto Schaeffer (Brazil), Steffen Schlömer (Germany), Karen Seto (USA), Kristin Seyboth (USA), Ralph Sims (New Zealand), Jim Skea (UK), Pete Smith (UK), Eswaran Somanathan (India), Robert Stavins (USA), Christoph von Stechow (Germany), Thomas Sterner (Sweden), Taishi Sugiyama (Japan), Sangwon Suh (Republic of Korea/USA), Kevin Chika Urama (Nigeria/UK), Diana Ürge-Vorsatz (Hungary), David Victor (USA), Dadi Zhou (China), Ji Zou (China), Timm Zwickel (Germany)

Draft Contributing Authors

Giovanni Baiocchi (UK/Italy), Helena Chum (USA/Brazil), Jan Fuglestvedt (Norway), Helmut Haberl (Austria), Edgar Hertwich (Norway/Austria), Elmar Kriegler (Germany), Joeri Rogelj (Switzerland/Belgium), H.-Holger Rogner (Germany), Michiel Schaeffer (Netherlands), Steven J. Smith (USA), Detlef van Vuuren (Netherlands), Ryan Wiser (USA)

This Summary for Policymakers should be cited as:

IPCC, 2014: Summary for Policymakers, In: Climate Change 2014, Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Table of Contents

SPM.1 Introduction

The Working Group III contribution to the IPCC's Fifth Assessment Report (AR5) assesses literature on the scientific, technological, environmental, economic and social aspects of mitigation of climate change. It builds upon the Working Group III contribution to the IPCC's Fourth Assessment Report (AR4), the Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) and previous reports and incorporates subsequent new findings and research. The report also assesses mitigation options at different levels of governance and in different economic sectors, and the societal implications of different mitigation policies, but does not recommend any particular option for mitigation.

This Summary for Policymakers (SPM) follows the structure of the Working Group III report. The narrative is supported by a series of highlighted conclusions which, taken together, provide a concise summary. The basis for the SPM can be found in the chapter sections of the underlying report and in the Technical Summary (TS). References to these are given in square brackets.

The degree of certainty in findings in this assessment, as in the reports of all three Working Groups, is based on the author teams' evaluations of underlying scientific understanding and is expressed as a qualitative level of confidence (from very low to very high) and, when possible, probabilistically with a quantified likelihood (from exceptionally unlikely to virtually certain). Confidence in the validity of a finding is based on the type, amount, quality, and consistency of evidence (e.g., data, mechanistic understanding, theory, models, expert judgment) and the degree of agreement.[1] Probabilistic estimates of quantified measures of uncertainty in a finding are based on statistical analysis of observations or model results, or both, and expert judgment.[2] Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers. Within paragraphs of this summary, the confidence, evidence, and agreement terms given for a bolded finding apply to subsequent statements in the paragraph, unless additional terms are provided.

SPM.2 Approaches to climate change mitigation

Mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases. Mitigation, together with adaptation to climate change, contributes to the objective expressed in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC):

> *The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.*

Climate policies can be informed by the findings of science, and systematic methods from other disciplines. [1.2, 2.4, 2.5, Box 3.1]

---

[1] The following summary terms are used to describe the available evidence: limited, medium, or robust; and for the degree of agreement: low, medium, or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high, and very high, and typeset in italics, e.g., *medium confidence*. For a given evidence and agreement statement, different confidence levels can be assigned, but increasing levels of evidence and degrees of agreement are correlated with increasing confidence. For more details, please refer to the guidance note for Lead Authors of the IPCC Fifth Assessment Report on consistent treatment of uncertainties.

[2] The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100 % probability, very likely 90–100 %, likely 66–100 %, about as likely as not 33–66 %, unlikely 0–33 %, very unlikely 0–10 %, exceptionally unlikely 0–1 %. Additional terms (more likely than not >50–100 %, and more unlikely than likely 0–<50 %) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*.

Sustainable development and equity provide a basis for assessing climate policies and highlight the need for addressing the risks of climate change.[3] Limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication. At the same time, some mitigation efforts could undermine action on the right to promote sustainable development, and on the achievement of poverty eradication and equity. Consequently, a comprehensive assessment of climate policies involves going beyond a focus on mitigation and adaptation policies alone to examine development pathways more broadly, along with their determinants. [4.2, 4.3, 4.4, 4.5, 4.6, 4.8]

Effective mitigation will not be achieved if individual agents advance their own interests independently. Climate change has the characteristics of a collective action problem at the global scale, because most greenhouse gases (GHGs) accumulate over time and mix globally, and emissions by any agent (e.g., individual, community, company, country) affect other agents.[4] International cooperation is therefore required to effectively mitigate GHG emissions and address other climate change issues [1.2.4, 2.6.4, 3.2, 4.2, 13.2, 13.3]. Furthermore, research and development in support of mitigation creates knowledge spillovers. International cooperation can play a constructive role in the development, diffusion and transfer of knowledge and environmentally sound technologies [1.4.4, 3.11.6, 11.8, 13.9, 14.4.3].

Issues of equity, justice, and fairness arise with respect to mitigation and adaptation.[5] 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. The evidence suggests that outcomes seen as equitable can lead to more effective cooperation. [3.10, 4.2.2, 4.6.2]

Many areas of climate policy-making involve value judgements and ethical considerations. These areas range from the question of how much mitigation is needed to prevent dangerous interference with the climate system to choices among specific policies for mitigation or adaptation [3.1, 3.2]. Social, economic and ethical analyses may be used to inform value judgements and may take into account values of various sorts, including human wellbeing, cultural values and non-human values [3.4, 3.10].

Among other methods, economic evaluation is commonly used to inform climate policy design. Practical tools for economic assessment include cost-benefit analysis, cost-effectiveness analysis, multi-criteria analysis and expected utility theory [2.5]. The limitations of these tools are well-documented [3.5]. Ethical theories based on social welfare functions imply that distributional weights, which take account of the different value of money to different people, should be applied to monetary measures of benefits and harms [3.6.1, Box TS.2]. Whereas distributional weighting has not frequently been applied for comparing the effects of climate policies on different people at a single time, it is standard practice, in the form of discounting, for comparing the effects at different times [3.6.2].

Climate policy intersects with other societal goals creating the possibility of co-benefits or adverse side-effects. These intersections, if well-managed, can strengthen the basis for undertaking climate action. Mitigation and adaptation can positively or negatively influence the achievement of other societal goals, such as those related to human health, food security, biodiversity, local environmental quality, energy access, livelihoods, and equitable sustainable development; and vice versa, policies toward other societal goals can influence the achievement of mitigation and adaptation objectives [4.2, 4.3, 4.4, 4.5, 4.6, 4.8]. These influences can be substantial, although sometimes difficult to quantify, especially in welfare terms [3.6.3]. This multi-objective perspective is important in part because it helps to identify areas where support for policies that advance multiple goals will be robust [1.2.1, 4.2, 4.8, 6.6.1].

---

[3] See WGII AR5 SPM.

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

[5] See FAQ 3.2 for clarification of these concepts. The philosophical literature on justice and other literature can illuminate these issues [3.2, 3.3, 4.6.2].

Climate policy may be informed by a consideration of a diverse array of risks and uncertainties, some of which are difficult to measure, notably events that are of low probability but which would have a significant impact if they occur. Since AR4, the scientific literature has examined risks related to climate change, adaptation, and mitigation strategies. Accurately estimating 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*) [2.5, 2.6, Box 3.9]. The choice of mitigation actions is also influenced by uncertainties in many socio-economic variables, including the rate of economic growth and the evolution of technology *(high confidence*) [2.6, 6.3].

The design of climate policy is influenced by how individuals and organizations perceive risks and uncertainties and take them into account. People often utilize simplified decision rules such as a preference for the status quo. Individuals and organizations differ in their degree of risk aversion and the relative importance placed on near-term versus long-term ramifications of specific actions [2.4]. With the help of formal methods, policy design can be improved by taking into account risks and uncertainties in natural, socio-economic, and technological systems as well as decision processes, perceptions, values and wealth [2.5].

SPM.3 Trends in stocks and flows of greenhouse gases and their drivers

Total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute decadal increases toward the end of this period (*high confidence*). Despite a growing number of climate change mitigation policies, annual GHG emissions grew on average by 1.0 gigatonne carbon dioxide equivalent ($GtCO_2eq$) (2.2 %) per year from 2000 to 2010 compared to 0.4 $GtCO_2eq$ (1.3 %) per year from 1970 to 2000 (Figure SPM.1).[6,7] Total anthropogenic GHG emissions were the highest in human history from 2000 to 2010 and reached 49 (±4.5) $GtCO_2eq$/yr in 2010. The global economic crisis 2007/2008 only temporarily reduced emissions. [1.3, 5.2, 13.3, 15.2.2, Box TS.5, Figure 15.1]

CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78 % of the total GHG emission increase from 1970 to 2010, with a similar percentage contribution for the period 2000–2010 (*high confidence*)**.** Fossil fuel-related CO_2 emissions reached 32 (±2.7) $GtCO_2$/yr, in 2010, and grew further by about 3 % between 2010 and 2011 and by about 1–2 % between 2011 and 2012. Of the 49 (±4.5) $GtCO_2eq$/yr in total anthropogenic GHG emissions in 2010, CO_2 remains the major anthropogenic GHG accounting for 76 % (38±3.8 $GtCO_2eq$/yr) of total anthropogenic GHG emissions in 2010. 16 % (7.8±1.6 $GtCO_2eq$/yr) come from methane (CH_4), 6.2 % (3.1±1.9 $GtCO_2eq$/yr) from nitrous oxide (N_2O), and 2.0 % (1.0±0.2 $GtCO_2eq$/yr) from fluorinated gases (Figure SPM.1). Annually, since 1970, about 25 % of anthropogenic GHG emissions have been in the form of non-CO_2 gases.[8] [1.2, 5.2]

---

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

[7] In this SPM, uncertainty in historic GHG emission data is reported using 90 % uncertainty intervals unless otherwise stated. GHG emission levels are rounded to two significant digits throughout this document; as a consequence, small differences in sums due to rounding may occur.

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

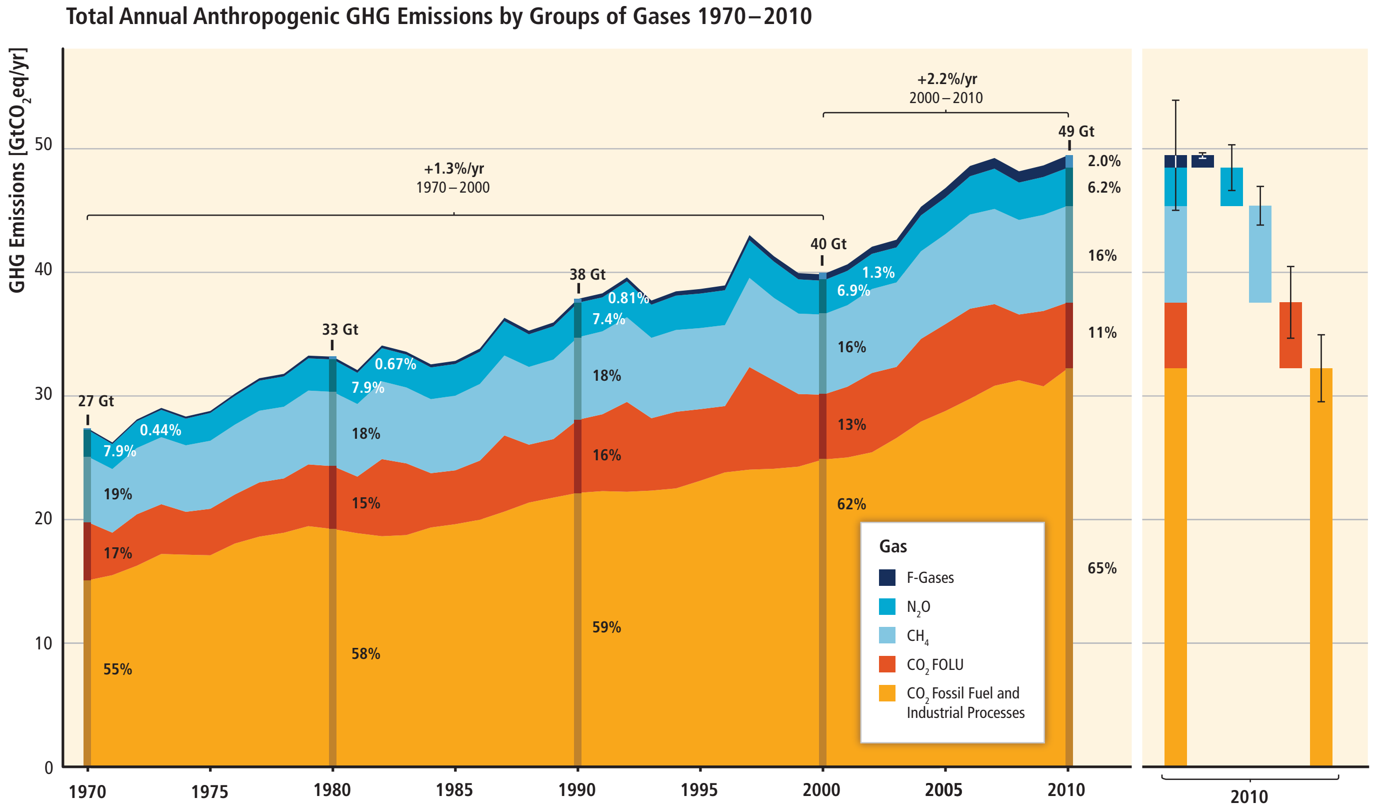


Figure SPM.1 | Total annual anthropogenic GHG emissions (GtCO$_2$eq/yr) by groups of gases 1970–2010: CO$_2$ from fossil fuel combustion and industrial processes; CO$_2$ from Forestry and Other Land Use (FOLU); methane (CH$_4$); nitrous oxide (N$_2$O); fluorinated gases[8] covered under the Kyoto Protocol (F-gases). At the right side of the figure GHG emissions in 2010 are shown again broken down into these components with the associated uncertainties (90 % confidence interval) indicated by the error bars. Total anthropogenic GHG emissions uncertainties are derived from the individual gas estimates as described in Chapter 5 [5.2.3.6]. Global CO$_2$ emissions from fossil fuel combustion are known within 8 % uncertainty (90 % confidence interval). CO$_2$ emissions from FOLU have very large uncertainties attached in the order of ±50 %. Uncertainty for global emissions of CH$_4$, N$_2$O and the F-gases has been estimated as 20 %, 60 % and 20 %, respectively. 2010 was the most recent year for which emission statistics on all gases as well as assessment of uncertainties were essentially complete at the time of data cut-off for this report. Emissions are converted into CO$_2$-equivalents based on GWP$_{100}$[6] from the IPCC Second Assessment Report. The emission data from FOLU represents land-based CO$_2$ emissions from forest fires, peat fires and peat decay that approximate to net CO$_2$ flux from the FOLU as described in chapter 11 of this report. Average annual growth rate over different periods is highlighted with the brackets. [Figure 1.3, Figure TS.1]

