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Working Group III – Mitigation of Climate Change

TS

Technical Summary

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Technical Summary

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TS.1 Introduction

Working Group III of the IPCC is charged with assessing scientific research related to the mitigation of climate change. "Mitigation" is any human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs). Because mitigation lowers the likely effects of climate change as well as the risks of extreme impacts, it is part of a broader policy strategy that includes adaptation to climate impacts—a topic addressed in more detail by Working Group II. Governments acknowledged this interdependence when approving the Synthesis Report of the AR4 and unanimously expressed their view of making **risk management** a unifying perspective for the AR5: "*Responding to climate change involves an iterative risk management process that includes both mitigation and adaptation, taking into account actual and avoided climate change damages, co-benefits, sustainability, equity and attitudes to risk*", (IPCC 2007:64). Managing the risks of climate change affects individual and collective rights and values throughout the world and over long periods of time. As the quote emphasizes, it is therefore crucial to look at climate change within the larger context of **sustainable development**. The literature assessed in the AR5 was thus examined with a much more detailed focus on the **ethics** of climate policy than was done in the AR4.

Since the AR4, a number of important developments in both politics and science influenced the way the mitigation challenge is seen today. Global GHG emissions have continued to grow and reached an all-time high of 50.1 billion tonnes of carbon dioxide equivalents (CO_2eq) in 2010. Anthropogenic GHG emissions increased against the background of a worldwide economic recession beginning around 2008 that has affected patterns of emissions and investment as well as political priorities in many countries. Meanwhile, the flexibility of viewing mitigation as part of a broader array of sustainable development goals has encouraged analysts to look more closely at the factors that have encouraged countries to adopt policies that mitigate emissions. Policies are pursued for reasons that have many reinforcing benefits — known as "co-benefits" — making it hard to assign costs and benefits to any single policy in isolation. The plethora of international institutions addressing matters related to climate change has inspired social scientists to look at how these institutions might interact — including where they might conflict — rather than focusing only on the global UN-based organizations dedicated to the task of managing climate issues. This insight has also led to many model-based assessments of future emissions, mitigation and climate impacts that reflect a likely real-world "muddling through" policy rather than optimal global design.

Given the many uncertainties involved in the assessment of mitigation strategies, there is a need for an iterative, comprehensive and transparent process linking science with the design of policies that are "robust" across a variety of scenarios. The full report offers much more detail on areas where scientific research has helped to resolve some uncertainties since AR4 while also 'discovering' new ones. Since the assessment of mitigation strategies is particularly difficult to disentangle from assumptions about social system behaviour including the many normative notions of ethics and sustainability, boxes throughout the Summary shed some light on the many crucial assumptions implicit in scientific methodologies (see Box TS.1).

This Summary provides an overview of those main areas where the scientific understanding has advanced since AR4 and refers to sections of the report [in square brackets] where more detail can be found. It is structured as follows: Section 2 synthesizes findings on past emission trends and drivers; Section 3 provides information on future mitigation scenarios that are commensurate with a range of stabilization goals; Section 4 presents new findings on technologies, processes, and practices that can be used in different economic sectors to mitigate climate change; and Section 5 discusses institutional options that can be used at multiple governance levels to encourage the adoption of mitigation technologies, processes and practices. Throughout the Summary, the degree of certainty in key findings is expressed as qualitative levels of *confidence* or *evidence* and *agreement* as described in the IPCC Guidance Note on the Consistent Treatment of Uncertainties.

Box TS.1. Transparency over assessment concepts and methods.

Scientific methodologies rest on many assumptions that have large impacts on results. For example, the weighing of different GHGs is typically based on the assumption that 100 years is the appropriate time horizon for climate decisions (Box TS.2). Shortening that time horizon would lead analysts to focus, to a greater degree, on near-term climatic impacts and on the mitigation of climate pollutants such as methane and soot that have shorter time horizons. Another example concerns the choice of a discount factor in economic analysis (Box TS.8). Discounting allows costs and benefits incurred at different points in time to be compared. It requires using a social discount rate, which incorporates ethical judgments. The choice of the discount rate is crucial for the evaluation of climate policies because of the long timeframes involved and the fact that the costs of mitigation action generally precede the benefits in the form of reduced climate change impacts.

TS.2 GHG emission trends and drivers

TS.2.1 Emission trends

At current levels, an amount of fossil-fuel related CO_2 emissions comparable to the total cumulative emissions before 1970 is released every 12 years (*high confidence*). Since AR4 (2004 data), global anthropogenic GHG emissions have continued to grow and reached an all-time high of 50.1 Gt CO_2-equivalent (CO_2eq) in 2010 based on global warming potential with a 100 year time horizon (GWP-100; see Box TS.2). GHG emission growth has continued to be driven by CO_2 emissions increases. In 2010, CO_2 emissions exceeded 75% of the total of GHG emissions. CH_4 contributed 16%, N_2O about 6% and the combined fluorinated-gases about 2%. Between 1970 and 2010, global anthropogenic CO_2 emissions increased by about 80%, while CH_4 and N_2O grew by 45% and 40% respectively. Fluorinated gases, which represented about 0.1% of global emissions in 1970, increased to comprise between 1 and 2% in 2010. [1.3, 5.2]

Despite existing mitigation policies, including the UNFCCC and the Kyoto Protocol, GHG emissions have grown more rapidly between 2000 and 2010 than in previous decades (*high confidence*). Since 1970 anthropogenic GHG emissions have grown by more than 75%. Growth in the recent decade (2000-2010) has been faster than in any decade since 1970, more than twice as fast than during the periods 1980-1990 and 1990-2000. The observed 2000-2010 emission rise was at the high end of projected emission levels. [1.3, 5.2]

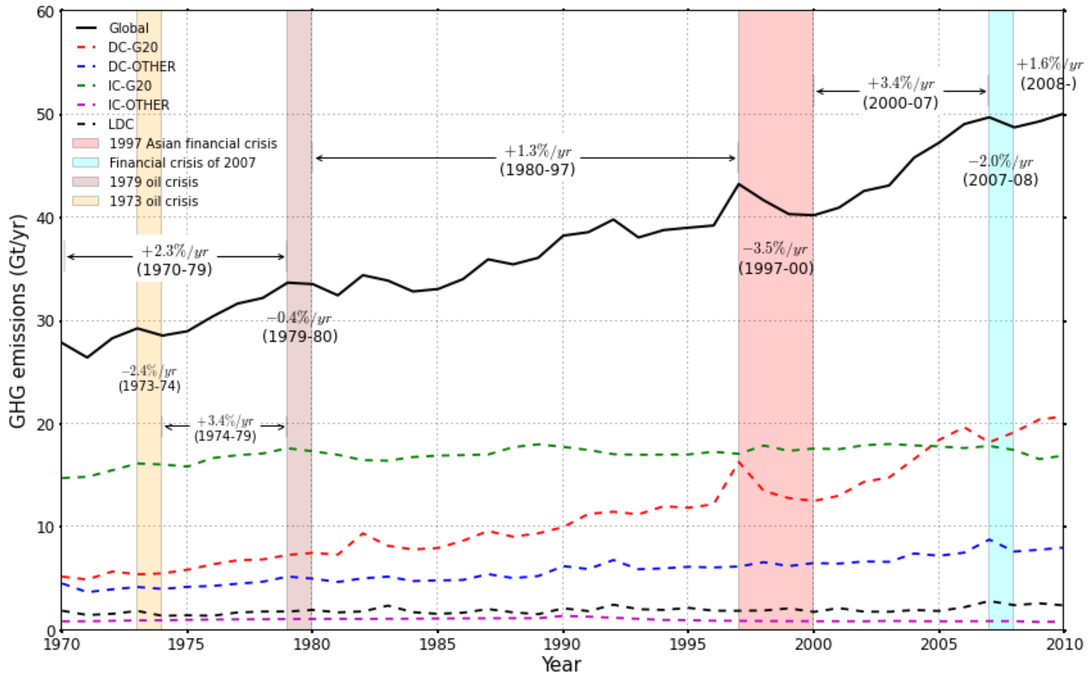


Figure TS.1. Change in global anthropogenic GHG emissions by major economic regions 1970-2010. GHG emissions are measured in gigatonnes per year (Gt/yr) of CO_2 equivalent (CO_2eq). Non CO_2 greenhouse gases are converted to CO_2 equivalents using 100-year global warming potentials (see Box TS.2). Trend lines show emission of industrialised countries with G20 membership (IC-G20, green), other industrialised countries (IC-other, purple), developing countries with G20 membership (DC-G20, red), least developed countries (LDC, dashed black), other developing countries (DC-other, blue). Global emission trends (Global) are shown by the solid black line. Periods of major global economic recessions are identified by coloured areas in the chart. [Figure 1.4]

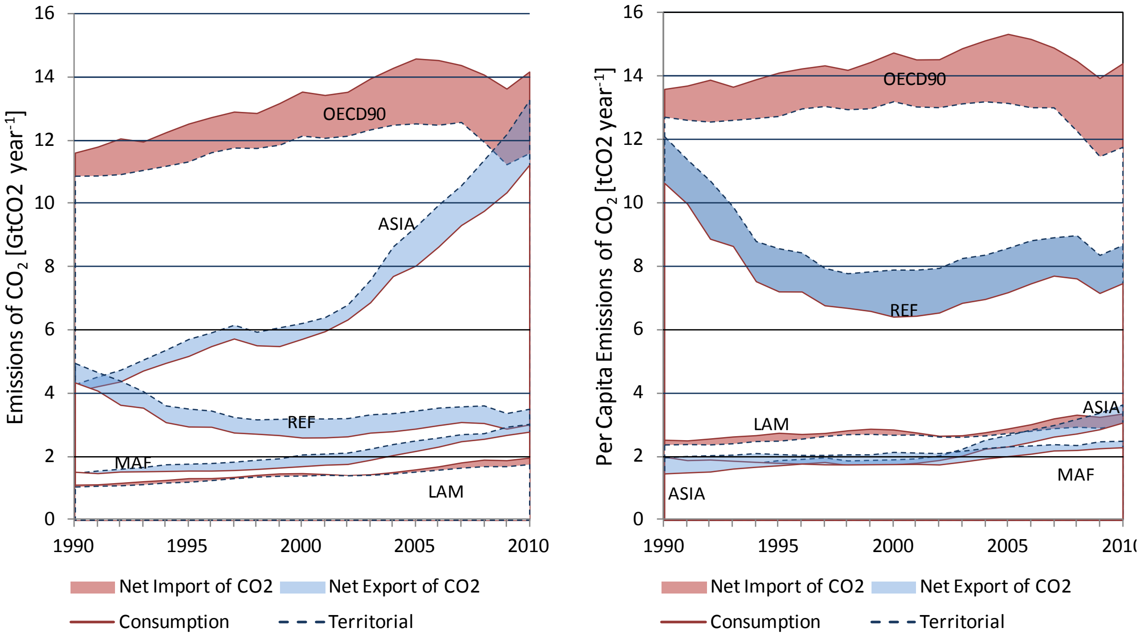


Figure TS.2. Territorial (blue lines) versus consumption-based (red dotted lines) CO_2 emissions from fossil fuel combustion in five world regions, from 1990 to 2010. The left panel presents total emissions, while the right panel presents per capita emissions. The red areas indicate that a region is a net importer of embedded GHG emissions. The blue area indicates a region is a net exporter of embedded GHG. Regions include: OECD90 (OECD1990 countries), EIT (Reforming Economies/Economies in Transition), LAM (Latin America and Caribbean), MAF (Middle East and Africa), ASIA (Asia). For country mappings please see Report Annex II. [Figure 5.5.1]

Developing countries tend to be net exporters of CO_2 emissions, while developed countries tend to be net importers of emissions *(high confidence)*. A considerable share of CO_2 emissions from fossil fuel combustion in developing countries (non-Annex B) is released in the production of goods and services exported to developed countries (Annex B). Less CO_2 emissions are released in developed countries in the production of goods and services imported by developing countries. CO_2 emissions released across the global supply chain in the production of goods and services consumed in developed countries are often higher than their territorial emissions. [5.5, 1.3]

Developing countries have higher emissions than developed countries, but their per capita contributions remain considerably lower – particularly in the case of the least developed countries *(robust evidence, high agreement)*. Since AR4, territorial and consumption-based CO_2 emissions from fossil fuel combustion of developing countries (non-Annex B) surpassed those of developed countries (Annex B). On a per capita basis, developed countries' CO_2 emissions remain approximately four times higher than developing countries' emissions in 2010 with very large variations existing within these groupings (Figure TS.2). A growing number of developing countries show per capita CO_2 emissions in the range of industrialised countries from a territorial and consumption perspective. [1.3, 5.5]

Asia's current emission trajectory is similar to the one OECD countries experienced before 1970 *(medium confidence)*. Since AR4, the vast majority of CO_2 emission growth from fossil fuel combustion has taken place in Asia. Of the 33% growth in global CO_2 emissions between 2000 and 2010 roughly 83% can be attributed to Asia from a territorial and 72% from a consumption perspective. These sharp CO_2 emission increases result from an industrialization process that tends to be energy intensive. This process is similar to the experience of current OECD countries experienced prior to 1970, though with lower energy requirements per capita equivalent income. The OECD countries contributed most to the pre-1970 emissions, but in 2010 developing countries, and Asia in particular, began to make up the major share of annual emissions (Figure TS.3). [5.2, 14.3]

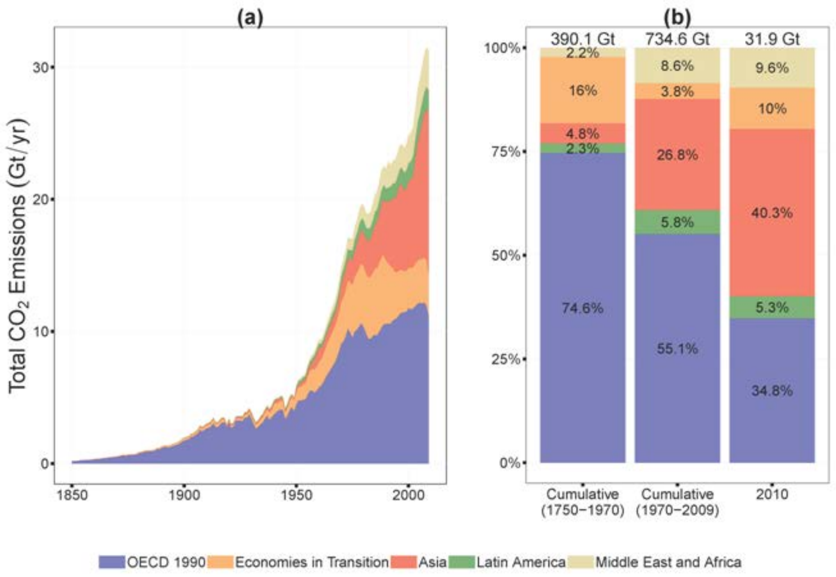


Figure TS.3. Current and historical anthropogenic CO_2 emissions from fossil fuel combustion in five major world regions. Panel (a) shows the annual emissions between 1850 and 2010 in gigatonnes of CO_2 per year. Panel (b) shows the regional contributions to cumulative global CO2 emissions between 1850 and 1970, cumulative global CO_2 emissions between 1970 and 2009 and global CO_2 emissions in 2010. The five regions covered are OECD countries (blue), economies in transition (orange), Asia (red), Latin America (green) and Middle East and Africa (ocher). For country mappings please see Report Annex II. [Figure 5.2.2]

The largest share of anthropogenic CO_2 emissions is emitted by a small number of countries *(high confidence)*. For example, in 2010 ten countries accounted for 70% of global territorial-based (production) CO_2 emissions, if the 27 members of the EU are treated as a single country (Figure TS.4). A similar relationship is found for consumption-based emissions as well as cumulative emissions going back to 1751. This suggests that while all countries have important roles to play in climate change mitigation, if climate change mitigation goals are to be achieved, the mitigation effort may be concentrated in these few countries. [1.3, 5.2]

Uncertainties associated with estimates of historic anthropogenic GHG emissions vary by type of gas and decrease with the level of aggregation. Global CO_2 emissions from fossil fuel combustion are known within 10% uncertainty (95% confidence interval) with individual national total fossil-fuel CO_2 emissions ranging from a few per cent to more than 50%. LULUCF related CO_2 emissions have very large uncertainties attached in the order of ±50%. The uncertainty range of global CO_2 emission trends reduces to ±5%, if LULUCF related emissions are excluded. For global emissions of CH_4, N_2O and the F-gases uncertainty estimates of 25%, 30% and 20% are assumed in the literature. [5.2]

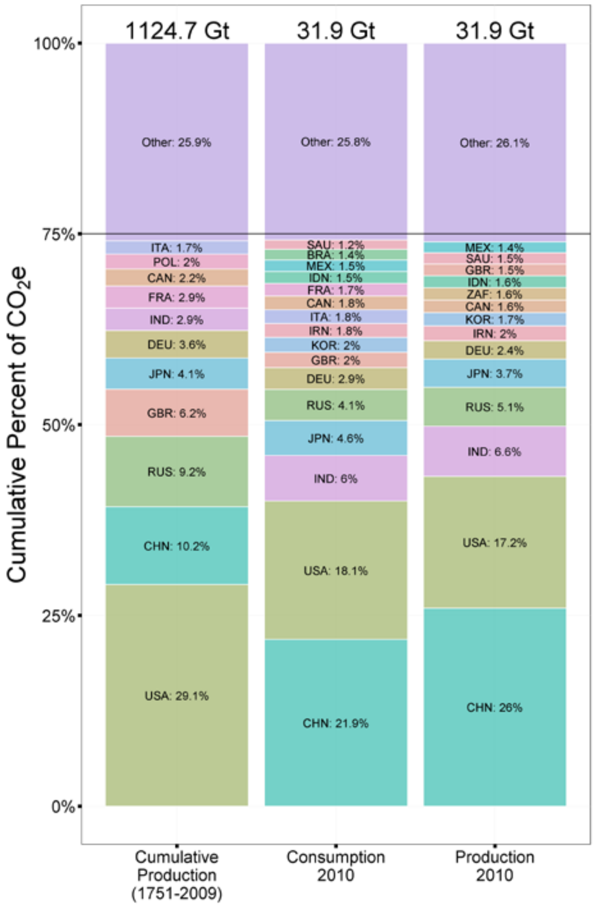


Figure TS.4. Shares of largest country contributors to 75% of global anthropogenic CO_2 emissions from fossil fuel combustion. Stacked bar on the left shows cumulative territorial emissions for the period 1751-2009, stacked bar in the middle shows consumption based emissions in 2010 and the stacked bar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

Box TS.2. Choice of GHG metric has important implications for mitigation strategy. [3.8, 6.3]

Different greenhouse gases (GHG) have different physical characteristics. Per molecule in the atmosphere, methane is a more potent GHG than CO_2, yet methane has a much shorter residence time in the atmosphere. Furthermore, additions to radiative forcing now that dissipate within a few decades are likely less consequential than similar additions of gases which persist in the atmosphere into the next century, when greenhouse gas concentrations are expected to be much higher. How emissions of different GHGs are aggregated by a common metric matters for the evaluation of mitigation strategies across gases, the calibration of policy instruments, and the comparison between countries and sectors that differ in their emissions profiles. The aggregation of GHGs could be based on the differential physical or economic consequences of emitting each gas, or the differential costs of abatement. Many metrics have been proposed. [3.8.5]

The basic physical outcome metric is accumulated radiative forcing as an absolute value, calculated as the effect of the emission of each gas over a given time horizon. The *relative* outcome metric, using accumulated radiative forcing as the outcome and taking CO_2 as the base, is known as the Global Warming Potential (GWP). This metric is currently used to compute countries' aggregate or 'CO_2-equivalent' emissions for reporting to the UNFCCC and as an 'exchange rate' between gases within emissions trading schemes, usually using a 100-year horizon. There is no conclusive scientific argument for the choice of 100 years. The choice is value-based since it depends on the importance assigned to effects at different times. GWP puts zero weight on effects beyond the chosen time horizon. The choice of time horizon is particularly important for short-lived gases, notably methane: when computed with a shorter time horizon their share in calculated total warming effect is larger [1.2.1.5].For example, the GWP for methane with a 100-year horizon is 82; with an horizon of 20 years, the GWP drops to 28 [3.11]. There are other physical metrics available such as the Global Temperature change Potentials (GTP), integrated GTP, Global Damage Potential (GDP) and Global Cost Potential (GCP).

Conceptually, the most appropriate metric in the context of climate change mitigation would include the physical effects of different gases (e.g. in terms of radiative forcing or temperature change) over time, measures of the economic damages over time , as well as intertemporal discounting. Comprehensive economic metrics such as the global damage potential are measured for example as equivalent change in global gross domestic product or income resulting from an extra ton of each GHG. However, taking into account the poor state of knowledge of the monetary value of climate damage, these measures are impractical and fraught with uncertainty [3.8.2]. Simple physical metrics such as the GWP are relatively easy to calculate and transparent, but are also uncertain in representing damages caused. An economic approach that avoids the problems associated with using a damage function frames the issue instead in terms of minimizing the cost of mitigation for attaining a prescribed target concentration level or a target degree of warming. It is important to be aware that all metric choices, including widely-used metrics, contain uncertainties, implicit assumptions, value judgments and parameter choices that shape the analysis. In particular the calculated share of methane in total CO_2-equivalent emissions is affected by the choices.

