INTERGOVERNMENTAL PANEL ON climate change

Working Group III – Mitigation of Climate Change

Foreword

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December 17th, 2013

Foreword to the Final Draft of the IPCC Working Group III contribution to the Fifth Assessment Report (AR5) on Mitigation of Climate Change

Sir/Madam,

The Intergovernmental Panel on Climate Change (IPCC) Working Group III (WGIII) on the Mitigation of Climate Change is pleased to present the Final Draft of its contribution to the IPCC Fifth Assessment Report (AR5).

The IPCC decided at its 28th Session in Budapest, Hungary, in April 2008 to prepare the AR5 according to IPCC Principles and Procedures. Following a Scoping Meeting in Venice, Italy, in July 2009, the outline of the WGIII contribution to AR5 was approved at the 10th Session of Working Group III and accepted by the 31st Session of the IPCC in Bali, Indonesia, in October 2009. The Panel also decided that the WGIII contribution would be completed in April 2014.

Following an IPCC call for nominations on 15 January 2010 to member governments and observer organizations for experts to participate in the WGIII AR5, Coordinating Lead Authors, Lead Authors and Review Editors were selected from the large number of nominations received by the WGIII Bureau and approved at the 41st Session of the IPCC Bureau in May 2010. The first and second order drafts of the WGIII contribution to AR5 were reviewed by experts, from 22 July to 14 September 2012, and by Governments and experts, from 25 February to 22 April 2013, respectively. The report has now been revised and finalized by the authors in response to comments received in the two rounds of reviews. Your Government is invited to submit written comments on the Final Draft of the Summary for Policymakers (SPM) in the period **17 December 2013 to 11 February 2014**.

The purpose of this final round of review by Governments on the Final Draft of the SPM is to ensure that it provides a balanced and comprehensive assessment of the current information, consistent with the WGIII mandate, and presents the scientific and technical findings of the underlying Report clearly. We ask all Governments to closely examine the Final Draft of the SPM in accordance with Annex 1 of Appendix A to the Principles Governing IPCC Work[1] and to comment on the accuracy and completeness of the scientific/technical/socio-economic content of this document and its overall balance.

The Final Draft of WGIII's contribution to the AR5 is the result of a great global and cooperative effort of more than 300 Coordinating/Lead Authors and Review Editors, as well as a large number of Contributing Authors. The strength of this draft can be attributed to their extensive efforts and the time they have voluntarily invested in addition to their daily professional commitments. We would like to extend our gratitude and highest appreciation for their dedication.

[1] http://www.ipcc.ch/pdf/ipcc-principles/ipcc-principles-appendix-a.pdf

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The Final Draft of the SPM is available to Governments for review on the IPCC WGIII website via the following link:

http://www.ipcc-wg3.de/ar5review/

Please note that **the underlying chapters, annexes and Technical Summary are also provided for your information to facilitate the generation of specific comments on the SPM, but these documents are not open for comment**. We would like to remind you that the Final Draft is a confidential document in its entirety and made available solely for the purposes of the IPCC review process; thus **it must not be cited, quoted or distributed**. The review process is completed only after acceptance by the Session of the Working Group III in April 2014 after which the report will be published.

The aforementioned website also provides the excel spreadsheet for download, into which your comments on the Final Draft of the SPM should be inserted. Please read the instructions on the website and in the comment sheet carefully. Once completed, your comments should be submitted via the upload function of the website. Comments sent to the TSU via email or in alternative formats (e.g. Word documents) will be rejected.

As a reminder, the Government Review of the WGIII Final Draft of SPM ends and the Review site closes for input on **Tuesday 11 February 2014, 6 pm CET**. Please be advised that late comments cannot be accepted. Please also note that **all comments will be published** following the final approval and publication of the report.

Should you have any questions, please contact the IPCC WGIII Technical Support Unit at contact@ipcc-wg3.de.

Sincerely,

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Co-Chair IPCC WGIII	Co-Chair IPCC WGIII	Co-Chair IPCC WGIII

INTERGOVERNMENTAL PANEL ON climate change
Working Group III – Mitigation of Climate Change

SPM

Summary for Policy Makers

Title:	Summary for Policymakers
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SPM: Summary for Policymakers

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SPM.1 Introduction and framing

"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 goal expressed in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) to "*prevent dangerous anthropogenic interference with the climate system… within a time frame to allow ecosystems to adapt… to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner*". Prudent climate policy employs the methods of science to predict the effects of each policy. It also employs systematic methods from various disciplines to value these effects. Judgements of value derived by these methods rest ultimately on ethical principles.

This report does not recommend particular goals for mitigation but assesses the options available at different levels of governance and in different economic sectors, and the societal implications of different mitigation policies. The remainder of this Summary offers the report's main findings.[1] This Section continues with providing a framing of important concepts and methods that help to contextualise the findings presented in subsequent sections. Section 2 presents evidence on past trends in stocks and flows of GHGs and the factors that drive emissions at the global, regional, and sectoral scales including economic growth, technology or population changes. Section 3.1 provides findings from studies that analyse the technological, economic and institutional requirements of long-term mitigation scenarios. Section 3.2 provides details on mitigation measures and policies that are used in different economic sectors and human settlements. Section 4 summarizes insights on the interactions of mitigation policies between governance levels, economic sectors, and instrument types. References in [square brackets] indicate chapters, sections, figures, tables, and boxes in the underlying report where supporting evidence can be found.

Climate Change is a global commons problem that implies the need for international cooperation in tandem with local, national, and regional policies on many distinct matters. Because the emissions of any agent (individual, company, country) affect every other agent, an effective outcome will not be achieved if individual agents advance their interests independently of others. International cooperation can contribute by defining and allocating rights and responsibilities with respect to the atmosphere [1.2.4, 3.1, 4.2, 13.2.1]. Moreover, research and development (R&D) in support of mitigation is a public good, which means that international cooperation can play a constructive role in the coordinated development and diffusion of technologies [1.4.4, 3.11, 13.9, 14.4.3]. This gives rise to separate needs for cooperation on R&D, opening up of markets, and the creation of incentives to encourage private firms to develop and deploy new technologies and households to adopt them.

International cooperation on climate change involves ethical considerations, including equitable effort-sharing. Countries have contributed differently to the build-up of GHG in the atmosphere, and have varying capacities to contribute to mitigation and adaptation. Engaging countries in effective international cooperation requires strategies for sharing the costs and benefits of mitigation, in ways that are perceived to be equitable. Evidence suggests that perceived fairness can influence the level of cooperation among individuals, and that finding may suggest that processes and outcomes seen as fair will lead to more international cooperation as well. [3.10, 4.2, 13.2.2.4]

[1] Throughout this Summary, the validity of findings is expressed as a qualitative level of *confidence* and, when possible, probabilistically with a quantified *likelihood*. Confidence in the validity of findings is based on the type, amount, quality, and consistency of *evidence* (e.g. theory, data, models, expert judgment) and the degree of *agreement*. Levels of evidence and agreement can be disclosed instead of aggregate confidence levels. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers. For more details, please refer to the Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties.

Economic evaluation can be useful for policy design and be given a foundation in ethics, provided appropriate distributional weights are applied. The literature provides significant guidance on inter-temporal weighting – the social discount rate for consumption. The discount rate depends primarily on the anticipated growth in per capita income and inequality aversion [3.5.2]. Practical tools for policy assessment include cost-benefit analysis, cost-effectiveness analysis, multi-criteria analysis, and expected utility theory [2.5].

Analysis contained in the literature of moral and political philosophy can contribute to resolving ethical questions that are raised by climate change. These questions include how much overall climate mitigation is needed to avoid 'dangerous interference', how the effort or cost of mitigating climate change should be shared among countries and between the present and future, how to account for such factors as historical responsibility for emissions, and how to choose among alternative policies for mitigation and adaptation. Ethical issues of wellbeing, justice, fairness, and rights are all involved. [3.2, 3.3, 3.4]

Most climate policies intersect with other goals creating the possibility of 'co-benefits' or 'adverse side-effects'. Mitigation can also address other goals, such as local environmental protection or energy security, as a 'co-benefit'. This multi-objective perspective is important because it helps to identify areas where support for policies that advance multiple goals will be robust. Moreover, in many societies the presence of multiple objectives may make it easier for governments to sustain the political support needed to mitigate emissions. [1.2.1, 4.8, 6.6.1]

Trade-offs and synergies with other societal goals can be evaluated in a sustainable development framework. The many diverse goals that societies value are often called "sustainable development". A comprehensive assessment of climate policy therefore involves going beyond a narrow focus on distinct mitigation and adaptation options and their specific co-benefits. Instead it entails incorporating climate issues into the design of comprehensive strategies for equitable and sustainable development at regional, national, and local levels. [4.2, 4.4, 4.5, 4.6, 4.8]

Variations in goals reflect, in part, the fact that humans perceive risks and opportunities differently. Policies can be improved by taking into account risks and uncertainties in natural, social, and technological systems, people's values, and their perceptions and decision processes. Individuals misperceive risks and utilize simplified decision rules such as the tendency to maintain the status quo. They also differ in their degree of risk aversion, and the relative importance they place on near-term versus longer-term ramifications [2.4.6]. Formal methods can systematically address issues of risk and uncertainty, even when probabilities and outcomes cannot be precisely specified. [2.5]

Climate policy involves building institutions and capacity for governance. Responding effectively to the climate challenge is not merely a technical exercise. It involves diverse actors and institutions at the international [13.4], regional [14.1], national and sub-national scales [15.1]. It also involves issues related to procedural equity and the distribution of power, resources, and decision-making authority among the potential winners and losers. [4.3]

Risks associated with the full range of outcomes are relevant to the assessment of mitigation options. The risk associated with extreme climate change may be an important determinant of the appropriate level of mitigation, adaptation and other responses. Some of the risks are essentially unknown—such as some "tipping points" that might trigger new climate regimes. This implies the need to integrate all risks into a management system that is adaptive to new information. [2.5, Box 3.9]

SPM.2 Trends in flows and stocks of greenhouse gases and their drivers

This section summarizes the recent developments in historic GHG emission trends and drivers. While AR4 focussed on the period 1970 to 2004, the present report examines trends to 2010, the year through which most data sets are complete as well as some emission sources through 2012. As in most of the underlying literature, all aggregate GHG emission estimates are converted to CO_2-equivalents (CO_2eq) based on Global Warming Potentials with a 100 year time horizon (GWP_{100}) from the Second Assessment Report (SAR) unless stated otherwise. Although GWP values have been updated several times since, including in AR5, the SAR values are widely used in policy settings, including the Kyoto Protocol, as well as in many national and international emission accounting systems [Box TS.5].

Global GHG emissions have risen more rapidly between 2000 and 2010 *(high confidence)*. Current GHG emissions trends are at the high end of projected levels for the last decade and have reached 49 $GtCO_2eq$ in 2010. Despite the presence of a wide array of multilateral institutions as well as national policies aimed at climate change mitigation GHG emissions grew on average 2.2% per year between 2000 and 2010 compared to 1.3% per year over the entire period 1970 to 2000 (Figure SPM.1). The global economic crisis 2007/2008 has temporarily reduced emissions but not changed the trend. Initial evidence suggests that growth in global CO_2 emissions from fossil fuel combustion has continued by about 3% between 2010 and 2011 and by about 1-2% between 2011 and 2012. [1.3, 5.2, 13.3, 15.2]

CO_2 remains the major anthropogenic GHG with about 76% of total GHG emissions in 2010 weighed by GWP_{100} (*high confidence*). 16% come from CH_4, 6% from N_2O, and 2% from fluorinated gases (Figure SPM.1). Using GWPs with shorter time horizons increases the share of total non-CO_2 greenhouse gases. The choice of type of emission metric and time horizon involves explicit or implicit value judgements. [1.2, 3.9, 5.2, Box TS.2].