About half of cumulative anthropogenic CO$_2$ emissions between 1750 and 2010 have occurred in the last 40 years (*high confidence*). In 1970, cumulative CO$_2$ emissions from fossil fuel combustion, cement production and flaring since 1750 were 420±35 GtCO$_2$; in 2010, that cumulative total had tripled to 1300±110 GtCO$_2$ (Figure SPM.2). Cumulative CO$_2$ emissions from Forestry and Other Land Use (FOLU)[9] since 1750 increased from 490±180 GtCO$_2$ in 1970 to 680±300 GtCO$_2$ in 2010. [5.2]

---

[9] Forestry and Other Land Use (FOLU)—also referred to as LULUCF (Land Use, Land-Use Change, and Forestry)—is the subset of Agriculture, Forestry and Other Land Use (AFOLU) emissions and removals of GHGs related to direct human-induced land use, land-use change and forestry activities excluding agricultural emissions and removals (see WGIII AR5 Glossary).

Annual anthropogenic GHG emissions have increased by 10 $GtCO_2eq$ between 2000 and 2010, with this increase directly coming from energy supply (47 %), industry (30 %), transport (11 %) and buildings (3 %) sectors (*medium confidence*)**. Accounting for indirect emissions raises the contributions of the buildings and industry sectors** (*high confidence*)**.** Since 2000, GHG emissions have been growing in all sectors, except AFOLU. Of the 49 (±4.5) $GtCO_2eq$ emissions in 2010, 35 % (17 $GtCO_2eq$) of GHG emissions were released in the energy supply sector, 24 % (12 $GtCO_2eq$, net emissions) in AFOLU, 21 % (10 $GtCO_2eq$) in industry, 14 % (7.0 $GtCO_2eq$) in transport and 6.4 % (3.2 $GtCO_2eq$) in buildings. When emissions from electricity and heat production are attributed to the sectors that use the final energy (i. e. indirect emissions), the shares of the industry and buildings sectors in global GHG emissions are increased to 31 % and 19 %[7], respectively (Figure SPM.2). [7.3, 8.2, 9.2, 10.3, 11.2]

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

Greenhouse Gas Emissions by Economic Sectors

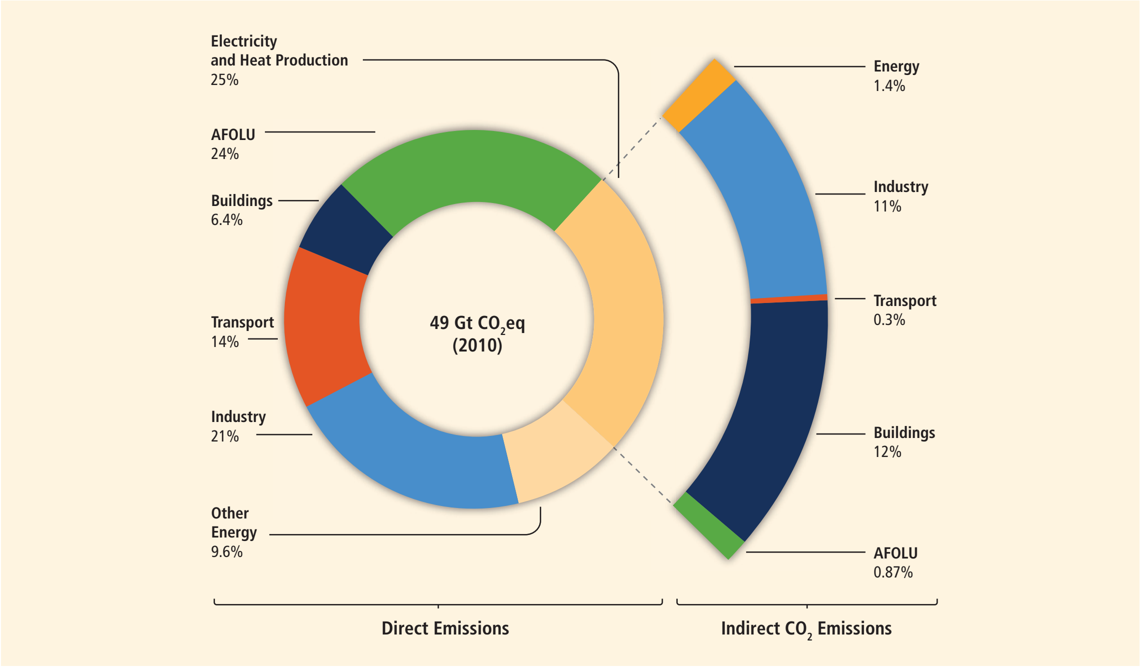


Figure SPM.2 | Total anthropogenic GHG emissions ($GtCO_2eq/yr$) by economic sectors. Inner circle shows direct GHG emission shares (in % of total anthropogenic GHG emissions) of five economic sectors in 2010. Pull-out shows how indirect CO_2 emission shares (in % of total anthropogenic GHG emissions) from electricity and heat production are attributed to sectors of final energy use. 'Other Energy' refers to all GHG emission sources in the energy sector as defined in Annex II other than electricity and heat production [A.II.9.1]. The emissions data from Agriculture, Forestry and Other Land Use (AFOLU) includes land-based CO_2 emissions from forest fires, peat fires and peat decay that approximate to net CO_2 flux from the Forestry and Other Land Use (FOLU) sub-sector as described in Chapter 11 of this report. Emissions are converted into CO_2-equivalents based on GWP_{100}[6] from the IPCC Second Assessment Report. Sector definitions are provided in Annex II.9. [Figure 1.3a, Figure TS.3 a/b]

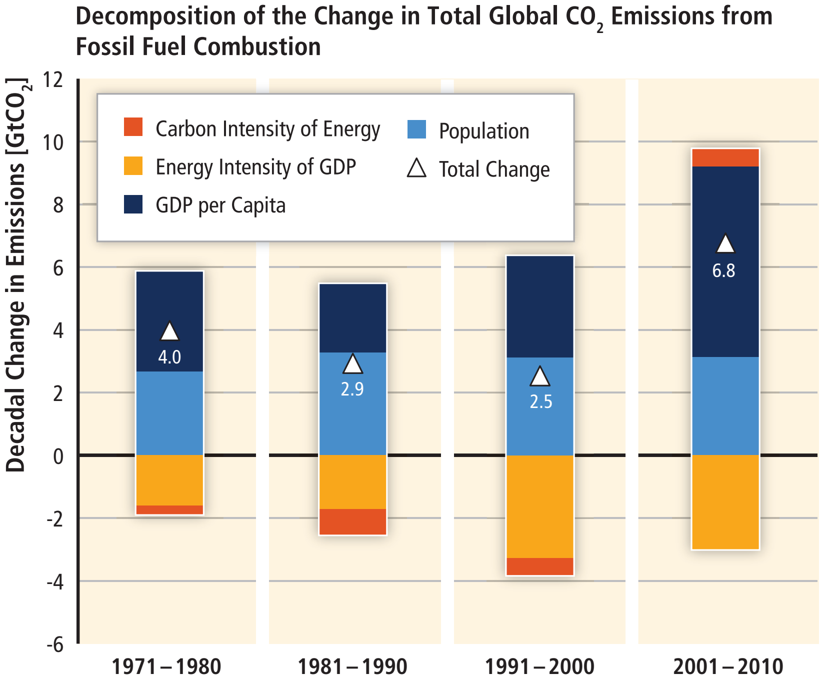


Figure SPM.3 | Decomposition of the decadal change in total global CO_2 emissions from fossil fuel combustion by four driving factors: population, income (GDP) per capita, energy intensity of GDP and carbon intensity of energy. The bar segments show the changes associated with each factor alone, holding the respective other factors constant. Total decadal changes are indicated by a triangle. Changes are measured in gigatonnes (Gt) of CO_2 emissions per decade; income is converted into common units using purchasing power parities. [Figure 1.7]

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. Baseline scenarios, those without additional mitigation, result in global mean surface temperature increases in 2100 from 3.7 °C to 4.8 °C compared to pre-industrial levels[10] (median values; the range is 2.5 °C to 7.8 °C when including climate uncertainty, see Table SPM.1)[11] (*high confidence*)**.** The emission scenarios collected for this assessment represent full radiative forcing including GHGs, tropospheric ozone, aerosols and albedo change. Baseline scenarios (scenarios without explicit additional efforts to constrain emissions) exceed 450 parts per million (ppm) CO_2eq by 2030 and reach CO_2eq concentration levels between 750 and more than 1300 ppm CO_2eq by 2100. This is similar to the range in atmospheric concentration levels between the RCP 6.0 and RCP 8.5 pathways in 2100.[12] For comparison, the CO_2eq concentration in 2011 is estimated to be 430 ppm (uncertainty range 340–520 ppm)[13]. [6.3, Box TS.6; WGI Figure SPM.5, WGI 8.5, WGI 12.3]

---

[10] Based on the longest global surface temperature dataset available, the observed change between the average of the period 1850–1900 and of the AR5 reference period (1986–2005) is 0.61 °C (5–95 % confidence interval: 0.55–0.67 °C) [WGI SPM.E], which is used here as an approximation of the change in global mean surface temperature since pre-industrial times, referred to as the period before 1750.

[11] The climate uncertainty reflects the 5th to 95th percentile of climate model calculations described in Table SPM.1.

[12] For the purpose of this assessment, roughly 300 baseline scenarios and 900 mitigation scenarios were collected through an open call from integrated modelling teams around the world. These scenarios are complementary to the Representative Concentration Pathways (RCPs, see WGIII AR5 Glossary). The RCPs are identified by their approximate total radiative forcing in year 2100 relative to 1750: 2.6 Watts per square meter (W m^{-2}) for RCP2.6, 4.5 W m^{-2} for RCP4.5, 6.0 W m^{-2} for RCP6.0, and 8.5 W m^{-2} for RCP8.5. The scenarios collected for this assessment span a slightly broader range of concentrations in the year 2100 than the four RCPs.