Modelling studies show that the choice of metric is critical for the optimal timing of reductions in methane emissions, but does not strongly affect global mitigation costs. The changes in GWP values from the 2nd to the 4th AR have little impact on the optimal timing of CH_4 reductions. Limited literature exists on the impact of the choice of metrics on regional costs in the context of international climate regimes. Impacts on economic cost will generally depend on the regional share of CH_4 emissions. [6.3.4.2]

TS.2.2 Emission drivers

Emissions are driven by technological, infrastructure and behavioural choices. Technological change drives overall economic growth as well as the energy intensity of growth and the carbon-intensity of energy. Some new technologies lead to lower GHG emissions, but other innovations improve labour productivity and increase emissions. Moreover, technological innovations that potentially decrease emissions (e.g. energy-saving technologies) are sometimes offset by the rebound effect. Infrastructural choices before the 1970s have had long-lasting effects on emissions after 1970s, as they determined, for example, the fuel of choice. Infrastructure also guides the choices in technological innovation. The mechanism is reasonably understood, but data are insufficient to quantify its role in facilitating or impeding reductions in GHG emissions. Behavioural choices are important agents for change in emissions trends; the literature mainly considers behaviour through changes in the demand for goods and services towards those that entail lower emissions. There is not much quantitative evidence on the effects of specific behavioural changes on past emissions trends, but there is evidence on large variations in emissions implied by different consumption patterns and lifestyles. Across countries various policies and strategies have been used to change individual choices, sometimes through changing the context in which decisions are made, at varying degrees of success. [5.1]

Emission growth from consumption continues to outpace emission savings from efficiency improvements *(robust evidence, high agreement)*. Together with the growth in population, global CO_2 emissions from fossil energy maintained a stable upward trend, which characterizes the overall increase in global GHG emission over the last two decades. Global CO_2 emissions from fossil fuel combustion increased by 47% over the last two decades, which can be explained by a combination of a modest 4% increase in CO_2 intensity in energy resources, 24% decrease in energy intensity in GDP, 43% increase in GDP per capita, and 31% increase in population (Figure TS.5). In the most recent decade for the first time since 1970 the carbon intensity of energy has contributed to growth in CO_2 emissions from fossil fuel combustion due to a rising importance of coal, especially in the rapidly growing developing countries. By contrast, across the highly industrialized world this ratio has been declining due to the shift away from high carbon fuels (notably coal) to natural gas and also to renewable energy sources. [1.3, 5.3]

Energy and resource use are increasing exponentially. The global annual use (extraction) of material resources – i.e., ores and industrial minerals, construction materials, biomass, and fossil energy carriers – increased eightfold during the 20th century, reaching about 55 Gt in 2000, while the average resource use per capita (the metabolic rate) doubled, reaching 8.5-9.2 tonnes per capita per year in 2005. The value of the global consumption of goods and services (the global GDP) has increased six-fold since 1960 while consumption expenditures per capita has almost tripled. Consumption-based GHG emissions increased between 1990 and 2009 in the world's major economies, except the Russian Federation, ranging from 0.1-0.2% per year in the EU27, to 4.8-6.0% per year in China. [4.4]

Global resource consumption has risen slower than GDP. This is particularly true since around 1970, indicating some decoupling of economic development and resource use, signifying an increase in resource productivity by about 1-2% annually at the global level. This dematerialization of economic activity has been most pronounced in the industrialized countries. Metabolic rates across countries are highly unequal, varying by a factor of 10 or more, due in large part to variations in economic development, but there is also significant cross-country variation in the relation between GDP and resource use. [4.4]

Historically, higher levels of economic growth are associated with increasing emissions. There is a wide variation in emissions per capita, and energy use per capita, for countries at equal income levels, but there has been a robust relation over the period 1970-2010 between economic growth (GDP) and the growth of (territorial) emissions. [5.3]

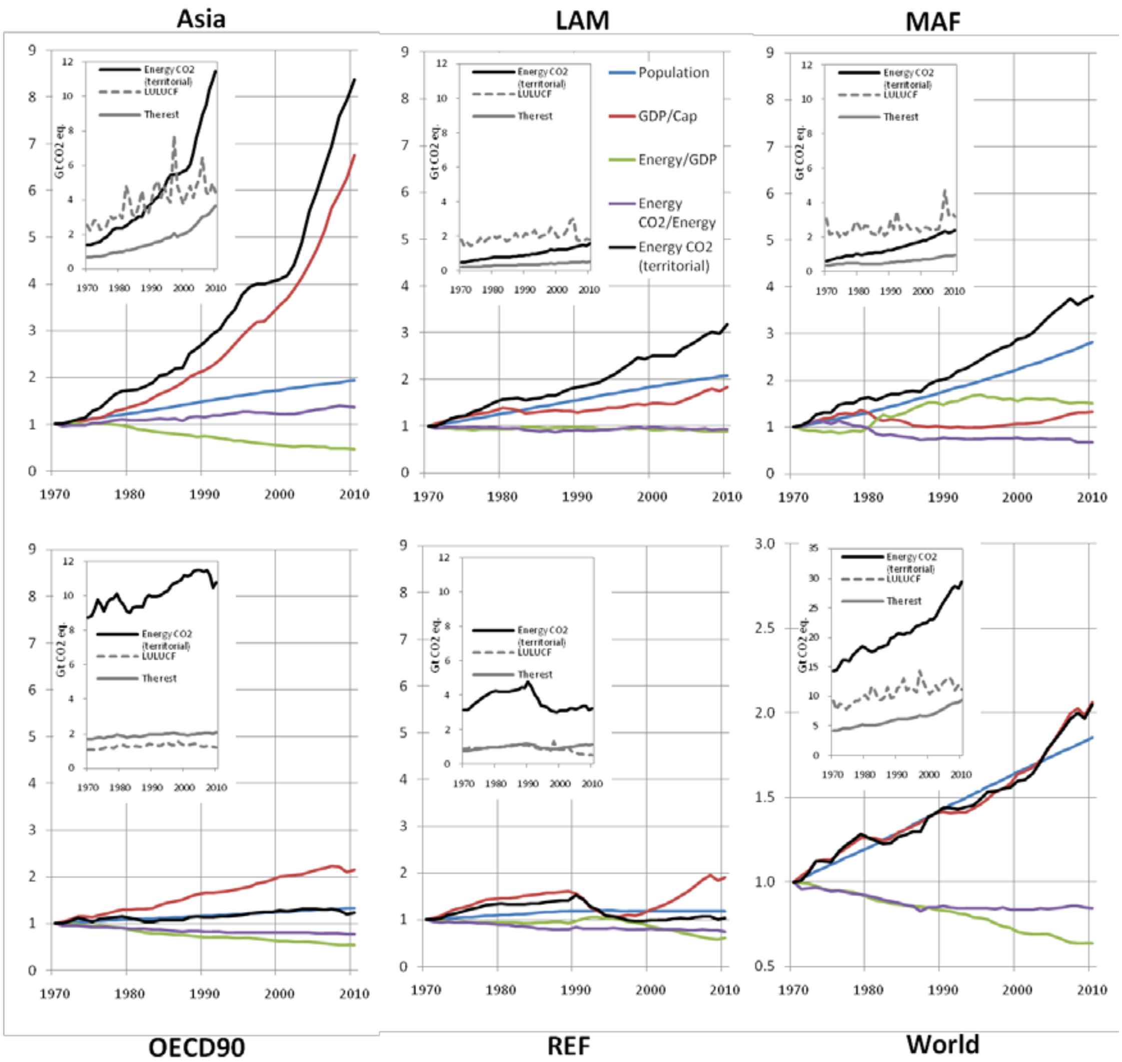


Figure TS.5. Four factor decomposition of territorial fossil energy CO_2 emission at regional level (1970 – 2010); note that only the bottom-right panel for the World has a different scale for its vertical axis. Regions include: OECD90 (OECD1990 countries), REF (Reforming Economies), LAM (Latin America and Caribbean), MAF (Middle East and Africa), ASIA (Asia). For country mappings please see Report Annex II. [Figure 5.3.1]

Without explicit efforts to reduce emissions, GHG concentrations will exceed 450 ppm CO_2eq before 2030 and 850 ppm CO_2eq by 2100 *(high confidence).* Increasing emissions are due to continued economic growth at a global level and will not be meaningfully ameliorated by improvements in technology or the nature of remaining fossil resources. None of the baseline emission trajectories from fossil and industrial sources is consistent in the long-run with the pathways in the two most stringent RCP scenarios (2.6 and 4.5 W/m^2). The majority of these fall between the 6.0 and 8.5 pathways even though decelerated emissions growth is projected in most of the baseline scenarios - especially compared to the rapid rate observed in the past decade. Some projections appear to under-estimate current and very near-term emissions, most likely due to inconsistencies in calibration and data sources. Baseline projections for global land-related carbon emissions and sequestration made by a smaller subset of models are subject to greater uncertainty.

As in AR4, most projections suggest declining annual net CO_2 emissions in the long run, but none of the more recent scenarios projects growth in the near-term as in AR4. [6.3]

Scenarios stabilizing GHG concentration at 550 ppm CO_2eq or lower require improvements in carbon intensity at a pace that is unprecedented in human history. The scenario literature suggests that carbon intensity of energy will likely have to make a large break from past trends in the long-run on pathways toward stabilization of atmospheric concentrations at 450 or 550 ppm CO_2eq. Contributions from energy intensity are more flexible within these scenarios. To some degree, this result in scenarios can be partially attributed to assumptions about the flexibility to achieve reductions in end-use energy demand relative to decarbonization of supply in integrated models, about which there is a great deal of uncertainty. However, this result is also a natural consequence of the fact that, although energy use reduction is fundamental to mitigation, the ultimate potential for end use reduction is limited; some energy will always be required to provide energy services. [6.3]

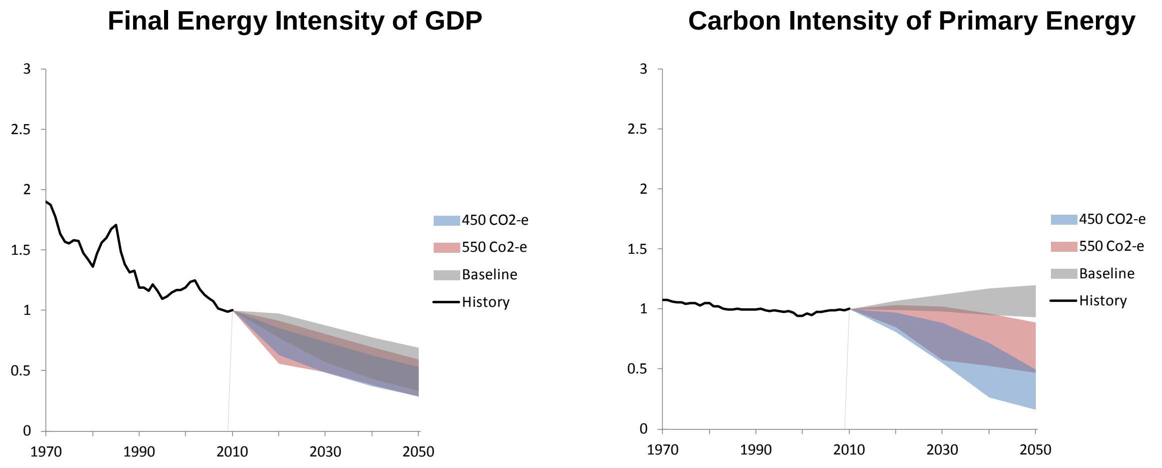


Figure TS.6. Evolution in final energy intensity (left panel) and carbon intensity of primary energy (right panel) along transformation pathways. [Figure 6.13]

TS.3 Long-term mitigation scenarios

This Section assesses the literature on long-term mitigation scenarios. It focuses on the technological, economic and institutional requirements of scenarios that explore the neighbourhood of a 1.5 and 2°C warming. This focus is no indication of the adequacy of these targets. Information relevant for a review of the ambition level in international climate policy will require information from all three IPCC Working Groups that will be brought together in the Synthesis Report. Advances in the published scientific literature since AR4 include: low stabilization goals; overshoot emissions trajectories with and without carbon dioxide removal (CDR) technologies; fragmented, delayed and constrained near-term international action on mitigation; implications of variations in technology cost, performance and availability; and the exploration of linkages between mitigation and other societal objectives.

TS.3.1 Ethics and sustainable development

Sustainable development (SD) is a framework for describing and analyzing multiple (development) objectives as well as for organizing ethical considerations for climate policy. SD is variably conceived as development that preserves the interests of future generations, that preserves natural and environmental resources, or that harmonizes the co-evolution of three pillars (economic, social, environmental). SD implicates concerns about social justice within and between generations. Objectives such as development, the elimination of poverty, and the convergence of living standards across countries and within countries can resonate with or conflict with the challenges of managing climate change. Considering multiple development objectives and the associated synergies and trade-offs is needed when choosing between combinations of interrelated climate mitigation options within the context of SD. While mitigation pathways interact with and can be a means to achieve multiple objectives, different policy and other social responses to climate change affect regions, nations, and localities differently and thereby their possibilities for achieving sustainability. [4.2]

Climate policy choices involve many ethical considerations. What duties and responsibilities do present generations have towards future generations, in view of the fact that present emissions affect environmental conditions in the future, and consequently the quality of life of future generations? How should the responsibility to reduce emissions or enhance sinks be allocated among nations and individuals within societies, so that fair outcomes are achieved – who should act and who should bear the costs? Do those who may suffer disproportionally from the consequences of climate change have a claim to compensation? While there are many ways to weigh these ethical choices, the literature points to two important perspectives—the process through which decisions are made and the outcomes of such processes—and many different methods for assessment. [3.2, 3.10]

Climate policy decisions often affect other societal objectives through co-benefits and/or adverse side-effects. Limiting climate change is one of many economic, social, and environmental policy objectives. Mitigation objectives and options may therefore be adequately assessed within a multi-objective framework and may be aligned with other societal priorities in order to maximize synergistic effects and to avoid trade-offs. This implies that policy design and implementation practices may need to consider local priorities in order to create appropriate incentives. Since the relative importance of different goals differs among various stakeholders and may change over time, transparency on the multiple effects that accrue to different actors at different points of time is important. The possibility of harnessing near-term co-benefits of mitigation policy may increase the incentives for a global climate agreement now rather than waiting. [3.5, 4.8, 6.6]

Box TS.3. Value an aggregation. [3.2]

Climate change affects many different values, including human wellbeing, cultural and social values, and also the wellbeing of animals and according to some views even an intrinsic value possessed by nature. The methods of economics provide an anthropocentric measure of value to individual human beings, which can be powerful tool for informing decision-making. Yet some cultural, social and other values that can be important to societies may not be effectively taken into account in economic analyses. Neither do economic analyses take into account people’s rights or claims of justice. The wellbeing of different people is often aggregated through a ‘value function’ or ‘social welfare function’ to determine an overall value for a society. A social welfare function is an aggregate measure of the wellbeing of members of a society. It gives a basis for evaluating the effects of climate change and of mitigation measures, through economic techniques such as cost-benefit analysis. Different social welfare functions reflect different views about the value of equality.

In cost-benefit analysis, the effect of a change in social value at a point in time is found by taking the monetary value of the change to each person, weighted appropriately, and adding up these weighted amounts. Nearly all theories of value imply that those who are better off might be reasonably assigned lower weight on their monetary values when determining social value. Much practical cost-benefit adds up monetary values without any weighting factor. This is to assume implicitly that the distributional weight is the same for each person. This approach could leads to serious error in cost-benefit analysis concerned with climate change mitigation, which often needs to take into account the extremes of wealth between rich and poor countries, as well as within countries *(high confidence)*.

Box TS.4. Methodological challenges for the comprehensive assessment of co-benefits and adverse side-effects. [3.5, 3.7, 6.6]

The comprehensive assessment of the net effects of climate change mitigation co-benefits (or adverse effects) on overall welfare and human well-being is a complex task. First, for many mitigation options multiple co-benefits or adverse effects are possible (Table TS.5). Whether they are realized or not, depends critically on local circumstances and implementation practices. Second, possible co-benefits and trade-offs may occur simultaneously and affect other downstream or upstream economic sectors. The possibility of a local co-benefit does thus not necessarily translate automatically into an overall net welfare gain. The full assessment of the net welfare gains of climate policy in the context of multi-objective decision-making requires thus a systems perspective that permits the full accounting of the impacts of each of the multiple objectives on social welfare.

This poses a significant challenge, since costs of climate mitigation needs to be weighed against multiple benefits for other objectives that are traditionally measured in different units (e.g., health benefits of reduced air pollution in terms of life years saved, or benefits in terms of improved energy security and reliability of energy supply). In addition, weighting the different objectives in a single social welfare function implies subjective choices about the ranking or relative importance of policy priorities. Ultimately, however, the ranking of priorities with respect to different objectives remains a policy variable. Hence, different approaches are used in the literature for the integration across different objectives. The two most common approaches are 1) cost-benefit analysis, including the monetization of different impacts/co-benefits in a single welfare function and 2) multi-criteria approaches and scenario sensitivity analysis. While the former focuses on the assessment of the optimal level of controls, the latter focuses on the implications of different policy prioritisation frame-works on potential synergies and trade-offs between objectives. Figure TS.9 provides results from two recent major studies using different methodologies.

In theory, only a comprehensive evaluation of all co-benefits and adverse side effects relative to all relevant objectives can determine the total contribution to welfare of the contemplated policy. Based on such a comprehensive and coherent assessment of co-benefits and risks of mitigation, policymakers could be better equipped to identify potential synergies and trade-offs across multiple policy objectives for particular policy instruments at different geographical and temporal scales. A comprehensive welfare analysis of co-benefits and adverse side effects is rarely undertaken in the literature. Co-benefits estimated from disjunctive studies are incommensurable and cannot be added-up.

TS.3.2 Overview of scenario results

The choice of efficient long-term emissions and technology pathways to meet temperature stabilization goals is subject to a wide range of uncertainties. A range of emissions pathways could be constructed to meet any long-term temperature stabilization goal. Key uncertainties that influence the choice among pathways include the relationship between atmospheric concentration and temperature, the future costs and availability of technologies, and the future commitments of different countries and other political units (see Box TS.6). From WGI, the most likely climate sensitivity is 3.0 W/m2. At this level, a long-term equilibrium concentration of 450ppm CO_2eq corresponds to a two degree increase in global mean surface temperature. This is often used as a proxy for a two degree goal. [2.4, 6.3]

Atmospheric concentration pathways cannot be directly linked to a specific temperature pathway largely because of the high uncertainties in the relationship between concentration and temperature. Because of these uncertainties, temperature targets can be expressed in terms of a probability with which a particular temperature might be exceeded along a particular emissions pathway. The probability of remaining below 2°C warming is approximately 60% for scenarios aiming at stabilizing atmospheric GHG concentrations around 450 ppm CO_2eq in 2100. The probability is approximately 40% to 50% for 500 ppm scenarios. All other categories have a probability of substantially below 50%. Model results show that delay in international mitigation efforts leads to a considerably higher rate of temperature increase in the next decades and translates into a higher probability of temporarily exceeding the 2°C target. [6.3]

Considering the consequences of both Type I and Type II errors, the balance of evidence suggests that the appropriate response to most of the relevant uncertainties is to accelerate mitigation efforts compared to what would be most appropriate in the absence of such uncertainties (Table TS.1). For instance, mitigation efforts should be increased in the short term when there is uncertainty about future policy stringency due to the asymmetry of future states of nature. The "no policy" case implies a slower pace in the aggregation of low-carbon capital stock and technological knowledge; the associated short-term economic gains would be more than outweighed by the potential for substantial economic losses if a "stringent climate policy" state of nature were realized and extremely rapid decarbonization were then needed. [2.4]

Table TS.1. Number of peer-reviewed publications, types of uncertainty considered, and their effect on mitigation action. [Table 2.2]

Type of Uncertainty Considered	**Effect on Mitigation Action**		
	Accelerates / Increases Mitigation Action	Delays / Decreases Mitigation Action	Ambiguous Effect
Up Stream (emission drivers)	6	0	0
Down Stream (climate and damages) - Continuous	3	3	10
Down Stream (climate and damages) - Catastrophic event	15	1	0
Policy Response	6	2	0
Multiple sources of Uncertainty	14	1	1

Box TS.5. Representation of human decision-making in assessment methods. [2.2]

Mitigation policies are designed to change current production or consumption decisions of actors, who can be individuals, groups, communities, corporations and industries, or government institutions at all scales. For policies to achieve their desired effect, policy makers need a comprehensive and realistic understanding of the social and psychological factors that determine human decisions and actions in addition to economic factors. Changes in information presentation/framing and the social context can influence decisions even when objective outcomes and levels of risk and uncertainty of choice alternatives are the same. Allowing for the fact that actors may decide for or against change in ways that deviate from the rational expectations and utility maximization assumptions of economic models provides additional tools to guide and influence such decisions, but also requires consideration of additional ways in which actors can differ.

Decision-making shortcuts, called heuristics, help human actors with finite attention and processing capacity to simplify complex problems. Instead of calculating the outcomes of choice options as implicitly assumed by rational models of choice, human actors often rely on past experience and emotional reactions to guide their choices. Much behaviour is not deliberated, but simply repeats what worked in the past or copies what others do. Such shortcuts are suitable for many purposes but can result in failures. There are two implications for climate mitigation: (1) behavioural routines, once established, are difficult to change; because they are automatic, they do not respond to incremental change in knowledge or prices. Only when the external change becomes dramatic enough that individuals focus attention on the issue, does behaviour change occur. (2) Judicious information (re)description (framing) and choice editing (e.g. through defaults or standards) can be effective in helping consumers achieve more optimal outcomes and can be justified from a welfare perspective.

Box TS.6. Sources of natural and social system uncertainty. [2.1]

The AR4 primarily examined the effects of natural system uncertainty on climate policy, but many more sources of uncertainty affect mitigation choices: (1) **Climate impacts and damage costs uncertainty.** Climate system uncertainties are discussed by WG I - the way in which they cascade into even greater uncertainties with respect to climate impacts is discussed by WG II, with the conclusion that focus on potentially catastrophic low-probability high-impact events is important when choosing climate change targets. (2) **Technologies and technological systems uncertainty.** Many mitigation technologies are new, with uncertainty about their level of performance, costs, and potential environmental, health, or safety risks. Country-level decisions about encouraging the developments of new forms of energy, for example, are impacted by such *technological uncertainty,* which raises questions regarding the types of *policy instruments* a sovereign state should utilize and what *mitigation pathway* it should follow. (3) **Socio-economic pathways uncertainty.** The states of the environment and society will be determined by a large number of factors in addition to climate change. The new set of shared socio-economic pathways (SSPs) in the AR5 highlights a range of possible future greenhouse gas emissions, costs and benefits of mitigation, and people's and ecosystems' vulnerability to impacts. (4) **Regulatory and market uncertainty.** Climate policy for adaptation and especially mitigation is concerned with creating incentives for private sector actors to alter their investment behaviour that may also require well-enforced regulations. Many incentive and regulatory instruments, such as emissions trading systems and technology subsidies, are relatively new policy developments, and their effectiveness is still being tested and evaluated. (5) **Perceptions, preferences, and actions uncertainty.** In making climate change policy decisions it is important to understand and predict how people perceive and respond to uncertain climate risks today as well as how they are likely to react to future conditions. A new section in AR5 reviews the mounting evidence that a broader range of responses than rational deliberation of all response options with a full time horizon needs to be expected. Choices between response options are often made by focusing on short-term costs and expected benefits, with attention given to a subset of outcome dimensions and choice objectives. (6) **Goals and values.** There is no single 'correct' ethical perspective on climate change. Political consensus can reduce such moral uncertainty, scientific analysis cannot. Scientific analysis can only provide some evidence and transparency over implicit normative assumptions that need to be made when assessing mitigation options. (7) **Expectations about how other decision-making units will respond**. Because of interdependencies in policy choices and impacts, uncertainties also arise in the expectation of how other decision-making units will respond. These issues are especially important at the international level where formal agreements that are acceptable to states depend on what each state expects others will accept and implement.