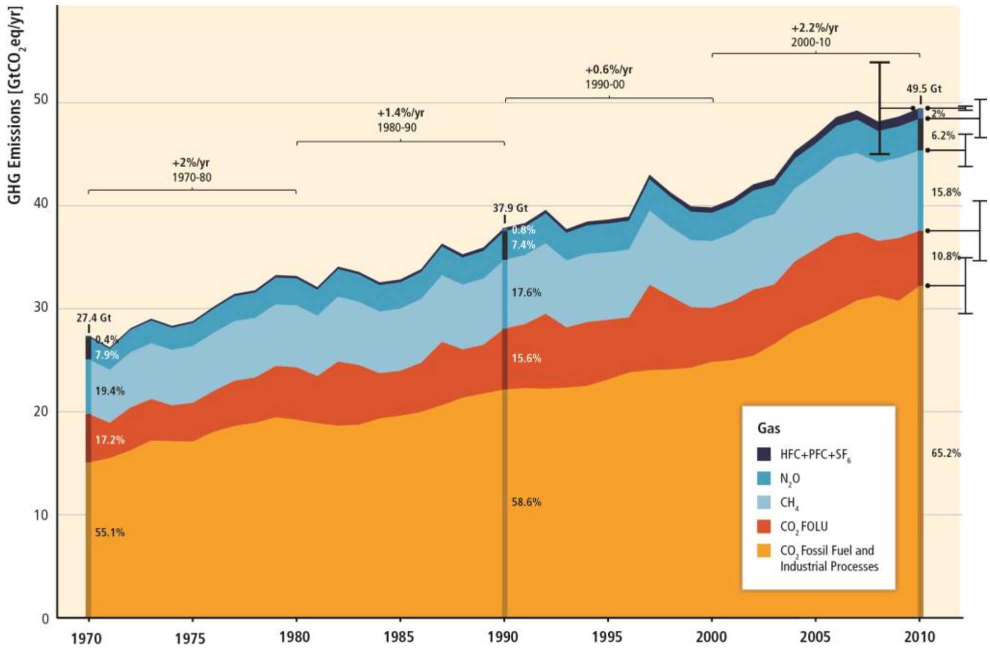

Figure SPM.1. Total annual GHG emissions by groups of gases 1970-2010: CO_2 from fossil fuel combustion and industrial processes (yellow); CO_2 from Forestry and Other Land Use (FOLU; orange); CH_4 (light blue); N_2O (blue); fluorinated gases (F-gases, dark blue). All emissions are reported in $GtCO_2eq$ per year based on GWP_{100}. The emissions data from FOLU represents land-based CO_2 emissions from forest and peat fires and decay that approximate to net CO_2 flux from the FOLU sub-sector as described in chapter 11 of this report. The uncertainty ranges provided by the whiskers for 2010 are illustrative given the limited literature on GHG emission uncertainties. [Figure 1.3]

Over the last four decades total cumulative CO_2 emissions have increased by a factor of 2 from about 900 $GtCO_2$ for the period 1750 - 1970 to 2000 $GtCO_2$ for 1750 - 2010 (*high confidence*). In 1970 the cumulative fossil CO_2 emissions since 1750 was 420 ±35; in 2010 that cumulative total had tripled to 1300 ±110 $GtCO_2$ (Figure SPM.2). Cumulative CO_2 emissions from FOLU since 1750 increased from about 490±180 $GtCO_2$ in 1970 to approximately 680±300 $GtCO_2$ in 2010. [5.2]

The upward trend in global fossil fuel related CO_2 emissions is robust across databases and despite uncertainties (*high confidence*). 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_2O and the F-gases has been estimated as 20%, 60% and 20%. Combining these values yields an illustrative total global GHG uncertainty estimate of order 10%. Uncertainties can increase at finer spatial scales and for specific sectors. Attributing emissions to the country of final consumption increases uncertainties, but literature is just emerging. GHG emission estimates in the AR4 were 5-10% higher than the estimates reported here, but lie well within the uncertainty range. [5.2]

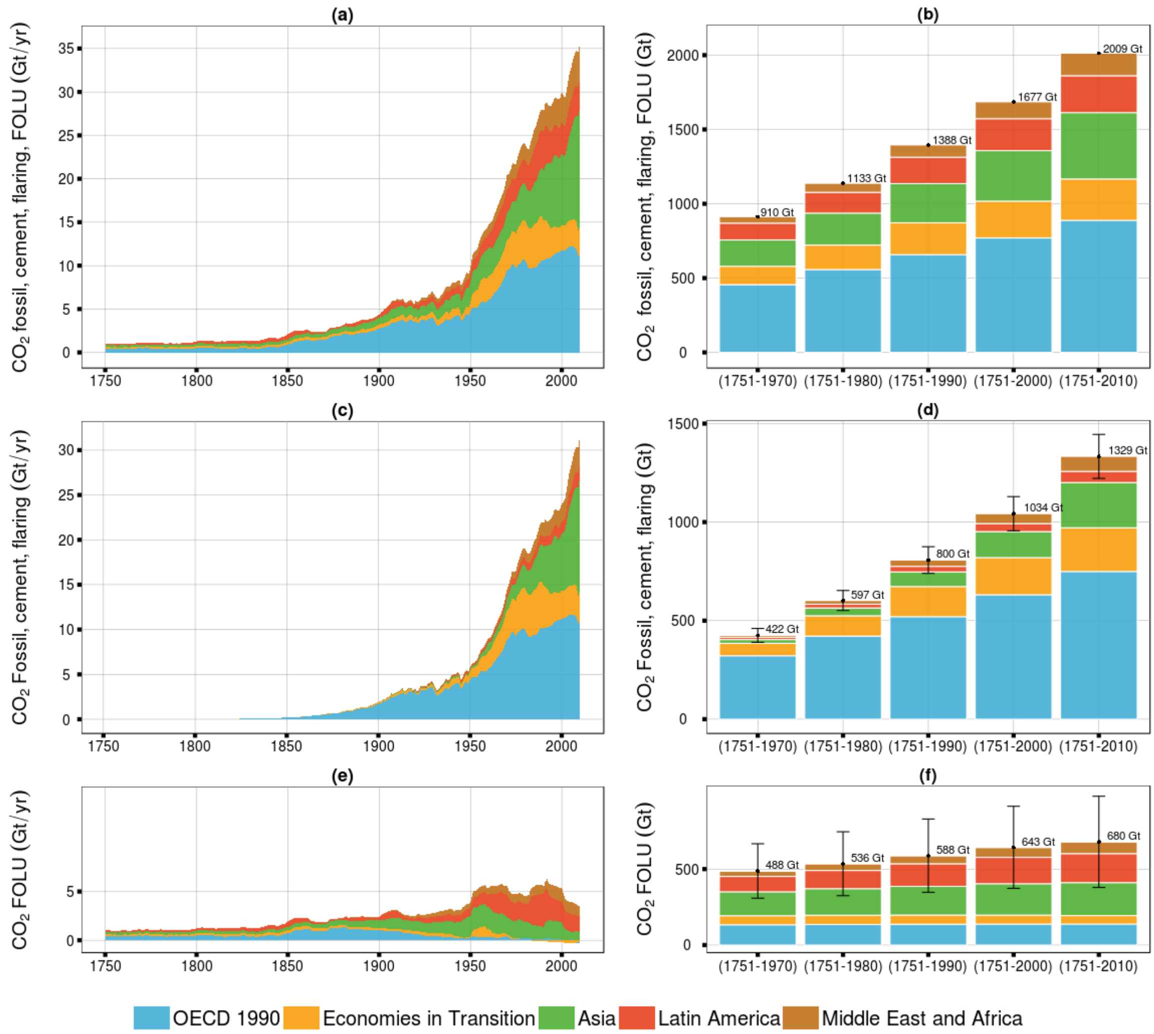

Figure SPM.2. Historical anthropogenic CO_2 emissions from fossil fuel combustion, flaring, cement, FOLU in five major world regions: OECD1990 (blue); Economies in Transition (yellow); Asia (green); Latin America (red); Middle East and Africa (brown). Emissions are reported in $GtCO_2$ per year. Left panels show regional CO_2 emission trends 1750-2010 from: (a) all sources (c+e); (c) fossil fuel combustion, flaring and cement; (e) FOLU. The right panels show regional contributions to cumulative CO_2 emissions at selected time periods from: (b) all sources (d+f); (d) fossil fuel combustion, flaring and cement; (f) FOLU. Whiskers on (d) and (f) give an indication of the uncertainty range. [Figure 5.3]

Regional patterns of GHG emissions are shifting along with changes in the world economy *(high confidence)*. More than 75% of the 10 Gt increase in annual GHG emissions between 2000 and 2010 was emitted in the energy supply (47%) and industry (30%) sectors. 5.9 $GtCO_2eq$ of this sectoral increase comes from upper-middle income countries, where economic growth and infrastructure build-up has been highest. [1.3, 5.3]

Current GHG emission levels are dominated by contributions from the energy supply, AFOLU and industry sectors; industry and building gain considerably in importance if indirect emissions are accounted for *(robust evidence, high agreement)*. In 2010, 35% of GHG emissions were released in the energy supply sector, 24% in AFOLU, 21% in industry, 14% in transport and 6% in buildings. When indirect emissions from electricity and heat production are assigned to sectors of final energy use, the shares of the industry and buildings sectors in global GHG emissions grow by 11%- and 12%-points to 32% and 18%, respectively (Figure SPM.3). [1.3, 7.3, 8.2, 9.2, 10.3, 11.2]

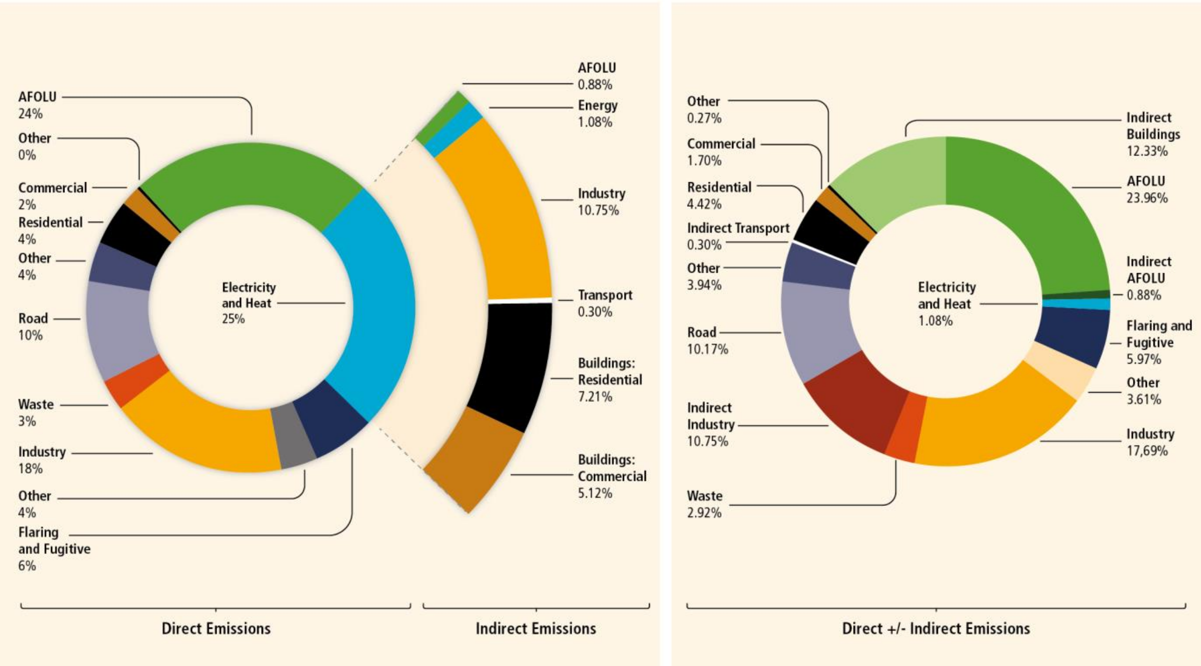

Figure SPM.3. Allocation of GHG emissions across economic sectors in 2010**.** Left panel: Share (in %) of direct GHG emissions in 2010 across sectors. Pull out allocates indirect CO_2 emission shares from electricity and heat production to the sectors of final energy use. Right panel: Shares (in %) of direct and indirect GHG emissions in 2010 by major economic sectors with CO_2 emissions from electricity and heat production allocated to the sectors of final energy use. The emission data from Agriculture, Forestry and Other Land Use (AFOLU) includes land-based CO_2 emissions from forest and peat fires and decay that approximate to net CO_2 flux from the FOLU sub-sector as described in chapter 11 of this report. [Figure 1.3]

Per-capita emissions are highly unequal *(high confidence)***.** In 2010, median per capita emissions (1.4t CO_2eq/cap) for the group of low-income countries are around 9 times lower than median per capita emissions (13t CO_2eq/cap) of high income countries (Figure SPM.4). For high-income countries, the largest source of emissions is typically from the industry and energy sectors; for most low-income countries, the largest source of emissions is from AFOLU. There are substantial variations in per capita emissions within income groups with emissions at the 10th percentile level more than double those at the 90th percentile level. [1.3, 5.2, 5.3]