[13] This is based on the assessment of total anthropogenic radiative forcing for 2011 relative to 1750 in WGI, i.e. 2.3 W m^{-2}, uncertainty range 1.1 to 3.3 W m^{-2}. [WGI Figure SPM.5, WGI 8.5, WGI 12.3]

SPM.4 Mitigation pathways and measures in the context of sustainable development

SPM.4.1 Long-term mitigation pathways

There are multiple scenarios with a range of technological and behavioral options, with different characteristics and implications for sustainable development, that are consistent with different levels of mitigation. For this assessment, about 900 mitigation scenarios have been collected in a database based on published integrated models.[14] This range spans atmospheric concentration levels in 2100 from 430 ppm CO_2eq to above 720 ppm CO_2eq, which is comparable to the 2100 forcing levels between RCP 2.6 and RCP 6.0. Scenarios outside this range were also assessed including some scenarios with concentrations in 2100 below 430 ppm CO_2eq (for a discussion of these scenarios see below). The mitigation scenarios involve a wide range of technological, socioeconomic, and institutional trajectories, but uncertainties and model limitations exist and developments outside this range are possible (Figure SPM.4, top panel). [6.1, 6.2, 6.3, TS.3.1, Box TS.6]

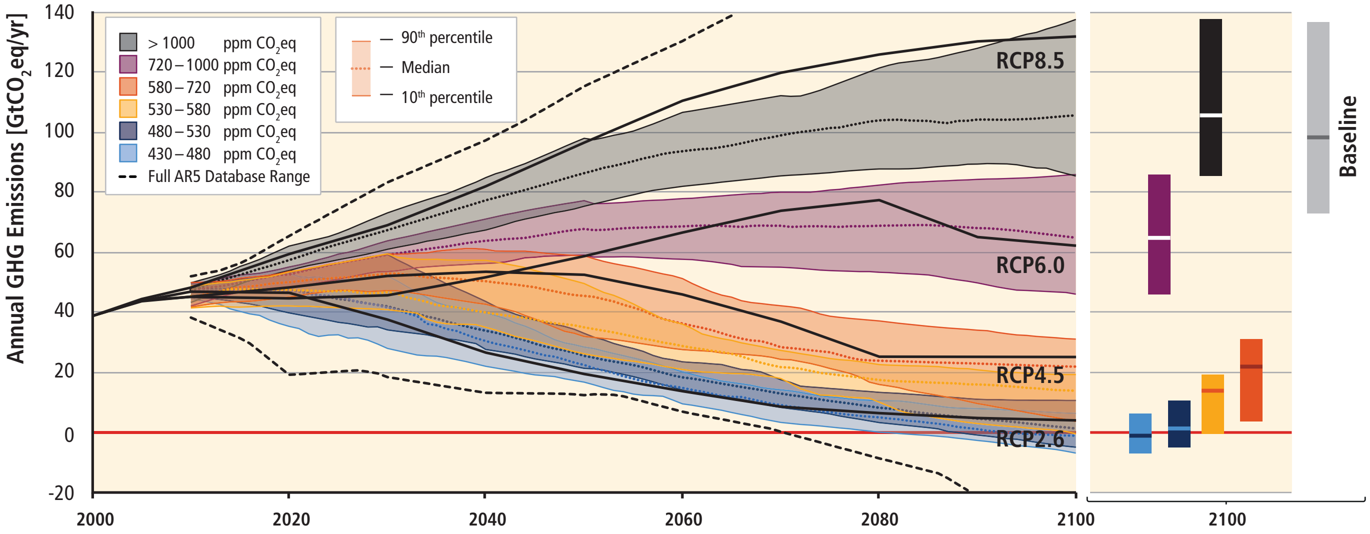
Mitigation scenarios in which it is *likely* that the temperature change caused by anthropogenic GHG emissions can be kept to less than 2 °C relative to pre-industrial levels are characterized by atmospheric concentrations in 2100 of about 450 ppm CO_2eq (*high confidence*)**.** Mitigation scenarios 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 relative to pre-industrial levels, unless they temporarily 'overshoot' concentration levels of roughly 530 ppm CO_2eq before 2100, in which case they are *about as likely as not* to achieve that goal.[15] Scenarios that reach 530 to 650 ppm CO_2eq concentrations by 2100 are *more unlikely than likely* to keep temperature change below 2 °C relative to pre-industrial levels. Scenarios that exceed about 650 ppm CO_2eq by 2100 are *unlikely* to limit temperature change to below 2 °C relative to pre-industrial levels. Mitigation scenarios in which temperature increase is *more likely than not* to be less than 1.5 °C relative to pre-industrial levels 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. Probability statements regarding other levels of temperature change can be made with reference to Table SPM.1. [6.3, Box TS.6]

---

[14] The long-term scenarios assessed in WGIII were generated primarily by large-scale, integrated models that project many key characteristics of mitigation pathways to mid-century and beyond. These models link many important human systems (e.g., energy, agriculture and land use, economy) with physical processes associated with climate change (e.g., the carbon cycle). The models approximate cost-effective solutions that minimize the aggregate economic costs of achieving mitigation outcomes, unless they are specifically constrained to behave otherwise. They are simplified, stylized representations of highly-complex, real-world processes, and the scenarios they produce are based on uncertain projections about key events and drivers over often century-long timescales. Simplifications and differences in assumptions are the reason why output generated from different models, or versions of the same model, can differ, and projections from all models can differ considerably from the reality that unfolds. [Box TS.7, 6.2]

[15] Mitigation scenarios, including those reaching 2100 concentrations as high as or higher than 550 ppm CO_2eq, can temporarily 'overshoot' atmospheric CO_2eq concentration levels before descending to lower levels later. Such concentration overshoot involves less mitigation in the near term with more rapid and deeper emissions reductions in the long run. Overshoot increases the probability of exceeding any given temperature goal. [6.3, Table SPM.1]

GHG Emission Pathways 2000–2100: All AR5 Scenarios



Associated Upscaling of Low-Carbon Energy Supply

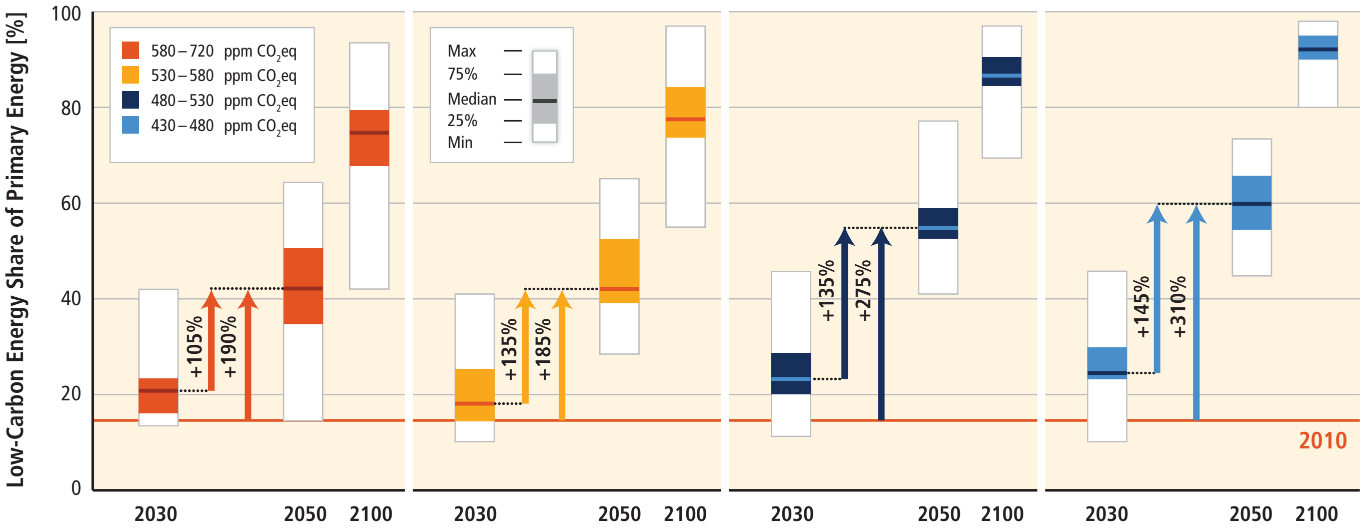


Figure SPM.4| Pathways of global GHG emissions (GtCO$_2$eq/yr) in baseline and mitigation scenarios for different long-term concentration levels (upper panel) and associated upscaling requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100 compared to 2010 levels in mitigation scenarios (lower panel). The lower panel excludes scenarios with limited technology availability and exogenous carbon price trajectories. For definitions of CO$_2$-equivalent emissions and CO$_2$-equivalent concentrations see the WGIII AR5 Glossary. [Figure 6.7, Figure 7.16]

Table SPM.1 | Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters, the 10th to 90th percentile of the scenarios is shown.[1, 2] [Table 6.3]

CO_2eq Concentrations in 2100 (CO_2eq) Category label (concentration range)[9]	Subcategories	Relative position of the RCPs[5]	Cumulative CO_2 emissions[3] ($GtCO_2$)		Change in CO_2eq emissions compared to 2010 in (%)[4]		Temperature change (relative to 1850–1900)[5, 6]				
			2011–2050	2011–2100	2050	2100	2100 Temperature change (°C)[7]	Likelihood of staying below temperature level over the 21st century[8]			
								1.5 °C	2.0 °C	3.0 °C	4.0 °C
< 430	Only a limited number of individual model studies have explored levels below 430 ppm CO_2eq										
450 (430–480)	Total range[1, 10]	RCP2.6	550–1300	630–1180	−72 to −41	−118 to −78	1.5–1.7 (1.0–2.8)	More unlikely than likely	Likely	Likely	Likely
500 (480–530)	No overshoot of 530 ppm CO_2eq		860–1180	960–1430	−57 to −42	−107 to −73	1.7–1.9 (1.2–2.9)	Unlikely	More likely than not		
	Overshoot of 530 ppm CO_2eq		1130–1530	990–1550	−55 to −25	−114 to −90	1.8–2.0 (1.2–3.3)		About as likely as not		
550 (530–580)	No overshoot of 580 ppm CO_2eq		1070–1460	1240–2240	−47 to −19	−81 to −59	2.0–2.2 (1.4–3.6)		More unlikely than likely[12]		
	Overshoot of 580 ppm CO_2eq		1420–1750	1170–2100	−16 to 7	−183 to −86	2.1–2.3 (1.4–3.6)				
(580–650)	Total range	RCP4.5	1260–1640	1870–2440	−38 to 24	−134 to −50	2.3–2.6 (1.5–4.2)				
(650–720)	Total range		1310–1750	2570–3340	−11 to 17	−54 to −21	2.6–2.9 (1.8–4.5)		Unlikely	More likely than not	
(720–1000)	Total range	RCP6.0	1570–1940	3620–4990	18 to 54	−7 to 72	3.1–3.7 (2.1–5.8)	Unlikely[11]		More unlikely than likely	
>1000	Total range	RCP8.5	1840–2310	5350–7010	52 to 95	74 to 178	4.1–4.8 (2.8–7.8)		Unlikely[26]	Unlikely	More unlikely than likely

---

[1] The ‘total range’ for the 430–480 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) fall into the >1000 and 720–1000 ppm CO_2eq categories. The latter category also includes 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] For comparison of the cumulative CO_2 emissions estimates assessed here with those presented in WGI, an amount of 515 [445–585] GtC (1890 [1630–2150] $GtCO_2$), was already emitted by 2011 since 1870 [Section WGI 12.5]. Note that cumulative emissions are presented here for different periods of time (2011–2050 and 2011–2100) while cumulative emissions in WGI are presented as total compatible emissions for the RCPs (2012–2100) or for total compatible emissions for remaining below a given temperature target with a given likelihood. [WGI Table SPM.3, WGI SPM.E.8]

[4] 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, CH_4, N_2O as well as F-gases).

[5] The assessment in WGIII involves a large number of scenarios published in the scientific literature and is thus not limited to the RCPs. To evaluate the GHG concentration and climate implications of these scenarios, the MAGICC model was used in a probabilistic mode (see Annex II). For a comparison between MAGICC model results and the outcomes of the models used in WGI, see Section WGI 12.4.1.2 and WGI 12.4.8 and 6.3.2.6. Reasons for differences with WGI SPM Table.2 include the difference in reference year (1986–2005 vs. 1850–1900 here), difference in reporting year (2081–2100 vs 2100 here), set-up of simulation (CMIP5 concentration driven versus MAGICC emission-driven here), and the wider set of scenarios (RCPs versus the full set of scenarios in the WGIII AR5 scenario database here).

[6] Temperature change is reported for the year 2100, which is not directly comparable to the equilibrium warming reported in WGIII AR4 (Table 3.5, Chapter 3). For the 2100 temperature estimates, the transient climate response (TCR) is the most relevant system property. The assumed 90th percentile uncertainty range of the TCR for MAGICC is 1.2–2.6 °C (median 1.8 °C). This compares to the 90th percentile range of TCR between 1.2–2.4 °C for CMIP5 (WGI 9.7) and an assessed likely range of 1–2.5 °C from multiple lines of evidence reported in the IPCC AR5 WGI report (Box 12.2 in chapter 12.5).

[7] Temperature change in 2100 is provided for a median estimate of the MAGICC calculations, which illustrates differences between the emissions pathways of the scenarios in each category. The range of temperature change in the parentheses includes in addition the carbon cycle and climate system uncertainties as represented by the MAGICC model (see 6.3.2.6 for further details). The temperature data compared to the 1850–1900 reference year was calculated by taking all projected warming relative to 1986–2005, and adding 0.61 °C for 1986–2005 compared to 1850–1900, based on HadCRUT4 (see WGI Table SPM.2).

[8] The assessment in this table is based on the probabilities calculated for the full ensemble of scenarios in WGIII using MAGICC and the assessment in WGI of the uncertainty of the temperature projections not covered by climate models. The statements are therefore consistent with the statements in WGI, which are based on the CMIP5 runs of the RCPs and the assessed uncertainties. Hence, the likelihood statements reflect different lines of evidence from both WGs. This WGI method was also applied for scenarios with intermediate concentration levels where no CMIP5 runs are available. The likelihood statements are indicative only (6.3), and 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.

[9] The CO_2-equivalent concentration includes the forcing of all GHGs including halogenated gases and tropospheric ozone, aerosols and albedo change (calculated on the basis of the total forcing from a simple carbon cycle/climate model MAGICC).

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

[11] For scenarios in this category no CMIP5 run (WGI Chapter 12, Table 12.3) as well as no MAGICC realization (6.3) stays below the respective temperature level. Still, an ‘unlikely’ assignment is given to reflect uncertainties that might not be reflected by the current climate models.

[12] Scenarios in the 580–650 ppm CO_2eq category include both overshoot scenarios and scenarios that do not exceed the concentration level at the high end of the category (like RCP4.5). The latter type of scenarios, in general, have an assessed probability of *more unlikely than likely* to exceed the 2 °C temperature level, while the former are mostly assessed to have an *unlikely* probability of exceeding this level.