Scenarios stabilizing GHG concentration at 450 ppm CO_2eq by the end of the century require a rapid change to energy systems and the use of global land surface. These transitions are decidedly at odds with both long-term trends and those prevalent since the publication of the AR4. A large suite of scenarios (more than 250 Category 0 and 1 scenarios) published since the AR4 are consistent with the long-term ambition of stabilizing atmospheric GHG concentrations at 450 ppm (Figure TS.7). This has allowed for substantial advancements in knowledge on the requirements for low stabilization since AR4. In an idealised context, meeting a goal of 450 ppm CO_2eq by 2100, allowing for CO_2eq concentrations to exceed this goal in the interim, would call for a reduction in global emissions below 2010 levels of 15% to over 50% in 2030 and 40% to almost 80% in 2050, and anywhere from a moderate increase to roughly a tripling of low-carbon energy above 2010 levels in 2030 and from a tripling to a seven-fold increase by 2050. [6.3]

A majority of scenarios stabilizing GHG concentrations at 450 ppm CO_2eq by 2100 rely upon a temporary overshoot of these concentrations *(high confidence)*. Overshoot scenarios are scenarios for which target values are exceeded during the period before the target date. They are possible because carbon is removed from the atmosphere by the oceans over an extended period of time, and can be further extended by the ability of society to create negative emissions. Negative emissions may be from Bioenergy with carbon dioxide capture & storage (BECCS) or large-scale afforestation, but there are also other Carbon Dioxide Removal (CDR) options that could produce negative emissions. There are scenarios in which global concentrations are maintained below 450 ppm, as current forcing is already near that level. In such scenarios only strong and immediate mitigation can achieve this stabilization level. [6.3, 6.4, 7.11]

For stabilizing atmospheric GHG concentrations at 450 ppm, delay in international cooperation will increasingly require the large-scale application of CDR technologies *(high confidence)*. Although delayed mitigation lowers near-term requirements for transformation, it relies on future decision-makers and future generations undertaking more rapid and costly future transformation. Without climate policy, evidence strongly suggests that GHG concentrations will exceed 450 ppm CO_2eq before 2030. Sufficient delays – for example, delaying global action beyond 2030 – can render ambitious mitigation levels such as 450 ppm CO_2eq by 2100 physically infeasible without substantial overshoot along with negative global emissions in the second half of the century using BECCS or other CDR technologies. Indeed, many integrated models cannot produce scenarios that meet a concentration of 450 ppm CO_2eq by 2100 even with overshoot when there is a delay in global mitigation efforts or delays by a large component of the world's emissions (e.g., the OECD countries or the non-OECD countries) beyond 2030. [6.3, 7.11]

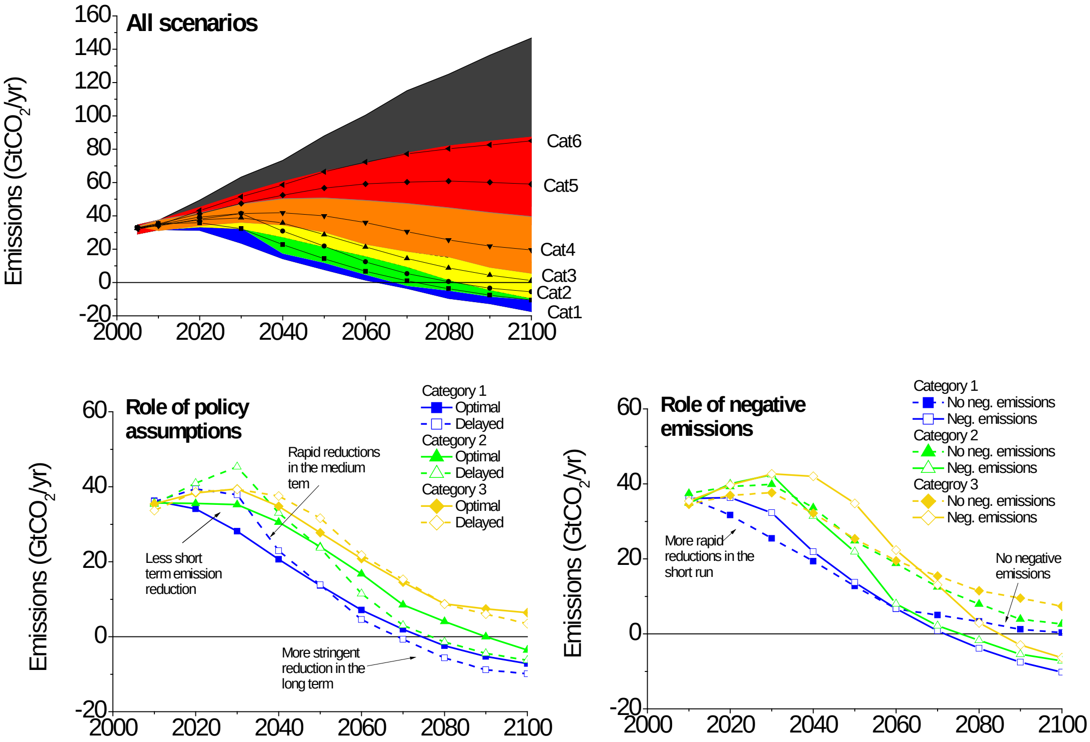


Figure TS.7. Mean CO_2 emission pathways for different scenario categories according to atmospheric CO_2 concentration stabilization levels in 2100: Category 1 (blue, 375-420 ppm CO_2), Category 2 (green, 400-450 ppm CO_2), Category 3 (yellow, 450-495 ppm CO_2). The upper-left panel shows 10-90th percentile of the scenarios included in Table 6.1 (bands) and the means of each group (lines).

The bottom figures show the means of each group (category 1-3) for optimal and delayed policy responses (left panel) and scenarios with negative emissions (right panel). [Figure 6.7]

The Cancun Agreements are broadly consistent with stabilization at 550 ppm CO_2eq and are consistent with 450 ppm CO_2eq emissions trajectories only when negative emission technologies are widely used *(medium confidence)*. Emission pathways in the range of global emissions associated with implementation of 2020 commitments under the Cancun agreement are inconsistent with any available not-to-exceed scenario and any scenario without negative emission technologies for stabilizing atmospheric GHG concentration at 450 ppm (Figure TS.8). The Cancun range corresponds most closely to the published range of 450 CO_2eq scenarios with delay constraints and negative emissions options. Alternatively the Cancun range is consistent with a 550 CO_2eq target under most circumstances, although most not-to-exceed pathways to this target indicate lower emissions levels.

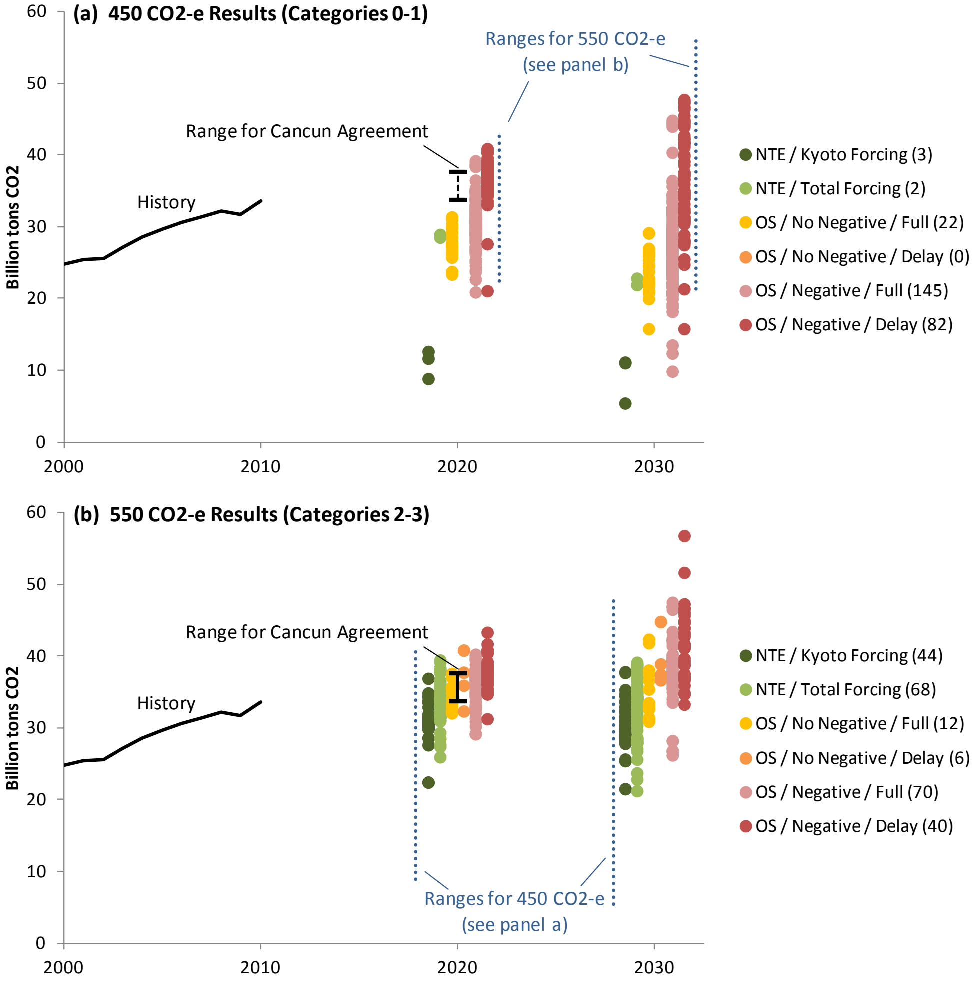
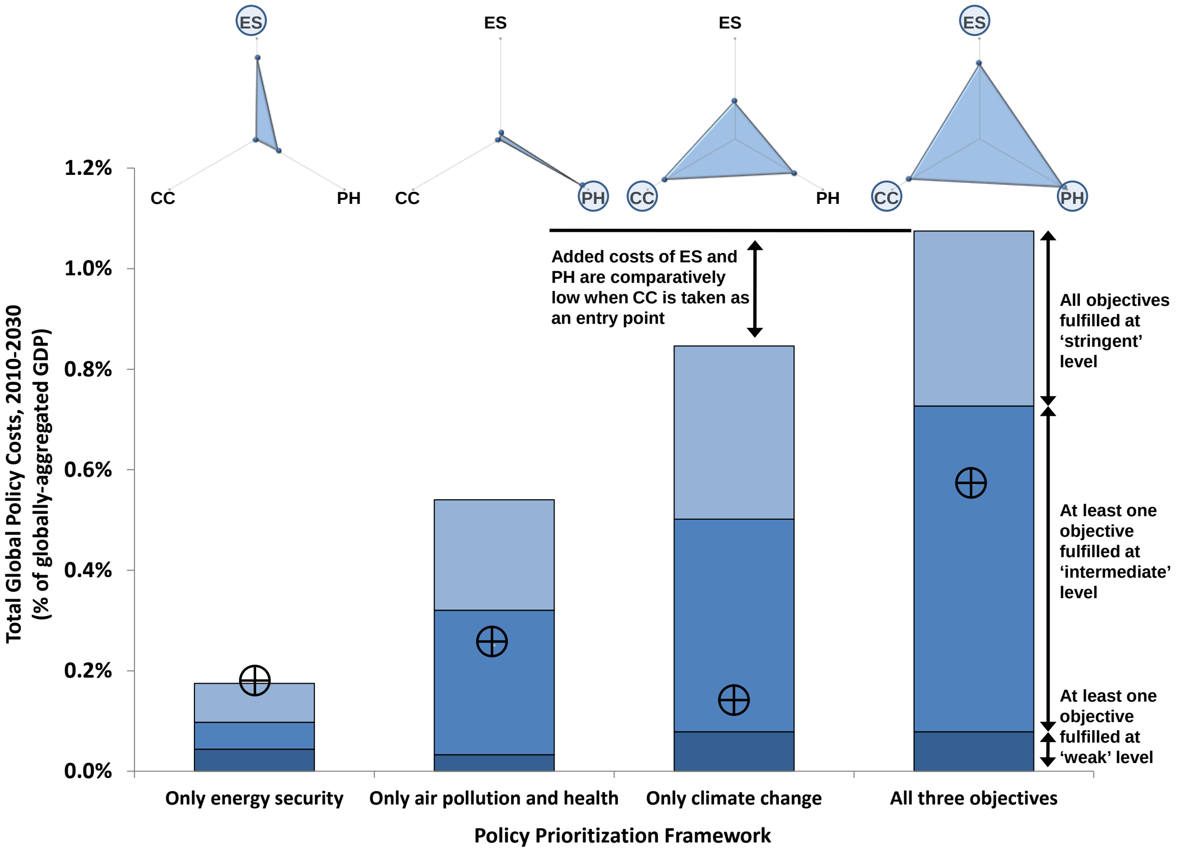


Figure TS.8. Near-Term Global Emissions from Scenarios Achieving Long-Term Targets of (a) 450 CO_2eq (Categories 0-1) and (b) 550 CO_2eq (Categories 2-3). Individual model results are indicated with colours referring to scenario classification as not-to-exceed (NTE) vs. overshoot (OS); CO_2 equivalence in terms of Kyoto gas contributions or total contributions to forcing; availability of a negative emissions technology; and timing of international participation (full vs. delay). Number of reported results is shown in legend (254 total for 450 CO_2eq, 240 total for 550 CO_2eq). [Note that figure is not yet fully comprehensive, and may miss some relevant studies] [Figure 1.8; Figure 6.31]

Stabilization scenarios for 550 ppm or lower require GHG emission reductions in the first half of the 21st Century similar to those associated with 450 ppm CO_2eq scenarios with overshoot. Because there is more time required to reach 550 ppm CO_2eq, some growth in GHG emissions is also still consistent with a 550 ppm CO_2eq pathway. There is significant overlap between the range of pathways for the two target categories, particularly when comparing the 450 CO_2eq overshoot range assuming the availability of a negative emissions technology to the 550 CO_2eq not-to-exceed range, suggesting that in the near-term these pathways are roughly interchangeable. [6.3, 6.5]

Climate policy could provide an entry point to achieve a broader set of non-climate objectives. Long-term transformation scenario studies have typically focused on the goal of reducing GHG emissions. However, mitigation choices will impact other societal objectives and non-climate policies may affect mitigation efforts. In many cases, if stringent climate policies are in place, synergistic relationships between societal objectives tend to be stronger and the added costs of any supplementary policies to reach other objectives (energy security/air pollution) at stringent levels can be significantly reduced - particularly in the near term (Figure TS.9). The extent of the synergies will depend on the ambition level for the different objectives. [3.5, 4.2, 6.6]



Energy security [global primary energy trade (EJ/yr), 2030]	**Air pollution and health** [%-reduction in global health impacts from baseline, 2030]	**Climate change mitigation (CC)** [climate stabilization categories]	**Fulfilment**
<120	>80%	0 – 1	Stringent
120 – 140	25% – 80%	2 – 3 – 4	Intermediate
>140	<25%	5 – 6	Weak

Figure TS.9. Costs of achieving societal objectives for energy sustainability under different policy prioritization frameworks. For the coloured bars, policy costs are derived from an ensemble of more than 600 scenarios and represent the net financial requirements (cumulative discounted energy-system and pollution-control investments, variable costs, and operations and maintenance costs) over and above baseline energy-system development, which itself is estimated at 2.1% of globally-aggregated GDP. For the pink circles, policy costs are derived from a set of four distinct scenarios and are calculated as GDP losses (cumulative discounted) relative to a no-policy baseline. Triangular schematics summarize the performance of scenarios that achieve ‘stringent’ fulfilment only for the objective(s) targeted under the corresponding policy frameworks (axis values normalized from 0 to 1 based on the full range of scenario ensemble outcomes). [Figure 6.32]

TS.3.3 Technological and economic requirements of long-term mitigation scenarios

Scenarios do not support the notion of a single, globally preferred portfolio of mitigation options. Instead, portfolio choices will depend on local circumstances, including linkages to other societal objectives such as sustainable development concerns and perceived risks. A range of different technological pathways can be pursued to reduce emissions. A range of different energy supply configurations and demand reductions are consistent with meeting specific long-term goals. In some cases, the choice among options will be determined by the cost, performance, and availability of particular technologies or technology systems. In other cases, choices will be based on linkages to other societal objectives such as energy security or local air pollution. All of these will vary among countries and regions. Some pathways may focus more heavily on end use reduction, whereas others may focus more heavily on decarbonizing supply in the near-term. Bioenergy, electricity, and even hydrogen can ultimately substitute for liquid, solid, and gaseous fuels; and scenarios differ in the potential long-term mix of these. Multiple alternative transition pathways are available for both the global energy system and for individual regional energy systems. The unique circumstances associated with individual countries or regions imply greater regional variety in energy mitigation portfolios than in the global portfolio. [6.6]

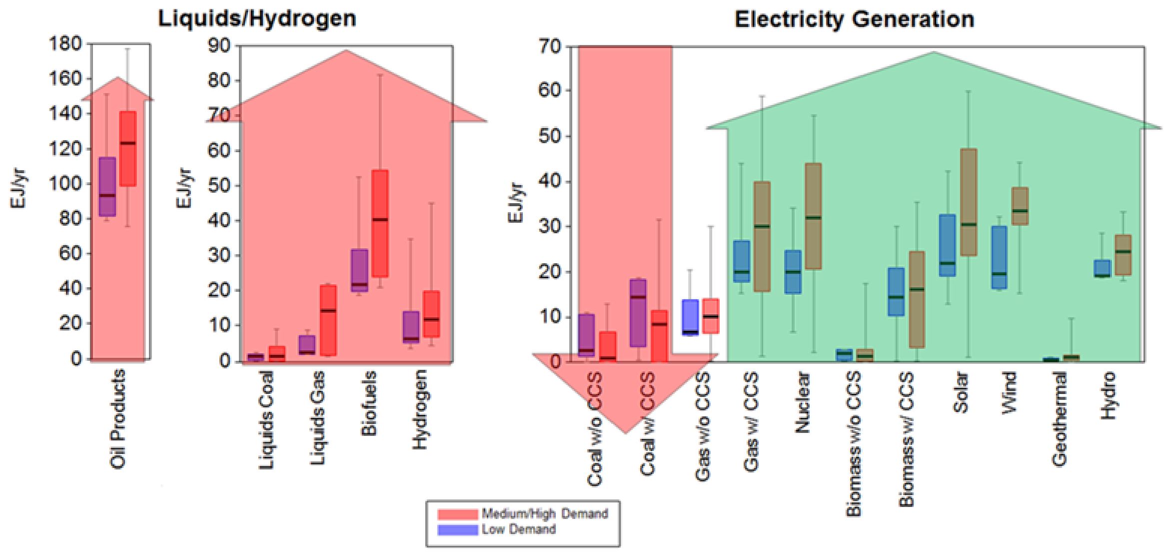


Figure TS.10. Influence of energy demand on the deployment of energy supply technologies in low stabilization scenarios (category 1) in 2050. Green arrows indicate increasing contribution of low-carbon electricity options due to higher demand with the exception of coal-CCS. Red bars show the impact of higher demand on other groups of technologies. Bars show the 25th-75th percentile of individual technology groups. [Figure 7.17]

To limit the costs of mitigation, stabilization scenarios for 450 or 550 ppm CO_2eq require a substantial near-term scale-up of low-carbon energy supply technologies, even if demand growth can be controlled. Scenarios indicate that a scale-up of anywhere from a modest increase to upwards of three times today’s low carbon energy in 2030 is consistent with a 450 ppm CO_2eq goal. A scale up of anywhere from roughly a tripling to over seven times today’s levels in 2050 is consistent with this same goal. On the one hand, the degree of scale up depends critically on the degree of overshoot, which allows emissions reductions to be pushed into the future. On the other hand, greater energy demand reduction require less pervasive and rapid up-scaling of supply side options. Figure TS.10shows that scenarios with relatively higher energy demand are generally accompanied by higher deployment rates for low-carbon options and reduced use of fossil fuels without CCS. The exception to the generally observed reduced use of fossil fuels in category 1 scenarios is oil production. [6.3, 7.11]

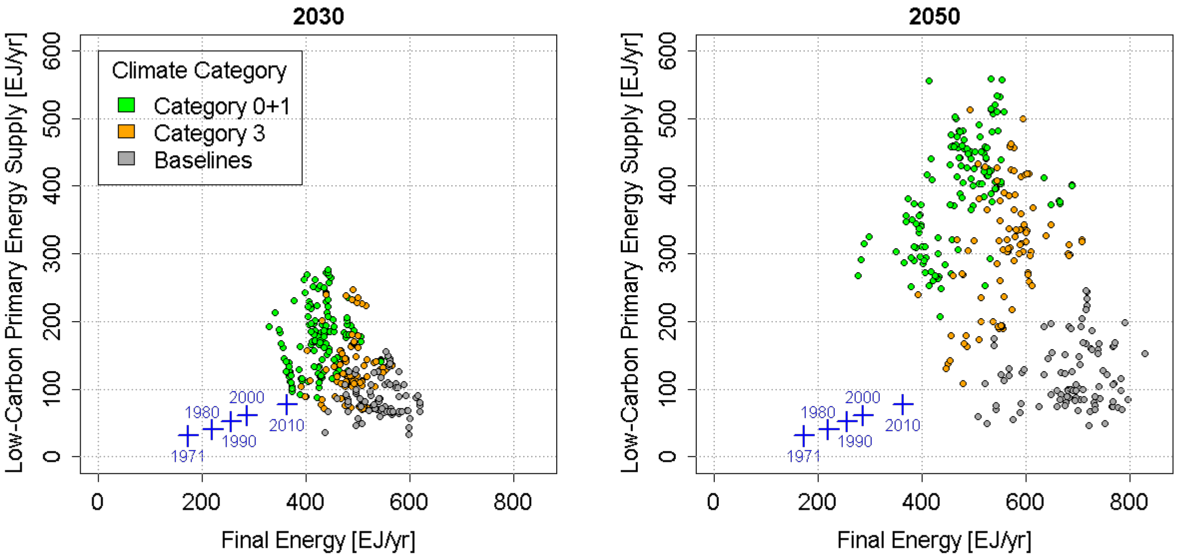


Figure TS.11. Global low carbon primary energy supply (direct equivalent) vs. total final energy use in the reviewed long-term mitigation scenarios by 2030 and 2050 assuming a cost-minimizing mitigation profile over the near-term. The colour coding is based on categories of climate stabilization as defined in Section 6.3.2. [Figure 6.14]

Estimates of century-long mitigation costs from integrated modelling analyses vary widely. Cumulative macroeconomic costs associated with mitigation over a century-long time horizon are extraordinarily hard to estimate, leading to substantial variability among cost estimates from different studies. Key factors that influence estimates include: model structure (which, among other things, captures assumptions about how easy or hard it might be to substitute technologies for one another), concepts of economic cost, underlying socioeconomic drivers such as population and economic growth, assumptions about technology cost and performance, resources and international trade, assumptions about energy demand and assumptions about residual emissions in the energy sector. In addition, because costs increase over time with increasing mitigation stringency, net present value costs are highly sensitive to the choice of discount rate. They reduce by up to a factor of two when choosing a discount rate of 8% instead of 5%, and they double to triple when adopting a discount rate of 1%. [6.3]

Under the most advantageous conditions for limiting costs, scenarios indicate that stabilization at 450 ppm CO$_2$eq could be achieved while reducing economic indicators such as GDP or personal consumption by less than 4% (assuming a discount rate of 5%) *(medium confidence)*. **Costs for maintaining concentrations below 550 ppm CO$_2$eq are estimated to be roughly 1/2 to 2/3 lower** *(medium confidence)* (Figure TS.12). However, this idealized scenario implementation is notional at best. It requires that all countries begin mitigation immediately, mitigation is be undertaken where it is least expensive, emissions reductions are be allocated over time in a way that minimizes the total cumulative cost over time, and no important mitigation technologies (e.g., nuclear power, bioenergy, carbon dioxide capture and storage, BECCS) are be removed as options because of potential adverse side-effects. Deviations from any of these requirements could substantially increase mitigation costs. Even under these idealized conditions, many models have produced estimate that are well above these levels. [6.3]

Box TS.7. Concepts of macroeconomic mitigation cost. [3.8]

Estimates of the aggregate macroeconomic costs of mitigation represent only direct mitigation costs and do not take into account a range of other potential costs and benefits of mitigation. Macroeconomic cost estimates are generally estimated against a baseline scenario without any explicit efforts to reduce GHG emissions. These estimates focus only on a constrained set of direct market effects. They do not take into account important co-benefits or adverse side-effects of mitigation actions, such as health benefits from reduced air pollution or changes in landscapes. Further, these costs are only those of mitigation; they do not capture the benefits of reducing greenhouse gas concentrations and limiting climate change. It is against these benefits of mitigation that the potential costs of mitigation must ultimately be weighed.