A growing share of global emissions is released in the manufacture of products that are traded across international borders *(medium evidence; high agreement)*. Since AR4 several data sets have quantified the difference between traditional “territorial” and “consumption-based” emission estimates that assign all emission released in the global production of goods and services to the country of final consumption (Figure SPM.5). A growing share of CO_2 emissions from fossil fuel combustion in developing countries is released in the production of goods and services exported, notably from upper middle income countries to high income countries. Total annual industrial CO_2 emissions from the non-Annex I group now exceed those of the Annex I group using territorial and consumption accounting methods, but per-capita emissions are still markedly higher in the Annex I group. [1.3, 5.3]

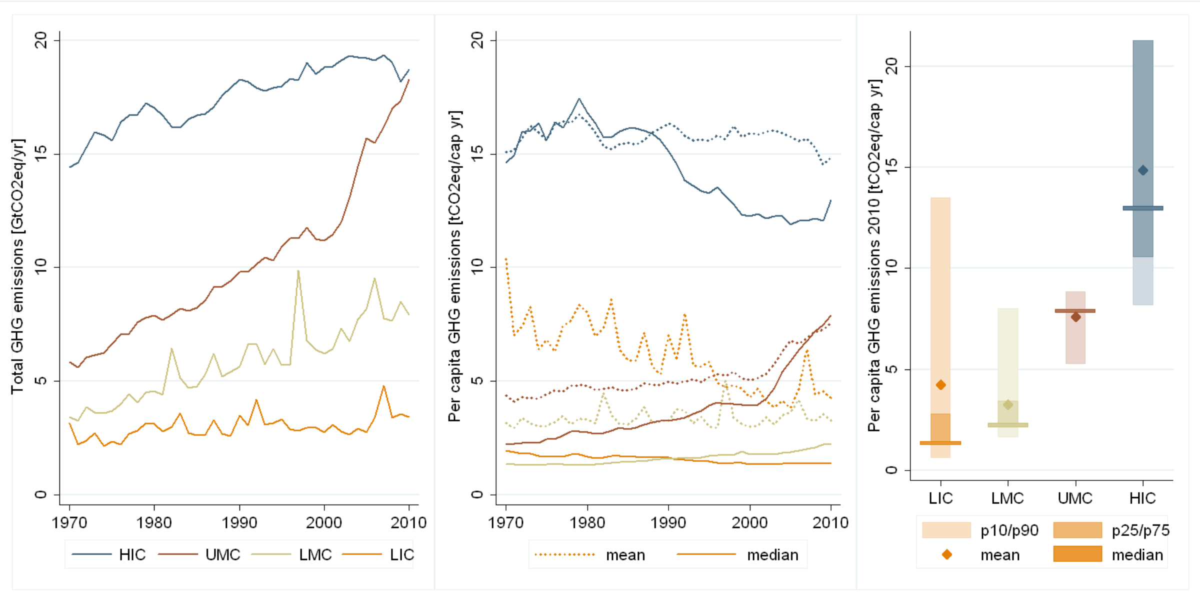

Figure SPM.4. Regional trends in GHG per economic region: High Income Countries (HIC), Upper-Middle income Countries (UMC), Lower-Middle income Countries (LMC), Low Income Countries (LIC). Left panel shows the total annual GHG emissions 1970-2010 in $GtCO_2eq$ per year. Panel in the middle shows trends in annual per capita mean and median GHG emissions 1970-2010 in tonnes of CO_2eq (t/cap/year). Right panel shows the annual per capita GHG emissions in 2010 in tonnes of CO_2eq (t/cap/year). Shadings show the 10^{th} to 90^{th} percentile range (light) as well as the 25^{th} to 75^{th} percentile range (dark). The horizontal bar identifies the median and diamond the mean. [Figure 1.4, Figure 1.8]

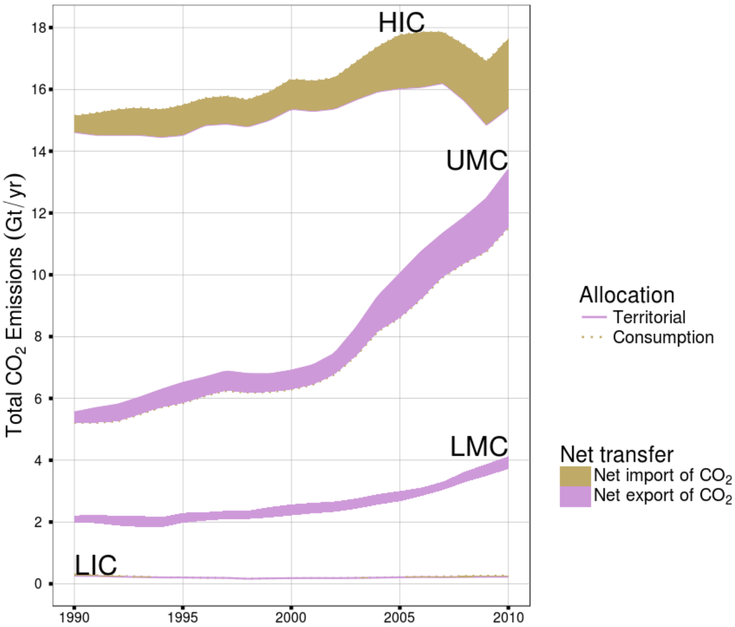

Figure SPM.5. CO_2 emissions from fossil fuel combustion for four economic regions attributed on the basis of territory (solid line) and final consumption (dotted line) in $GtCO_2$ per year. Regions are Low Income Countries (LIC), Lower-Middle income Countries (LMC), Upper-Middle income Countries (UMC) and High Income Countries (HIC). The shaded areas are the net CO_2 trade balance (difference) between each of the four country groupings and the rest of the world. Brown shading indicates that the region is a net importer of emissions, leading to consumption-based CO_2 emission estimates that are higher than traditional production-based emission estimates. Pink indicates the reverse situation - net exporters of embodied emissions. [Figure 1.5]

Regardless of the perspective taken, a small number of countries account for a large share of global CO_2 emissions (*high confidence*). In 2010, ten countries accounted for about 70% of CO_2 emissions from fossil fuel combustion and industrial processes. A similarly small number of countries emit the largest share of consumption-based CO_2 emissions as well as cumulative CO_2 emissions going back to 1750. [1.3]

Economic and population growth continue to be the two main drivers for increases in global fossil fuel CO_2 emissions over 2000-2010, outpacing the decline in energy intensity (*high confidence*). Over the last decade the importance of economic growth as a driver of global emissions has risen sharply while population growth has remained roughly steady (Figure SPM.6). The energy intensity of economic output has steadily declined worldwide, and that decline has had an offsetting effect on global emissions that is nearly of the same magnitude as growth in population. Between 2000 and 2010, increased use of coal relative to other energy sources has reversed a long-standing pattern of gradual decarbonisation of the world's energy supply. [1.3, 5.3]

Without explicit efforts to reduce GHG emissions, the fundamental drivers of emissions growth are expected to persist despite major improvements in energy supply and end-use technologies (*high confidence*). Atmospheric concentrations in baseline scenarios collected for this assessment (scenarios without explicit additional efforts to constrain emissions) exceed 450 ppm CO_2eq by 2030 and reach CO_2eq concentration levels between 750 to more than 1300 ppm CO_2eq by 2100. This corresponds to about the range of forcing between the RCP 6.0 and RCP 8.5 pathways by 2100, with the majority falling below the latter. Based on calculations consistent with the scenario evidence presented in this report, atmospheric CO_2eq concentrations were about 400ppm CO_2eq in 2010. These represent full radiative forcing including greenhouse gases, halogenated gases, tropospheric ozone, aerosols and albedo change. [6.3.1]

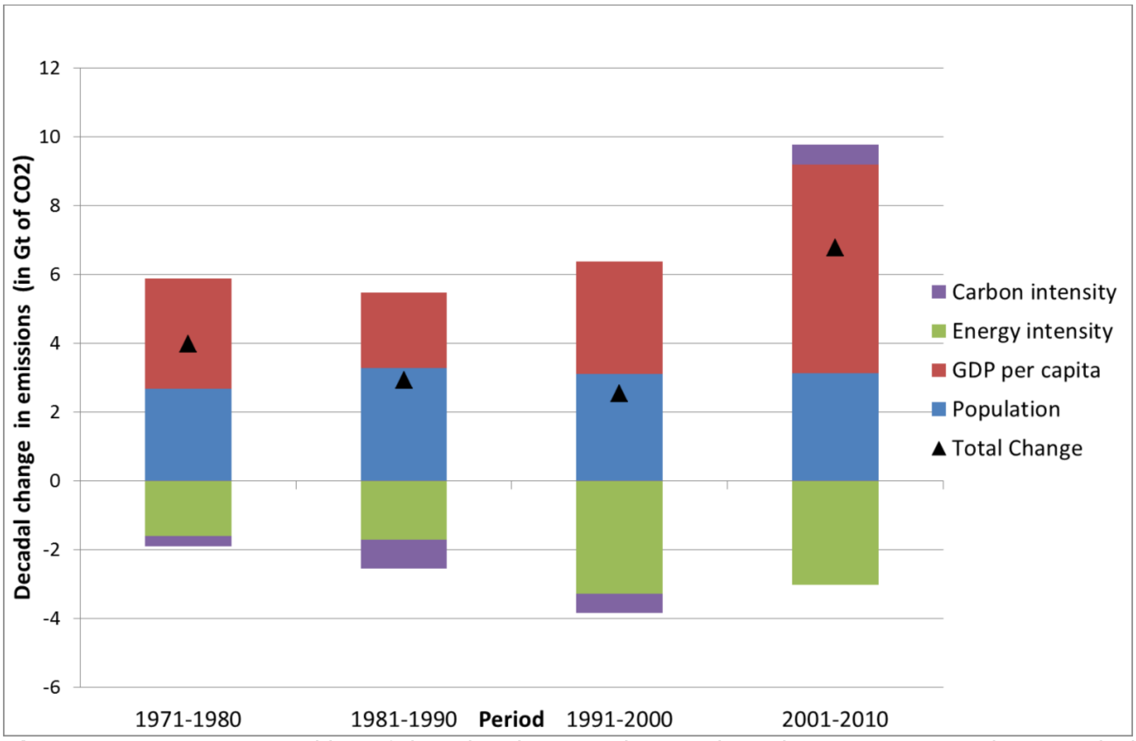

Figure SPM.6. Decomposition of decadal absolute changes in global energy-related CO_2 emissions:; population (blue), GDP per capita (red), energy intensity of GDP (green) and carbon intensity of energy (purple). Total decadal changes are indicated by a black triangle. Changes are measures in $GtCO_2$ emissions. [Figure 1.6]

SPM.3 Mitigation pathways and measures in the context of sustainable development

SPM.3.1 Long-term mitigation pathways

Mitigation scenarios point to a range of technological and behavioral options that would allow the world's societies to follow emissions pathways compatible with atmospheric concentration levels between about 450 ppm CO_2eq to more than 750 ppm CO_2eq by 2100; this is comparable to forcing levels between RCP 2.6 and RCP 6.0 (*high confidence*). As part of this assessment, about 900 mitigation scenarios (out of more than 1200 total scenarios) have been collected. The scenarios indicate a wide range of possible pathways to different concentration levels based on different technological, socioeconomic, and institutional assumptions (Figure SPM.7, left panel). No multi-model comparison study and only a limited number of individual studies have explored pathways to atmospheric concentrations of below 430 ppm CO_2eq by 2100. [6.3]

Limiting peak atmospheric concentrations over the course of the century – not only reaching long-term concentration levels – is critical for limiting temperature change (*high confidence*). The majority of scenarios reaching long-term concentrations between 430 to 480 ppm CO_2eq in 2100 are *likely* to keep temperature change below 2°C over the course of the century and are associated with peak concentrations below 515 ppm CO_2eq. Scenarios that exceed 580 ppm CO_2eq during the course of the century are *unlikely* to keep temperatures below 2°C. Only a limited number of studies have explored emissions pathways where temperature peaks over the course of the century and is brought back to 1.5°C with a *likely* chance at the end of the century. The scenarios assume immediate introduction of climate policies as well as the rapid upscaling of the full portfolio of mitigation technologies combined with low energy demand in order to bring concentration levels below 430 ppm CO_2eq in 2100 (Table SPM.1). [6.3, Box TS.6]