Scenarios reaching atmospheric concentration levels of about 450 ppm CO_2eq by 2100 (consistent with a *likely* chance to keep temperature change below 2 °C relative to pre-industrial levels) include substantial cuts in anthropogenic GHG emissions by mid-century through large-scale changes in energy systems and potentially land use (*high confidence*)**.** Scenarios reaching these concentrations by 2100 are characterized by lower global GHG emissions in 2050 than in 2010, 40 % to 70 % lower globally[16], and emissions levels near zero GtCO_2eq or below in 2100. In scenarios reaching 500 ppm CO_2eq by 2100, 2050 emissions levels are 25 % to 55 % lower than in 2010 globally. In scenarios reaching 550 ppm CO_2eq, emissions in 2050 are from 5 % above 2010 levels to 45 % below 2010 levels globally (Table SPM.1). At the global level, scenarios reaching 450 ppm CO_2eq are also characterized by more rapid improvements of energy efficiency, 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 SPM.4, lower panel). These scenarios describe a wide range of changes in land use, reflecting different assumptions about the scale of bioenergy production, afforestation, and reduced deforestation. All of these emissions, energy, and land-use changes vary across regions.[17] Scenarios reaching higher concentrations include similar changes, but on a slower timescale. On the other hand, scenarios reaching lower concentrations require these changes on a faster timescale. [6.3, 7.11]

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. Depending on the level of the overshoot, overshoot scenarios typically rely on the availability and widespread deployment of BECCS and afforestation in the second half of the century. 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 (*high confidence*) (see Section SPM.4.2).[18] CDR is also prevalent in many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive. There is only limited evidence on the potential for large-scale deployment of BECCS, large-scale afforestation, and other CDR technologies and methods. [2.6, 6.3, 6.9.1, Figure 6.7, 7.11, 11.13]

Estimated global GHG emissions levels in 2020 based on the Cancún Pledges are not consistent with cost-effective long-term mitigation trajectories that are at least *as likely as not* to limit temperature change to 2 °C relative to pre-industrial levels (2100 concentrations of about 450 and about 500 ppm CO_2eq), but they do not preclude the option to meet that goal (*high confidence*)**.** Meeting this goal would require further substantial reductions beyond 2020. The Cancún Pledges are broadly consistent with cost-effective scenarios that are *likely* to keep temperature change below 3 °C relative to preindustrial levels. [6.4, 13.13, Figure TS.11]

Delaying mitigation efforts beyond those in place today through 2030 is estimated to substantially increase the difficulty of the transition to low longer-term emissions levels and narrow the range of options consistent with maintaining temperature change below 2 °C relative to pre-industrial levels (*high confidence*)**.** Cost-effective mitigation scenarios that make it at least *as likely as not* that temperature change will remain below 2 °C relative to pre-industrial levels (2100 concentrations between about 450 and 500 ppm CO_2eq) are typically characterized by annual GHG emissions in 2030 of roughly between 30 GtCO_2eq and 50 GtCO_2eq (Figure SPM.5, left panel). Scenarios with annual GHG emissions above 55 GtCO_2eq in 2030 are characterized by substantially higher rates of emissions reductions from 2030 to 2050 (Figure SPM.5, middle panel); much more rapid scale-up of low-carbon energy over this period

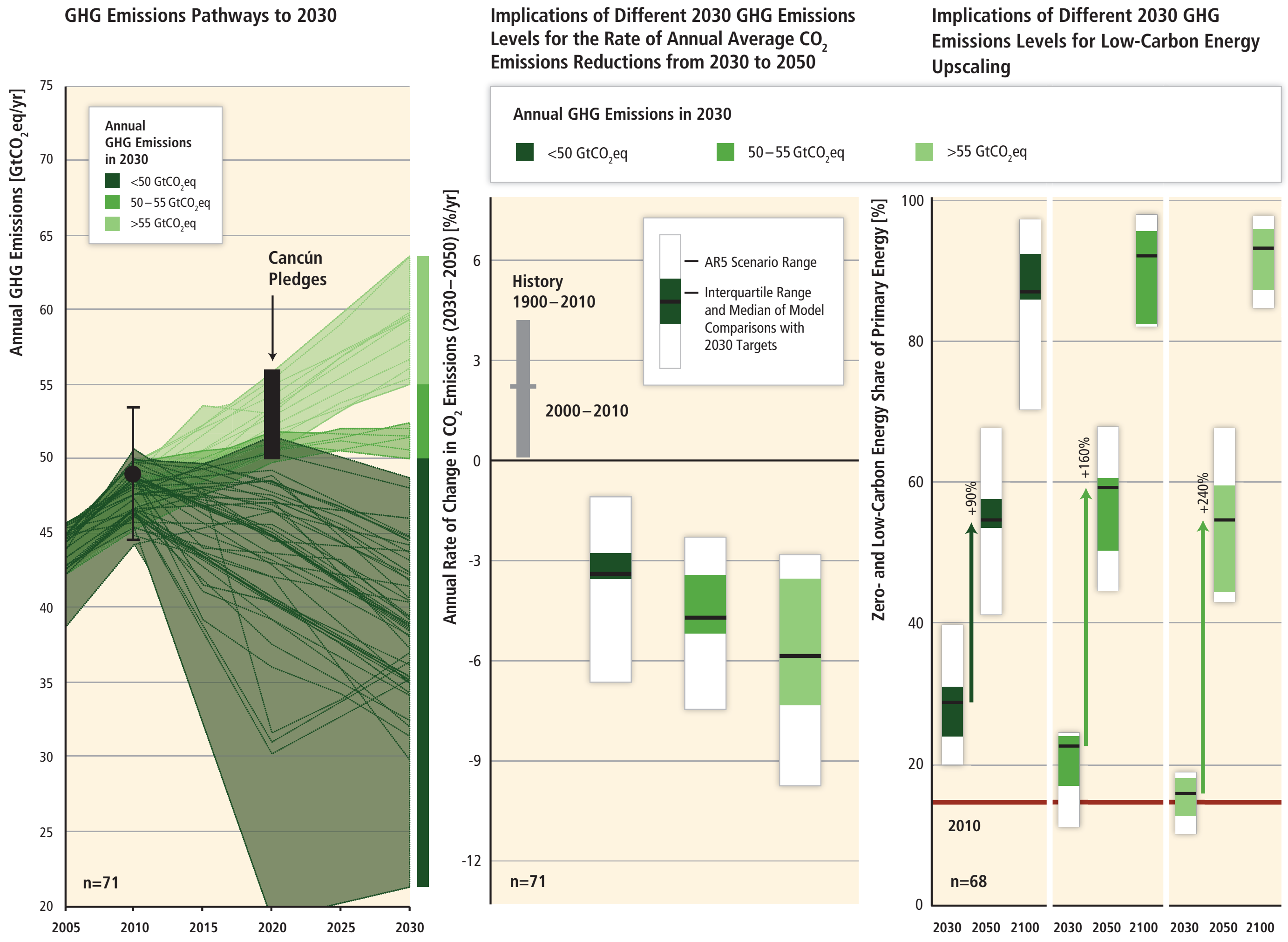
---

[16] This range differs from the range provided for a similar concentration category in AR4 (50 %–85 % lower than 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 net negative emissions technologies (see below). 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 emissions in 2050 are characterized by a greater reliance on Carbon Dioxide Removal (CDR) technologies beyond mid-century.

[17] At the national level, change is considered most effective when it reflects country and local visions and approaches to achieving sustainable development according to national circumstances and priorities [6.4, 11.8.4, WGII SPM].

[18] According to WGI, CDR methods have biogeochemical and technological limitations to their potential on the global scale. There is insufficient knowledge to quantify how much CO_2 emissions could be partially offset by CDR on a century timescale. CDR methods carry side-effects and long-term consequences on a global scale. [WGI SPM.E.8]

(Figure SPM.5, right panel); a larger reliance on CDR technologies in the long-term (Figure SPM.4, top panel); and higher transitional and long-term economic impacts (Table SPM.2). Due to these increased mitigation challenges, many models with annual 2030 GHG emissions higher than 55 $GtCO_2eq$ could not produce scenarios reaching atmospheric concentration levels that make it *as likely as not* that temperature change will remain below 2 °C relative to pre-industrial levels. [6.4, 7.11, Figures TS.11, TS.13]


GHG Emissions Pathways to 2030

Implications of Different 2030 GHG Emissions Levels for the Rate of Annual Average CO_2 Emissions Reductions from 2030 to 2050

Implications of Different 2030 GHG Emissions Levels for Low-Carbon Energy Upscaling

Figure SPM.5| The implications of different 2030 GHG emissions levels (left panel) for the rate of CO_2 emissions reductions (middle panel) and low-carbon energy upscaling from 2030 to 2050 (right panel) 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, fossil energy with carbon dioxide capture and storage (CCS), and bioenergy with CCS (BECCS). Note: Only scenarios that apply the full, unconstrained mitigation technology portfolio of the underlying models (default technology assumption) are shown. Scenarios with large net negative global emissions (>20 $GtCO_2/yr$), scenarios with exogenous carbon price assumptions, and scenarios with 2010 emissions significantly outside the historical range are excluded. The right-hand panel includes only 68 scenarios, because three of the 71 scenarios shown in the figure do not report some subcategories for primary energy that are required to calculate the share of zero- and low-carbon energy. [Figure 6.32, 7.16, 13.13.1.3]

Estimates of the aggregate economic costs of mitigation vary widely and are highly sensitive to model design and assumptions as well as the specification of scenarios, including the characterization of technologies and the timing of mitigation (*high confidence*)**.** 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 SPM.2, grey segments). Under these assumptions, mitigation scenarios that reach atmospheric concentrations of about 450 ppm CO_2eq by 2100 entail losses in global consumption—not including benefits of reduced climate change as well as co-benefits and adverse side-effects of mitigation[19]—of 1 % to 4 % (median: 1.7 %) in 2030, 2 % to 6 % (median: 3.4 %) in 2050, and 3 % to 11 % (median: 4.8 %) in 2100 relative to consumption in baseline scenarios that grows anywhere from 300 % to more than 900 % over the century. These numbers correspond to an annualized reduction of consumption growth by 0.04 to 0.14 (median: 0.06) percentage points over the century relative to annualized consumption growth in the baseline that is between 1.6 % and 3 % per year. Estimates at the high end of these cost ranges are from models that are relatively inflexible to achieve the deep emissions reductions required in the long run to meet these goals and/or include assumptions about market imperfections that would raise costs. Under the absence or limited availability of technologies, mitigation costs can increase substantially depending on the technology considered (Table SPM.2, orange segment). Delaying additional mitigation further increases mitigation costs in the medium- to long-term (Table SPM.2, blue segment). Many models could not achieve atmospheric concentration levels of about 450 ppm CO_2eq by 2100 if additional mitigation is considerably delayed or under limited availability of key technologies, such as bioenergy, CCS, and their combination (BECCS). [6.3]

---

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

Table SPM.2 | Global mitigation costs in cost-effective scenarios[1] 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 grey columns show consumption losses in the years 2030, 2050, and 2100 (light grey) and annualized consumption growth reductions (grey) over the century in cost-effective scenarios relative to a baseline development without climate policy. 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 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] [Figures TS.12, TS.13, 6.21, 6.24, 6.25, Annex II.10]

	Consumption losses in cost-effective scenarios[1]				**Increase in total discounted mitigation costs in scenarios with limited availability of technologies**				**Increase in medium- and long-term mitigation costs due to delayed additional mitigation until 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]**			
2100 Concentration (ppm CO_2eq)									≤55 $GtCO_2eq$		>55 $GtCO_2eq$	
	2030	2050	2100	2010–2100	No CCS	Nuclear phase out	Limited Solar/Wind	Limited Bioenergy	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)								

---

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

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

[3] No CCS: CCS is not included in these scenarios. Nuclear phase out: No addition of nuclear power plants beyond those under construction, and operation of existing plants until the end of their lifetime. Limited Solar/Wind: a maximum of 20 % global electricity generation from solar and wind power in any year of these scenarios. Limited Bioenergy: a maximum of 100 EJ/yr modern bioenergy supply globally (modern bioenergy used for heat, power, combinations, and industry was around 18 EJ/yr in 2008 [11.13.5]).