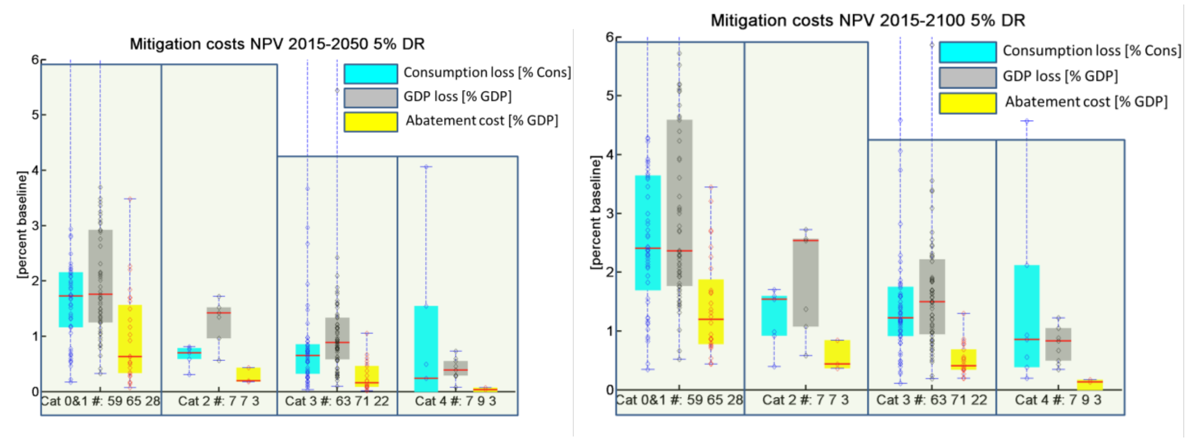


Figure TS.12. Global mitigation costs of idealized implementation scenarios as reported in the AR5 database. Costs are expressed as a fraction of aggregate production – or in the case of consumption losses – consumption in the baseline. Left panel shows net present value costs until 2050 and right panel until 2100. Box plots show range (whiskers), 25 to 75 percentile (box) and median (red line) of scenario samples. Sample size is indicated at the bottom. GDP and consumption losses are drawn from almost identical samples of general equilibrium model results. Abatement costs are drawn from a complementary sample of partial equilibrium model results. One model reports substantially higher costs than 6%. Preliminary results subject to update of the AR5 scenario database and sampling choices. [Figure 6.20]

Technology cost, performance, and availability have an increasingly large influence on the costs of mitigation for more ambitious stabilization goals (Figure TS.13). In general, scenarios indicate that there is flexibility to focus regional strategies on particular combinations of technologies that best fit local conditions, leaving particular technologies out of the mitigation portfolio, with only modest increases in macroeconomic costs. However, macroeconomic costs will be substantially higher if substantial elements of the portfolio are unavailable or if prospects for emerging technologies are less than hoped. Studies show that macroeconomic costs under broadly pessimistic assumptions about technology would increase the costs of reaching 450 ppm CO_2eq by the end of the century by four times to orders of magnitude, and the costs of reaching 550 ppm CO_2eq to the same degree, even assuming idealized national and international policy architectures. However, at the tighter, 450 ppm CO_2eq constraint, many models in recent multi-model comparisons could not produce scenarios with limited technology portfolios, particularly when assumptions preclude the use of BECCS technologies. [6.3]

450 ppm CO_2eq scenarios increasingly depend on net negative emissions (e.g. BECCS) in the second half of the 21st century - particularly in the case of delayed mitigation. As a result, the ability of policymakers to determine technology portfolio choices freely and manage the associated risks is increasingly constrained. The availability of BECCS as a mitigation option must be considered uncertain, largely because of constraints with respect to the use of CCS (both technical and societal) and biomass supply. On the bioenergy side possible risks relate to reduction of land carbon stock and increased N_2O emissions, and leakage of storage. It is unknown whether large-scale bioenergy deployment can be reconciled with competing land, water, livelihood and biodiversity considerations. The assumption of sufficient spatially appropriate CCS capture, pipeline and storage infrastructure are uncertain, too. Strong financial incentives (carbon prices and/or BECCS subsidies) are needed as neither CCS nor BECCS is currently financially competitive. Another challenge is the possible lock-in of fossil fuels by establishing CCS, and hence, delaying the introduction/ technological learning of other low-carbon primary energy sources. [6.3, 7.5, 11.13]

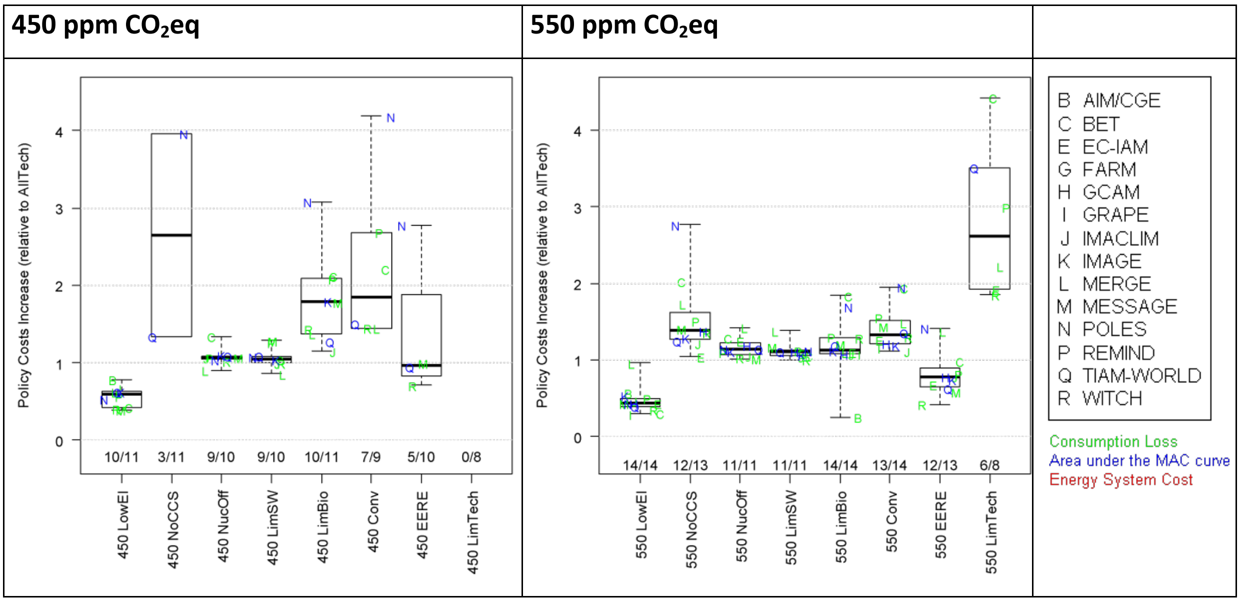


Figure TS.13. Relative mitigation cost increase in case of technology portfolio variations compared to the default (AllTech) technology portfolio under a 450 ppm (left panel) and 550 ppm (right panel) CO_2eq stabilization target from the EMF27 study. The numbers at the bottom of both panels indicate the number of models that attempted the reduced technology portfolio scenarios and how many in each sample were feasible. The conventional (Conv) scenario combines pessimistic assumptions for bioenergy and other RE with availability of CCS and nuclear and the higher energy intensity pathway and the energy efficiency and renewable energy (EERE) case combines optimistic bioenergy and other RE assumptions with a low energy intensity future and non-availability of CCS and nuclear. LimTech refers to a case in which essentially all supply side options are constrained and energy intensity develops in line with historical records in the baseline. [Figure 6.23]

Box TS.8. Discounting future costs and benefits. [3.5]

Quantitative analysis of climate change policy options requires valuation of economic and environmental assets through time. In economic analysis, discounting allows costs and benefits incurred at different points in time to be compared, using a social discount rate which incorporates ethical judgments. Because of the long timeframes involved, the choice of the discount rate is crucial to decisions on how much cost to incur today for the benefit of future generations. For example, a benefit of $1 million occurring in 100 years has a present value of $369,000 if the discount rate is 1%, and only $1,152 if the discount rate is 7%.

The choice of discount rate may be viewed from a normative perspective, making a decision about what discount rate to use for evaluating climate change policy and impacts across generations; and from a positive perspective, focusing on how individuals and markets actually make intertemporal decisions, as revealed by market interest rates. Both approaches can be relevant depending on the application.

Normatively determining a social discount rate involves making assumptions about the pure rate of time preference (whether and how much costs and benefits in the future should be discounted simply because they occur later in time), the stability of preferences over long spans of time, the growth rate of consumption, and aversion to inequality and risk. In a growing economy, investing is socially desirable only if its social return is large enough to compensate for the increased intergenerational inequality that this action generates. This normative argument is summarized by the Ramsey Rule, which derives discount rates from parameters for the collective time preference and aversion to inequality. The Stern Review on the economics of climate change in 2007 has generated an intense debate on the calibration of the Ramsey Rule, and its extensions to take account of the uncertainty affecting the long-term growth rate of the economy.

Although a significant amount of uncertainty and debate regarding these parameters remains for evaluating mitigation options, a selection of typical analyses in the literature implies a real social discount rate between 1% and 7% per annum (medium confidence) or between 0% and 8% per year (high confidence). These estimates include a risk premium originating from the uncertainty surrounding future climate impacts.

Integrated Assessment Models tend to use a central value for the discount rate in the range of 3% to 5% per year. While the choice of discount rate matters most for the evaluation of costs and benefits of different levels of global mitigation and their consequences, it also plays a role in the modelling of scenarios that achieve specified cumulative emissions levels. For a given overall mitigation effort, a lower discount rate tends to increase the effort and the marginal cost of abatement in earlier periods, and decrease it in later periods.

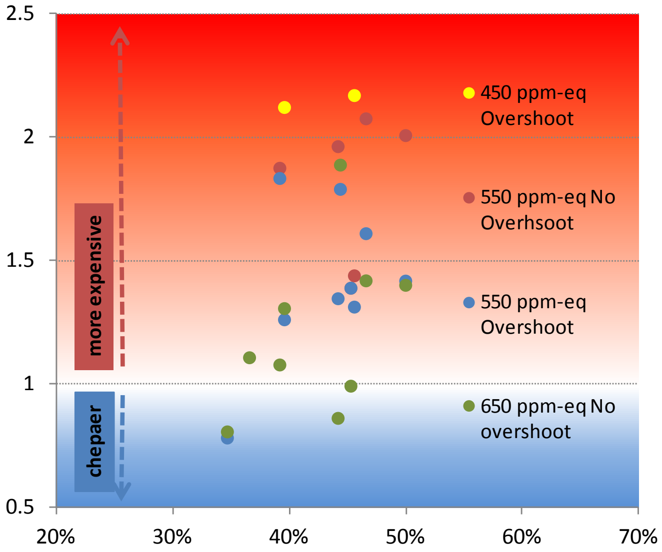


Figure TS.14. The economic implications of partial cooperation under four different stabilization goals. The x axis shows the fraction of CO_2 emissions covered by the international climate policy in the period 2020-2050. The y axis shows the ratio of the global policy costs in the partial cooperation scenarios with respect to same ones under full cooperation. Blue and red colours identify areas in which policy costs respectively increase or decrease as a result of partial cooperation. Policy costs are calculated as GDP losses or area under the marginal abatement cost curve in net present value terms (at 5% discounting). [Figure 6.24]

Current investment patterns need to change in order to become compatible with most stabilization scenarios. Climate policy is expected to induce a partial redirection of investments in the energy sector from fossil fuel based (up-stream production, processing and power plants) to renewable power generation, nuclear energy and fossil fuels with CCS, with limited incremental net investment needs for energy supply. In addition, annual incremental investments in energy efficiency are required in the building sector of USD 215 (175 to 254) billion until 2030, USD 267 (150 to 384) billion in the transport sector, and USD 104 (77 to 131) billion in the industry sector are needed in scenarios compatible with a 450 ppm pathway. [16.2]

Delays in international cooperation can dramatically increase the costs of mitigation particularly for ambitious goals such as 450 ppm CO_2eq *(medium confidence)*. Although more limited near-term mitigation lowers near-term requirements for transformation, it relies on future decision-makers undertaking a more rapid and costly future transformation. Such delays can dramatically increase the costs of mitigation particularly for ambitious goals such as 450 ppm CO_2eq, often several-fold or more, depending on the nature of the near-term action (Figure TS.14). [6.3]

TS.3.4 Institutional requirements of long-term mitigation scenarios

Scenario results are based on the assumption that most substantial emitters around the world are given a credible incentive to make efforts to control their GHG emissions. Mitigation can be encouraged by various forms of policy interventions, such as technology regulations or caps on emissions. These interventions send a signal to firms and households that they need to alter their behaviour, such as by investing in the invention and deployment of new technologies. Salient interventions, such as a prominent tax on emissions, can also help coordinate behaviour around common goals. Stabilization scenarios typically rely on the assumption that, for a given mitigation pathway, governments will adopt the needed incentives in a way that is highly credible and thus give maximum advance notice and flexibility. In reality, however, policy interventions may be more erratic and thus less credible; rules may be written in ways that impede flexibility. The differences between model assumptions and real world outcomes in which governments adopt policy interventions that are less timely and credible suggest that real world costs for mitigation could be higher than estimated. [1.3]

Stabilization scenarios assume the availability of appropriate institutions to address an array of market failures that affect the behaviour of firms. Assessment models are typically not designed to look at the microeconomic factors at work within particular firms or other organizations as they make choices that affect the economy's overall level and cost of mitigation. For example, least cost pathways for substantial mitigation of emissions require substantial innovation and deployment of new technologies. Yet even if firms have perfect, credible information about impending regulations and market interventions they may still under-invest in new technologies. The benefits of new technologies may be impossible to appropriate fully, which weakens the incentive to invest in innovation especially in settings where intellectual property rights are weak. There may be very high transaction costs in contracting for the many different forms of intellectual property and tangible materials needed to test and deploy new technologies. Some technologies may be so risky - especially at early demonstration phases - that individual firms will not invest without additional public support or other mechanisms for reducing risk. Models also typically include many other assumptions that lead to a similar gap between expected and real outcomes, such as the assumption that information is widely available at little or no cost. [1.3]

Scenario results might vary if assessment models accounted for the way in which institutions influence human preferences. Although the discussion in this section emphasizes real world factors that could lead to higher costs than estimated by models, there are some institutional factors that could lead to lower costs. That is because the models used to assess economy-wide costs usually rely on the assumption that economies are already in equilibrium and preferences remain stable over time. Deviations from that equilibrium are costly. Yet institutions that diffuse information and attitudes around the world could change attitudes and preferences, such as those that relate to the choice of energy technologies, behaviour, diet and other factors that affect the scale of the mitigation challenge. There is substantial evidence that diffusion of information has affected preferences in other areas of economic activity, although modelling these processes is complicated and not yet a major part of any of the models in use. Under some conditions, changes in preferences—such as toward more emission-intensive lifestyles—might also lead to mitigation costs that are higher than estimated. [3.9]

Stabilization scenarios assume the availability of institutions that can separate the place of mitigation effort from the place of cost incidence. Least-cost scenarios that are commensurate with stabilizing GHG concentrations at 550 ppm CO_2eq or lower assume the availability of global effort sharing institutions that operate at zero transaction cost. For instance, effort sharing could be introduced explicitly via regional emissions allowances traded on a global carbon market. Payment transfers depend on the regional abatement opportunities, the distribution of allowances, and the stabilisation target. Multi model studies indicate that the size of the carbon market would be significant in relation to the global mitigation reduction, on the order of hundred billions of U.S. dollars per year before mid-century. For some regions, financial flows would be on the same order of magnitude as the investment requirements for emissions reductions. The last two decades of diplomacy under the UNFCCC have demonstrated that creating global institutions for mitigating climate change is difficult. Diplomatic history as well as social science research also suggests that international institutions relevant to climate change mitigation will be decentralized and fragmented rather than tightly integrated around a single least-cost global optimum. [1.3]

The costs of mitigation vary substantially across countries and regions if effort sharing institutions are not available (Figure TS.15). Mitigation costs will not be identical across countries. This is influenced by the nature of international participation in mitigation, allowance allocations, and transfer payments. In the idealized scenario setting, a universal carbon price encourages mitigation where it is globally most efficient. A robust result of modelling studies is that, in the absence of transfer payments, OECD costs would be lower than the global average, Latin America would be on average around the global mean, and that other regions would face costs higher than the global mean. If some countries delay their mitigation efforts while others take on an expanded role in mitigation, then the former will take on lower mitigation and costs in the near-term. However, total costs borne over the century can be higher because of faster reductions that may be necessary for meeting long-term stabilization goals. [6.3]

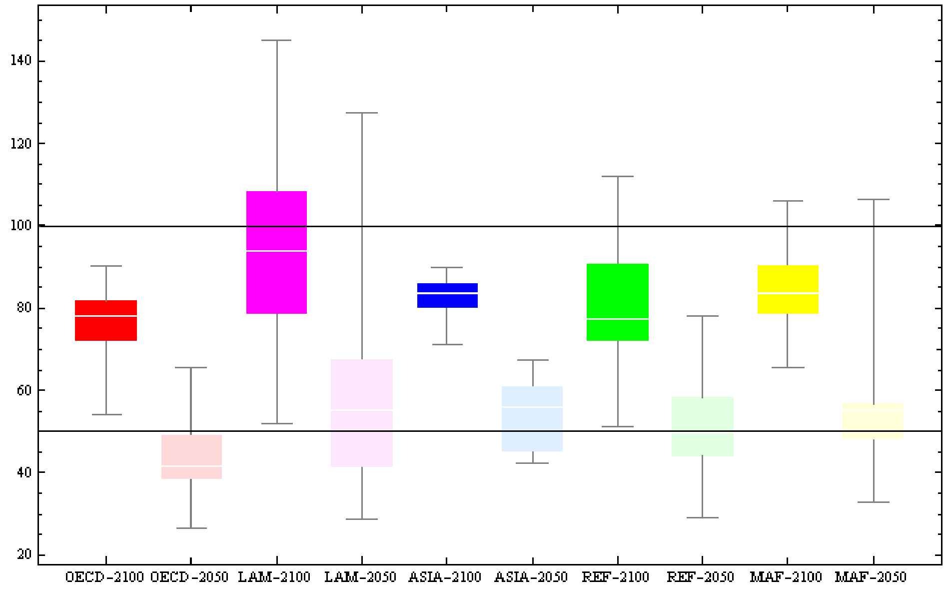


Figure TS.15. Regional distribution of the relative mitigation effort in an optimal 450 ppm CO_2eq scenario. Mitigation is calculated as reductions from BAU of both cumulative CO_2 emissions till 2100 (dark colours) and till 2050 (light colours). The two lines indicate cumulative emissions reductions of 50% and 100%. Values above 100% can be achieved with negative emissions. Box plots indicate variations across models (median, 25% and 75%, and maximum and minimum). Regions include: OECD (OECD1990 countries), REF (Reforming Economies), LAM (Latin America and Caribbean), MAF (Middle East and Africa), ASIA (Asia). For country mappings please see Report Annex II. [Figure 6.27]

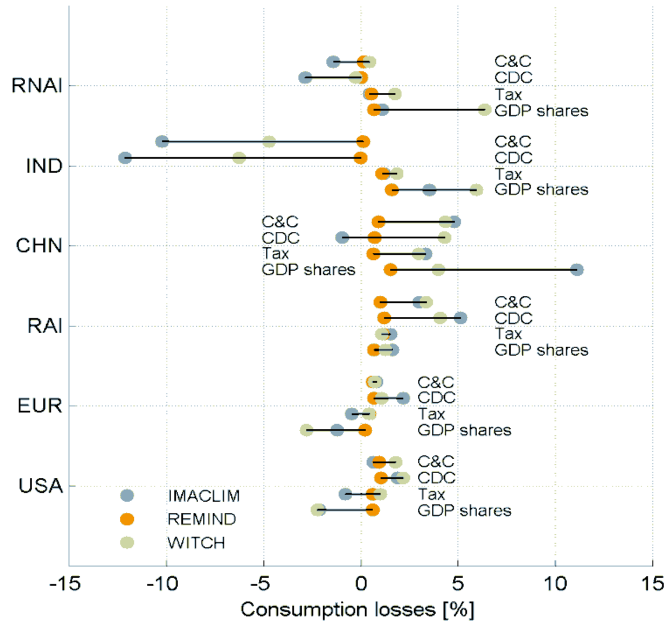


Figure TS.16. Policy costs for key regions and different allocation principles (C&C=Contraction and Convergence, CDC=Common but differentiated Convergence, Tax=Uniform Carbon Tax, GDP Shares= equal emission right of emission per unit of GDP) from the RECIPE project for a 450 ppm CO_2 stabilization target. [Figure 6.30]

The choice of stabilization level and effort sharing principle are both of high significance for the regional distribution of policy costs, in particular in the near term *(high confidence)*. The payment transfers associated with different burden sharing schemes have a direct impact on the regional distribution of climate policy cost (Figure TS.16). These costs are sensitive to the given allocation scheme, especially for developing countries; and they are highly dependent on the concentration stabilisation target. For the most ambitious stabilisation level under any effort sharing approach, allowances in OECD and EITs are a fraction of today's emissions in 2050, and below current levels in 2050 for LAM, AME and Asia. This holds for all of the fundamentally different effort sharing approaches included in the analysed studies. Also for higher stabilization scenarios most studies show a significant decline in allowances for OECD and EITs by 2050. Most studies show a decline in allowances for the LAM region, mostly increasing for the AME region and an inconsistent picture for ASIA. The range of emission allowances widens over time (from 2020 to 2050). [6.3]

Effort sharing principles determine the direction of transfer payments and the distributional impact of different allocation schemes. Different effort sharing principles have been proposed in discussions on climate change mitigation (Table TS.2). Proposals focussing on “responsibility” and “capability” are relatively stringent “early” emitters assigning to them lower allocations. These approaches put high weight on the larger responsibility and capability of developed countries. Proposal based on “potential” are less stringent to “early” emitters as they capture the mitigation potential in developing countries, which is assumed to be relatively cost effective. Especially for low stabilization levels, the approaches differ in the extent to which they rely on own contributions from all countries and on international assistance between countries. Approaches in the categories “Carbon budget” and “Responsibility, capability and need” result in significantly stricter targets for developed countries and therefore to higher financial transfers from developed to developing countries than other approaches. Some studies in the category RCP 2.9, i.e. 450 ppm CO_2eq, show reduction targets for the developed countries in the 25-40% reduction target range. There are studies based on regimes assuming an accumulated per-capita emission convergence approach, carbon budget approaches and Greenhouse Development Rights showing more stringent reductions of developed countries than the 25 to 40% range. [6.3, 13.4]

Table TS.2. Effort sharing principles. Effort sharing proposals can be categorised in seven categories, dependant on which of four equity principles they apply. Some approaches are based on one of the four key equity principles: responsibility, capability, potential and equality. Responsibility and capability are used in the UNFCCC in the phrase “common but differentiated responsibilities and respective capabilities”. The principle of need for sustainable development or for basic needs is also often used. It is closely related to the principle of capability. In addition, several approaches are based on the principle of equality sometimes meaning equal rights per person. While some approaches take emission reduction potential into account, other approaches combine mainly two of the four: carbon budgets which combine equality with responsibility and development focussed approaches, which combine responsibility and capability. Staged approaches constitute a compromise over all equity principles. [Table 6.3]

Categories	**Responsibility**	**Capability**	**Equality**	**Potential**	**Description**
Responsibility	X				Concept first directly proposed by Brazil in the run-up of the Kyoto negotiations, without allocations. Allowances quantified by only a few studies.
Capability		X			Frequently used for allocation relating reductions or reduction costs to GDP or human development index (HDI).
Equality			X		A multitude of studies provide allocations based on immediate or converging per capita emissions. Later studies refine the approach using also per capita distributions within countries;
Potential				X	Modelling studies often use “equal marginal abatement cost” as a reference case for cost globally effective mitigation. Also approaches based on sectors such as the Triptych approach (ref) or sectoral approaches consider as basic principle the reduction potential. Finally also studies using equal percentage reductions, also called grandfathering, are placed in this category.
Responsibility, capability and need	X	X			Recent studies used explicitly responsibility and capability as a basis, e.g. Greenhouse Development Rights
Carbon budget	X		X		Several studies allocate equal cumulative per capita emission rights based on a global carbon budget, combining the principles of responsibility and equality. Studies diverge on how they assign the resulting budget for a country to individual years
Staged approaches	X	X	X	X	A suite of studies propose or analyse approaches, where countries take differentiated commitments in various stages. Categorisation to a stage and the respective commitments are determined by indicators using all four equity principles.