Atmospheric concentrations peak during the 21st century before descending toward their 2100 level in many scenarios that reach atmospheric concentrations of 430 to 580 ppm CO_2eq by 2100 (*high confidence*). Concentration overshoot allows relatively less mitigation in the near term, but involves more rapid and deeper emissions reductions in the long run. The vast majority of scenarios with overshoot of greater than 35-50 ppm CO_2eq (concentration) deploy CDR technologies to an extent that net global CO_2 emissions become negative. These scenarios are associated with lower flexibility with respect to choices about the technology portfolio, since they are reliant on CDR technologies (Figure SPM.7; right Panel). [6.3, 6.9]

Reaching atmospheric concentrations levels of 430 to 530 ppm CO_2eq by 2100 will require large-scale changes of the global energy system as well as cuts in GHG emissions over the coming decades (*high confidence*). The majority of scenarios reaching these atmospheric concentration levels are characterized by a tripling to nearly a quadrupling of the share of zero- and low-carbon energy supply from renewables, nuclear energy and fossil energy with CCS by the year 2050 relative to 2010 [about 17%] (Figure SPM.9, left panel). The majority of scenarios in which concentrations remain below 530ppm CO_2eq throughout the 21st century are associated with GHG emissions reductions between 40% to 70% by 2050 compared to 2010. [6.3, 7.11]

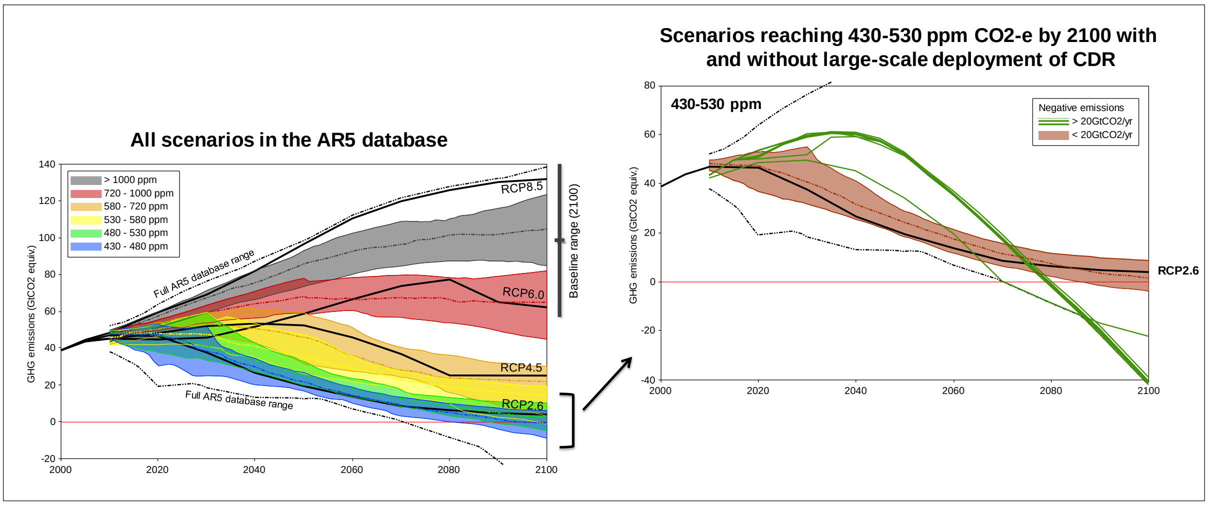

Figure SPM.7. Development of global GHG emission for different long-term concentration levels (left-hand panel) and for scenarios reaching 430-530 ppm CO_2eq in 2100 with and without negative CO_2 emissions larger than 20 $GtCO_2$/year (right-hand panel). Ranges are given for the 10-90th percentile of scenarios. [Figure 6.7]

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

CO_2eq Conc in 2100 (ppm CO_2eq)	*Representative Concentration Pathways (RCPs)*		*CO_2 emission budget[2] ($GtCO_2$)*		*CO_2eq emissions in 2050 relative to 2010 (%)*	*Temperature change (relative to 1850-1870)[3,4]*			
			2011-2050	*2011-2100*		*2100 Temperature (degrees C)[5]*	*Probability of staying below 1.5 degrees C (%)*	*Probability of staying below 2 degrees C (%)*	*Probability of staying below 2.5 degrees C (%)*
<430		*Only limited number of studies from individual research groups*							
430 – 480	RCP 2.6	Total range	550-1270	630-1180	31-65	1.5-1.8 (1.2-2.3)	Less likely than not	Likely	Very likely
480 - 530		No exceedance of 530 ppm CO_2eq	900-1220	1020-1280	43-60	1.8-1.9 (1.4-2.4)	Unlikely	More likely than not	Likely
		Exceedance of 530 ppm CO_2eq	1190-1620	990-1550	51-119	1.9-2.2 (1.5-2.9)	Very unlikely	More unlikely than not	More likely than not
530 – 580		No exceedance of 580 ppm CO_2eq	1110-1600	1220-2130	52-98	2.1-2.3 (1.7-2.9)	Very unlikely	More unlikely than not	Likely
		Exceedance of 580 ppm CO_2eq	1510-1790	1160-1970	98-123	2.2-2.3 (1.7-2.9)	Extremely unlikely	Unlikely	More likely than not
580 – 650	RCP 4.5	Total range	1260-1640	1880-2430	68-139	2.3-2.7 (1.8-3.4)	Extremely unlikely	Unlikely	About as likely as not
650 – 720		Total range	1320-1720	2620-3320	103-131	2.6-2.9 (2.1-3.6)	Exceptionally unlikely	Very unlikely	Unlikely
720 – 1000	RCP 6.0	Total range	1600-1930	3620-4990	128-168	3.1-3.7 (2.5-4.7)	Exceptionally unlikely	Extremely unlikely	Unlikely to very unlikely
>1000	RCP 8.5	Total range	1840-2320	5350-6950	165-220	4.1-4.8 (3.3-6.3)	Exceptionally unlikely	Exceptionally unlikely	Exceptionally unlikely

[1] The 'total range' for the 430 to 480 ppm CO2-eq scenarios corresponds to the range of the 10-90th percentile of the subcategory of these scenarios shown in table 6.3.

[2] For comparison of the cumulative CO_2 budget results assessed here with those presented in WG1, emissions from 1850 to 2011 are estimated to be about 2035 $GtCO_2$.

[3] Estimates of concentrations and climate change are based on MAGICC model calculations using the MAGICC model in a probabilistic mode (6.3 and Annex II). For a comparison between MAGICC model results and the outcomes of the models used in WG1 see 6.3.2.6.

[4] The likelihood statements are indicative only (6.3), and follow broadly the terms used by the WG1 SPM: 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%. In addition the terms extremely likely: 95–100%, more likely than not >50–100%, more unlikely than not 0-50% and extremely unlikely 0–5% are used. The likelihood statements here were selected based on the coverage of the uncertainty terms by 10-90th percentile of the uncertainty range of the scenarios.

[5] Temperature 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 also the climate system uncertainties as represented by the MAGICC model (see 6.3.2.6 for further details).

Delaying mitigation through 2030 will increase the challenges of, and reduce the options for, bringing atmospheric concentration levels to 530 ppm CO_2eq or lower by the end of the century (*high confidence*). The majority of scenarios leading to atmospheric concentration levels between 430 ppm CO_2eq and 530 ppm CO_2eq in 2100 are characterized by 2030 emissions roughly between 30 GtCO_2eq and 50 GtCO_2eq. Scenarios with emissions above 55 GtCO_2eq in 2030 are predominantly driven by delays in mitigation (Figure SPM.8, left panel). These scenarios are characterized by substantially higher rates of emissions reductions from 2030 to 2050 (Figure SPM.8, right panel); much more rapid scale-up of low-carbon energy over this period (Figure SPM.9, right panel); a larger reliance on CDR technologies in the long term (Figure SPM.7, right panel); and higher transitional and long term economic impacts. Due to these increased challenges, many models with 2030 emissions in this range could not produce scenarios reaching atmospheric concentrations levels in the range between 430 and 480 ppm CO_2eq in 2100. [6.4, 7.11, Figure TS.11, Figure TS.13]

The Cancun Pledges for 2020 are higher than GHG emission levels from scenarios that reach atmospheric concentrations levels between 430 and 530 ppm CO_2eq by 2100 at lowest global costs. The Cancun Pledges correspond to scenarios that explicitly delay mitigation through 2020 or beyond relative to what would achieve lowest global cost (*robust evidence, high agreement*). The Cancun Pledges are broadly consistent with scenarios reaching 550 ppm CO_2eq to 650 ppm CO_2eq by 2100 without delays in mitigation. Studies confirm that delaying mitigation through 2030 has substantially larger influence on the subsequent challenges of mitigation than do delays through 2020. [Figure TS.11, 6.4]

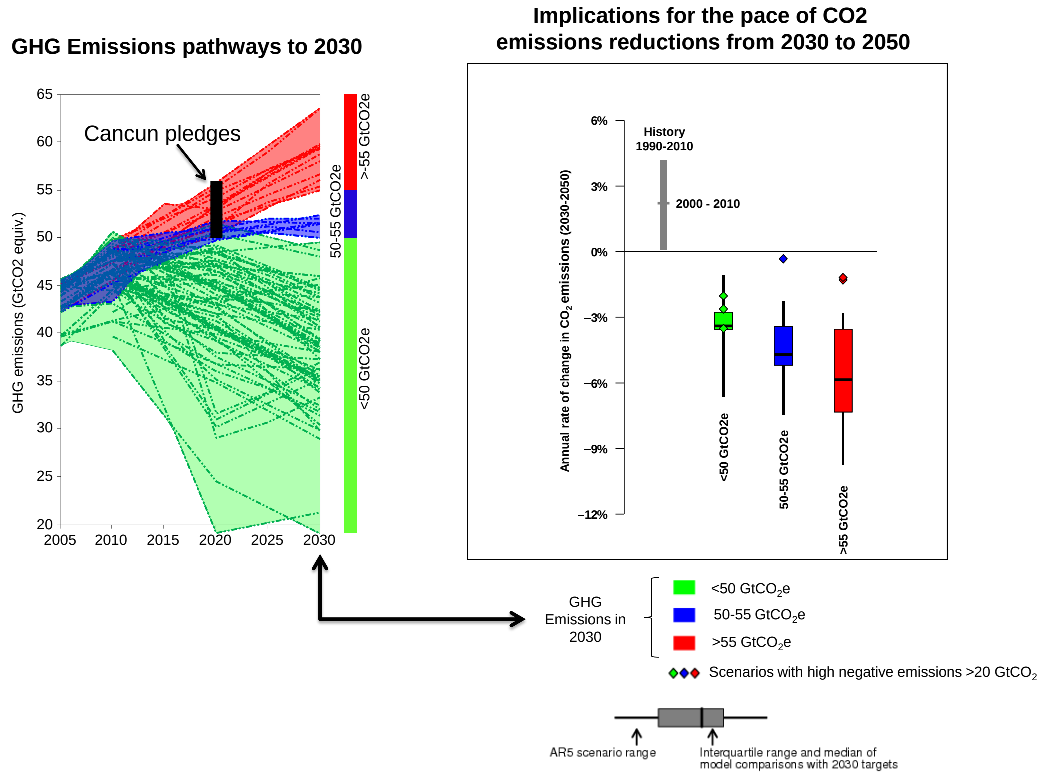

Figure SPM.8. The implications of different 2030 GHG emissions levels for the pace of CO_2 emissions reductions to 2050 in low mitigation scenarios reaching 430-530 ppm CO_2eq concentrations by 2100. Left panel shows the development of GHG emissions to 2030. Right-hand panel denotes the corresponding annual CO_2 emissions reduction rates for the period 2030-2050. The scenarios are grouped according to different emissions levels by 2030 (colored in red, blue and green). The right panel compares the median and interquartile range across scenarios from recent intermodeling comparisons with explicit 2030 interim goals with the range of scenarios in the Scenario Database for AR5. Annual rates of historical emissions change (sustained over a period of 20 years) are shown in grey. Note: Only scenarios with default technology assumptions are shown. Scenarios with non-optimal timing of mitigation due to exogenous carbon price trajectories are excluded. [Figure 6.32]