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

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

Only a limited number of studies have explored scenarios that are *more likely than not* to bring temperature change back to below 1.5 °C by 2100 relative to pre-industrial levels; these scenarios bring atmospheric concentrations to below 430 ppm CO_2eq by 2100 (*high confidence*)**.** Assessing this goal is currently difficult because no multi-model studies have explored these scenarios. The limited number of published studies consistent with this goal produces scenarios that are characterized by (1) immediate mitigation action; (2) the rapid upscaling of the full portfolio of mitigation technologies; and (3) development along a low-energy demand trajectory.[20] [6.3, 7.11]

Mitigation scenarios reaching about 450 or 500 ppm CO_2eq by 2100 show reduced costs for achieving air quality and energy security objectives, with significant co-benefits for human health, ecosystem impacts, and sufficiency of resources and resilience of the energy system; these scenarios did not quantify other co-benefits or adverse side-effects (*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 (Figure SPM.6) 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. [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; WGII 11.9]

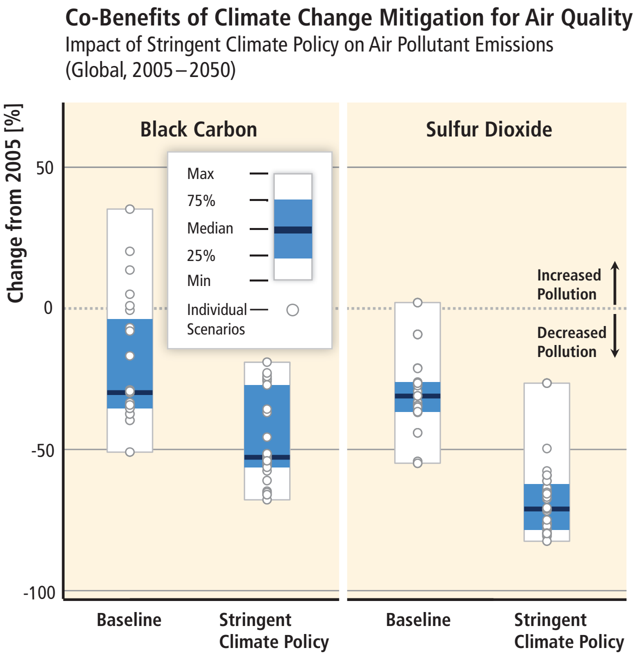


Figure SPM.6 | Air pollutant emission levels for black carbon (BC) and sulfur dioxide (SO_2) in 2050 relative to 2005 (0=2005 levels). Baseline scenarios without additional efforts to reduce GHG emissions beyond those in place today are compared to scenarios with stringent mitigation policies, which are consistent with reaching about 450 to 500 (430–530) ppm CO_2eq concentrations by 2100. [Figure 6.33]

---

[20] In these scenarios, the cumulative CO_2 emissions range between 655 and 815 GtCO_2 for the period 2011–2050 and between 90 and 350 GtCO_2 for the period 2011–2100. Global CO_2eq emissions in 2050 are between 70 and 95 % below 2010 emissions, and they are between 110 and 120 % below 2010 emissions in 2100.

There is a wide range of possible adverse side-effects as well as co-benefits and spillovers from climate policy that have not been well-quantified (*high confidence*)**.** Whether or not side-effects materialize, and to what extent side-effects materialize, will be case- and site-specific, as they will depend on local circumstances and the scale, scope, and pace of implementation. Important examples include biodiversity conservation, water availability, food security, income distribution, efficiency of the taxation system, labour supply and employment, urban sprawl, and the sustainability of the growth of developing countries. [Box TS.11]

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. [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]

Mitigation policy could devalue fossil fuel assets and reduce revenues for fossil fuel exporters, but differences between regions and fuels exist (*high confidence*)**.** Most mitigation scenarios are associated with reduced revenues from coal and oil trade for major exporters (*high confidence*). The effect of mitigation on natural gas export revenues is more uncertain, with some studies showing possible benefits for export revenues in the medium term until about 2050 (*medium confidence*). The availability of CCS would reduce the adverse effect of mitigation on the value of fossil fuel assets (*medium confidence*). [6.3.6, 6.6, 14.4.2]

SPM.4.2 Sectoral and cross-sectoral mitigation pathways and measures

SPM.4.2.1 Cross-sectoral mitigation pathways and measures

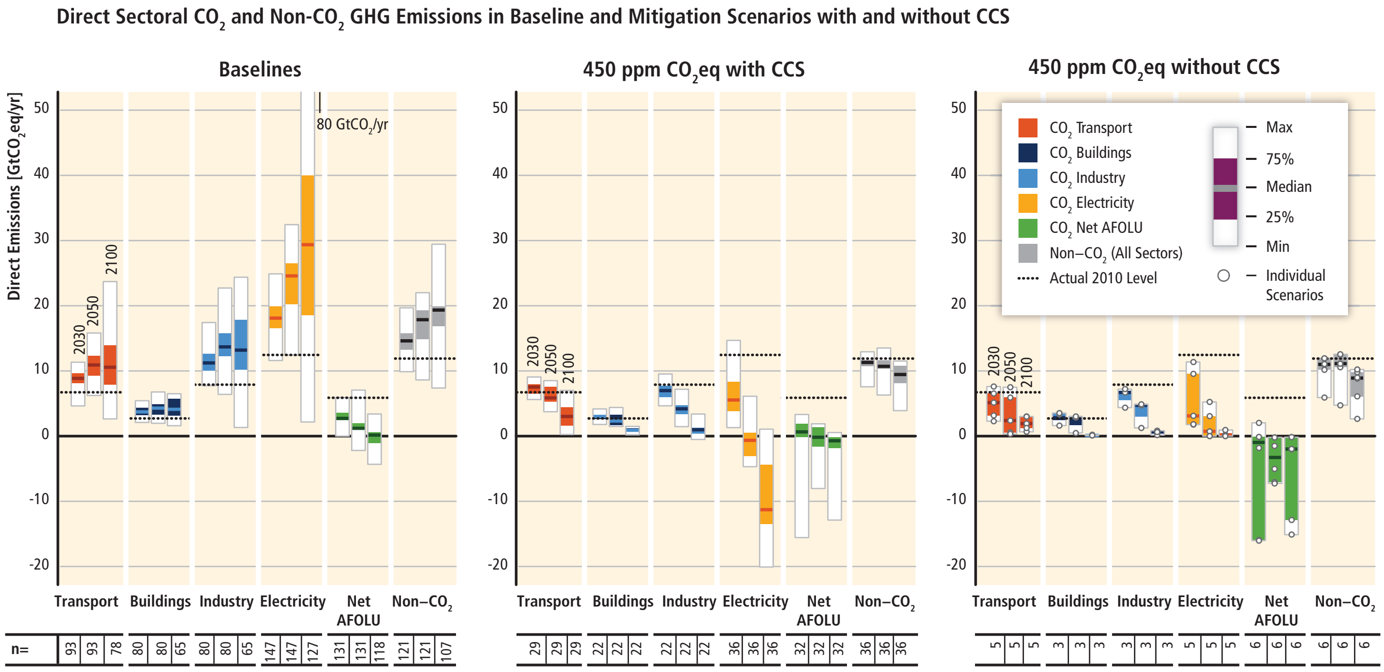
In baseline scenarios, GHG emissions are projected to grow in all sectors, except for net CO_2 emissions in the AFOLU sector[21] (*robust evidence, medium agreement*)**.** Energy supply sector emissions are expected to continue to be the major source of GHG emissions, ultimately accounting for the significant increases in indirect emissions from electricity use in the buildings and industry sectors. In baseline scenarios, while non-CO_2 GHG agricultural emissions are projected to increase, net CO_2 emissions from the AFOLU sector decline over time, with some models projecting a net sink towards the end of the century (Figure SPM.7).[22] [6.3.1.4, 6.8, Figure TS.15]

Infrastructure developments and long-lived products that lock societies into GHG-intensive emissions pathways may be difficult or very costly to change, reinforcing the importance of early action for ambitious mitigation (*robust evidence, high agreement*)**.** This lock-in risk is compounded by the lifetime of the infrastructure, by the difference in emissions associated with alternatives, and the magnitude of the investment cost. As a result, lock-in related to infrastructure and spatial planning is the most difficult to reduce. However, materials, products and infrastructure with long lifetimes and low lifecycle emissions can facilitate a transition to low-emission pathways while also reducing emissions through lower levels of material use. [5.6.3, 6.3.6.4, 9.4, 10.4, 12.3, 12.4]

---

[21] Net AFOLU CO_2 emissions include emissions and removals of CO_2 from the AFOLU sector, including land under forestry and, in some assessments, CO_2 sinks in agricultural soils.

[22] A majority of the Earth System Models assessed in WGI project a continued land carbon uptake under all RCPs through to 2100, but some models simulate a land carbon loss due to the combined effect of climate change and land-use change. [WGI SPM.E.7, WGI 6.4]



Direct Sectoral CO_2 and Non-CO_2 GHG Emissions in Baseline and Mitigation Scenarios with and without CCS

Baselines

450 ppm CO_2eq with CCS

450 ppm CO_2eq without CCS

Figure SPM.7 | Direct emissions of CO_2 by sector and total non-CO_2 GHGs (Kyoto gases) across sectors in baseline (left panel) and mitigation scenarios that reach around 450 (430–480) ppm CO_2eq with CCS (middle panel) and without CCS (right panel). The numbers at the bottom of the graphs refer to the number of scenarios included in the range which differs across sectors and time due to different sectoral resolution and time horizon of models. Note that many models cannot reach 450 ppm CO_2eq concentration by 2100 in the absence of CCS, resulting in a low number of scenarios for the right panel [Figures 6.34 and 6.35].

There are strong interdependencies in mitigation scenarios between the pace of introducing mitigation measures in energy supply and energy end-use and developments in the AFOLU sector (*high confidence*)**.** The distribution of the mitigation effort across sectors is strongly influenced by the availability and performance of BECCS and large scale afforestation (Figure SPM.7). This is particularly the case in scenarios reaching CO_2eq concentrations of about 450 ppm by 2100. Well-designed systemic and cross-sectoral mitigation strategies are more cost-effective in cutting emissions than a focus on individual technologies and sectors. At the energy system level these include reductions in the GHG emission intensity of the energy supply sector, a switch to low-carbon energy carriers (including low-carbon electricity) and reductions in energy demand in the end-use sectors without compromising development (Figure SPM.8). [6.3.5, 6.4, 6.8, 7.11, Table TS.2]

Mitigation scenarios reaching around 450 ppm CO_2eq concentrations by 2100 show large-scale global changes in the energy supply sector (*robust evidence, high agreement*)**.** In these selected scenarios, global CO_2 emissions from the energy supply sector are projected to decline over the next decades and are characterized by reductions of 90 % or more below 2010 levels between 2040 and 2070. Emissions in many of these scenarios are projected to decline to below zero thereafter. [6.3.4, 6.8, 7.1, 7.11]

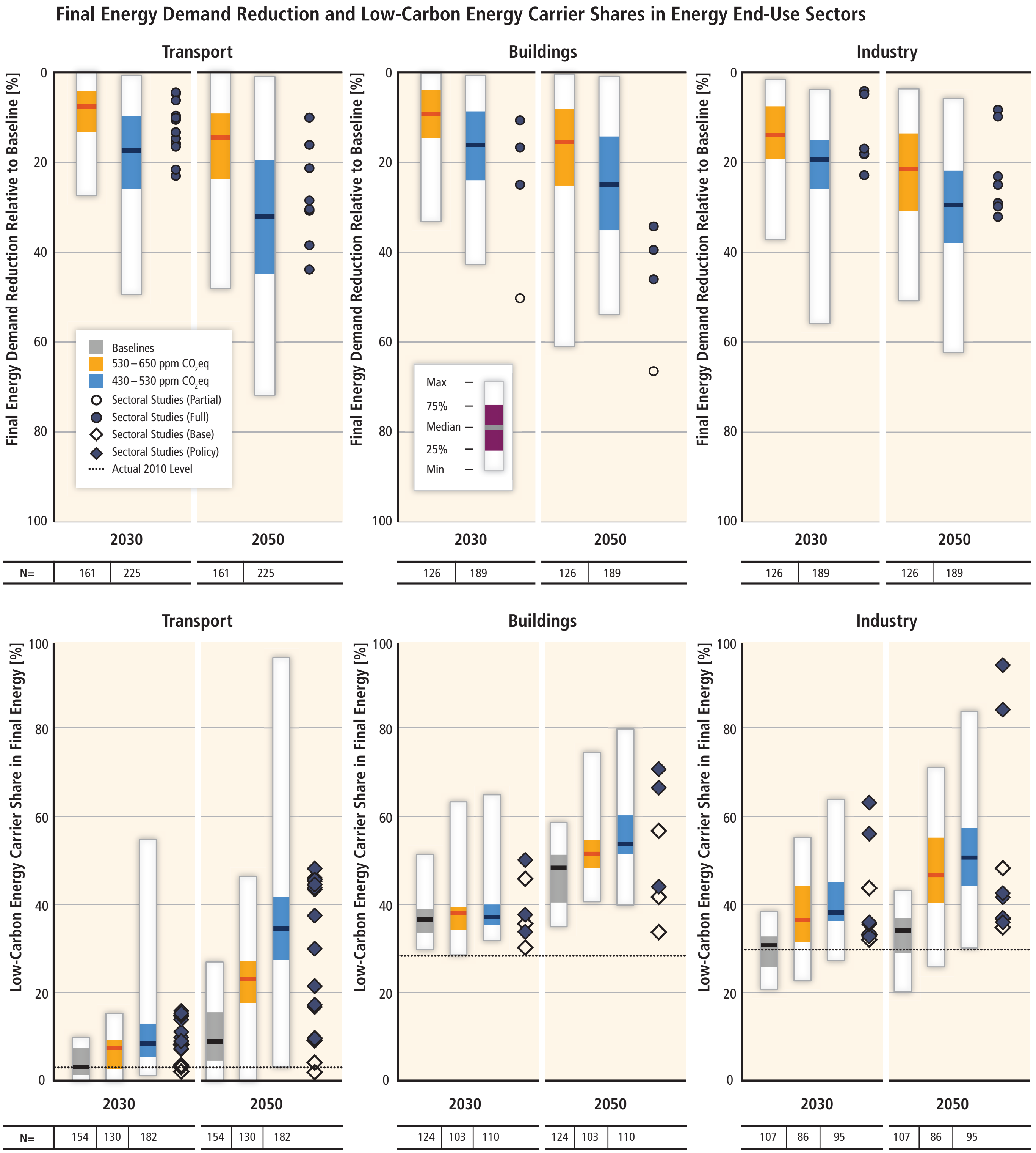


Figure SPM.8 | Final energy demand reduction relative to baseline (upper row) and low-carbon energy carrier shares in final energy (lower row) in the transport, buildings, and industry sectors by 2030 and 2050 in scenarios from two different CO_2eq concentration categories compared to sectoral studies assessed in Chapters 8–10. The demand reductions shown by these scenarios do not compromise development. Low-carbon energy carriers include electricity, hydrogen and liquid biofuels in transport, electricity in buildings and electricity, heat, hydrogen and bioenergy in industry. The numbers at the bottom of the graphs refer to the number of scenarios included in the ranges which differ across sectors and time due to different sectoral resolution and time horizon of models. [Figures 6.37 and 6.38]