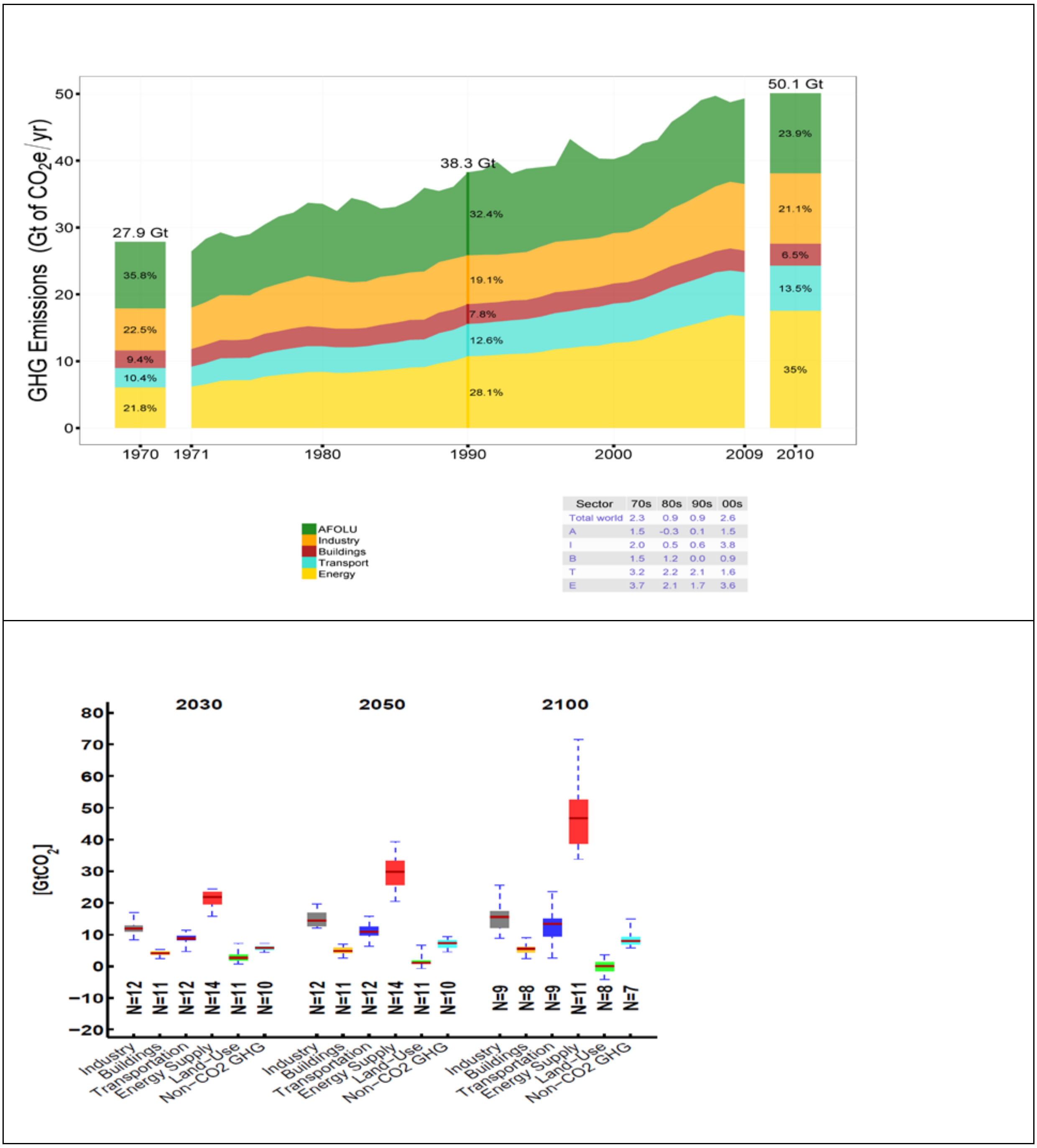
Stabilization scenarios assume the existence of highly effective institutions to build and operate mitigation technologies including infrastructure. Energy systems work mainly through complex and costly infrastructures such as networks of natural gas pipelines and electric power grids. Large-scale deployment of renewable energy sources or nuclear power or the more extensive use of electricity to replace petroleum fuels, for example, is viable only in settings where firms and governments have the incentive to build and operate electric grids. If the infrastructure of long-distance, complex supply chains for fissile material are not secure, for example, then nuclear power options that many scenarios deploy may not be practical or politically sustainable. [7.10]

TS.4 Technological and behavioural options by economic sector

This Section assesses the evidence available in the literature on a variety of mitigation technologies, processes and practices that actors in different economic sectors can adopt. Institutions that could encourage the adoption and prudent use of these options are discussed in the subsequent Section.

TS.4.1 Sectors in long-term mitigation scenarios

GHG emissions in the energy and transport sectors dominate growth in global emissions *(high confidence)*. While GHG emissions from the energy sector have tripled since 1970, emissions from transportation have doubled. Since 1990 emissions from electricity and heat production increased by 27% for the group of OECD countries; in the rest of the world the rise has been 64%. Over the same period, emissions from road transport increased by 29% in OECD countries and 61% in the other countries. In 2010, global GHG emissions stemmed for one-quarter from electricity and heat production and for one-third from the total energy sector. Industry (including waste) and AFOLU (agriculture, forestry, and other land uses) both contributed roughly one-quarter, with agriculture about half of total AFOLU. The transport and buildings sector contributed about 13% and 7%, respectively. [1.3, 5.2]



Sector	70s	80s	90s	00s
Total world	2.3	0.9	0.9	2.6
A	1.5	-0.3	0.1	1.5
I	2.0	0.5	0.6	3.8
B	1.5	1.2	0.0	0.9
T	3.2	2.2	2.1	1.6
E	3.7	2.1	1.7	3.6

Figure TS.17. Evolution of GHG emissions over time by economic sectors historically (upper panel) and in baseline scenarios (lower panel). GHG emissions are measured in gigatonnes per year (Gt/yr) of CO_2 equivalent (CO_2eq). Non CO_2 greenhouse gases are converted to CO_2 equivalents using 100-year global warming potentials (see Box TS.2). The table shows average annual growth rates by decade and sector. [Figure 5.2.3; Figure 6.34]

Limiting the cost of stabilization ultimately requires the adoption of substantial mitigation actions in all economic sectors *(high confidence).* Ambitious climate goals, such as 450 ppm CO_2eq, require that GHG emissions toward the end of the century be reduced to a fraction of what they are today.

This means that GHG emissions in all sectors need to be substantially reduced; approaches that emphasize only a subset of sectors or a subset of actions will either be insufficient to meet this goal or dramatically raise the costs of mitigation. [6.8]

There are natural ways to phase the emphasis of emissions reductions over time, across different sectors, and across types of actions in order to limit the costs of mitigation *(high confidence)*. The mitigation options within and across sectors vary substantially. To contain the costs of mitigation, mitigation efforts need to emphasize those options that are least expensive in the near-term, moving toward more expensive options in the long-run. However, near-term cost minimisation needs to keep a long-term strategy in perspective in order to avoid lock-in effects, particularly important for the case of long-lived infrastructure such as buildings, roads and urban morphology, which can significantly increase the costs of long-term mitigation or may even jeopardise the achievability of low stabilisation targets. The movement from low-cost to higher-cost options implies a natural phasing along low-cost mitigation pathways. Phasing is also supported by the interactions between different mitigation options. For example, increasing the use of electricity is increasingly valuable as a mitigation option as the electricity sector is decarbonized. [6.8]

A phased strategy must account for interactions between sectors to prevent unintended consequences *(high confidence)*. Sectors are inextricably tied together. For example, an approach that focuses heavily on decarbonizing electricity generation in the near-term could raise the price of electricity. Without out accounting for this effect, electricity use could decrease, resulting in an increase in other, more carbonaceous fuels such as natural gas. Reductions in materials flows may be important for reducing industrial emissions but are ultimately actions associated with other sectors. Complementary actions will be required to address these interactions between sectors. [6.8]

Decarbonization of electricity is a near-term option in virtually all transformation scenarios that meet 450 ppm or 550 ppm goals while limiting the costs of mitigation *(high confidence)*. This is based on the notion that there are multiple viable options available to produce low-carbon electricity, so it will be relatively easier to reduce emissions in the electricity sector relative to the demand sectors. The availability of BECCS (or other CDR technologies) has a substantial effect on this dynamic. It further reduces the cost of emissions reductions, allowing for deeper reductions and an earlier decarbonization of electricity. [6.8]

The emissions reduction effects of energy demand reductions are highest in the near-term before electricity and other fuels are decarbonized *(high confidence)*. Energy carriers such as liquid fuels and electricity today are associated with high direct or upstream emissions in most regions of the world. Electricity is often generated from freely-emitting fossil fuels and liquid, gaseous, and solid fuels come largely from fossil sources. Reducing the use of these fuels over the next several decades through energy use reduction can lead to large reductions in both direct and upstream emissions. In the long-run, as fuels are progressively decarbonized, for example decarbonizing electricity, end use reductions will lead to progressively smaller emissions reductions. Energy reduction remains valuable for minimizing the need for low-carbon energy supply and if reduced demand can displace fossil supply at the margin. Mitigation efforts that emphasise demand reductions have larger flexibility in the choice of supply options to meet low stabilisation targets. Bottom up studies of end use options often focus on energy reduction precisely because these studies focus on near-term strategies, when energy supply has not been largely decarbonized. [6.8]

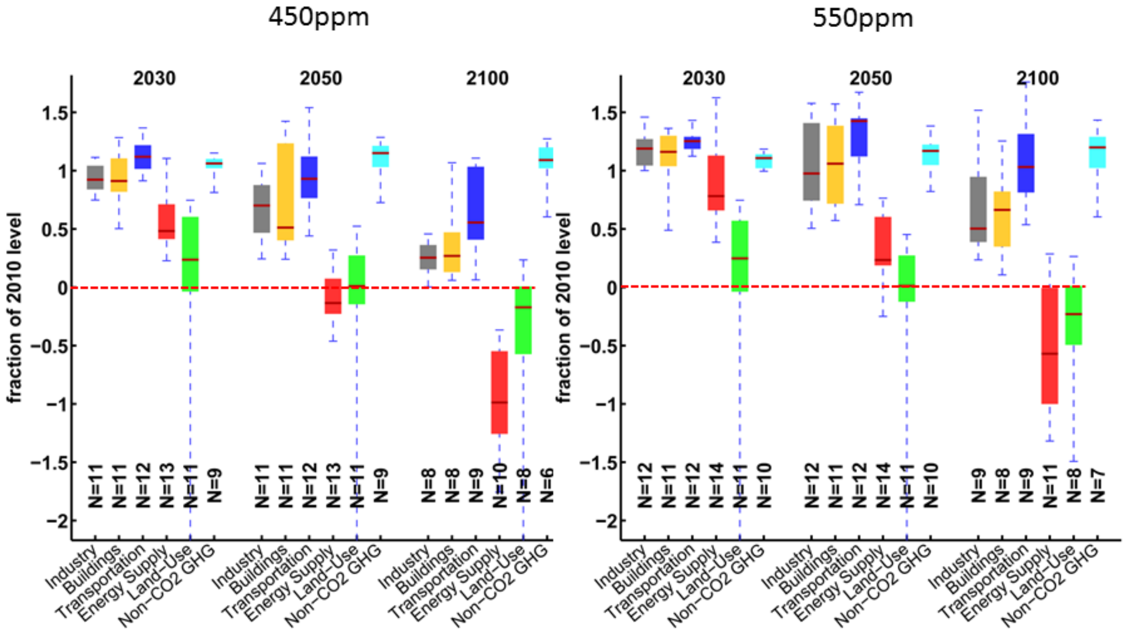


Figure TS.18. Direct CO_2 emissions across sectors. The thick black line corresponds to the median, the coloured box to the inter-quartile range (25th to 75th percentile) and the whiskers to the total range across all reviewed scenarios. The blue dashed lines refer to historical data as of 2009. [Figure 6.35]

Large differences remain between long-term, integrated studies and bottom-up studies regarding the potential for energy use reductions *(medium confidence)*. Although both long-term integrated studies and bottom-up studies indicate an important role for energy reductions for climate mitigation, there remains a large divide regarding the cost-effective potential for such reductions. Such differences mostly originate from two key reasons: assumptions about the existence of options that occur at a net benefit to the end-user and sector vs. economy-wide optimization. More concretely, most integrated studies assume that all energy efficiency options that are at a net profit to the investor have been taken up, while bottom-up studies acknowledge that there are market barriers and thus large opportunities remain for such investments. Equally, integrated studies optimise and balance mitigation opportunities across the entire economy, while many bottom-up studies investigate the details of how and how much that sector could contribute to mitigation or energy use reduction goals. [3.7, 6.8]

In the long-run, switching to low-carbon fuels in end use sectors will be necessary to deliver deep emissions reductions consistent with stabilization *(high confidence)*. Although energy reduction remains a valuable element of mitigation in all long-term scenarios, the potential for energy reduction is ultimately limited. Some amount of energy will always be required to produce industrial goods and transport people and goods. This means that these services must be supplied by low-carbon fuels if CO_2 emissions in particular are to be reduced to a fraction of today's levels. Most analyses envision important roles for bioenergy and electricity in this regard. Major breakthroughs in hydrogen generation, storage and use would be required for it to serve as a competitive low-carbon fuel. [6.8]

Many studies indicate that, in the long-run, the transportation sector and non-CO_2 gases provide the greatest challenges for deep emissions reductions *(medium confidence)*. In the long-run, as emissions must be reduced to a fraction of today's levels, the ability to mitigate these final fractions becomes increasingly important. Most studies indicate that the most challenging and costly final reductions will be those in the transportation sector and in the reduction of non-CO_2 gases. Indeed, the long-term challenges associated with reductions in these two sectors exert the largest influence on long-term mitigation costs in most long-term, integrated studies. The primary challenge in the transport sector is the need for high density fuels. On the other hand, studies that envision substantial advances in battery or fuel cell and hydrogen storage technologies do not envision transport as a long-term roadblock. Challenging emissions reductions of non-CO_2 gases include those from land use processes. [6.8]

In the majority of transformation pathways, deforestation is largely halted by mid-century *(high confidence)*. Many scenarios focus on afforestation and reforestation, in which case the land use sector can become a carbon sink by mid-century (Figure TS.18). [6.8]

TS.4.2 Energy systems

The amount of fossil fuels available, albeit decreasing, will not contribute to the limitation of global GHG concentrations to levels consistent with the Cancun Agreement. Since the industrial revolution, fossil fuel combustion released almost 400 GtC into the atmosphere. The remaining hydrocarbon reserves alone contain two to four times of that amount of carbon. [7.4]

The main mitigation options in the energy sector are those applicable in the field of fuel extraction and conversion (efficiency improvements, mitigation of fugitive emissions), fuel switching, energy efficiency improvements in transmission and distribution systems, carbon capture and storage (CCS) as well as the use of renewable energies and nuclear energy. [7.5]

Significant reductions in GHG emissions can be obtained by replacing existing coal-fired heat and/or power plants with highly efficient natural gas combined cycle (NGCC) power plants or combined heat and power (CHP) plants *(medium evidence, medium agreement)*. LCA evidence shows that the specific lifecycle emissions of modern NGCC power plants (when fuelled from a low GHG natural gas source) are 50% lower than the contemporary world average of the specific emissions of coal fired power plants. More modest emissions reductions are achievable by applying best available coal technologies or less advanced gas power plants (Figure TS.19 left panel). Compared to the AR4, the advent of shale gas led to a relaxation of natural gas resource concerns. In addition, a better appreciation of the importance of fuel chain issues (especially those related to fugitive methane emissions) resulted in a downward adjustment of the estimated benefit from fuel switching. [7.5]

The long-term emissions of NGCC are too high to meet stringent long-term stabilization targets if NGCC is used for base-load power demand *(robust evidence, high agreement)*. Beyond energy efficiency improvements and fuel switching, low carbon energy supply technologies therefore are indispensable if these goals are to be achieved. [7.5]

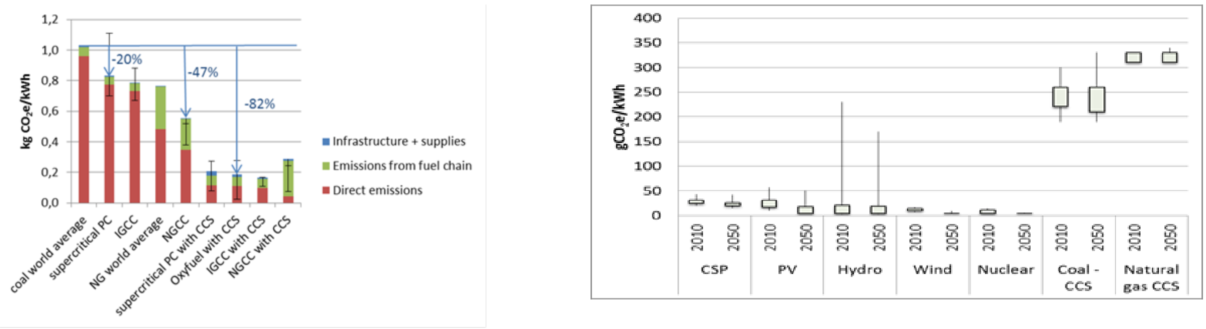


Figure TS.19. Left panel: Specific greenhouse gas emissions from current world average coal and gas fired power plants and mitigation opportunities associated with going to best available technology (BAT) conventional plants and plants with CO_2 capture and storage (CCS) taking into account new estimates for fugitive emissions from fossil fuel production. Note: The percentage values indicate the percentage change in the specific emission values, not the global mitigation potential. [Figure 7.8]
Right panel: Comparative life-cycle greenhouse gas emissions from a range of different technologies for electricity production. The presented range reflects the variation of the regional conditions and among investigated technologies or cases within a single category, but not the uncertainty in the technology. Biogenic emissions from hydropower are not included. [Figure 7.9]

CCS technologies can significantly reduce the specific carbon dioxide emissions of fossil-fired power plants, albeit to a lower extent than either RE or nuclear (Figure TS.19 right panel)**. BECCS might allow negative emissions by effectively removing CO_2 from the atmosphere** *(medium evidence, medium agreement).* All of the components of integrated carbon dioxide capture and storage (CCS) systems exist and are in use today in various parts of the fossil energy chain. A variety of recent pilot and demonstrations projects led to critical advances in the knowledge of CCS systems and their engineering, technical, economic and policy impacts. However, as of early 2013, CCS has not yet been applied to a large, commercial fossil-fired generation facility. [7.5, 7.8]

There is 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 formation caused by CO_2 storage (such as induced seismicity and potential human health as well as environmental consequences from CO_2 that migrates out of the primary injection zone) as well as on actively reducing this. In order to ensure the safety, efficacy, and permanence of the captured CO_2's isolation from the atmosphere, measurement, monitoring and verification (MMV) technologies play a critical role. *(medium evidence, medium agreement)* [7.5]

Total practical geologic storage capacity is large and likely sufficient to meet demand for CO_2 storage over the course of this century, but that capacity is geographically unevenly distributed. *(limited evidence, medium agreement)* [7.5]

Since AR4, renewable energy technologies have advanced substantially *(medium evidence, high agreement)*. The price of photovoltaic (PV) modules has declined steeply as a result of policy instruments, increased supply competition, improvements in manufacturing processes and photovoltaic (PV) cell efficiencies, and reductions in materials use (Figure TS.20 right panel). Continued increases in the size of wind turbines have helped to reduce the levelized cost of land-based wind energy, and have improved the prospects for offshore wind energy. Concentrated solar thermal power plants (CSP) were built in a couple of countries – often together with heat storages or as gas-CSP hybrid systems. Improvements have also been made in cropping systems, logistics, and multiple conversion technologies for bioenergy. [7.5]

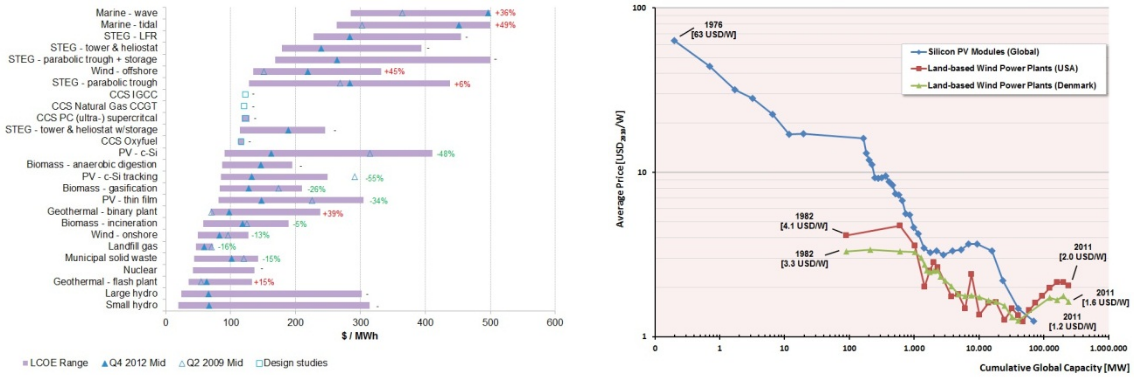


Figure TS.20. Left panel: Levelized cost in \$/MWh of electricity for commercially available energy technologies as observed for the fourth quarter of 2012 (and for the second quarter of 2009). For nuclear and CCS projected costs are shown. [Figure 7.10] **Right panel:** Selected experience curves in logarithmic scale for the price of silicon PV modules as well as land-based wind power plants for USA and for Denmark; both per unit capacity. [Figure 7.11]