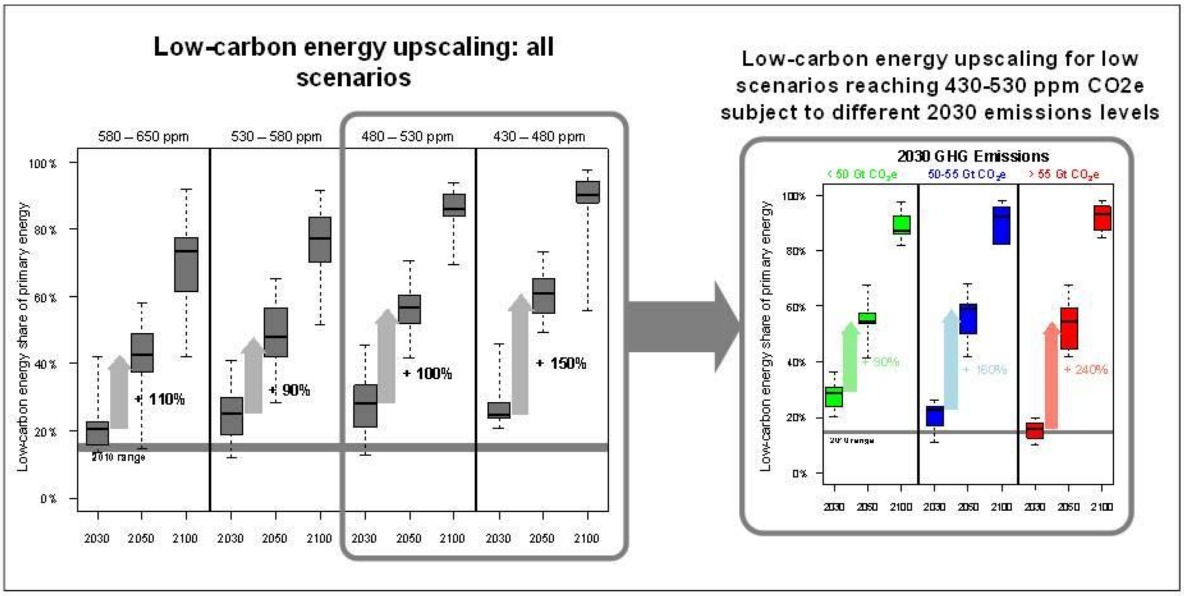

Figure SPM.9. The up-scaling of low-carbon energy in scenarios meeting different 2100 CO_2eq concentration levels (left panel). The right panel shows the rate of up-scaling subject to different 2030 GHG emissions levels in stringent mitigation scenarios (430-530 ppm CO_2eq by 2100 from model intercomparisons with explicit 2030 emissions targets). Bars show the interquartile range and error bands the full range across the scenarios. Low-carbon technologies include renewables, nuclear energy and fossil fuels with CCS. Note: Only scenarios with default technology assumptions are shown. In addition, scenarios with non-optimal timing of mitigation due to exogenous carbon price trajectories are excluded in the right panel. [Figure 7.16]

Estimates of the aggregate economic costs of mitigation vary widely, but increase with stringency of mitigation (*high confidence*). Most scenario studies collected for this assessment that are based on the assumptions that all countries of the world begin mitigation immediately, there is a single global carbon price applied to well-functioning markets, and key technologies are available, estimate that reaching 430-480 ppm CO_2eq by 2100 would entail global consumption losses of 1% to 4% in 2030, 2% to 6% in 2050, and 2% to 12% in 2100 relative to what would happen without mitigation. Costs for maintaining concentrations at around 550 ppm CO_2eq are estimated to be roughly 1/3 to 2/3 lower than for 450 ppm CO_2eq scenarios. These costs do not consider the benefits of mitigation, including the reduction in climate impacts. Substantially higher and lower cost estimates have been obtained based on assumptions about less idealized policy implementations, interactions with pre-existing distortions, non-climate market failures, or complementary policies. [6.3]

Effort-sharing frameworks can help to clarify discrepancies between the distribution of costs based on mitigation potential and the distribution of responsibilities based on ethical principles, and help reconcile those discrepancies through international financial transfers (*medium confidence*)**.** Studies find that in order to reach concentrations of roughly 450 to 550 ppm CO_2eq at lowest global cost, the majority of mitigation investments over the course of century will occur in the non-OECD countries. Studies estimate that the financial transfers to ameliorate this asymmetry could be in the order of hundred billions of USD per year before mid-century to bring concentrations in the range of 450 ppm CO_2eq in 2100. [6.3, 13.4.2.4]

Mitigation scenarios reaching 430 and 530 ppm CO_2eq in 2100 reduce the costs of energy security and air quality objectives, and are associated with significant co-benefits for human health, ecosystem impacts as well as the sufficiency and resilience of the energy system (*medium confidence*) Mitigation scenarios show improvements in terms of the sufficiency of resources to meet national energy demand as well as the resilience of the energy supply, resulting in energy systems that are less vulnerable to price volatility and supply disruptions. The welfare impacts of reduced health and ecosystem impacts associated with major cuts in air pollutant emissions significantly below baseline scenarios are particularly high where currently legislated and planned air pollution controls are weak, such as in many developing countries. There is a wide range of co-benefits and adverse side-effects other than air quality and energy security. Overall, the number of co-benefits for energy end use measures outweighs the number of the adverse side-effects, whereas the evidence suggests this is not the case for all supply side measures. [WG3 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; WG2 11.9]

Mitigation policy may devalue endowments of fossil fuel exporting countries, but differences between regions and fuels exist (*medium confidence*). The effect of mitigation on coal exporters is expected to be largely negative while natural gas exporters could benefit in the medium term as coal is replaced by gas. Several studies suggest that mitigation policies reduce export revenues from oil; however, some studies find that mitigation policies could increase the relative competitiveness of conventional oil vis-à-vis more carbon-intensive unconventional oil and coal-to-liquids. [6.3.6, 6.6, 14.4.2]

SPM.3.2 Sectoral and cross-sectoral mitigation pathways and measures

SPM.3.2.1 Cross-sectoral mitigation pathways and measures

Without new mitigation policies GHG emissions are projected to grow in all sectors, except for CO_2 emissions in the land-use sector (*robust evidence, medium agreement*). Energy supply sector emissions are expected to continue to be the major source of GHG emissions in baseline scenarios. As a result, significant increases in indirect emissions from electricity use of the buildings and industry sectors are expected. Deforestation decreases in most of the baseline scenarios, which leads to a decline in CO_2 emissions from the land-use sector. In some scenarios the land-use sector changes from an emission source to a net emission sink around 2050. [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 (*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, land-use planning related lock-in is the most difficult to eliminate. However, longer lifetimes of low-emission products and infrastructure can ensure positive lock-in as well as avoid emissions through dematerialisation. [5.6.3, 9.4, 12.3, 12.4]

Systemic and cross-sectoral approaches to mitigation are expected to be more cost-efficient and more effective in cutting emissions than sector-by-sector policies (*medium confidence*). Integrated models identify three categories of energy system related mitigation measures: decarbonization of the energy supply sector, final energy demand reductions and switching to low-carbon fuels, including electricity, in the energy end use sectors *(robust evidence, high agreement)* [6.3.4, 6.8, 7.11]. The broad range of sectoral mitigation options available mainly relate to achieving reductions in GHG emission intensity, improvements in energy efficiency and changes in activity [7.5, 8.3, 8.4, 9.3, 10.4, 12.4, Table TS.2]. Integrated models and sectoral studies broadly agree on the opportunities for energy use reductions and fuel switching in each energy-end-use sector (Figure SPM.10). [6.8, 8.9, 9.8, 10.10]

Demand reductions in the energy end-use sectors are a key mitigation strategy and determine the scale of the mitigation challenge for the energy supply side (*high confidence*). Limiting energy demand 1) increases policy choices by maintaining flexibility in the technology portfolio, 2) reduces the required pace for up-scaling low-carbon energy supply and hedges against related supply side risks, 3) avoids lock-in to new, or a potentially premature retirement of, carbon-intensive infrastructures, 4) maximizes co-benefits for other policy objectives and 5) increases the cost effectiveness of the transformation (*medium confidence*). [6.3.4, 6.6, 7.11, 10.4]

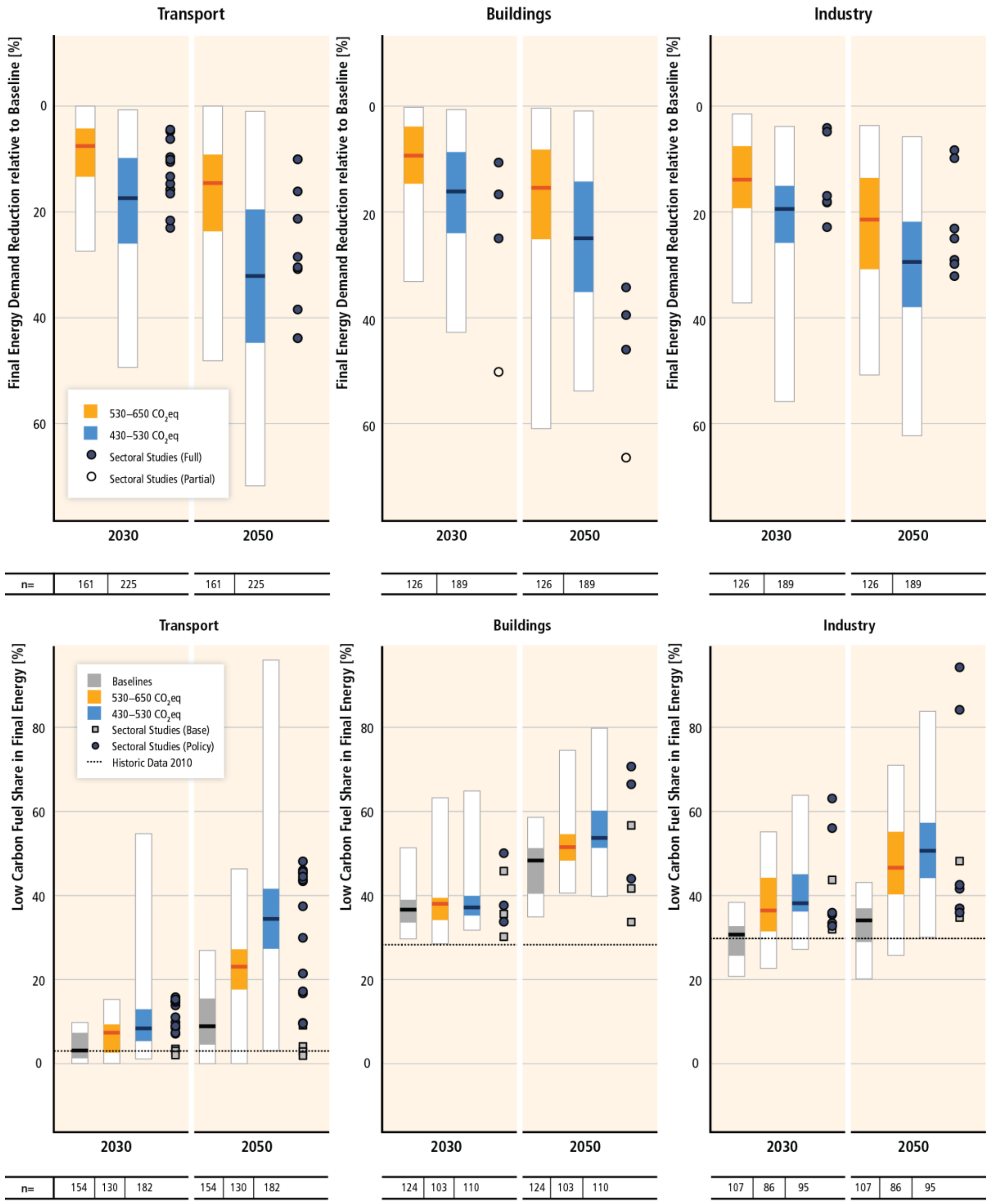

Figure SPM.10. Sectoral final energy reduction relative to baseline (upper row) and development of final energy low-carbon fuel shares (lower row) in the end-use sectors, transport, buildings, and industry by 2030 and 2050 in mitigation scenarios from two different concentration categories (see Section 6.3.2) compared to sectoral studies assessed in Chapters 8-10. Low-carbon fuels include electricity, hydrogen and liquid biofuels in transport, electricity in buildings and electricity, heat, hydrogen and bioenergy in industry. The thick black line corresponds to the median, the coloured box to the inter-quartile range (25th to 75th percentile) and the whiskers to the total range across all reviewed scenarios. Filled circles correspond to sectoral studies with full sectoral coverage while empty circles correspond to studies with only partial sectoral coverage (e.g. heating and cooling only for buildings). [Figures 6.37 and 6.38]