Efficiency enhancements and behavioural changes, in order to reduce energy demand compared to baseline scenarios without compromising development, are a key mitigation strategy in scenarios reaching atmospheric CO_2eq concentrations of about 450 or 500 ppm by 2100 (*robust evidence, high agreement*)**.** Near-term reductions in energy demand are an important element of cost-effective mitigation strategies, provide more flexibility for reducing carbon intensity in the energy supply sector, hedge against related supply-side risks, avoid lock-in to carbon-intensive infrastructures, and are associated with important co-benefits. Both integrated and sectoral studies provide similar estimates for energy demand reductions in the transport, buildings and industry sectors for 2030 and 2050 (Figure SPM.8). [6.3.4, 6.6, 6.8, 7.11, 8.9, 9.8, 10.10]

Behaviour, lifestyle and culture have a considerable influence on energy use and associated emissions, with high mitigation potential in some sectors, in particular when complementing technological and structural change[23] (*medium evidence, medium agreement*)**.** Emissions can be substantially lowered through changes in consumption patterns (e.g., mobility demand and mode, energy use in households, choice of longer-lasting products) and dietary change and reduction in food wastes. A number of options including monetary and non-monetary incentives as well as information measures may facilitate behavioural changes. [6.8, 7.9, 8.3.5, 8.9, 9.2, 9.3, 9.10, Box 10.2, 10.4, 11.4, 12.4, 12.6, 12.7, 15.3, 15.5, Table TS.2]

SPM.4.2.2 Energy supply

In the baseline scenarios assessed in AR5, direct CO_2 emissions from the energy supply sector are projected to almost double or even triple by 2050 compared to the level of 14.4 $GtCO_2$/year in 2010, unless energy intensity improvements can be significantly accelerated beyond the historical development (*medium evidence, medium agreement*)**.** In the last decade, the main contributors to emission growth were a growing energy demand and an increase of the share of coal in the global fuel mix. The availability of fossil fuels alone will not be sufficient to limit CO_2eq concentration to levels such as 450 ppm, 550 ppm, or 650 ppm. [6.3.4, 7.2, 7.3, Figures 6.15, TS.15, SPM.7]

Decarbonizing (i.e. reducing the carbon intensity of) electricity generation is a key component of cost-effective mitigation strategies in achieving low-stabilization levels (430–530 ppm CO_2eq); in most integrated modelling scenarios, decarbonization happens more rapidly in electricity generation than in the industry, buildings, and transport sectors (*medium evidence, high agreement*) (Figure SPM.7). In the majority of low-stabilization scenarios, the share of low-carbon electricity supply (comprising renewable energy (RE), nuclear and CCS) increases from the current share of approximately 30 % to more than 80 % by 2050, and fossil fuel power generation without CCS is phased out almost entirely by 2100 (Figure SPM. 7). [6.8, 7.11, Figures 7.14, TS.18]

Since AR4, many RE technologies have demonstrated substantial performance improvements and cost reductions, and a growing number of RE technologies have achieved a level of maturity to enable deployment at significant scale (*robust evidence, high agreement*)**.** Regarding electricity generation alone, RE accounted for just over half of the new electricity-generating capacity added globally in 2012, led by growth in wind, hydro and solar power. However, many RE technologies still need direct and/or indirect support, if their market shares are to be significantly increased; RE technology policies have been successful in driving recent growth of RE. Challenges for integrating RE into energy systems and the associated costs vary by RE technology, regional circumstances, and the characteristics of the existing background energy system (*medium evidence, medium agreement*). [7.5.3, 7.6.1, 7.8.2, 7.12, Table 7.1]

Nuclear energy is a mature low-GHG emission source of baseload power, but its share of global electricity generation has been declining (since 1993). Nuclear energy could make an increasing contribution to low-carbon energy supply, but a variety of barriers and risks exist (*robust evidence, high agreement*)**.** Those include:

---

[23] Structural changes refer to systems transformations whereby some components are either replaced or potentially substituted by other components (see WGIII AR5 Glossary).

operational risks, and the associated concerns, uranium mining risks, financial and regulatory risks, unresolved waste management issues, nuclear weapon proliferation concerns, and adverse public opinion (*robust evidence, high agreement*). New fuel cycles and reactor technologies addressing some of these issues are being investigated and progress in research and development has been made concerning safety and waste disposal. [7.5.4, 7.8, 7.9, 7.12, Figure TS.19]

GHG emissions from energy supply can be reduced significantly by replacing current world average coal-fired power plants with modern, highly efficient natural gas combined-cycle power plants or combined heat and power plants, provided that natural gas is available and the fugitive emissions associated with extraction and supply are low or mitigated (*robust evidence, high agreement*)**.** In mitigation scenarios reaching about 450 ppm CO_2eq concentrations by 2100, natural gas power generation without CCS acts as a bridge technology, with deployment increasing before peaking and falling to below current levels by 2050 and declining further in the second half of the century (*robust evidence, high agreement*). [7.5.1, 7.8, 7.9, 7.11, 7.12]

Carbon dioxide capture and storage (CCS) technologies could reduce the lifecycle GHG emissions of fossil fuel power plants (*medium evidence, medium agreement*)**.** While all components of integrated CCS systems exist and are in use today by the fossil fuel extraction and refining industry, CCS has not yet been applied at scale to a large, operational commercial fossil fuel power plant. CCS power plants could be seen in the market if this is incentivized by regulation and/or if they become competitive with their unabated counterparts, for instance, if the additional investment and operational costs, caused in part by efficiency reductions, are compensated by sufficiently high carbon prices (or direct financial support). For the large-scale future deployment of CCS, well-defined regulations concerning short- and long-term responsibilities for storage are needed as well as economic incentives. Barriers to large-scale deployment of CCS technologies include concerns about the operational safety and long-term integrity of CO_2 storage as well as transport risks. There is, however, a growing body of literature on how to ensure the integrity of CO_2 wells, on the potential consequences of a pressure build-up within a geologic formation caused by CO_2 storage (such as induced seismicity), and on the potential human health and environmental impacts from CO_2 that migrates out of the primary injection zone (*limited evidence, medium agreement*). [7.5.5., 7.8, 7.9, 7.11, 7.12, 11.13]

Combining bioenergy with CCS (BECCS) offers the prospect of energy supply with large-scale net negative emissions which plays an important role in many low-stabilization scenarios, while it entails challenges and risks (*limited evidence, medium agreement*)**.** These challenges and risks include those associated with the upstream large-scale provision of the biomass that is used in the CCS facility as well as those associated with the CCS technology itself. [7.5.5, 7.9, 11.13]

SPM.4.2.3 Energy end-use sectors

Transport

The transport sector accounted for 27 % of final energy use and 6.7 $GtCO_2$ direct emissions in 2010, with baseline CO_2 emissions projected to approximately double by 2050 (*medium evidence, medium agreement*)**.** This growth in CO_2 emissions from increasing global passenger and freight activity could partly offset future mitigation measures that include fuel carbon and energy intensity improvements, infrastructure development, behavioural change and comprehensive policy implementation (*high confidence*). Overall, reductions in total transport CO_2 emissions of 15–40 % compared to baseline growth could be achieved in 2050 (*medium evidence, medium agreement*). (Figure SPM.7) [6.8, 8.1, 8.2, 8.9, 8.10]

Technical and behavioural mitigation measures for all transport modes, plus new infrastructure and urban redevelopment investments, could reduce final energy demand in 2050 by around 40 % below the baseline, with the mitigation potential assessed to be higher than reported in the AR4 (*robust evidence, medium agreement*)**.** Projected energy efficiency and vehicle performance improvements range from 30–50 % in 2030 relative to 2010 depending on transport mode and vehicle type (*medium evidence, medium agreement*). Integrated urban planning, transit-oriented development, more compact urban form that supports cycling and walking, can all lead to modal shifts as can, in the longer term, urban redevelopment and investments in new infrastructure such as high-speed rail systems that reduce short-haul air travel demand (*medium evidence, medium agreement*). Such mitigation measures are challenging, have uncertain outcomes, and could reduce transport GHG emissions by 20–50 % in 2050 compared to baseline (*limited evidence, low agreement*). (Figure SPM.8 top panel) [8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 12.4, 12.5]

Strategies to reduce the carbon intensities of fuel and the rate of reducing carbon intensity are constrained by challenges associated with energy storage and the relatively low energy density of low-carbon transport fuels (*medium confidence*)**.** Integrated and sectoral studies broadly agree that opportunities for switching to low-carbon fuels exist in the near term and will grow over time. Methane-based fuels are already increasing their share for road vehicles and waterborne craft. Electricity produced from low-carbon sources has near-term potential for electric rail and short-to medium-term potential as electric buses, light-duty and 2-wheel road vehicles are deployed. Hydrogen fuels from low-carbon sources constitute longer-term options. Commercially available liquid and gaseous biofuels already provide co-benefits together with mitigation options that can be increased by technology advances. Reducing transport emissions of particulate matter (including black carbon), tropospheric ozone and aerosol precursors (including NO_x) can have human health and mitigation co-benefits in the short term (*medium evidence, medium agreement*). [8.2, 8.3, 11.13, Figure TS.20, right panel]

The cost-effectiveness of different carbon reduction measures in the transport sector varies significantly with vehicle type and transport mode (*high confidence*)**.** The levelized costs of conserved carbon can be very low or negative for many short-term behavioural measures and efficiency improvements for light- and heavy-duty road vehicles and waterborne craft. In 2030, for some electric vehicles, aircraft and possibly high-speed rail, levelized costs could be more than USD100/tCO_2 avoided (*limited evidence, medium agreement*). [8.6, 8.8, 8.9, Figures TS.21, TS.22]

Regional differences influence the choice of transport mitigation options (*high confidence*)**.** Institutional, legal, financial and cultural barriers constrain low-carbon technology uptake and behavioural change. Established infrastructure may limit the options for modal shift and lead to a greater reliance on advanced vehicle technologies; a slowing of growth in light-duty vehicle demand is already evident in some OECD countries. For all economies, especially those with high rates of urban growth, investment in public transport systems and low-carbon infrastructure can avoid lock-in to carbon-intensive modes. Prioritizing infrastructure for pedestrians and integrating non-motorized and transit services can create economic and social co-benefits in all regions (*medium evidence, medium agreement*). [8.4, 8.8, 8.9, 14.3, Table 8.3]

Mitigation strategies, when associated with non-climate policies at all government levels, can help decouple transport GHG emissions from economic growth in all regions (*medium confidence*)**.** These strategies can help reduce travel demand, incentivise freight businesses to reduce the carbon intensity of their logistical systems and induce modal shifts, as well as provide co-benefits including improved access and mobility, better health and safety, greater energy security, and cost and time savings (*medium evidence, high agreement*). [8.7, 8.10]

Buildings

In 2010, the buildings sector[24] accounted for around 32 % final energy use and 8.8 $GtCO_2$ emissions, including direct and indirect emissions, with energy demand projected to approximately double and CO_2 emissions to increase by 50–150 % by mid-century in baseline scenarios (*medium evidence, medium agreement*)**.** This energy demand growth results from improvements in wealth, lifestyle change, access to modern energy services and adequate housing, and urbanisation. There are significant lock-in risks associated with the long lifespans of buildings and related infrastructure, and these are especially important in regions with high construction rates (*robust evidence, high agreement*). [9.4, Figure SPM.7]

---

[24] The buildings sector covers the residential, commercial, public and services sectors; emissions from construction are accounted for in the industry sector.