The global technical potential of all available renewable energy (RE) sources does not pose a practical constraint on their contribution to mitigate climate change during the 21st Century although regional potentials of single technologies might be limited *(medium evidence, medium agreement).* [7.4]

Nuclear energy is a mitigation option that can provide carbon free electricity at the plant site and low carbon electricity on a life-cycle basis *(robust evidence, high agreement)*. [7.8]

Although nuclear power has been used for five decades, unresolved issues remain for a future worldwide expansion of nuclear energy. The related barriers include operational safety, proliferation risks, waste management and the economics of power plants. Constraints to resource availability are limited if recycling options (via reprocessing plants) are taken into account. Efforts are underway to develop new fuel cycles and reactor technologies that address the concerns of nuclear energy use. *(medium evidence, medium agreement)* [7.5]

Many RE technologies will only be competitive with market energy prices and grow in their contribution if they are directly or indirect subsidized, if there is an intention to further increase their market share. The same is and will be true for CCS plants due to the additional equipment attached to the power plant and the decreased efficiency. The post Fukushima assessment of the economics and future fate of nuclear power is mixed. Additional barriers are seen in the field of technology transfer, capacity building and in some cases public perception. *(medium evidence, medium agreement)* [7.8, 7.9, 7.10]

TS.4.3 Transport

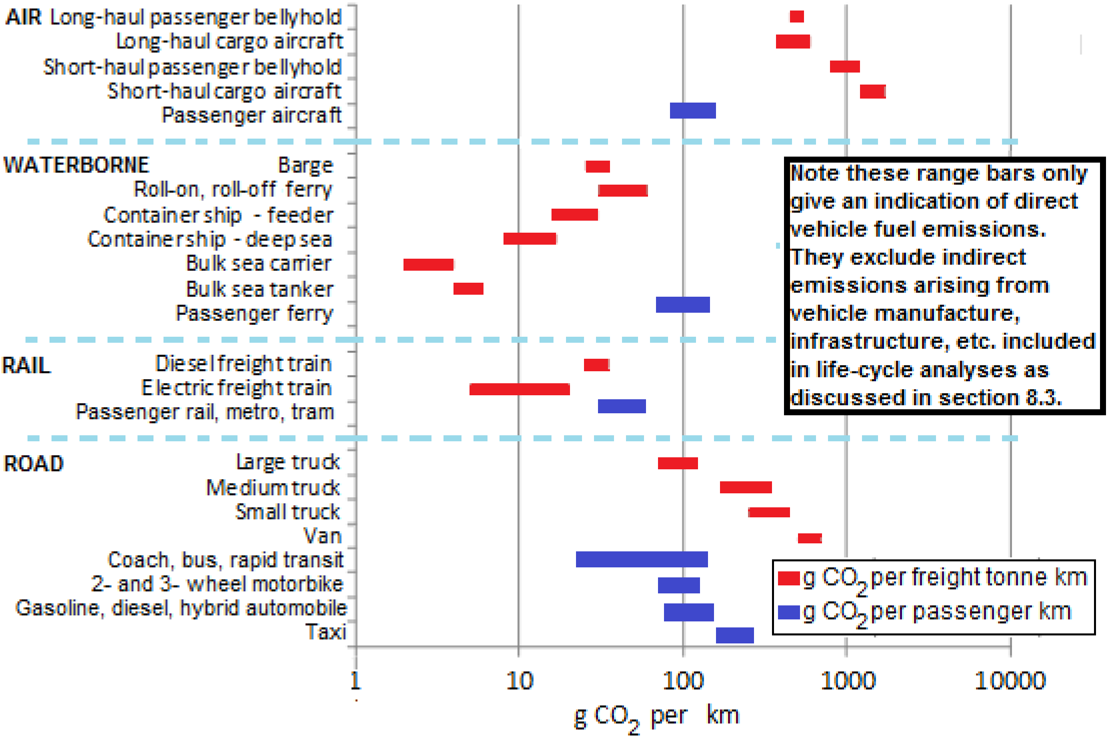
Growing transport demands and high energy density requirements of many transport fuels make mitigation in this sector particularly challenging *(high confidence)*. The transport sector's share of total GHG emissions is growing with rapidly rising emissions from emerging economies and from aviation predicted. Combustion of fossil fuel products in aircraft, boats, trains and land vehicles is the norm, with their relatively low cost and high energy density making it difficult for alternatives to compete, with the exception of electric rail. Mitigation options in the transport sector can be categorized into reducing fuel carbon intensity, improving energy intensity, modal shifts, developing infrastructure, and reducing activity (the need for journeys). [8.3, 8.6]

In Integrated Assessment Model (IAM) scenarios, total passenger transport demand (passenger km / year) more than doubles, or even triples between 2010 until 2050 with freight demand (tonne km / year) growing by around 80% over the same period *(medium confidence)*. This substantial increase is mostly driven by assumed exponentially rising incomes, and population growth. The freight sector is assumed to be more sensitive to price signals and policy instruments. While OECD countries stabilize their transport demand, emerging economies nearly triple theirs. [8.1]

Technological "improve" and behavioural "shift" and "avoid" options may contribute more to mitigation than was assumed in AR4 *(medium confidence)*. Activity reduction in future decades (due to internet shopping, video conferencing, social networking etc.) against baseline could impact on climate change mitigation. In urban areas, city tolls and congestion charges can reduce light duty vehicle (LDV) transport demand by up to 20%-30%, while inducing social benefits, as is also the case in emerging economies. Some cities are already experiencing "peak car" demand. Conversely, in many developing countries, sustainable development depends upon improving mobility and access to markets for rural communities where currently transport options are very limited.

Better urban planning (e.g. mixed-use development; prohibition of retailers in green field areas) can reduce transport demand per capita by an additional 5-10%, and between 10-20% for cities with rapidly growing populations. Policy packages to support urban planning appear reasonable options as part of a comprehensive co-benefit analysis. Costs of transport demand management can be negative, such as raising revenue via road charges and air fare taxes. However, low-carbon, land-use planning and demand measures are likely to translate into higher land prices, especially in the location of efficient public transport stations. A comprehensive cost evaluation of activity-related mitigation options is difficult to achieve, and may depend on subjective criteria of quality of life [8.6]. Modal shift can be encouraged where low-C transport options and suitable infrastructure, such as cycleways, bus rapid transit (BRT) and light-rail transit (LRT), exist. Denser cities can decrease total LDV transport demand, and enable a shift from private to public transport. BRT can be the most cost-effective option, especially where it involves simply dedicating an existing road lane for buses only . Improved cycling and walking infrastructure can contribute to modal shift and improved safety, particularly in smaller cities. In total, diverting investments from road infrastructures into BRT and high-speed Rail can decrease emissions by around 5% globally by modal shift, while saving 0.2% of global GDP in terms of infrastructure investments. [8.4, 8.6]

Energy intensity reduction through improved vehicle and engine designs provides high potential for climate change mitigation *(high confidence)*. From the transport-sector perspective, there is significant potential to reduce emissions (FigureTS.21) by reducing energy intensity in all vehicle types. IAM scenarios see much lower rates of energy intensity improvements. Direct energy inputs vary widely with vehicle type but indirect GHG emissions from vehicle manufacture and infrastructure construction are key elements so also need to be considered.



FigureTS.21. Typical ranges of direct CO_2 emissions per kilometre for passengers and per tonne-kilometre for freight, for the main transport modes when fuelled by fossil fuels including thermal electricity for rail. [Figure 8.1.6]

Nearly every major OECD country has adopted aggressive targets and introduced new standards that aim to cut direct energy use and GHG emissions for new road vehicles, (in the US by 50 % between 2010 and 2025 and in the EU by about 50% from 2005 till 2020). Some emerging economies, including China, are also adopting increasingly aggressive performance standards. The first mass-produced electric vehicles have entered markets, supporting the realization of these fuel economy standards, and possibly enabling further improvements after 2025. In total, reducing vehicle fuel consumption of newly sold vehicles by 50% globally in 2030 is an ambitious but feasible target, translating into about 50% reduction of fuel use by LDVs in 2050. The high share of total operating costs from fuel purchases for aircraft and boats is driving improved performance efficiency. Annual improvement rates of 3% (1.7% between 2005 and 2008) are feasible by countries/ regions with ambitious policies. Most fuel-economy technologies are commercially available and cost-effective (giving net savings for consumers). However, high discount rates of consumers, uncertainty in savings due to oil price fluctuations, lack of information and status competition towards high power/high weight vehicles pose considerable non-monetary barriers. These barriers can be overcome by fuel economy standards, fuel taxes, labelling, feebates (or CO_2-based vehicle taxes), and possibly a transformed perception of positional goods. An additional 5-10% fuel savings can possibly be achieved by fuel economy measures such as ship speeds, eco-driving, improved aviation and airport logistics. Better traffic management, intelligent transport systems, better vehicle and road maintenance may achieve another 5-10% in fuel savings. Efficiency improvements in heavy duty vehicles (HDVs) could achieve at least a 30% reduction in fuel consumption by 2050, but at moderate to high costs. Aircraft could achieve efficiency improvements of 50% by 2050 compared to 2005 levels; and large ships up to 60% per t km by 2050. For rail, the EU has targeted a 50% reduction in specific CO_2 emissions by 2030. [8.3, 8.8, 8.10]

The total potential and costs for reducing the carbon intensity of fuels is very uncertain. Electric, hydrogen or biofuel technologies could all help to bring carbon intensity close to zero in 2100 if technological breakthroughs allowed the affordable and sustainable use of one or more of these technologies produced from low-C sources. Due to their relatively low energy density and related costs, electric and hydrogen technologies are more likely to be adopted for short-range travel in urban areas than for long-range inter-city travel. Costs in the case of hydrogen and electric options, and unsustainability and competition for land use in the case of some biofuels are key barriers. Battery electric vehicles (BEVs) are considerably cheaper so more likely to be cost-competitive sooner than fuel cell electric vehicles IAM scenarios and transport-specific literature tend to disagree on specific long-term technology options and the potential for reducing carbon intensity. [8.3, 8.6]

TS.4.4 Buildings

Technological options, design practices and behavioural changes can achieve a two to ten-fold reduction in energy requirements of new buildings and a two to four-fold reduction in energy requirements of existing buildings *(robust evidence, high agreement)*. From the perspective of technological options, energy uses in buildings can be broken into those that are commonly regulated through building codes (combination of heating, cooling, ventilation and partially lighting energy uses) and those that might be regulated through equipment standards (appliances, consumer electronics, office and lighting equipment). According to AR4, remaining key energy efficiency gains are found especially with system approaches, such as through integrated design processes, i.e. interactions involving all members of the design and building team from the start, instead of conventional linear processes and taking into consideration building orientation, form, thermal mass and envelope (enabling energy savings of the order of 35-50% for a new commercial building, compared to standard practice); maximized passive heating, cooling, ventilation, and day-lighting; efficient systems to meet remaining loads; efficient and well sized individual energy-using devices; and proper commissioning (utilization of more advanced or less conventional approaches has often achieved savings on the order of 50-80%). Retrofits can achieve savings of 25-95% of heating and cooling energy use. [9.3]

Since AR4, there have been important performance improvements and cost reductions of several technologies and systems, e.g. very low-energy buildings, net zero energy buildings, insulation materials, use of thermal energy storage, heat pumps, other heating and cooling equipment, cool-coloured materials, fuel cells, digital building automation and control systems, smart meters and grids, and advanced biomass systems and cook stoves. Another factor is the increasing application of existing state-of-the-art knowledge and technologies in both new and retrofitted buildings. [9.3]

There has been significant progress in the adoption of voluntary and mandatory standards for low- and zero-energy buildings since AR4 with promising long-term energy implications. For residential buildings, a number of voluntary standards have been developed. For instance, over 30,000 buildings worldwide have been certified to meet the German Passive House standard (maximum heating load 15 kWh/m^2/yr, a factor of up to 30 in reduction), with more meeting the requirements but not certified. For cooling energy use, proper passive design may dispense mechanical air conditioning most or all of the time. Net zero energy and carbon buildings (NZEBs, with consumed energy or related carbon emissions equalling those produced on site or purchased from zero-carbon sources) and nearly zero energy buildings have been very dynamically incorporated by legislations in a large number of developed countries, regions or cities. However, NZEBs may not always be the most optimal solutions for minimised climate and environmental impact at a given cost. Whether the remaining low energy needs after a very high performance design and installation of high-efficiency equipment is best to be supplied by building-integrated or external low-carbon energy sources requires analyses for feasibility, costs, sustainability and life-cycle energy use. [9.3]

In commercial buildings, energy intensities of modern office and retail space can be reduced by a factor of 5 for heating and 4 for cooling. Advanced building control systems and high-efficiency appliances/equipment are a key to obtaining very low energy intensities in commercial buildings. [9.3]

In order to significantly reduce the energy requirements of the existing building stock by 2050, retrofits are a key part of any mitigation strategy in countries with established building stocks, as buildings are very long-lived and a large fraction of them will be in place in 2050 already exists today. Concerning reductions of heating/cooling energy use by (i) 50-80% for detached single-family homes and (ii) 70 - 90% for multi-family housing (e.g. apartment blocks) have been achieved by many best practices. With regard to developing countries such as China, (iii) modest envelope upgrades to multi-family housing have achieved reductions in cooling energy use by about one third to one half, and reductions in heating energy use by two-thirds. (iv) In commercial buildings, savings in total HVAC (heating, ventilation and air conditioning) energy use achieved through upgrades to equipment and control systems, but without changing the building envelope, are typically on the order of 25-50%; (v) re-cladding of building facades offers further savings, as do lighting retrofits. [9.3.4]

Consumer electronics, household appliances and office equipment are expected to have increasing aggregate energy consumption. This is due to dynamically growing product types, ownership and usage rates. These patterns are not likely to change unless, in an effective way, efficiency standards are used to induce close to the maximum technically achieved reduction in unit energy requirements [9.3.5]

In many parts of the world where mechanical systems are not affordable, principles of low-energy vernacular designs have evolved over centuries and provide sufficient comfort conditions. To this, it is necessary to consider the cultural and convenience factors and perceptions concerning “modern” approaches, as well as the environmental performance, that influence the decision to adopt or abandon vernacular approaches, as well as improvements by modern knowledge and techniques. Modern techniques also in richer regions also benefit from the consideration of many of these vernacular design approaches and need to be utilised more for low energy alternatives. Biomass, the single largest source of energy for buildings at the global scale, play an important role for space heating, production of SHW and for cooking in many developing countries. Significantly improved cook stoves have come on the market since the AR4. [9.3]

Behavioural aspects in the operation of buildings, equipment and appliances can lead to considerable reduction of buildings’ energy requirements *(robust evidence, high agreement)*. In buildings, key behavioural issues pertain to thermostat temperature settings for heating and cooling, the way in which equipment and appliances are operated, whether or not advantage is taken of opportunities for natural ventilation and passive cooling, frugality with respect to the use of hot water, and choices of lighting equipment and whether or not lighting is left on when not needed, and the number of electronic gadgets that are acquired and the way and amount they are used (as including their standby modes). In low-energy buildings, an increase in the mean indoor-to-outdoor temperature difference by 10% increases the heating energy requirement by up to 30%. Similarly, increasing the thermostat setting for cooling from 24ºC to 28ºC will reduce annual cooling energy use by more than a factor of 2-3. Behavioural issues – involving the cooperation of building occupants – are crucial to the correct operation of passive and hybrid ventilation systems in office buildings. Behavioural factors interact with the choice of technology. Centralized chillers, twice more efficient than individual older systems, may use up to 9 times more energy than small decentralized units that are used selectively. [9.3]

There is significant evidence that very low-energy construction and retrofits can be economic and in some cases incur no additional costs compared to conventional buildings or even cost less. Incremental costs of specific low-energy buildings in the residential sector, are 5-16% of the construction cost (50-200 €/m^2 for Passive House standard); in the US, to achieve 34-76% reduction in energy use are about $30-162/m^2 (excluding solar PV for both savings and costs); meeting the ‘Advanced’ thermal envelope standard in the UK reduces heating energy use by 44% costs more 7-9% (about £70-80/m^2). The incremental cost of low-energy buildings in the commercial sector is less than in the residential sector, due to the greater opportunities for simplification of the HVAC system, and that it is possible for low-energy commercial buildings to cost less than conventional buildings. The keys to delivering low-energy buildings at zero or little additional cost are through implementation of the integrated design process and the design-bid-build process. [9.7]

For retrofitting existing buildings, potential reductions in heating energy requirements are 50-75% in single-family housing and 50-90% in multi-family housing at costs of about $100-400/m^2 *(robust evidence, high agreement).* Significant (around 16%) savings can be achieved at very low cost, simply through retro-commissioning of equipment. Demonstration projects had savings in primary energy demand almost always exceeding 50%, with average savings of 76% and some reaching the Passive House standard for heating energy use. Although retrofits generally entail a large upfront cost, they also generate large annual cost savings, and so are often attractive from a purely economic point of view. Shallow retrofits can result in greater life-cycle costs than deep retrofits. Evaluation of retrofit measures identified near-cost-neutral packages providing between 29% and 48% energy savings in the US. Studies in old European buildings indicate that the total and marginal cost of conserved energy both tend to be relatively uniform for savings of up to 70-80%, but increase markedly for savings of greater than 80% or for final heating energy intensities of less than about 40 kWh/m^2/yr. Key findings from regional and national assessments of the potential reduction in building-related energy use are presented in the Table TS.3 below. [9.7]

Table TS.3. Key findings from regional and national assessments of the potential reduction in building-related energy use. Notes:1) The Table presents the potential of final energy use reduction (if another is not specified) compared to the baseline and/or base year for the end-uses given in the column 3 and for the sectors indicated in the column 5. 2) H – space heating; C – space cooling; W – hot water; L – lighting; APPL – appliances; ALL – all end-uses; BS – the whole building sector; RS – residential sector; CS – commercial sector; T – technical; T-E – techno-economical; EE – energy efficiency; RES – renewable energy sources; HVAC – heating, ventilation and air-conditioning; ZEB – zero-energy building; pr.en. – primary energy; electr. – electricity; red. – reduction; app. – approximately.3) Reg. – region; ES – Spain, WO – world, US – United States of America, TH – Thailand, N.Eu – Northern Europe, Cat – Catalonia, BH – Bahrain, CHN- China, EU27 – European Union, DK – Denmark, HK – Hong Kong, CH – Switzerland, DE – Germany, FR – France, LT – Lithuania. [Table 9.4]

Reg	Description of mitigation measures/package (year)	End-uses	Type	Sector	Base-end yrs	% change to baseline	% change to base yr
CARBON EFFICIENCY							
ES	Optimal implementation of Spanish Technical Building Code and usage of 17% of the available roof surface area	W	T-E	BS	2009	-68.4%	
TECHNICAL EFFICIENCY							
WO	Efforts to fully exploit potentials for EE, all cost-effective RES for heat and electricity generation, production of bio fuels, EE equipment	ALL	T	BS	2007-50	-29%	
US	Principal technologies or efficiency improvement assumptions (commercially available in 2008)for each end-use.	ALL	T-E	RS	2010-30	app. -29%	
		ALL	T-E	CS	2010-30	app. -35%	
NO	Wide diffusion of heat pumps and other energy conservation measures, e.g. replacement of windows, additional insulation, heat recovery etc.	ALL	T	BS	2005-35	-9.50%	-21%
TH	Building energy code and building energy labelling widely implemented, requirements towards NZEBs are gradually strengthened by 2030	ALL	T	CS	by 2030	-43% (LPG) -47% (electr.) -57% (oil)	
N. Eu	Improvements in lamp, ballast, luminaire technology, use of task/ambient lighting, reduction of illuminance levels, switch-on time, manual dimming, switch-off occupancy sensors, day lighting	L	T	CS	2011	-50%	
Cat, ES	Implementation of Technical Code of Buildings for Spain, using insulation and construction solutions that ensure the desired thermal coefficients	H/C	T	BS	2005-15		-29%
BH	Envelope codes requiring well-insulated and efficient glazing is	C	T	CS	1 year		-25%
UK	Fabric improvements, HVAC changes (incl. ventilation heat recovery), lighting and appliance improvements and renewable energy generation	ALL	T	CS	2005-30		-50% (CO_2)

Reg	Description of mitigation measures/package (year)	End-uses	Type	Sector	Base-end yrs	% change to baseline	% change to base yr
CHN	Best Practice Scenario (BPS) examined the potential of an achievement of international best-practice efficiency in broad energy use today	APPL	T	RS, CS	2009-30	-35%	
SYSTEMIC EFFICIENCY							
WO	Today's cost-effective best practice integrated design & retrofit as standard	H/C	T-E	BS	2005-50	-70%	-30%
WO	Goal of halving global energy-related CO_2 emissions by 2050 (compared to 2005 levels); deployment of existing and new low-carbon technologies	ALL	T-E	BS	2007-50	-34%	
WO	High-performance thermal envelope, maximized the use of passive solar energy for heating, ventilation and day lighting, EE equipment and systems	ALL	T	BS	2005-50	-48%	
US	Advanced technologies, infrastructural improvements and some displacement of existing stock, configurations of the built environment that reduce energy requirements for mobility, but not yet commercially available	ALL	T-E	BS	2010-50	-54%	-39%
EU27	Accelerated renovation rates up to 4%; 100 % refurbishment at high standards; in 2010 20 % of new built buildings are at high EE standard; 100% - by 2025	ALL	T	RS	2004-30	-66%	-71%
	A full technology diffusion of best energy saving technologies to the technical limits. This is a hypothetical maximum that will never be reached in practice	H/C/W	T	CS	2004-30	-56%	-67%
	A full technology diffusion of best energy saving technologies to the technical limits. This is a hypothetical maximum that will never be reached in practice	APPL	T	CS	2004-30	-23%	10%
DK	Energy consumption for H in new RS will be reduced by 30% in 2005, 10, 15, 20; renovated RS upgraded to energy requirements applicable for new ones	H	T-E	RS	2005-50		-80%
HK	Implementation of performance-based Building Energy Code	ALL	T	CS	1 year	-20.5%	
CH	Compliance with the standard comparable to the MINERGIE-P5, the Passive House and the standard A of the 2000 Watt society with low-carbon systems for H and W	H/W	T	RS	2000-50	-60%	-68%
	Buildings comply with zero energy standard (no heating demand)	H/W	T	RS	2000-50	-65%	-72%
DE	Proportion of very high-energy performance dwellings increases by up to 30% of the total stock in 2020; the share of nearly zero and ZEBs makes up 6%	H/W	T	BS	2010-20		-25%(pr.en) -50% (CO_2)
DEMAND EFFICIENCY							
FR	EE retrofits, information acceleration, learning-by-doing and the increase in energy price. Some barriers to EE, sufficiency in H consumption are overcome	H	T	BS	2008-50	-58%	-47%
LT	Change in life style towards saving energy and reducing waste	ALL	T	RS	1 year	-44%	

TS.4.5 Industry

As limits to energy efficiency are being approached in some energy intensive industries, other options such as material use efficiency, product use efficiency, carbon intensity improvements or demand reductions become increasingly important. Industry sector mitigation options include energy efficiency, emissions efficiency (including fuel switching and CCS), material use efficiency, product use efficiency as well as demand reductions for goods and services (Figure TS.22). Although many of the options other than energy efficiency exhibit high potentials, currently they are less explored. [10.1]