Behaviour, lifestyle and culture have a considerable influence on energy use and its emissions, and can have a high mitigation potential when supplementing technological and structural change (*limited evidence, medium agreement*). Emissions can be substantially lowered through changes in consumption patterns (e.g. mobility demand, energy use in households, choice of longer-lasting products), dietary change and reduction in food wastes, and change of life style (e.g. stabilizing/lowering consumption in some of the most developed countries, sharing economy and other behavioural changes affecting activity). [8.1, 8.9, 9.2, 9.3, Box 10.2, 10.4, 11.4, 12.4, 12.6, 12.7, Table TS.2]

The availability of carbon dioxide removal technologies determines the mitigation challenge for the energy end-use sectors (*robust evidence, high agreement*) [6.8, 7.11]. There are strong interdependencies between the required decarbonization pace of energy supply and end-use sectors. A more rapid decarbonization of supply generally entails more flexibility for the end-use sectors. However, barriers to decarbonizing the supply side, including public acceptance issues [7.9.4], resulting from, for example, limited availability of CCS to achieve negative emissions when combined with bioenergy, require a more rapid and pervasive decarbonisation of the energy end-use sectors in scenarios achieving low CO_2eq concentration levels (Figure SPM.11). The ability of storing carbon in terrestrial systems also provides flexibility for the development of mitigation technologies in the energy supply and energy end-use sectors [11.3] (*limited evidence, medium agreement*), though there may be adverse impacts on sustainable development.

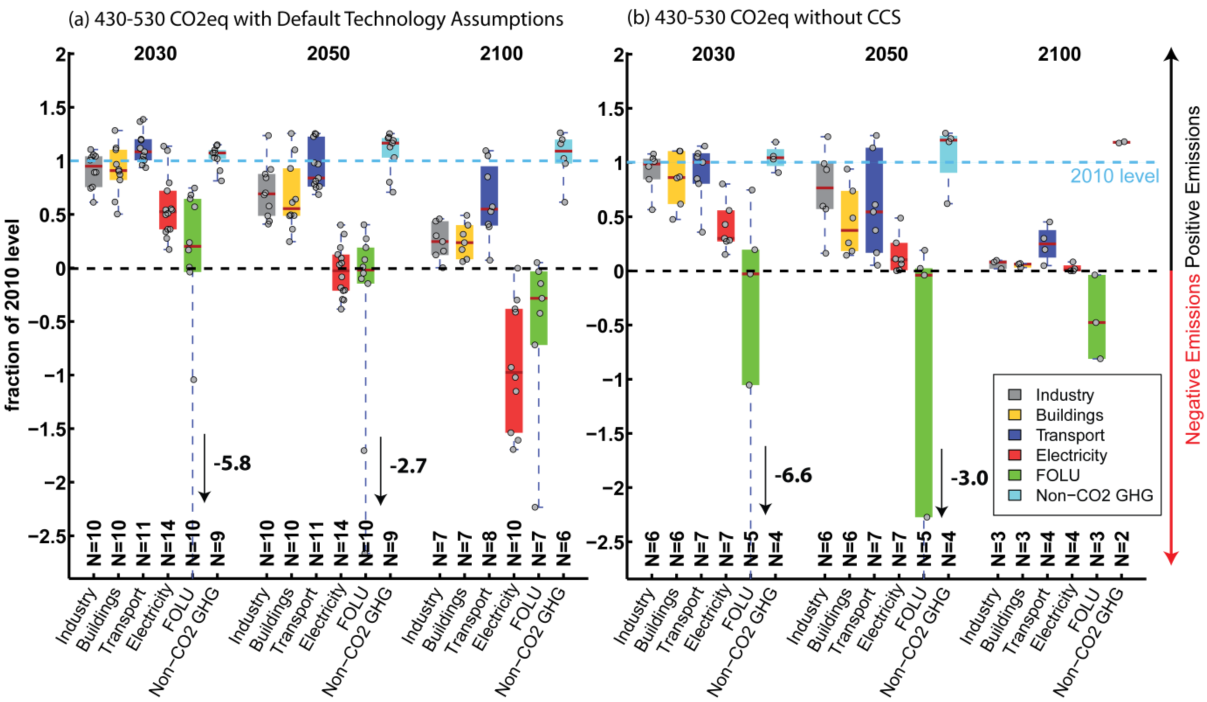

Figure SPM.11. Direct emissions by sector normalized to 2010 levels (light blue dished line) in 430-530 ppm CO_2eq scenarios with default technology assumptions (a) and in 430-530 ppm CO_2eq scenarios without CCS (b). The thick red lines corresponds to the median, the coloured boxes to the inter-quartile range (25th to 75th percentile) and the whiskers to the total range across scenarios. Grey dots refer to emissions of individual models to give a sense of the spread within the ranges shown. 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. [Figure 6.35]

SPM.3.2.2 Energy supply

The energy supply sector is the largest contributor to global GHG emissions, with the increasing demand for energy services and a growing share of coal in the global fuel mix contributing most to the increasing trend of its emissions (*robust evidence, high agreement*). Direct 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 in the baseline scenarios assessed in AR5, unless energy intensity improvements can be significantly accelerated beyond the historical development (*medium evidence, medium agreement*). [7.2, 7.3, Figure TS.15]

In integrated modelling studies, decarbonizing electricity generation is a key component of cost-effective mitigation strategies; in most scenarios, it happens more rapidly than the decarbonization of the building, transport and industry sectors (*medium evidence, high agreement*) (Figure SPM.3.11). In general, the rapid decarbonization of electricity generation is realized by a rapid reduction of conventional coal power generation associated with a limited expansion of natural gas without CCS over the near term. [6.8, 7.11, Figure TS.18].

Since AR4, many renewable energy (RE) technologies have substantially advanced in terms of performance and cost and a growing number of RE technologies achieved technical and economic maturity, making RE a fast growing category in energy supply (*robust evidence, high agreement*). Nevertheless many RE technologies still need direct (e.g., feed-in tariffs, RE quota obligations, and tendering/bidding) and/or indirect (e.g., sufficiently high carbon prices and the internalization of other externalities) support, if their market shares are to be increased. Additional enabling policies are needed to address their integration into future energy systems. (*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 technology but its share of global electricity generation is declining since 1993 (*robust evidence, high agreement*). Barriers to an increasing use of nuclear energy include concerns about operational safety, (nuclear weapon) proliferation risks, waste management security as well as financial and regulatory risks (*robust evidence, high agreement*). New fuel cycles and reactor technologies addressing some of these issues are under development. [7.5.4, 7.8, 7.9, 7.12, Figure TS.19]

Where natural gas is available and the fugitive emissions associated with its extraction and supply are low, near-term GHG emissions from energy supply can be reduced by replacing coal-fired with highly efficient natural gas combined cycle (NGCC) power plants or combined heat and power (CHP) plants (*robust evidence, high agreement*). In most stringent mitigation scenarios natural gas power generation without CCS is below current levels in 2050, and declines further in the second half of the century. [7.5.1, 7.8, 7.9, 7.11, 7.12]

Carbon capture and storage (CCS) technologies could reduce the life-cycle GHG emissions of fossil power plants (*medium evidence, medium agreement*). All components of integrated CCS systems exist and are in use, but CCS has not yet been applied at scale to a large, commercial fossil fuel power generation facility. CCS power plants will only become competitive with their unabated counterparts if the additional investment and operational costs are compensated. For a large-scale future deployment of CCS, well-defined regulations concerning short- and long-term responsibilities for storage need to complement economic incentives. Associated barriers include concerns about the operational safety and long-term integrity of geological CO_2 storage as well as CO_2 transport risks. [7.5.5., 7.8, 7.9, 7.11, 7.12]

Combining bioenergy and CCS (BECCS) could result in net removal of CO_2 from the atmosphere (*limited evidence, medium agreement*). Technological challenges and risks of BECCS are associated with the provision of the biomass feedstock as well as with the capture, transport and long-term geological storage of CO_2. [7.5.5., 7.9, 11.13]

SPM.3.2.3 Energy end-use sectors

Transport

Continuing rapid growth in GHG emissions from increasing global passenger and freight activity could outweigh future mitigation measures (*high confidence*). Without fuel carbon and energy intensity improvements together with comprehensive mitigation policy implementation, transport CO_2 emissions are projected to approximately double by 2050 from 6.7 $GtCO_2$/year in 2010 (*medium evidence, medium agreement*). [Figure TS.15, 6.8, 8.1, 8.2, 8.9, 8.10]

Strategies to reduce fuel carbon intensities can be both short and long term (*high confidence*). Methane-based fuels are already increasing their share; electricity and hydrogen fuels produced from low-carbon sources constitute longer term options (medium evidence, medium confidence) [8.2, 8.3]. Reducing black carbon and NO_x emissions also have short term, human health and mitigation benefits. The mitigation potential of biofuels will depend on technology advances and sustainably produced feedstocks [8.3].

Technical and behavioural mitigation measures , plus new infrastructure and urban redevelopment investments for all transport modes, could reduce final energy demand in 2050 by up to 40% below the baseline, a higher potential than shown in the AR4 [8.9] (*robust evidence, medium agreement*) (Figure TS.20a). Energy efficiency and vehicle performance improvements range from 30-50% in 2030 relative to 2010 depending on mode and type (medium evidence, medium agreement). Behavioural mitigation options are less certain but can increase potential in the short term. Over the longer term, investments in new infrastructure and urban redevelopment can encourage modal shifts (medium evidence, medium agreement). [8.2, 8.3, 8.4, 8.5, 8.6, 8.7]

Full societal mitigation costs for passenger and freight transport remain uncertain (*high confidence*). Mitigation costs range from very low or negative for many short-term behavioural measures and efficiency improvements for light- and heavy-duty vehicles and ships, to more than USD100/t CO_2 avoided in 2030 for some electric vehicles, aircraft and possibly high-speed rail (*limited evidence, medium agreement*) [8.6, 8.8, 8.9].

Regional differences influence the choice of mitigation options to decarbonize transport (*high confidence*). Institutional, legal, financial and cultural barriers constrain low-carbon transport technology uptake and behavioural change [8.8]. In OECD countries, existing infrastructure limits modal shift options leading to greater reliance on advanced vehicle technologies. For emerging economies with high rates of urban growth, investment in low-carbon transport infrastructure can avoid lock-in to carbon-intensive modes. In least developed countries, prioritizing access for pedestrians and integrating non-motorized and public transport services can improve economic and social prosperity. (*medium evidence, medium agreement*) [8.4, 8.9]

Strong and mutually-supportive policy measures are needed in all regions to decouple transport GHG emissions from GDP growth (*medium confidence*). Mitigation strategies at all government levels when associated with non-climate policies can lead to improved access, mobility and safety, better health, greater energy security, and cost and time savings. Pricing strategies, when accepted socially, can help reduce travel demand. Freight businesses can be incentivised to reduce the carbon intensity of their logistical systems. (*medium evidence, high agreement*) [8.7, 8.10]

Buildings

The building sector was responsible for 34% final energy use and 8.8 $GtCO_2$ emissions, including direct and indirect emissions, in 2010, with energy demand projected to approximately double and CO_2 emissions to increase by 50-150% by mid-century (*medium evidence, medium agreement*). This energy demand growth results from improvements in wealth, lifestyle, access to modern energy services and adequate housing, and urbanisation. Significant lock-in risks arise from long lifespans of buildings and related infrastructure, and are especially important in regions with high construction rates (*robust evidence, high agreement*). [9.4, Figure TS.15]

Recent proliferation of advanced technologies, know-how and policies make it feasible to stabilize or reduce global building sector energy use by mid-century (*robust evidence, high agreement*). Recent large improvements in performance and costs make very low energy construction and retrofits become economically attractive. For new buildings, the adoption of very low energy building codes is key and has progressed substantially since AR4. Retrofits are a key mitigation strategy in countries with established building stocks, as reductions of heating/cooling energy use by 50-90% have been achieved. [9.3]

Lifestyle, culture and behaviour significantly impact energy consumption in buildings (*low evidence, high agreement*). Studies show a factor of three to five difference in energy use for similar energy service levels [9.3].