Recent advances in technologies, know-how and policies provide opportunities to stabilize or reduce global buildings sector energy use by mid-century (*robust evidence, high agreement*)**.** For new buildings, the adoption of very low energy building codes is important and has progressed substantially since AR4. Retrofits form a key part of the mitigation strategy in countries with established building stocks, and reductions of heating/cooling energy use by 50–90 % in individual buildings have been achieved. Recent large improvements in performance and costs make very low energy construction and retrofits economically attractive, sometimes even at net negative costs. [9.3]

Lifestyle, culture and behaviour significantly influence energy consumption in buildings (*limited evidence, high agreement*)**.** A three-to five-fold difference in energy use has been shown for provision of similar building-related energy service levels in buildings. For developed countries, scenarios indicate that lifestyle and behavioural changes could reduce energy demand by up to 20 % in the short term and by up to 50 % of present levels by mid-century. In developing countries, integrating elements of traditional lifestyles into building practices and architecture could facilitate the provision of high levels of energy services with much lower energy inputs than baseline. [9.3]

Most mitigation options for buildings have considerable and diverse co-benefits in addition to energy cost savings (*robust evidence, high agreement*)**.** These include improvements in energy security, health (such as from cleaner wood-burning cookstoves), environmental outcomes, workplace productivity, fuel poverty reductions and net employment gains. Studies which have monetized co-benefits often find that these exceed energy cost savings and possibly climate benefits (*medium evidence, medium agreement*). [9.6, 9.7, 3.6.3]

Strong barriers, such as split incentives (e.g., tenants and builders), fragmented markets and inadequate access to information and financing, hinder the market-based uptake of cost-effective opportunities. Barriers can be overcome by policy interventions addressing all stages of the building and appliance lifecycles (*robust evidence, high agreement*). [9.8, 9.10, 16, Box 3.10]

The development of portfolios of energy efficiency policies and their implementation has advanced considerably since AR4. Building codes and appliance standards, if well designed and implemented, have been among the most environmentally and cost-effective instruments for emission reductions (*robust evidence, high agreement*)**.** In some developed countries they have contributed to a stabilization of, or reduction in, total energy demand for buildings. Substantially strengthening these codes, adopting them in further jurisdictions, and extending them to more building and appliance types, will be a key factor in reaching ambitious climate goals. [9.10, 2.6.5.3]

Industry

In 2010, the industry sector accounted for around 28 % of final energy use, and 13 GtCO_2 emissions, including direct and indirect emissions as well as process emissions, with emissions projected to increase by 50–150 % by 2050 in the baseline scenarios assessed in AR5, unless energy efficiency improvements are accelerated significantly (*medium evidence, medium agreement*)**.** Emissions from industry accounted for just over 30 % of global GHG emissions in 2010 and are currently greater than emissions from either the buildings or transport end-use sectors. (Figures SPM.2, SPM.7) [10.3]

The energy intensity of the industry sector could be directly reduced by about 25 % compared to the current level through the wide-scale upgrading, replacement and deployment of best available technologies, particularly in countries where these are not in use and in non-energy intensive industries (*high agreement, robust evidence*)**.** Additional energy intensity reductions of about 20 % may potentially be realized through innovation (*limited evidence, medium agreement*). Barriers to implementing energy efficiency relate largely to initial investment costs and lack of information. Information programmes are a prevalent approach for promoting energy efficiency, followed by economic instruments, regulatory approaches and voluntary actions. [10.7, 10.9, 10.11]

Improvements in GHG emission efficiency and in the efficiency of material use, recycling and re-use of materials and products, and overall reductions in product demand (e.g., through a more intensive use of products) and service demand could, in addition to energy efficiency, help reduce GHG emissions below the baseline level in the industry sector (*medium evidence, high agreement*)**.** Many emission-reducing options are cost-effective, profitable and associated with multiple co-benefits (better environmental compliance, health benefits etc.). In the long term, a shift to low-carbon electricity, new industrial processes, radical product innovations (e.g., alternatives to cement), or CCS (e.g., to mitigate process emissions) could contribute to significant GHG emission reductions. Lack of policy and experiences in material and product service efficiency are major barriers. [10.4, 10.7, 10.8, 10.11]

CO_2 emissions dominate GHG emissions from industry, but there are also substantial mitigation opportunities for non-CO_2 gases (*robust evidence, high agreement*)**.** CH_4, N_2O and fluorinated gases from industry accounted for emissions of 0.9 $GtCO_2eq$ in 2010. Key mitigation opportunities include, e.g., the reduction of hydrofluorocarbon emissions by process optimization and refrigerant recovery, recycling and substitution, although there are barriers. [Tables 10.2, 10.7]

Systemic approaches and collaborative activities across companies and sectors can reduce energy and material consumption and thus GHG emissions (*robust evidence, high agreement*)**.** The application of cross-cutting technologies (e.g., efficient motors) and measures (e.g., reducing air or steam leaks) in both large energy intensive industries and small and medium enterprises can improve process performance and plant efficiency cost-effectively. Cooperation across companies (e.g., in industrial parks) and sectors could include the sharing of infrastructure, information, and waste heat utilization. [10.4, 10.5]

Important options for mitigation in waste management are waste reduction, followed by re-use, recycling and energy recovery (*robust evidence, high agreement*)**.** Waste and wastewater accounted for 1.5 $GtCO_2eq$ in 2010. As the share of recycled or reused material is still low (e.g., globally, around 20 % of municipal solid waste is recycled), waste treatment technologies and recovering energy to reduce demand for fossil fuels can result in significant direct emission reductions from waste disposal. [10.4, 10.14]

SPM.4.2.4 Agriculture, Forestry and Other Land Use (AFOLU)

The AFOLU sector accounts for about a quarter (~ 10–12$GtCO_2eq$/yr) of net anthropogenic GHG emissions mainly from deforestation, agricultural emissions from soil and nutrient management and livestock (*medium evidence, high agreement*)**.** Most recent estimates indicate a decline in AFOLU CO_2 fluxes, largely due to decreasing deforestation rates and increased afforestation. However, the uncertainty in historical net AFOLU emissions is larger than for other sectors, and additional uncertainties in projected baseline net AFOLU emissions exist. Nonetheless, in the future, net annual baseline CO_2 emissions from AFOLU are projected to decline, with net emissions potentially less than half the 2010 level by 2050 and the possibility of the AFOLU sectors becoming a net CO_2 sink before the end of century (*medium evidence, high agreement*). (Figure SPM. 7) [6.3.1.4, 11.2, Figure 6.5]

AFOLU plays a central role for food security and sustainable development. The most cost-effective mitigation options in forestry are afforestation, sustainable forest management and reducing deforestation, with large differences in their relative importance across regions. In agriculture, the most cost-effective mitigation options are cropland management, grazing land management, and restoration of organic soils (*medium evidence, high agreement*)**.** The economic mitigation potential of supply-side measures is estimated to be 7.2 to 11 $GtCO_2eq$/year[25] in 2030 for mitigation efforts consistent with carbon prices[26] up to 100 USD/tCO_2eq, about a third of which can be achieved at a <20 USD/tCO_2eq (*medium evidence, medium agreement*). There are potential barriers to

---

[25] Full range of all studies: 0.49–11 $GtCO_2eq$/year

[26] In many models that are used to assess the economic costs of mitigation, carbon price is often used as a proxy to represent the level of effort in mitigation policies (see WGIII AR5 Glossary).

implementation of available mitigation options [11.7, 11.8]. Demand-side measures, such as changes in diet and reductions of losses in the food supply chain, have a significant, but uncertain, potential to reduce GHG emissions from food production (*medium evidence, medium agreement*). Estimates vary from roughly 0.76–8.6 $GtCO_2eq/yr$ by 2050 (*limited evidence, medium agreement*). [11.4, 11.6, Figure 11.14]

Policies governing agricultural practices and forest conservation and management are more effective when involving both mitigation and adaptation. Some mitigation options in the AFOLU sector (such as soil and forest carbon stocks) may be vulnerable to climate change (*medium evidence, high agreement*). When implemented sustainably, activities to reduce emissions from deforestation and forest degradation (REDD+[27] is an example designed to be sustainable) are cost-effective policy options for mitigating climate change, with potential economic, social and other environmental and adaptation co-benefits (e. g., conservation of biodiversity and water resources, and reducing soil erosion) (*limited evidence, medium agreement*). [11.3.2, 11.10]

Bioenergy can play a critical role for mitigation, but there are issues to consider, such as the sustainability of practices and the efficiency of bioenergy systems (*robust evidence, medium agreement*) [11.4.4, Box 11.5, 11.13.6, 11.13.7]**.** Barriers to large-scale deployment of bioenergy include concerns about GHG emissions from land, food security, water resources, biodiversity conservation and livelihoods. The scientific debate about the overall climate impact related to land-use competition effects of specific bioenergy pathways remains unresolved (*robust evidence, high agreement*). [11.4.4, 11.13] Bioenergy technologies are diverse and span a wide range of options and technology pathways. Evidence suggests that options with low lifecycle emissions (e. g., sugar cane, Miscanthus, fast growing tree species, and sustainable use of biomass residues), some already available, can reduce GHG emissions; outcomes are site-specific and rely on efficient integrated 'biomass-to-bioenergy systems', and sustainable land-use management and governance. In some regions, specific bioenergy options, such as improved cookstoves, and small-scale biogas and biopower production, could reduce GHG emissions and improve livelihoods and health in the context of sustainable development (*medium evidence, medium agreement*). [11.13]

SPM.4.2.5 Human settlements, infrastructure and spatial planning

Urbanization is a global trend and is associated with increases in income, and higher urban incomes are correlated with higher consumption of energy and GHG emissions (*medium evidence, high agreement*)**.** As of 2011, more than 52 % of the global population lives in urban areas. In 2006, urban areas accounted for 67–76 % of energy use and 71–76 % of energy-related CO_2 emissions. By 2050, the urban population is expected to increase to 5.6–7.1 billion, or 64–69 % of world population. Cities in non-Annex I countries generally have higher levels of energy use compared to the national average, whereas cities in Annex I countries generally have lower energy use per capita than national averages (*medium evidence, medium agreement*). [12.2, 12.3]

The next two decades present a window of opportunity for mitigation in urban areas, as a large portion of the world's urban areas will be developed during this period (*limited evidence, high agreement*)**.** Accounting for trends in declining population densities, and continued economic and population growth, urban land cover is projected to expand by 56–310 % between 2000 and 2030. [12.2, 12.3, 12.4, 12.8]

Mitigation options in urban areas vary by urbanization trajectories and are expected to be most effective when policy instruments are bundled (*robust evidence, high agreement*)**.** Infrastructure and urban form are strongly interlinked, and lock-in patterns of land use, transport choice, housing, and behaviour. Effective mitigation strategies involve packages of mutually reinforcing policies, including co-locating high residential with high employment densities, achieving high diversity and integration of land uses, increasing accessibility and investing in public transport and other demand management measures. [8.4, 12.3, 12.4, 12.5, 12.6]

---

[27] See WGIII AR5 Glossary.

The largest mitigation opportunities with respect to human settlements are in rapidly urbanizing areas where urban form and infrastructure are not locked in, but where there are often limited governance, technical, financial, and institutional capacities (*robust evidence, high agreement*)**.** The bulk of urban growth is expected in small- to medium-size cities in developing countries. The feasibility of spatial planning instruments for climate change mitigation is highly dependent on a city's financial and governance capability. [12.6, 12.7]

Thousands of cities are undertaking climate action plans, but their aggregate impact on urban emissions is uncertain (*robust evidence, high agreement*). There has been little systematic assessment on their implementation, the extent to which emission reduction targets are being achieved, or emissions reduced. Current climate action plans focus largely on energy efficiency. Fewer climate action plans consider land-use planning strategies and cross-sectoral measures to reduce sprawl and promote transit-oriented development[28]. [12.6, 12.7, 12.9]

Successful implementation of urban-scale climate change mitigation strategies can provide co-benefits (*robust evidence, high agreement*)**.** Urban areas throughout the world continue to struggle with challenges, including ensuring access to energy, limiting air and water pollution, and maintaining employment opportunities and competitiveness. Action on urban-scale mitigation often depends on the ability to relate climate change mitigation efforts to local co-benefits (*robust evidence, high agreement*). [12.5, 12.6, 12.7, 12.8]

SPM.5 Mitigation policies and institutions

SPM.5.1 Sectoral and national policies

Substantial reductions in emissions would require large changes in investment patterns. Mitigation scenarios in which policies stabilize atmospheric concentrations (without overshoot) in the range from 430 to 530 ppm CO_2eq by 2100 lead to substantial shifts in annual investment flows during the period 2010–2029 compared to baseline scenarios (Figure SPM.9). Over the next two decades (2010 to 2029), annual investment in conventional fossil fuel technologies associated with the electricity supply sector is projected to decline by about USD 30 (2–166) billion (median: −20 % compared to 2010) while annual investment in low-carbon electricity supply (i.e., renewables, nuclear and electricity generation with CCS) is projected to rise by about USD 147 (31–360) billion (median: +100 % compared to 2010) (*limited evidence, medium agreement*). For comparison, global total annual investment in the energy system is presently about USD 1200 billion. In addition, annual incremental energy efficiency investments in transport, buildings and industry is projected to increase by about USD 336 (1–641) billion (*limited evidence, medium agreement*), frequently involving modernization of existing equipment. [13.11, 16.2.2]

There is no widely agreed definition of what constitutes climate finance, but estimates of the financial flows associated with climate change mitigation and adaptation are available. Published assessments of all current annual financial flows whose expected effect is to reduce net GHG emissions and/or to enhance resilience to climate change and climate variability show USD 343 to 385 billion per year globally (*medium confidence*) [Box TS.14]. Most of this goes to mitigation. Out of this, total public climate finance that flowed to developing countries is estimated to be between USD 35 and 49 billion/yr in 2011 and 2012 (*medium confidence*). Estimates of international private climate finance flowing to developing countries range from USD 10 to 72 billion/yr including foreign direct investment as equity and loans in the range of USD 10 to 37 billion/yr over the period of 2008–2011 (*medium confidence*). [16.2.2]

---

[28] See WGIII AR5 Glossary.