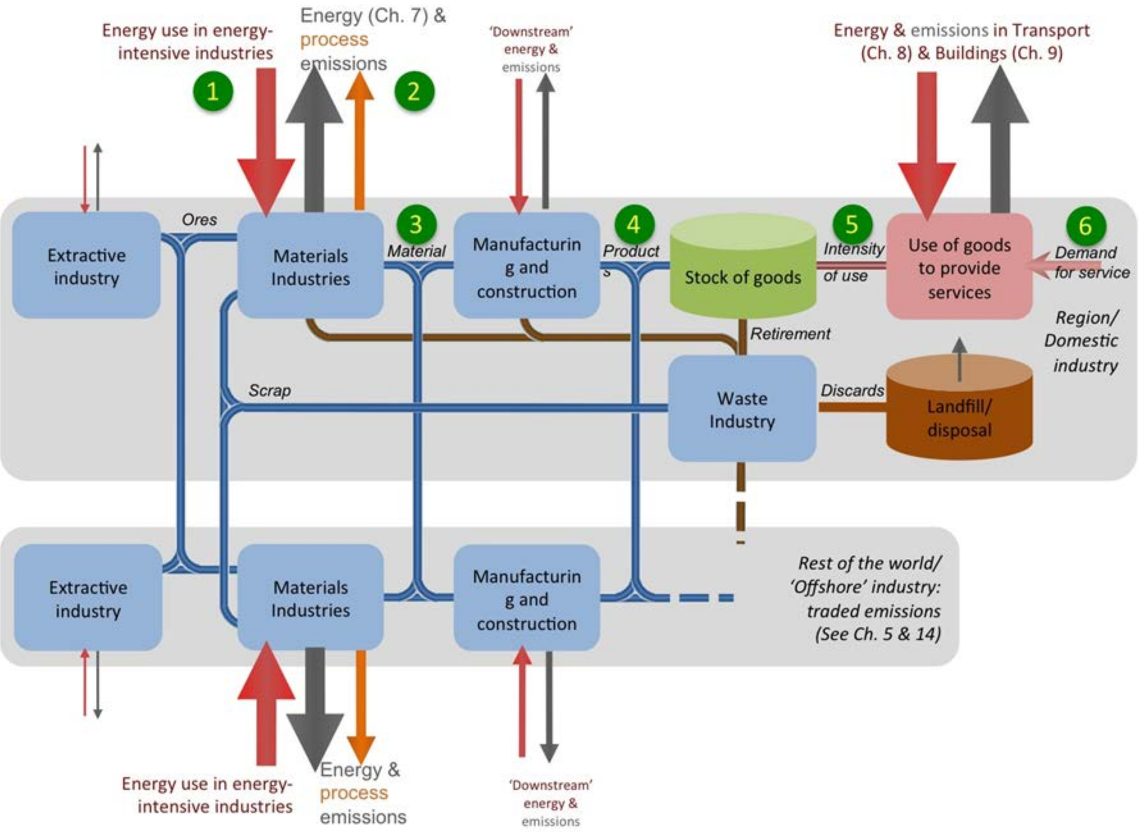


Figure TS.22. A schematic illustration of industrial activity over the whole supply chain. Options for GHG emission mitigation in the industry sector are indicated by the circled numbers: (1) Reducing energy requirements of processes; (2) Reducing emissions from energy use and processes; (3) Reducing material requirements for products and in processes; (4-6) Reducing demand for final manufactured products and for their use. [Figure 10.1]

The potential for future improvements in the energy intensity of industrial production is estimated to be 25% of current global industrial final energy consumption per unit output resulting in 12% to 26% savings in CO_2 emissions intensities for different industrial sectors. Key opportunities for efficiency are use of efficient motor driven systems, improvement in heat management through heat exchange between hot exhaust gases and cool incoming fuel and air, improved insulation, capture and use of heat in hot products, and use of exhaust heat for electricity generation. Recycling is cost effective in many industries, but constrained at the supply side by limited collection rates. Switching to natural gas, more efficient use of energy in industrial CHP installations, use of wastes and biomass, decarbonised electricity for wider use of heat pumps instead of boilers, solar thermal energy for drying, washing and evaporation awaits further development and wide scale implementation. [10.7]

Non-CO_2 emissions from industry can be managed by changing practices: e.g. HFC by leak repair, refrigerant recovery and recycling, proper disposal, replacement by alternative refrigerants (ammonia, HC, CO_2); emissions of HFC-23 can be reduced by process optimization and by thermal destruction, PFCs, SF6 can be countered by fuelled combustion, plasma and catalytic technologies; N_2O emissions from adipic and nitric acid production through the implementation of thermal destruction and secondary catalysts. [10.7]

Approximately one tenth of all paper, a quarter of all steel, and a half of all aluminium produced each year is scrapped which could be reduced by process innovations and new approaches to design. Re-use of structural steel in construction, new steels and production techniques to produce light-weight cars can reduce material use without loss of performance in use. At present, the high costs of labour relative to materials, and other barriers inhibit this opportunity. Using products for longer could reduce demand for replacement goods, and hence reduce industrial emissions. New business models could foster dematerialisation and more intense use of products. The ambition of the 'sustainable consumption' agenda and policies aims towards this goal, although evidence of its broad-scale application in practice remains scarce. [10.7]

Mitigation measures generateing significant co-benefits are adopted faster. Co-benefits include enhanced environmental compliance, health benefits through better local air and water quality and which generates less public resistance and reduced waste disposal costs, liability, training needs, are adopted faster. [10.8]

The pace and extent of mitigation in industry faces significant limitations unless barriers can be removed. Barriers that affect the development and diffusion of technologies are often common across sectors and comprise technological aspects, institutional, legal and cultural aspects as well as financial aspects. In combination with opportunities they influence investment and operational decisions. In addition to the general set of barriers for industry sector manifold specific barriers are relevant. Even though energy costs often form a significant fraction of overall costs in industry, a number of barriers limit the implementation of energy efficiency measures in the sector: expectation of high return on investment (short investment payback thresholds), high capital costs and long project development times for several technologies, limited access to capital, missing policy or market incentives (e.g. fair market value for cogenerated electricity to the grid), investments outside their core business etc. While energy-intensive industries - such as iron and steel – are quite aware of potential cost savings from investing in energy efficiency, which is automatically considered in investment decisions, others branches are not. For emissions efficiency improvements as feedstock/fuel change or application of CCS availability of alternative resources and competition among sectors is also relevant as very specific barriers like space constraints for CCS applications in retrofit situations. There are a wide range of opportunities to be harnessed from implementing material efficiency options, including the reduction in production costs, reduction in the demands for raw materials, and decreased amount of waste material going into the landfill, and emergence of new business opportunities related to material efficiency. However, commercial deployment so far remains at a small scale. Barriers to material efficiency include lack of human and institutional capacities to encourage management decisions and public participation. The reduction of non-CO_2GHGs also faces numerous barriers. Lack of awareness and lack of commercially available technologies (e.g. for HFC recycling and incineration) are typical examples. For product demand reduction besides economic and regulatory barriers, social obstacles are crucial. This includes for instance current incentive schemes (e.g. businesses are rewarded for growing sales volumes, and therefore motivated sell new products rather than promote longer-lasting products) as well as long response time of lifestyle choice. [10.9]

TS.4.6 AFOLU

The AFOLU sector is responsible for about a quarter (~9-10 $GtCO_2eq/yr$) of anthropogenic GHG emissions mainly from deforestation and agricultural emissions from livestock and soil and nutrient management *(robust evidence, high agreement)*. Forest degradation and biomass burning (forest fires and agricultural burning) also represent relevant contributions. The total GHG flux from the AFOLU sector was 9.3 Gt CO_2eq/yr during 2000-2009, with global emissions of 5.3 $GtCO_2eq/yr$ from agriculture and 4.0 $GtCO_2eq/yr$ from land use change, deforestation and fire. Non-CO_2 emissions derive largely from agriculture, dominated by N_2O emissions from agricultural soils and methane emissions from livestock enteric fermentation, manure and emissions from rice paddies, totalling 5.4-5.8 $GtCO_2eq/yr$ in 2010. [11.2]

AFOLU forms a significant component of mitigation in transformation pathways, offering a variety of mitigation options and a large, cost-competitive mitigation potential *(limited evidence, medium agreement)*. Opportunities for mitigation include supply-side measures such as reduction of emissions arising from land use change and land management, increasing carbon stocks by sequestration in soils and biomass, or the substitution of fossil fuels by biomass for energy production, and demand-side measures, such as reducing losses and wastes of food, changes in diet / wood consumption etc.) (Figure TS.23, Table TS.4). Large-scale energy generation or carbon sequestration in the AFOLU sector provides headroom for the development of mitigation technologies in the energy supply and energy end-use sectors as the technologies already exist and most of them are commercial. [11.3]

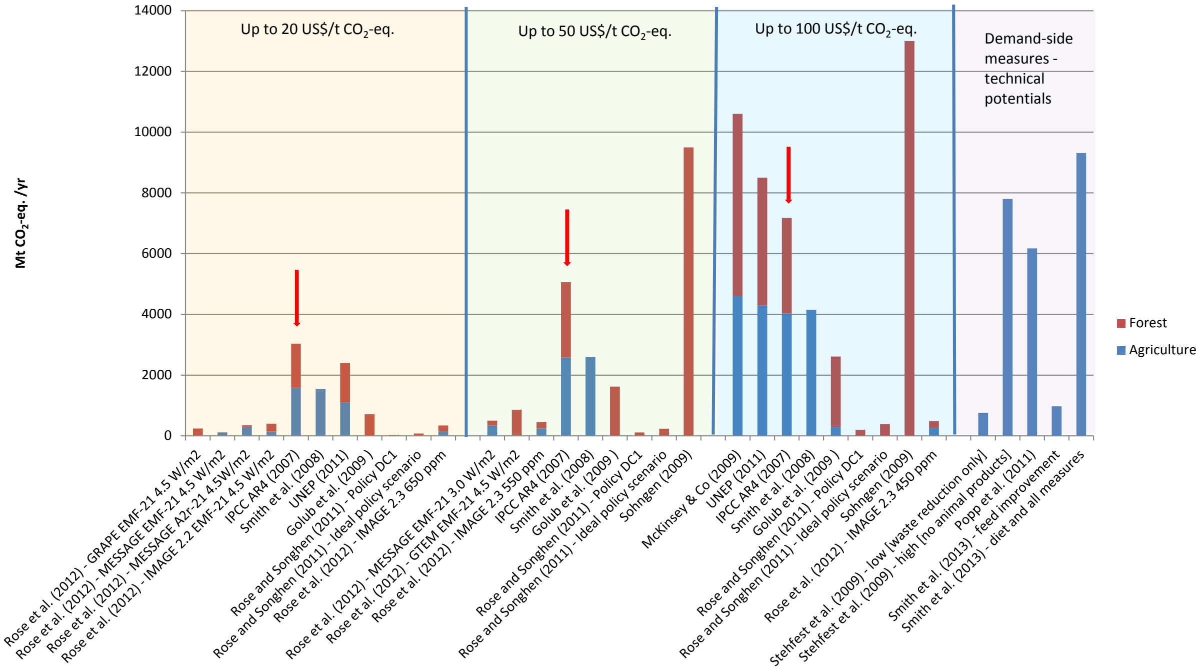


Figure TS.23. Estimates of economic mitigation potentials in the AFOLU sector published since AR4, (AR4 estimates shown for comparison, denoted by red arrows), including bottom-up, sectoral studies, and top-down, multi-sector studies. Some studies estimate potential for agriculture and forestry, others for one or other sector. Mitigation potentials are estimated for around 2030, but studies range from estimates for 2025 to 2035. Studies are collated for those reporting potentials at up to ~20 US$/$tCO_2$-eq. (actual range 1.64-21.45), up to ~50 US$/$tCO_2$eq. (actual range 31.39-50.00), and up to ~100 US$/$tCO_2$eq. (actual range 70.0-120.91). Demand-side measures (shown on the right hand side of the figure) are not assessed at a specific carbon price, and should be regarded as technical potentials. Not all studies consider the same measures or the same GHGs. [Figure 11.16]

Among supply-side measures, global estimates for economic mitigation potentials in the AFOLU sector by 2030 are 0.49 to 10.60 $GtCO_2eq$/yrat carbon prices up to 100 US$/$tCO_2eq$,about half of which can be achieved at a low carbon price *(medium evidence, medium agreement)*. New technologies, not assessed in AR4 (such as biochar) could increase this potential, but there is less evidence upon which to make robust estimates. Demand-side measures (e.g. dietary change and waste reduction) also provide significant technical potential, but the barriers to implementation are substantial. [11.6]

At carbon prices of around $100 t CO_2eq, the restoration of organic soils has the greatest potential, followed by cropland and grazing land management *(medium evidence, medium agreement)*. At lower prices (20 US$/$tCO_2$-eq), cropland management and grazing land management have the greatest economic mitigation potential. In other words, the composition of the agricultural mitigation portfolio varies with the carbon price. A comparison of estimates of economic mitigation potential in the AFOLU sector published since AR4 is shown in the above Figure. [11.6]

Among demand-side measures, changes in diet can have a significant impact on GHG emissions from food production (0.76-9.31 $GtCO_2eq$/yr by 2030), the range for which is determined by assumptions about the implementation of bioenergy *(limited evidence, low agreement)*. Other assumptions such as changes in productivity, feeding efficiency and waste reduction can also influence demand-side mitigation, with total combined potential of 1.5-15.6 $GtCO_2eq$/yr by 2050. [11.6]

Table TS.4. Changes in global land use and related GHG reduction potentials in 2050 assuming the implementation of measures to increase C sequestration on farmland, and use of spare land for either bioenergy or afforestation. Afforestation and bioenergy are both assumed to be implemented on spare land, i.e. are mutually exclusive. (* Cropland for food production and livestock grazing land. Potential C sequestration rates with improved management derived from global technical potentials; ** Spare land is cropland or grazing land not required for food production, assuming increased but still sustainable stocking densities of livestock). [Table 11.5]

Cases	Food crop area	Livestock grazing area	C sink on farmland*	Afforestation of spare land**	Bioenergy on spare land**	Total mitigation potential	Difference in mitigation from Reference case
	[Gha]		$GtCO_2eq.yr^{-1}$				
Reference	1.60	4.07	3.5	6.1	1.2-9.4	4.6-12.9	0
Diet change	1.38	3.87	3.2	11.0	2.1-17.0	5.3-20.2	0.7-7.3
Yield growth	1.49	4.06	3.4	7.3	1.4-11.4	4.8-14.8	0.2-1.9
Feeding efficiency	1.53	4.04	3.4	7.2	1.4-11-1	4.8-14.5	0.2-1.6
Waste reduction	1.50	3.82	3.3	10.1	1.9-15.6	5.2-18.9	0.6-6.0
Combined	1.21	3.58	2.9	16.5	3.2-25.6	6.1-28.5	1.5-15.6

Life-cycle assessments demonstrate that a plethora of pathways and technologies induce highly variable climate-relevant effects *(high confidence)*. Specifically, land-use change emissions, nitrous oxide emissions from soil and fertilizers, co-products, process design and process fuel use, end-use technology, and reference system can all impact the total attributional life-cycle emissions of bioenergy use. The large variance for specific pathways points to the importance of management decisions in reducing the life-cycle emissions of bioenergy use. The total marginal global warming impact of bioenergy can only be evaluated in a comprehensive setting that also addresses equilibrium effects, for example addressing indirect land-use change emissions, actual fossil fuel substitution and other effects. The lack of data and, more importantly, the structural uncertainty in modelling decisions, renders such evaluation exercises highly uncertain. The available data suggests a differentiation between options that offer low life-cycle emissions under good land-use management (e.g. sugarcane, Miscanthus, and fast-growing tree species) and those that are unlikely to contribute to climate change mitigation (e.g. soybean), pending new insights from more comprehensive consequential analysis. [11.9]

Land- and livelihood-related concerns need to be comprehensively integrated when considering bioenergy deployment *(high confidence)*. Land demand for bioenergy depends on (1) the share of bioenergy derived from wastes and residues; (2) the extent to which bioenergy production can be integrated with food or fibre production, which ideally mitigates land-use competition; (3) the extent to which bioenergy can be grown on areas with little current production; and (4) the volume of dedicated energy crops and their yields. Trade-off consideration with water, land and biodiversity needs to take central stage to avoid potentially harmful and even disastrous outcomes. A notable shortcoming of integrated assessment studies exists with regard to the analysis of livelihoods, in particular the incorporation of insights from human geography. The total impact on livelihood depends on global market factors, impacting income and income-related food-security, and place-specific factors such as land rights impacting land tenure and social capabilities. Further research is needed to evaluate the sustainable potential that improves rather than harms livelihoods. [11.9]

Imperfect policy conditions need further consideration. Many integrated assessment studies have focused on optimal scenarios for bioenergy deployment, notably assuming zero or close-to-zero GHG emissions of bioenergy use. This model characteristic is mostly introduced by assuming perfect global forest protection or a price on GHG emission from land sources, and ignoring climatic effects related to albedo and evaporation. While several studies investigate conditions involving considerable land carbon emissions, more research is needed to explore bioenergy deployment for climate change mitigation under imperfect policy conditions. [11.11]

Overall, bioenergy deployment offers significant potential for climate change mitigation, but also includes considerable risks *(medium confidence)*. In the IPCC’s Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) it was suggested that a sustainable bioenergy potential is no higher than 300EJ, but many studies suggest lower potential, depending on the assumptions taken Top-down scenarios project between 15-225 EJ/yr deployment in 2050. Sustainability and livelihood concerns might constrain beneficial deployment to lower values. Achieving such deployment levels would require, among other options, extensive use of agricultural residues and second-generation bioenergy to mitigate adverse impacts on land use and food production, and the co-processing of biomass with coal or natural gas with CCS to make low net GHG-emitting transportation fuels and / or electricity. Both mitigation potential and sustainability hinges crucially on land carbon (forest) protection, careful fertilizer application, interaction with food markets, and good land and water management. As noted, total livelihood effects require further evaluation. [11.9]

Barriers inhibit the broad implementation of some negative-cost mitigation options *(robust evidence, high agreement)*. The main categories of barriers to implementation of available mitigation options include economic, risk-related, institutional/political/bureaucratic, educational, cultural and logistical barriers. On the other hand, AFOLU mitigation options can promote innovation and many technological supply-side mitigation options also increase agricultural and silvicultural efficiency. Emphasis should be given to multifunctional systems that allow the delivery of multiple services from land. [11.8]

The sustainable management of agricultural, forested and other land is essential to achieving the estimated mitigation potential *(medium evidence, high agreement)*. There are important feedbacks to adaptation, conservation of natural resources such as water and terrestrial and aquatic biodiversity. There can be competition between different land-uses due to different motivations and objectives, but also potential for synergies, e.g. integrated systems or multi-functionality at landscape scale. Recent frameworks, such as those for assessing environmental or ecosystem services, provide tools for valuing the multiple synergies and trade-offs that may arise from mitigation actions. [11.6]

Policies governing practices in agriculture as well as forest conservation and management need to account for the needs of both mitigation and adaptation *(medium evidence, high agreement).* The implementation of REDD (Reducing Emissions from Deforestation and Forest Degradation) mechanisms and its variations that can represent a very cost-effective option for mitigation with high social and other environmental co-benefits (e.g. conservation of biodiversity and water resources). [11.10]

TS.4.7 Human Settlements and Infrastructures

Urbanization of the population and concomitant changes in consumption, lifestyles and physical structure of human settlements has shown a pronounced structural change over the last 100 years. In 1900, when the global population was 1.65 billion, only 13% of the population lived in urban areas. Today, more than half of the world population—about 3.6 billion—live in urban areas. By 2100, the urban population will increase to more than 9 billion, about 88% of the world population. [12.3]

Urban areas contributed considerably to global primary energy demand and energy-related CO_2 emissions in 2006, respectively *(high confidence)*. If emissions are allocated to the places where they are produced, then urban areas produce between 60 - 80% of global emissions. In contrast, consumption-based allocations show a few wealthy cities contributing to a majority of the emissions. The contribution of urban area to CO_2 emissions is estimated to increase to 76% by 2030. Regional variations are enormous; carbon emission from urban energy use amount to 85% in China, 80% in the USA, and 69% in Europe. [12.3]

The spatial form of how urban settlements develop — whether expansive or compact, with multifamily or single family homes, automobile dependent or transit-oriented development, with mixed- or single-use zoning — affects transportation choices and travel behaviour. There is also a growing body of scientific evidence that that urban land use changes have considerable impacts on climate by altering the cycling of water, carbon, aerosols, and nitrogen in the climate system. The urban built environment is a significant forcing function on the weather-climate system because it is a heat source, a poor storage system for water, an impediment to atmospheric motion, and a source of aerosols. [12.1]

There is path dependency with the built environment and infrastructure, which can "lock in" lifestyles and consumption patterns and limit mitigation options. Infrastructure is defined broadly as the provision of water, energy (including electricity), food, mobility/connectivity, waste management and built environment materials to a community as a whole (co-located homes, businesses and industries). [12.1]

TS.4.8 Co-benefits, risks and sustainable development

Climate policy decisions often lead to co-benefits and/or adverse side-effects for other societal objectives *(high confidence)***.** Limiting climate change is one of many economic, social, and environmental policy objectives. Mitigation objectives and options need thus to be assessed within a multi-objective framework in order to maximize synergistic effects and to avoid trade-offs with other policy objectives. This implies that policy design and implementation practices need to consider local priorities in order to create appropriate incentives. Since the relative importance of different goals differs among various stakeholders and may change over time, transparency on the multiple effects that accrue to different actors at different points of time is important. The possibility of harnessing near-term co-benefits of mitigation policies may increase the incentives for a global climate agreement. [3.5, 4.8, 6.6]

Many mitigation options result in co-benefits for air quality with significant short-term welfare gains *(high confidence)*. The most-recently-released Global Burden of Disease study indicates that household air pollution from solid fuels (caused mostly by the burning of biomass in traditional cook stoves) is responsible for between 2.7 and 4.5 million excess mortalities worldwide annually and now is seen as the fourth-largest risk factor globally in terms of disability-adjusted life. The range of the economic value of air quality co-benefits from climate change mitigation range from \$2/tCO_2 to \$196/tCO_2, with a mean of \$49/tCO_2, depending on diverse geographies, economic sectors, time horizons, and valuation techniques considered. Welfare gains from co-benefits tend to be higher in developing countries than industrialized countries due to higher pollution levels. Most energy supply and demand-side mitigation options show co-benefits for air quality, reducing the impacts on human health and ecosystems. [4.3, 6.6, 7.9, 8.7, 9.7, 10.8, 11.7]

Many mitigation options result in co-benefits for energy security *(medium confidence)***.** Mitigation options, such as renewable energy sources and energy efficiency, may cause reductions in global energy trade, and thus help reduce dependency on fossil fuel imports (see Table TS.5). Other mitigation options, such as CCS, however, reduce resource efficiency, and thus may have negative effects on energy security. The integrated assessment scenarios show that climate change mitigation may increase the diversity of energy sources used in the transport and electricity sectors (relative to today and to a baseline scenario in which fossil fuels remain dominant). These developments would make energy systems less vulnerable to various types of shocks and stresses. [6.6, 7.9, 8.7, 9.7]

Many mitigation options have adverse effects by increasing the cost of energy *(high confidence)*. Approximately 2.6 billion people worldwide (the poor, mostly in developing countries) do not have access to electricity and/or are dependent on traditional use of biomass – burnt in open fires or primitive cookstove designs with severe health implications. Increases in energy costs may impede reaching development objectives related to poverty, such as universal access to modern and clean energy and technologies. Design of climate policies will thus need to account for distributional effects and avoid adverse impacts for the affordability of energy for the impoverished parts of the population. [4.3, 6.6, 7.9, 9.8, 11.A.3, 15.7]

The effect of mitigation on water demand depends on technological choices *(high confidence)*. While the switch from a fossil fuel to renewable energy technologies like solar PV or wind can help reducing water use of the energy system, other renewables, such as hydropower, solar CSP, and especially bioenergy may contribute to an increase in water demand. [6.6, 7.9, 11.7]

There are incentives to adopt energy efficiency measures independent of their mitigation potential *(high confidence)*. In comparison to mitigation at the supply side, the literature documents a large number of co-benefits and a small number of risks for energy efficiency options. Local and sectoral employment gains and improved security of energy supply at the national level (e.g., resource efficiency, import dependency, exposure to energy price volatility) offer additional examples of robust co-benefits. Energy efficiency and conservation to reduce energy intensity (either through technological or structural/behavioural means) are the only general-purpose mitigation options that can lead to co-benefits in all sectors. An important barrier to the implementation of clean fuels and technologies (some of which are fundamental to societal well-being and sustainable development) is their limited availability to those households and firms which have restricted access to capital. [4.8, 6.6, 7.9, 8.7, 9.7, 10.8, 11.7]

Table TS.5. Main co-benefits and risks of selected mitigation options. The second column shows the contribution of the respective mitigation options to reach low stabilization targets. Ranges of baseline scenarios for the year 2050 are compared to the range in low stabilization scenarios (category 1). Co-benefits and risks are case- and site-specific, and depend on local circumstances as well as on the implementation practice [see Tables 7.4; 8.6.1; 9.6; 10.9; 11.9 and 11.A.2 in Chapters 7-11 and the Bioenergy Annex to Chapter 11]. The contribution of the mitigation options is thus not an indicator for the realized co-benefits or the magnitude of risks.