Most mitigation options in buildings have considerable and diverse co-benefits but strong barriers prevent the market-based proliferation of cost-effective technologies and practices (*medium evidence, high agreement*). The monetisable co-benefits alone often exceed energy cost savings and possibly climate benefits, and include improvements in energy security, health, environmental impacts, productivity and net employment, energy/fuel poverty, and reduced energy expenditures. [9.6, 9.7]

The availability of energy efficiency policy portfolios and their implementation advanced considerably since AR4 (*robust evidence, high agreement*).Building codes and appliance standards have been shown to be the most effective instruments. In some developed countries they contributed to a stabilization or reduction in total building energy use. Developing countries have also been adopting various policies, most notably appliance standards. . In order to reach ambitious climate goals, these need to be substantially strengthened and up-scaled to further jurisdictions and building and appliance types. [9.10]

Industry

Industry related emissions are expected to continue to grow under baseline conditions as they did over the past decades. Direct and indirect CO_2 emissions from industry are projected to increase from 13 $GtCO_2$/year in 2010 by 50-150% in 2050 in the baseline scenarios assessed in AR5, unless energy intensity improvements can be significantly accelerated beyond the historical development (*medium evidence, medium agreement*). Currently, emissions from industry are larger than the emissions from either the buildings or transport end-use sectors and represent just over 30% of global GHG emissions in 2010 (just over 40% if AFOLU emissions are not included). [Figure TS.15, 10.3]

The energy intensity of the sector could be reduced by approximately up to 25% compared to the current level through the wide-scale deployment of best available technologies, particularly in countries where these are not in practice and for non-energy intensive industries (*high agreement, robust evidence*). Through innovation, additional reductions of approximately up to 20% may potentially be realized (*low evidence, medium agreement*). Information programs are the most prevalent approach for promoting energy efficiency, followed by economic instruments, regulatory approaches and voluntary actions. [10.7, 10.9]

In addition to energy efficiency, other options such as emissions efficiency, material use efficiency, product use efficiency, or service demand reduction would be required to achieve an absolute reduction of GHG emissions in the industry sector (*medium evidence, high agreement)* [10.4, 10.7]. There is a lack of experience and often there are no clear incentives either for suppliers or consumers to address improvements in material or product service efficiency. Few policies have specifically pursued material efficiency or product service intensity so far [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*). Non-CO_2 GHG emissions have been in the range of 0.9 $GtCO_2eq$ in 2010. Key opportunities comprise e.g. reduction of HFC emissions by leak repair, refrigerant recovery and recycling. [10.7]

Cross-cutting technologies (e.g. efficient motors) and measures (e.g. reducing air or steam leaks) applicable in both large energy intensive industries and Small and Medium Enterprises (SMEs) can help to reduce GHG emissions (*high agreement, robust evidence*) [10.4]. Cooperation and cross-sectoral collaboration at different levels – e.g. sharing of infrastructure, information, waste heat, cooling, etc. may provide further mitigation potential in certain regions/industry types [10.5].

The hierarchy of waste management places waste reduction at the top, followed by re-use, recycling and energy recovery. As the share of recycled or reused material is still low, waste treatment technologies and recovering energy to reduce demand for fossil fuels can also be significant and result in direct emission reductions from waste disposal (*robust evidence, high agreement*). [10.4, 10.14]

SPM.3.2.4 Agriculture, Forestry and Other Land-Use (AFOLU)

Since AR4, emissions from the AFOLU sector have stabilized but the share of anthropogenic emissions has decreased (*robust evidence, high agreement*). Over the most recent years, most estimates of FOLU CO_2 fluxes indicated a decline in emissions, largely due to decreasing deforestation rates. However, there is significant uncertainty in historical as well as projected baseline AFOLU emissions. Nonetheless, in the future, net annual baseline CO_2 emissions from AFOLU are projected to decline over time, with emissions potentially less than half of the 2010 level by 2050 and the possibility of the terrestrial system becoming a net sink before the end of century. (*medium evidence, high agreement*) [6.3.1.4, 11.2, Figures 6.5 and TS.15]

The most cost-effective forestry options are reducing deforestation and forest management; in agriculture, low carbon prices favour cropland and grazing land management and high carbon prices favour restoration of organic soils. The economic mitigation potential of supply-side measures is estimated to be 7.2 to 11 (full range: 0.49-14) $GtCO_2eq$/year in 2030 at carbon prices up to 100 USD/ tCO_2eq, about a third of which can be achieved at a <20 USD/ tCO_2eq (*medium evidence, medium agreement*). Demand-side measures, such as changes in diet and reductions of losses in the food supply chain, could have a significant, but uncertain, impact on GHG emissions from food production (0.76-9.3 $GtCO_2eq$/year by 2050) (*limited evidence, low agreement*). [11.6]

Policies governing agricultural practices and forest conservation and management need to account for both mitigation and adaptation. Some mitigation options in the AFOLU sector (such as soil carbon storage, forest carbon stocks) may be vulnerable to climatic change (*medium evidence, medium agreement)*. REDD+ can be a very cost effective policy option for mitigating climate change, with potential economic, social and other environmental co-benefits if implemented sustainably (*limited evidence, medium agreement)*. [11.3.2, 11.10]

Bioenergy could play a critical role in stabilizing climate change, if conversion of high carbon density ecosystems (forests, grass- and peat-lands) is avoided and best-practice land management is implemented (*medium evidence, medium agreement*). The scientific debate about the marginal emissions of most bioenergy pathways, in particular around land-mediated equilibrium effects (such as indirect land use change), remains unresolved (*medium evidence, low agreement*). The potential, costs and risks of BECCS are subject to considerable scientific uncertainty (*low evidence, medium agreement*). [11.13.]

A clear and comprehensive policy framework is required for realizing the sustainable bioenergy potential (*robust evidence, high agreement*). Biomass for energy, in combination with improved cookstoves, biogas and small-scale biopower could reduce marginal GHG emissions and improve livelihoods and health. However, if policy conditions (e.g. price on fossil and terrestrial carbon, land-use planning, etc.) are not met, large scale bioenergy deployment could increase emissions, and compromise livelihoods, biodiversity and ecosystem services. (*robust evidence, high agreement*) [11.13]

SPM.3.2.5 Human Settlements, Infrastructure and Spatial Planning

Urbanization is a megatrend that is transforming societies and energy use (*medium evidence, high agreement*). By 2050, the global urban population is expected to almost double. Urban areas account for around 70% of global energy use and global energy-related CO_2 emissions *(limited evidence, medium agreement)*. [12.2, 12.3]

The next two decades present a window of opportunity for urban mitigation as most of the world's urban areas and their infrastructure have yet to be constructed (*robust evidence, high agreement*). Urban areas are expected to triple between 2000 and 2030. Continuing infrastructure expansion could produce cumulative emissions of 3000-7400 $GtCO_2$ up to 2100. Currently, average per capita emissions embodied in infrastructure are more than five times higher in industrialized than in developing countries. [12.2, 12.3, 12.4, 12.8]

Urban mitigation options vary by development levels and 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**.** Key mitigation strategies include co-locating high residential with high employment densities, achieving high land use mixes, increasing accessibility and investing in public transit and other supportive demand management measures. [8.4, 12.3, 12.4, 12.5, 12.6]

The largest opportunities for future urban GHG emissions reduction might be in rapidly urbanizing countries where infrastructure inertia has not set in; however, the required governance, technical, financial, and institutional capacities can be limited (*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 the extent of urban climate mitigation is highly uncertain (*robust evidence, high agreement*). There is little systematic reporting on implementation of urban mitigation policies, and even less evidence as to the GHG impacts. Current climate action plans largely focus on energy efficiency rather than broader land-use planning strategies and cross-sectoral measures to reduce sprawl and promote transit-oriented development. [12.6, 12.7]

SPM.4 Mitigation policies and institutions

This Section focuses on how governments and other actors in the private and public sectors design, implement and evaluate mitigation policies. The discussion first examines the main findings from AR5 on national and sector policies, which span a wide range that includes economic incentives, direct regulatory approaches, information programs, government provision, and voluntary actions. This diversity of policy instruments reflects large differences in how societies are organized and creates special challenges for evaluating individual policies. It then focuses on the particular issues that arise with international cooperation.

SPM.4.1 Sectoral and national policies

A transformation to a low-carbon economy implies new patterns of investment. Mitigation scenarios that stabilize atmospheric concentrations in the range from 430 to 530 ppm CO_2eq by 2100 (without overshoot) show substantial shifts in annual investment flows during the period 2010-2029 if compared to baseline scenarios [Figure SPM.12]: Investment in conventional technologies associated with the energy supply sector (e.g. fossil fuel power plants and fossil fuel extraction) would decline by 30 (2-166) billion USD per year (median: -20%) over the next decades (2010 to 2029) while investment in low carbon electricity supply (renewables, nuclear and generation with carbon capture and storage) would rise by 147 (31-360) billion USD per year (median: +100%) (*limited evidence, medium agreement*). In addition, energy efficiency investments in transport, buildings and industry are expected to increase by several USD 100 billion per year (*limited evidence, medium agreement*). For comparison, global total annual investment in the energy system is presently about USD 1200 billion. Current climate finance is estimated at USD 343to 385 billion per year (*limited evidence, medium agreement*); around USD 35 to 49 billion of that total climate finance constitutes public flows to developing countries (*medium confidence*). [13.11, 16.2.2]

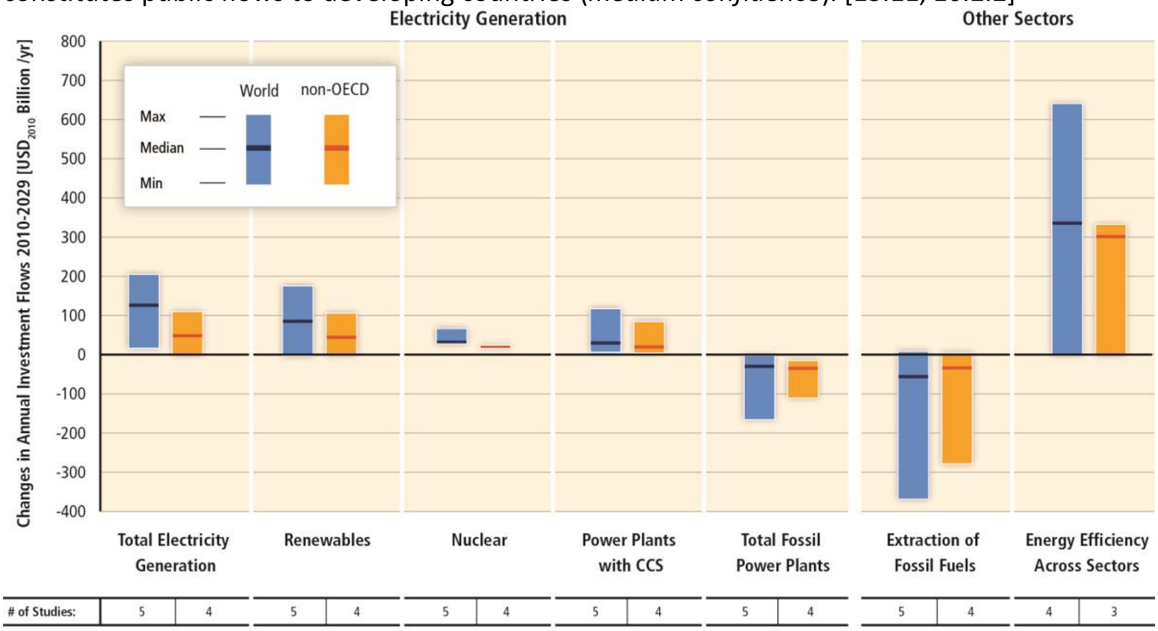

Figure SPM.12. Change of average annual investment in mitigation scenarios (2010-2029). Investment changes are calculated by a limited number of model studies and model comparisons for mitigation scenarios that stabilize concentrations within the range of approx. 430-530 ppm CO_2eq by 2100 compared to average baseline investments. 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, 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—underscoring 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 plans and strategies to address climate change since AR4. These plans and strategies are in their early stages in many countries, and there is inadequate evidence to assess their impact on future emissions (*medium evidence, high agreement*). [15.1, 15.2]

Since AR4, there is growing political and analytical attention to co-benefits and adverse side effects of climate policy on other objectives and vice versa that has resulted in an increased focus on policies designed to integrate multiple objectives, maximize synergies and minimize trade-offs. (*high confidence*). Co-benefits are often explicitly referenced in climate and sectoral plans and strategies; co-benefits have attracted attention in the scientific literature and by policy makers because policies with large co-benefits may attract broader and more durable political support [5.7, 6.6, 7.9, 8.7, 9.7, 10.8, 11.7, 11.13, 12.8, 15.2]. However, the analytical and empirical underpinnings for understanding interactive effects—for example, whether policies interact in ways that enhance or degrade welfare— are under-developed [1.2, 3.6.3, 4.2, 4.8]. The scope for co-benefits is greater in low-income countries, where complementary policies for other objectives, such as air quality, are often weak [5.7, 6.6, 15.2].