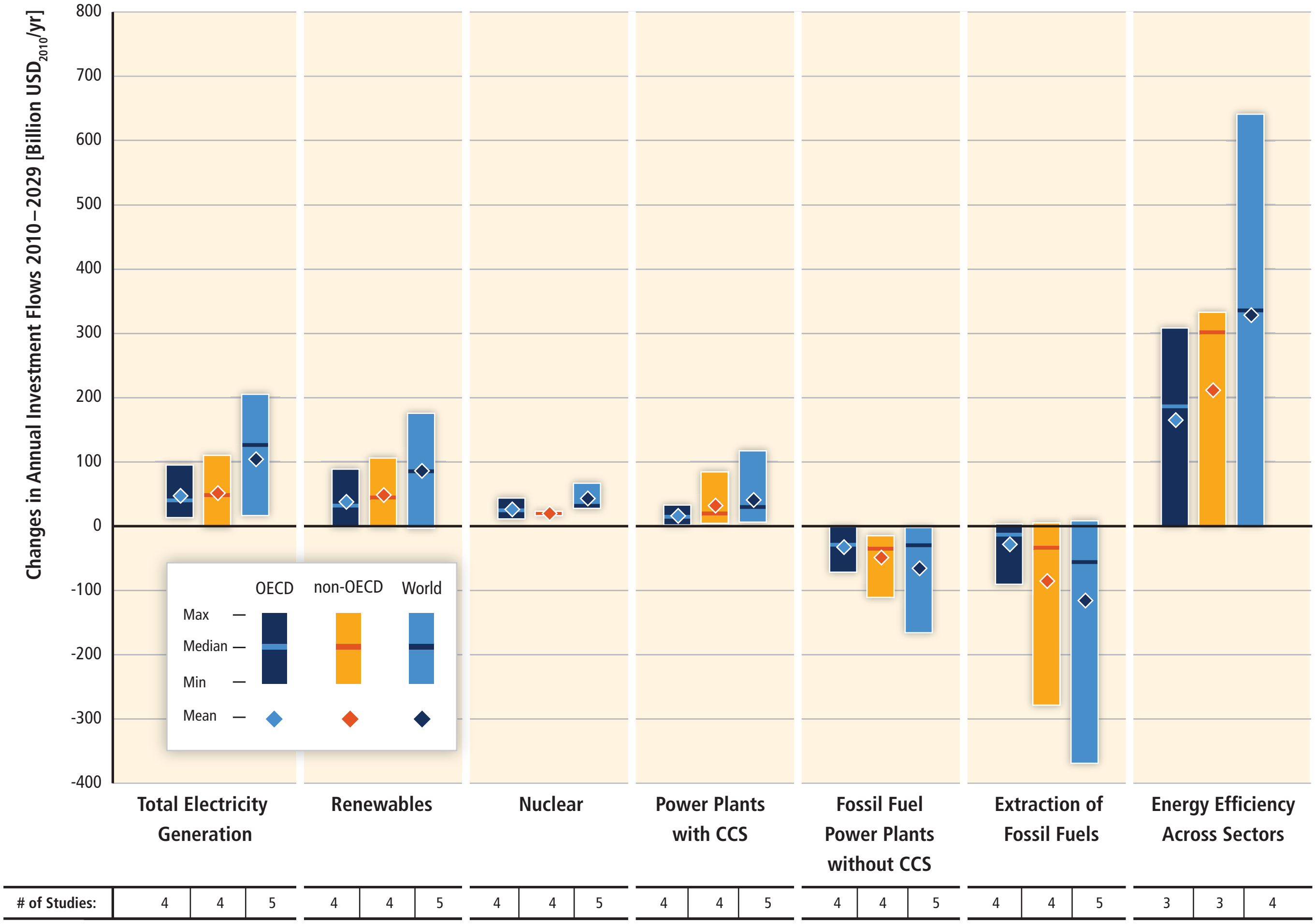


Figure SPM.9 | Change in annual investment flows from the average baseline level over the next two decades (2010–2029) for mitigation scenarios that stabilize concentrations within the range of approximately 430–530 ppm CO_2eq by 2100. Investment changes are based on a limited number of model studies and model comparisons. Total electricity generation (leftmost column) is the sum of renewables, nuclear, power plants with CCS and fossil fuel power plants without CCS. The vertical bars indicate the range between minimum and maximum estimate; the horizontal bar indicates the median. Proximity to this median value does not imply higher likelihood because of the different degree of aggregation of model results, the low number of studies available and different assumptions in the different studies considered. The numbers in the bottom row show the total number of studies in the literature used for the assessment. This underscores that investment needs are still an evolving area of research that relatively few studies have examined. [Figure 16.3]

There has been a considerable increase in national and sub-national mitigation plans and strategies since AR4. In 2012, 67 % of global GHG emissions were subject to national legislation or strategies versus 45 % in 2007. However, there has not yet been a substantial deviation in global emissions from the past trend [Figure 1.3c]. These plans and strategies are in their early stages of development and implementation in many countries, making it difficult to assess their aggregate impact on future global emissions (*medium evidence, high agreement*). [14.3.4, 14.3.5, 15.1, 15.2]

Since AR4, there has been an increased focus on policies designed to integrate multiple objectives, increase co-benefits and reduce adverse side-effects (*high confidence*)**.** Governments often explicitly reference co-benefits in climate and sectoral plans and strategies. The scientific literature has sought to assess the size of co-benefits (see Section SPM.4.1) and the greater political feasibility and durability of policies that have large co-benefits and small adverse side-effects. [4.8, 5.7, 6.6, 13.2, 15.2] Despite the growing attention in policymaking and the scientific literature since AR4, the analytical and empirical underpinnings for understanding many of the interactive effects are under-developed [1.2, 3.6.3, 4.2, 4.8, 5.7, 6.6].

Sector-specific policies have been more widely used than economy-wide policies (*medium evidence, high agreement*)**.** Although most economic theory suggests that economy-wide policies for the singular objective of mitigation would be more cost-effective than sector-specific policies, since AR4 a growing number of studies has demonstrated that administrative and political barriers may make economy-wide policies harder to design and implement than sector-specific policies. The latter may be better suited to address barriers or market failures specific to certain sectors, and may be bundled in packages of complementary policies. [6.3.6.5, 8.10, 9.10, 10.10, 15.2, 15.5, 15.8, 15.9]

Regulatory approaches and information measures are widely used, and are often environmentally effective (*medium evidence, medium agreement*)**.** Examples of regulatory approaches include energy efficiency standards; examples of information programmes include labelling programmes that can help consumers make better-informed decisions. While such approaches have often been found to have a net social benefit, the scientific literature is divided on the extent to which such policies can be implemented with negative private costs to firms and individuals. [Box 3.10, 15.5.5, 15.5.6] There is general agreement that rebound effects exist, whereby higher efficiency can lead to lower energy prices and greater consumption, but there is *low agreement* in the literature on the magnitude [3.9.5, 5.7.2, 14.4.2, 15.5.4].

Since AR4, cap and trade systems for GHGs have been established in a number of countries and regions. Their short-run environmental effect has been limited as a result of loose caps or caps that have not proved to be constraining (*limited evidence, medium agreement*)**.** This was related to factors such as the financial and economic crisis that reduced energy demand, new energy sources, interactions with other policies, and regulatory uncertainty. In principle, a cap and trade system can achieve mitigation in a cost-effective way; its implementation depends on national circumstances. Though earlier programmes relied almost exclusively on grandfathering (free allocation of permits), auctioning permits is increasingly applied. If allowances are auctioned, revenues can be used to address other investments with a high social return, and/or reduce the tax and debt burden. [14.4.2, 15.5.3]

In some countries, tax-based policies specifically aimed at reducing GHG emissions—alongside technology and other policies—have helped to weaken the link between GHG emissions and GDP (*high confidence*)**.** In a large group of countries, fuel taxes (although not necessarily designed for the purpose of mitigation) have effects that are akin to sectoral carbon taxes [Table 15.2]. The demand reduction in transport fuel associated with a 1 % price increase is 0.6 % to 0.8 % in the long run, although the short-run response is much smaller [15.5.2]. In some countries revenues are used to reduce other taxes and/or to provide transfers to low-income groups. This illustrates the general principle that mitigation policies that raise government revenue generally have lower social costs than approaches which do not. While it has previously been assumed that fuel taxes in the transport sector are regressive, there have been a number of other studies since AR4 that have shown them to be progressive, particularly in developing countries (*medium evidence, medium agreement*). [3.6.3, 14.4.2, 15.5.2]

The reduction of subsidies for GHG-related activities in various sectors can achieve emission reductions, depending on the social and economic context (*high confidence*)**.** While subsidies can affect emissions in many sectors, most of the recent literature has focused on subsidies for fossil fuels. Since AR4 a small but growing literature based on economy-wide models has projected that complete removal of subsidies for fossil fuels in all countries could result in reductions in global aggregate emissions by mid-century (*medium evidence, medium agreement*) [7.12, 13.13, 14.3.2, 15.5.2]. Studies vary in methodology, the type and definition of subsidies and the time frame for phase out considered. In particular, the studies assess the impacts of complete removal of all fossil fuel subsidies without seeking to assess which subsidies are wasteful and inefficient, keeping in mind national circumstances. Although political economy barriers are substantial, some countries have reformed their tax and budget systems to reduce fuel subsidies. To help reduce possible adverse effects on lower-income groups who often spend a large fraction of their income on energy services, many governments have utilized lump-sum cash transfers or other mechanisms targeted on the poor. [15.5.2]

Interactions between or among mitigation policies may be synergistic or may have no additive effect on reducing emissions (*medium evidence, high agreement*)**.** For instance, a carbon tax can have an additive environmental effect to policies such as subsidies for the supply of RE. By contrast, if a cap and trade system has a binding cap (sufficiently stringent to affect emission-related decisions), then other policies such as RE subsidies have no further impact on reducing emissions within the time period that the cap applies (although they may affect costs and possibly the viability of more stringent future targets) (*medium evidence, high agreement*). In either case, additional policies may be needed to address market failures relating to innovation and technology diffusion. [15.7]

Some mitigation policies raise the prices for some energy services and could hamper the ability of societies to expand access to modern energy services to underserved populations (*low confidence*)**. These potential adverse side-effects can be avoided with the adoption of complementary policies** (*medium confidence*)**.** Most notably, about 1.3 billion people worldwide do not have access to electricity and about 3 billion are dependent on traditional solid fuels for cooking and heating with severe adverse effects on health, ecosystems and development. Providing access to modern energy services is an important sustainable development objective. The costs of achieving nearly universal access to electricity and clean fuels for cooking and heating are projected to be between USD 72 and 95 billion per year until 2030 with minimal effects on GHG emissions (*limited evidence, medium agreement*). A transition away from the use of traditional biomass[29] and the more efficient combustion of solid fuels reduce air pollutant emissions, such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and black carbon (BC), and thus yield large health benefits (*high confidence*). [4.3, 6.6, 7.9, 9.3, 9.7, 11.13.6, 16.8]

Technology policy complements other mitigation policies (*high confidence*)**.** Technology policy includes technology-push (e.g., publicly funded R&D) and demand-pull (e.g., governmental procurement programmes). Such policies address market failures related to innovation and technology diffusion. [3.11, 15.6] Technology support policies have promoted substantial innovation and diffusion of new technologies, but the cost-effectiveness of such policies is often difficult to assess [2.6.5, 7.12, 9.10]. Nevertheless, program evaluation data can provide empirical evidence on the relative effectiveness of different policies and can assist with policy design [15.6.5].

In many countries, the private sector plays central roles in the processes that lead to emissions as well as to mitigation. Within appropriate enabling environments, the private sector, along with the public sector, can play an important role in financing mitigation (*medium evidence, high agreement*)**.** The share of total mitigation finance from the private sector, acknowledging data limitations, is estimated to be on average between two-thirds and three-fourths on the global level (2010–2012) (*limited evidence, medium agreement*). In many countries, public finance interventions by governments and national and international development banks encourage climate investments by the private sector [16.2.1] and provide finance where private sector investment is limited. The quality of a country's enabling environment includes the effectiveness of its institutions, regulations and guidelines regarding the private sector, security of property rights, credibility of policies and other factors that have a substantial impact on whether private firms invest in new technologies and infrastructures [16.3]. Dedicated policy instruments, for example, credit insurance, power purchase agreements and feed-in tariffs, concessional finance or rebates, provide an incentive for investment by lowering risks for private actors [16.4].

SPM.5.2 International cooperation

The United Nations Framework Convention on Climate Change (UNFCCC) is the main multilateral forum focused on addressing climate change, with nearly universal participation. Other institutions organized at different levels of governance have resulted in diversifying international climate change cooperation. [13.3.1, 13.4.1.4, 13.5]

Existing and proposed international climate change cooperation arrangements vary in their focus and degree of centralization and coordination. They span: multilateral agreements, harmonized national policies and decentralized but coordinated national policies, as well as regional and regionally-coordinated policies. [Figure TS.38, 13.4.1, 13.13.2, 14.4]

---

[29] See WGIII AR5 Glossary.

The Kyoto Protocol offers lessons towards achieving the ultimate objective of the UNFCCC, particularly with respect to participation, implementation, flexibility mechanisms, and environmental effectiveness (*medium evidence, low agreement*)**.** [5.3.3, 13.3.4, 13.7.2, 13.13.1.1, 13.13.1.2, 14.3.7.1, Table TS.9]

UNFCCC activities since 2007 have led to an increasing number of institutions and other arrangements for international climate change cooperation. [13.5.1.1, 13.13.1.3, 16.2.1]

Policy linkages among regional, national, and sub-national climate policies offer potential climate change mitigation and adaptation benefits (*medium evidence, medium agreement*)**.** Linkages can be established between national policies, various instruments, and through regional cooperation. [13.3.1, 13.5.3, 13.6, 13.7, 13.13.2.3, 14.4, Figure 13.4]

Various regional initiatives between the national and global scales are either being developed or implemented, but their impact on global mitigation has been limited to date (*medium confidence*)**.** Many climate policies can be more effective if implemented across geographical regions. [13.13, 13.6, 14.4, 14.5]