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

Regulatory approaches and information measures are widely used, and are often environmentally effective, though debate remains on the extent of their environmental impacts and cost-effectiveness (*medium evidence, medium agreement*). Examples include energy efficiency standards and labelling programs that can help consumers make better-informed decisions. While such approaches often work at a net social benefit, the scientific literature is divided on whether such policies are implemented with negative private costs to firms and individuals. [Box 3.10, 15.5.5, 15.5.6]. Since AR4 there has been continued investigation into "rebound" effects that arise when higher efficiency leads to lower energy prices and greater consumption. There is general agreement that such rebound effects exist, but there is low agreement in the literature on the magnitude [3.9.5, 5.7.2, 15.5.4].

Adding a mitigation policy to another may not necessarily enhance mitigation. For instance, if a cap and trade system has a sufficiently stringent cap then other policies such as renewable subsidies have no further impact on total emissions. A carbon tax, on the other hand, can have an additive environmental effect to policies such as subsidies to renewables. [15.7]

Cap and trade systems for GHGs are being established in a growing number of countries and regions but their short run environmental effect has been limited because tight caps have not yet come into effect (*limited evidence, medium agreement*). There appears to have been a trade-off between the political feasibility and environmental effectiveness of these programs, as well as between political feasibility and distributional equity in the allocation of permits. Revised designs such as banking of allowances along with ceilings and floors on prices are being considered in many jurisdictions and, by reducing uncertainty, could facilitate the adoption of more stringent emission caps. [14.4.2, 15.5.3]

Carbon taxes have been implemented in some countries and - alongside technology and other policies - have contributed to a decoupling of carbon emissions from GDP (*high confidence*). In a large group of countries, fuel taxes (although not designed for the purpose of mitigation) act as sectoral carbon taxes. In Europe where the fuel taxes are highest they have contributed to reductions in carbon emissions from the transport sector of roughly 50% for this group of countries [15.5.2]. In some countries the revenues are explicitly used to reduce other taxes in an environmental fiscal reform illustrating the general principle that climate mitigation policies that raise government revenue (e.g., auctioned emission allowances under a cap and trade system or taxes) generally have lower social costs than approaches which do not, although this depends on how the revenue is used [3.6.3]. Targeted distribution of revenues or free allocation of allowances have also been used in some countries to render policies more politically feasible [14.4.2, 15.5.2].

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

Potential adverse side-effects of mitigation due to higher energy prices, for example, on improving access of the poor to clean, reliable and affordable energy services, can be avoided (*medium confidence*). Whether transformation pathways will have adverse distributional effects and thus impede achieving energy access objectives will depend on the climate policy design and the extent to which complementary policies are in place to support the poor. Approximately three billion people worldwide do not have access to electricity and/or are dependent on traditional solid fuels for cooking and heating with adverse effects on development and severe health implications. Scenario studies show that the costs for achieving nearly universal access are between USD 72 to 95 billion per year until 2030. The contribution of RE to energy access can be substantial. Achieving universal energy access reduces short-lived climate pollutants and methane emissions, and yields negligibly higher GHG emissions from power generation. [4.3, 6.6, 7.9, 9.7, 11.13.6, 16.8]

There is a distinct role for technology policy as a complement to other mitigation policies (*high confidence*)*.* Technology policy includes technology-push (e.g. publicly funded R&D) and demand-pull (e.g. governmental procurement programs). Such policies address market failures particularly related to innovation. Technology support policies have promoted substantial diffusion and innovation of new energy technologies such as wind turbines and photovoltaic panels, but have raised questions about their economic efficiency, and introduced challenges for grid and market integration that may require innovations concerning transmission, back-up power and time of day pricing. [2.6.5, 7.12, 15.6.5]

The private sector plays a central role in mitigation within an appropriate enabling environment. In 2010 and 2011and on average, about 74% of global mitigation finance came from the private sector and at about 62% in 2011 and 2012 (*limited evidence, medium agreement*), but data are scarce and accounting systems highly imperfect. In many countries public sources such as national and international development banks complement climate investments [16.2.1]. A country's broader context—including the efficiency of its institutions, security of property rights, credibility of policies and other factors—have a substantial impact on whether private firms invest in new technologies and infrastructures. Those same broader factors have large impacts on whether and where investment occurs in response to mitigation policies. Dedicated policy instruments exist to lower these risks for private actors—for example, credit insurance, power purchase agreements and feed-in tariffs, concessional finance or rebates [16.4].

Regional initiatives focused on mitigation are taking shape in many areas but, outside of the EU, have had a small impact on mitigation (*medium confidence*). Because of co-location of infrastructures and the advantages of trade, many climate policies could be more environmentally and economically effective if implemented across broad geographical regions. Many regional initiatives oriented around goals other than climate change are broadly relevant for mitigation, such as coordinated investments in natural gas and electricity grids as well as regional trade and investment agreements. Since AR4 some new evidence has been published that power pools and regional gas grids have supported the replacement of high-emissions fuels with low emission or renewable energy sources. [14.4, 14.5]

SPM.4.2 International cooperation

International cooperation on climate change has become more institutionally diverse over the past decade (*very high confidence*). The United Nations Framework Convention on Climate Change (UNFCCC) remains a primary international forum for climate negotiations [13.3.1, 13.5]. Institutional diversity at multiple scales of climate policy arises in part from the growing inclusion of climate change issues in other policy arenas [13.3, 13.4, 13.5]. For example, the Montreal Protocol, aimed at protecting the stratospheric ozone layer, has also achieved significant reductions in global greenhouse gas emissions [13.3.3, 13.3.4, 13.13.1.4]. Also, international trade can promote or discourage international cooperation on climate change [13.8].

Existing and proposed international climate agreements vary in the degree to which their authority is centralized. The range of centralized formalization spans: strong multilateral agreements (such as the Kyoto Protocol targets), harmonized national policies (such as the Copenhagen/Cancún pledges), and decentralized but coordinated national policies (such as planned linkages of national and sub-national emissions trading schemes). [Figure SPM.13, 13.4, 13.13.2]

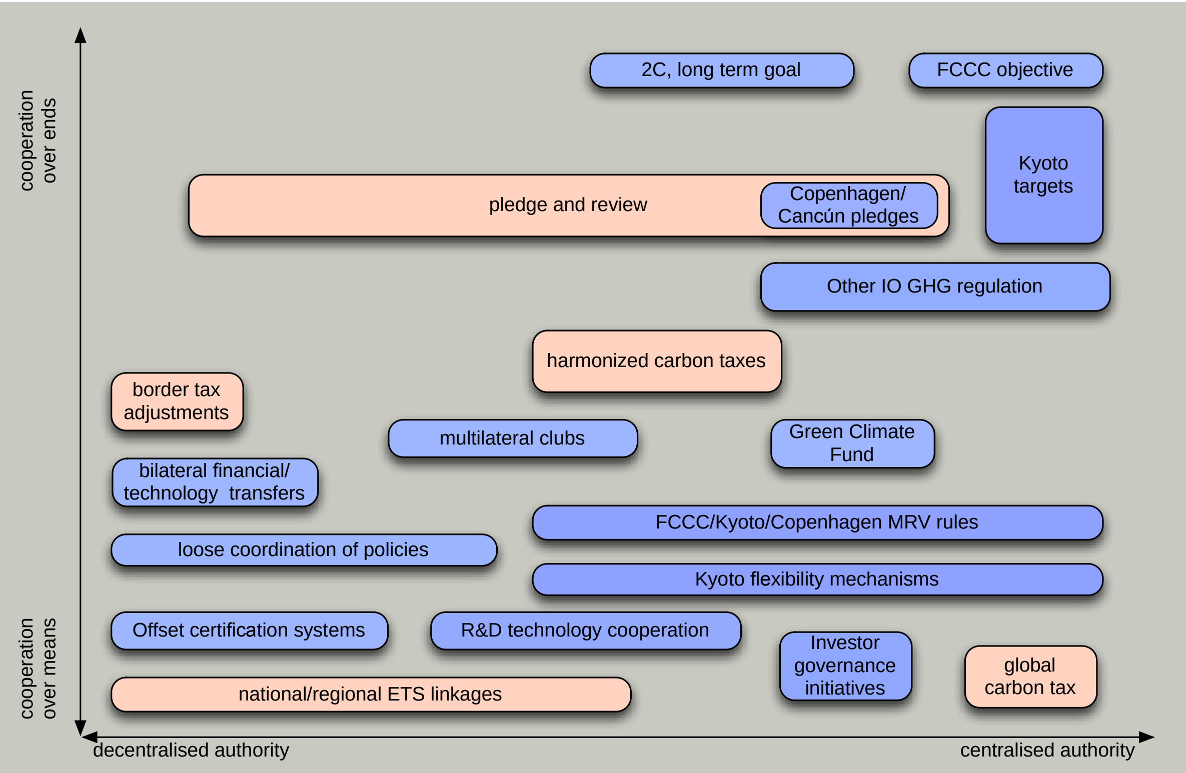

Figure SPM.13. International cooperation over ends and means and degrees of centralized authority. Examples in blue are existing agreements. Examples in pale pink are proposed structures for agreements. The width of individual boxes indicates the range of possible degrees of centralization for a particular agreement. The degree of centralization indicates the authority an agreement confers on an international institution, not the process of negotiating the agreement. [Figure 13.2]

The Kyoto Protocol was the first binding step toward implementing the principles and goals provided by the UNFCCC, but it has not been as successful as intended (*medium evidence, low agreement*). While the parties of the Kyoto Protocol surpassed their collective emission reduction target, the Protocol's environmental effectiveness has been less than it could have been because of the incomplete participation and compliance of Annex I countries and crediting for emissions reductions that would have occurred even in the absence of the Protocol, and because the Kyoto Protocol does not directly regulate the emissions of non-Annex I countries, which have grown rapidly over the past decade [5.2, 13.13.1.1]. The Kyoto Protocol's Clean Development Mechanism, which created a market for emissions offsets from developing countries, has generated credits equivalent to over 1.3 billion tCO_2eq as of July 2013, but has had mixed effects due to concerns about the additionality of projects and other issues that affect the integrity of offset credits [13.7.2, 13.13.1.2].

Recent UNFCCC negotiations have sought to include more ambitious commitments from the countries with commitments under the Kyoto Protocol, mitigation commitments from a broader set of countries, and substantial new funding mechanisms. Under the 2010 Cancún Agreement, developed countries formalized voluntary pledges of quantified, economy-wide emission reduction targets and developing countries formalized voluntary pledges to mitigation actions. The distributional impact of the agreement will depend in part on sources of financing, including the successful fulfilment by developed countries of their expressed joint commitment to mobilize USD 100 billion per year by 2020 for climate action in developing countries. [13.5.1.1, 13.13.1.3, 16.2.1.1]

In the absence of — or as a complement to — a binding, international agreement on climate change, policy linkages among existing and nascent international, regional, national, and sub-national climate policies offer potential climate benefits (*medium confidence*). Examples of prominent linkages among national policies include the European Union Emission Trading Scheme and international offsets planned for recognition by a number of jurisdictions [14.4.2].

There are a growing number of countries devising policies for adaptation, as well as mitigation. At the international level there may be benefits to considering the two within a common policy framework (*medium evidence, low agreement*). However, there are divergent views on whether adding adaptation to mitigation measures in the policy portfolio encourages or discourages participation [1.4.5, 13.3.3]. It is recognized that an integrated approach can be valuable, as there exist both synergies and trade-offs [16.6].