Mitigation options				**Non-climate objectives**			
Energy Supply	**Deployment[1]**		**Rate of change[1]**	**Economic**	**Social (including equity)**	**Environmental**	**Other**
	2010	***2050***					
Nuclear replacing coal power	10 EJ/yr	(8-24) *23-50* EJ/yr	(-0.5-2) *2-4* %/yr	Affordability (increases the cost of electricity generation) Energy security (import dependency)	Risk due to (unresolved) long-term waste disposal requirement Risk of large-scale accidents	Health and ecosystem benefits due to reduction of air pollution and mining accidents	Proliferation risk
RES (Wind, PV, CSP, hydro, geothermal, biomass) replacing fossil fuels	62 EJ/yr	(60-131) *166-270* EJ/yr	(0-2) *2.7-3.8* %/yr	Affordability (increases in many cases the cost of electricity generation) Energy security (import dependency)	Local employment and value added at the place of deployment Contribution to (off-grid) energy access and technology transfer to rural areas Risk of conflicts about the siting of plants (mainly wind and hydro) Noise (mainly wind) Displacement (hydro) Risk of food security and interference with subsistence farming (biomass, see AFOLU)	Health and ecosystem benefits due to reduction of most forms of air pollution (excluding biomass) and mining accidents Biomass: water security risk and other ecological impacts, e.g., biodiversity, soil quality etc. (see also AFOLU) Wind: impact on landscape, low water requirements PV: low water requirement Hydro: Risk of loss of habitat and other ecological impacts CSP & hydro: high water consumption Geothermal: water use and pollution	Supply from variable RES requires extra measures to match demand Higher material requirements (e.g. supply of rare earths)
Fossil CCS replacing coal	0 $GtCO_2$ stored	(0-0) *4-10* $GtCO_2$ stored	(0-0) *NA* %/yr	Affordability (increases the cost of electricity generation) Energy security (import dependency, resource efficiency) Possibly less controllable power output (but possibly better compared to variable and unpredictable RES)	Preserves fossil industry jobs, infrastructure and investments Risk of conflicts about the siting of storage facilities and transport pipelines Concern about risk of CO_2 leakage Lock-in effect	Environmental risk of CO_2 leakage Increase of upstream environmental risks due to higher fuel use	
BECCS replacing coal power	0 $GtCO_2$ stored	(0-0) *0-5* $GtCO_2$ stored	(0-0) *NA* %/yr	*See fossil CCS.*	*See fossil CCS. For possible upstream effect of biomass supply, see biomass supply and AFOLU*	*See fossil CCS. For possible upstream effect of biomass supply, see biomass supply and AFOLU*	Innovation risk because feasibility not yet established
Fugitive methane capture and use or treatment	NA	NA	NA	Energy security (potential to use gas in some cases)	Improved occupational safety at coal mines	Health benefits due to reduction of hydrocarbon emissions and hence summer smog	

Transport	**GHG Mitigation & Demand Reduction Potential**	*For possible upstream effects of low-carbon electricity, see energy supply. For possible upstream effects of biomass supply, see biomass supply and AFOLU.*			
Reduction of fuel carbon intensity: e.g. by electrification, biofuels, CNG and other measures	*Scenario ranges for the whole sector:* 1) carbon intensity in the transport sector 2010: 71 gCO_2/MJ BL (2050): 61-67 gCO_2/MJ Cat 1 (2050): 37-53 gCO_2/MJ 2) final energy demand in the transport sector 2010: 93 EJ High (2050): 147-262 EJ Low (2050): 55-132 EJ	Affordability (may increase or reduce costs for consumers and businesses) Energy security (reduction of oil dependency)	Lower exposure to oil price volatility risks Noise reduction (for electrification and fuel cells)	Electrification, hydrogen: Health and ecosystem benefits due to potential large reductions of local urban air pollution in many key pollutants CNG, biofuels: Health and ecosystem benefits are uncertain	Resource risk (e.g. limited supply of battery or fuel cell material inputs, infrastructure for hazardous wastes disposal)
Reduction of energy intensity		Affordability for businesses Energy security (reduction of oil dependency)	Improved transport affordability for households (lower travel costs for the consumer in most cases due to improved engine and vehicle performance efficiency)	Health and ecosystem benefits due to reduced urban air pollution.	
Improve urban form and infrastructure Modal shifts (e.g. from private to public or non-motorized transport)		Improved productivity due to reduced urban congestion and travel times across all modes Energy security (reduction of oil dependency)	More equitable mobility access and safety, particularly in DCs Potentially reduced risks of accidents by provision of safer transport (mainly modal shift) and infrastructure for pedestrians and cyclists	Health and ecosystem benefits due to (i) reduced urban air pollution and (ii) reduced exposures to air pollution Health benefits from shifts to active transport modes	
Journey reduction and avoidance		Affordability (lower fuel and travel costs for the consumer) Improved productivity due to reduced urban congestion and travel times Energy security (reduction of oil dependency)	Improved access and mobility	Reduced land use from transport infrastructure Potential risk of damages to vulnerable ecosystems from shifts to new and shorter routes Health and ecosystem benefits due to reduced urban air pollution	
Buildings	**GHG Mitigation & Demand Reduction Potential**	*For possible upstream effects of fuel switching and RES, see energy supply.*			
Fuel switching, RES incorporation, green roofs, and other measures reducing CI of buildings sector	*Scenario ranges for the whole sector:* 1) carbon intensity in the buildings sector 2010: 29 gCO_2/MJ BL (2050): 20-26 gCO_2/MJ Cat 1 (2050): 10-18 gCO_2/MJ	Affordability (increases in most cases the cost of energy for the consumer) Net employment gains Lower need for energy subsidies Enhanced asset values of buildings	Fuel poverty alleviation in some cases (in residential buildings) Lower exposure to energy price volatility risks Increased productive time for women and children (for switch to non-traditional cooking fuels in residential buildings in DCs)	Health benefits due to: (i) reduced outdoor air pollution, (ii) reduced indoor air pollution (in residential buildings in DCs), and (iii) fuel poverty alleviation (in residential buildings) Reduction of the heat island effect (in cities)	
Efficient equipment Retrofits of existing buildings (e.g. cool		Affordability (reduces in most cases the cost of energy for the consumer) Net employment gains	Fuel poverty alleviation in most cases (for retrofits of residential buildings and efficient equipment) Increased comfort (for new buildings	Health benefits due to: (i) reduced outdoor air pollution, (ii) improved indoor environmental conditions and reduced indoor air pollution (in residential buildings in DCs) (iii) lower indoor infectious disease spread rates (due	

roof, passive solar, etc.) Exemplary new buildings	2) final energy demand in the buildings sector 2010: 113 EJ High (2050): 195-291 EJ Low (2050): 93-159 EJ	Energy security (resource efficiency, power grid reliability, reduction of peak power demand, shifting demand to off-peak periods) Improved productivity (in commercial buildings) Lower need for energy subsidies Enhanced asset values of buildings (for exemplary new buildings and retrofits)	and retrofits) Lower exposure to energy price volatility risks Increased productive time for women and children (for replaced traditional cookstoves in residential buildings in DCs)	to better ventilation), and (iv) fuel poverty alleviation (in residential buildings) Reduced impacts on ecosystems, cultivations, materials, etc. Reduced water consumption and sewage production Reduction of the heat island effect (for retrofits &new buildings in cities)	
Behavioural changes reducing energy demand		Energy security (resource efficiency) Lower need for energy subsidies	Lower exposure to energy price volatility risks	Health benefits due to: (i) reduced outdoor air pollution, and (ii) improved indoor environmental conditions Reduced impacts on ecosystems, cultivations, materials, etc.	
Industry	**GHG Mitigation & Demand Reduction Potential**	*For possible upstream effects of low-carbon energy supply (incl CCS), see energy supply. For possible upstream effects of biomass supply, see biomass supply and AFOLU.*			
Reduction of energy intensity through new industrial processes and technologies	*Scenario ranges for the whole sector:* 1) carbon intensity in the industry sector 2010: 57 gCO_2/MJ BL (2050): 51-61 gCO_2/MJ Cat 1 (2050): 13-31 gCO_2/MJ 2) final energy demand in the industry sector 2010: 137 EJ High (2050): 72-204 EJ Low (2050): 216-355 EJ	Affordability (may increase or reduce costs for the consumer) Reduce energy input costs for businesses Energy security (resource efficiency, power grid reliability)	Improved energy access	Reduction of local pollution and associated positive impacts on biodiversity Reduction of water use (e.g. for new cement and pulp and paper production technologies)	Innovation risk because feasibility of some technologies not yet established (particularly for SMEs)
Material efficiency of goods, recycling, and product demand reductions		Affordability (reduces costs for the consumer due to longer life of products) Reduction of societal costs of waste disposal Reduction in production costs (for businesses) Reduction in national sales tax revenue in medium term (for product demand reduction and material efficiency)	Reduced threat of displacement from reduced demand for landfill sites Job creation in formal recycling market (potentially for poor in informal waste recycling market) and the service sector Potential short-term reduction in employment (for product demand reduction)	Reduction of local pollution and wastes(e.g. due to low post-consumption waste) Less use of virgin materials/natural resources Health benefits due to reduction of supply-chain accidents Reduced competing demand for land	Innovation risk because feasibility of some technologies not yet established (particularly for SMEs)

AFOLU	**GHG Mitigation Potential**				
Conservation of existing carbon pools and avoiding emissions (avoided deforestation; agricultural methane/nitrous oxide emissions reductions)	*Scenario ranges for the whole sector:* 1) carbon intensity ranges in 2030 and 2050 (Baselines compared to Category I scenarios)	New source of income for landowners through payment for ecosystem services (PES) or other transfers (for avoided/reduced deforestation (REDD+)) Transaction costs and costs of monitoring and evaluation Increased efficiency of feed conversion and fertilizer use (for CH_4/N_2O emissions reduction)	Food security due to reduced flexibility of land-use (e.g. for agricultural expansion in case of avoided/reduced deforestation(REDD+)) Food security (for CH_4 emissions reduction) Protection of cultural habitats and recreational areas (for avoided/reduced deforestation) Use of traditional practices and improved animal welfare (for CH_4 emissions reduction)	Ecosystem benefits (water and biodiversity) due to forest conservation, reduced water pollution (for N_2O emissions reduction) More efficient agriculture can increase or decrease pressure for forest conversion→ biodiversity loss /biodiversity conservation	Improvement or diminishing of tenure and property rights at the local level (for indigenous people and local communities) Access to participative agreements
Increase of existing carbon pools (Afforestation/reforestation & additional activities (cropland, forest, & grazing land management, revegetation)		Reduced flexibility of land-use once projects are validated. Diversified sources of income and access to new markets	Competition with other land-uses, food production and water Job creation through new enterprises	Opportunity to use sequestration projects to protect and restore watersheds and other landscapes→ water and biodiversity Competition with water supplies in some instances Monocultures reduce biodiversity Positive impacts on albedo and evaporation	Promote clarification of land tenure Promote participative schemes Concentration on decision making → marginalization of land users
Substitution of biological products for fossil fuels (bioenergy, harvested wood products, etc.)		Diversified sources of income and access to new markets	Can promote forest conversion → biodiversity loss Competition with other land-uses → reduced food production and/or water availability Job creation through new enterprises	Management of watersheds (nutrients, water) → water and biodiversity Environmental damage due to increased use of fertilizers or increased leakage → biodiversity loss, reduced water quality	Promote participative schemes Concentration on decision making → marginalization of land users

1) Scenario ranges for stabilization scenarios of category 1 (italics), and baseline scenarios (in parentheses). Ranges correspond to the interquartile of the distribution from stabilization scenarios assuming a full portfolio with stylized immediate action policy assumptions (P1)

TS.5 Institutional options by governance level

After providing information on human decision-making under uncertainty and risk, this Section assesses the literature on institutional options that policymakers can employ to encourage mitigation efforts at the international, national and sub-national governance levels. Climate policy is heterogeneous, involving many types of choices by many actors operating in many social contexts. The factors influencing policy decisions—and the most relevant risks and uncertainties—differ across the range of actors, contexts and choices (Figure TS.24.). A decision that involves setting a *climate change target* probably requires international cooperation at the global level. In contrast, *livelihood and lifestyle* decisions are made at the household or individual level. Decisions made at one level will influence decisions made at others. For example, an agreement on a climate change target by the international community might necessitate actions by sovereign states, in turn influencing the actions of firms, households, and individuals. Likewise, actions made by private actors, perhaps responding not to climate policy but rather to changes in technologies or values, could influence the relative attractiveness or even necessity of climate policy responses by governments.

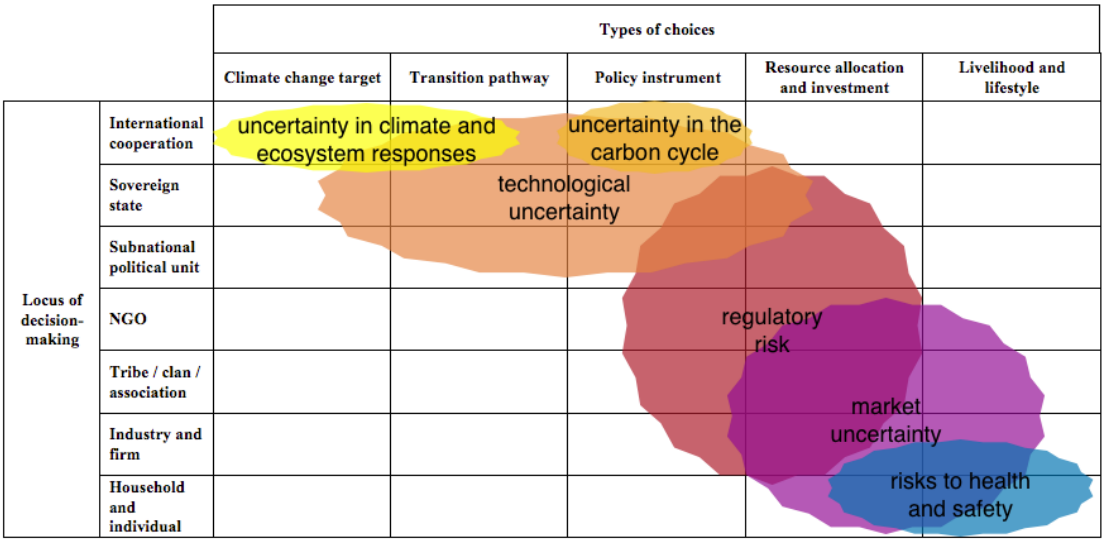


Figure TS.24. Types of climate policy choices (columns) and loci of decision-making (rows). Superimposed on the matrix are uncertainties that the literature has identified as influencing choices. [Table 2.1]

TS.5.1 Human decision-making

The success of climate policy depends on how people perceive and respond to climate and other risks in their choice context *(medium evidence, high agreement)*. Awareness of the factors that drive these perceptions can enrich expert assessments to reflect when (and how) key decision-makers are likely to respond to climate with respect to their choices of what actions to take or policies to pursue. Individuals, small groups and organizations often do not make decisions in the analytic or rational way envisioned by standard models of choice in the economics and management science literature. Risks frequently are perceived in ways that differ from expert judgments, which poses challenges for climate risk communications and response. For example, risks that are seen as proximate usually inspire greater concern and response than those that are more distant in time or geographical impact. Judging climate change from personal experience with local weather events such as unusually cold winters or severe losses from hurricanes or floods can easily distort risk judgments. An understanding of behavioural responses to risk and uncertainty can suggest ways of reframing the climate change issue. In this sense communication of uncertainty is a critical component of risk management. [2.2]

Humans typically manage complexity by relying on past experiences, expectations, beliefs, and goals *(robust evidence, high agreement)*. Decisions made in this way often lead to reasonable outcomes and require much less time and effort than a more detailed analysis of the trade-offs between options. However, this approach of relying on such simplifying processes and heuristics is least effective for choices that have probabilistic outcomes involving rare events and long-time horizons—a situation that is omnipresent for the policy choices surrounding climate change. There are a variety of decision tools and methodologies for informing choices by individuals, firms, public sector organizations and sovereign states when probabilities and/or outcomes are uncertain. These tools encompass expected utility theory, the use of IAMs in combination with cost-benefit and cost-effectiveness analysis, adaptive management, robust decision making and uncertainty analysis techniques such as structured expert judgment and scenario analysis. [2.2, 2.3, 3.7]

There is status-quo bias in human response to uncertainty and change. It is common for individuals, societies, and industries to defer action and postpone taking on new costs or altering established preferences. Psychological mechanisms giving rise to this tendency to reject change, sometimes referred to as status-quo bias, include risk-, ambiguity-, and loss-aversion. Education and incentives are two traditional categories of intervention, with incentives having two subclasses, positive inducements for responsible behaviour and negative deterrents to not making responsible choices. More recently, new theory in behavioural economics and psychology has provided a third class of strategies or tactics, namely choice architecture interventions that describe or present action alternatives in ways that minimize status-quo biases. [2.2, 2.4]

Whereby earlier events and experiences pattern human responses to new stimuli, path-dependence in responses to uncertainty and change can affect mitigation potentials. Partly as a consequence of adaptive expectations (i.e., agents observe the past and form expectations about the future on the basis of the past) and partly because of path-dependency (infrastructure lock-in and technology learning factors) mitigation options may underperform. The decisions undertaken today by an agent are strongly influenced, through adaptive expectations, social norms and other processes, by past choices made by other agents in the population, and this in turn influences future choices of others. [5.6]

Additional research is needed on interactions and nonlinearity in human responses (rebound and ripple effects). New technology that reduces use of fossil fuel (efficiency or renewable/nuclear energy) does not necessarily lead to a proportional reduction of CO_2 emissions, due to a number of mechanisms. Negative feedback that reduces the emission reduction from expected levels is sometimes collectively referred to as rebound effects including: (a) In response to lower energy service costs due to efficiency gains, the energy service demand is increased or other energy services are consumed from the saved money. (b) Fossil fuel prices are reduced due to reduced fossil fuel demand, leading to new uses or wider access to potential users that were economically excluded. (c) Efficiency and new resources contribute to economic growth, stimulating further energy demand. Rebound effects can be mitigated through energy/emissions pricing and studies have shown them to decrease energy savings by 5-50% of the technically possible levels, except in cases of extreme energy poverty where the rebound can be more than 100%. Positive feedback that increases the emission reduction from expected levels is referred to as ripple effects: Energy efficiency and non-fossil technologies enable new climate mitigation opportunities, such as hydrogen, fuel cells, and passive houses, which can lead to sometimes substantial welfare gains. Ripple effects have not been systematically investigated and the literature does not converge on their importance. In addition to these economical and technological reasons for positive or negative feedback effects, there are also psychological rebound and ripple effects, but neither one is well understood.

Research is also needed on social creativity and new behavioural attitudes that may create new socio-economic conditions and niches of innovation that can spread or enhance the mitigation potential. An open-ended search for dynamically changing transitions and ongoing innovation in services and technology may generate new openness to climate change mitigation. However such change may also increase the complexity of interactions among actors, possibly impacting the acceptability of policies and technologies offering choices that contrast with accepted mainstream cultural consumer choices. Favouring continuous learning particularly of actions linking self-regulation with social and economic improvement can be critical to mitigation. Decisions may influence subsequent decisions as routines get set, available options change as markets react and demand drives supply, and the choice of others gains traction (through social imitation), thus leading to a gradual transition of the larger and complex energy system over time. Therefore, repeated interactions among simple agents might give rise to changes in behaviour at the individual and in communities, societies, and institutions (commercial and governance), but these dynamics are not well understood.

TS.5.2 International and regional cooperation

Climate change can be framed as a global commons problem because GHG emissions from any source mix globally in the atmosphere and have global impacts. Therefore, the atmosphere is overused as a disposal space for GHGs. In addition, given that GHGs mix globally, climate change mitigation through GHG emissions reduction, enhancement of sinks yields benefits from which no individual or institution (e.g., government) on Earth can be excluded. This public good character of climate change mitigation creates incentives for actors to “free ride” on other actors’ efforts. Hence, if “free riding” occurs, those who compromise bear a larger fraction of the policy costs than the rest. [13.2]

Adaptation funding can provide effective incentives for international cooperation. The difference between the nature of mitigation and adaptation policies is related to their public good characteristics. In contrast to mitigation, benefits of adaptation are often local. Hence, the main issue regarding adaptation is not to commit countries to adapt (since they will perceive fully their benefits), but to commit international funds to help doing so. At the same time, financing for locally important adaptation may offer fewer reciprocal benefits to the funding country than would finance mitigation. The incentives for international participation in adaptation efforts may thus depend on the particular settings and types of measures being considered. Some studies indicate that adaptation reduces the marginal benefits from mitigation measures, and vice versa. Other studies find that the joint provision of mitigation and adaptation is welfare improving. [WG II; 13.3, 13.10]

Geo-engineering options have an inconclusive impact on the incentives for international cooperation. Some studies have shown that Solar Radiation Management (SRM) strategies imply, as climate change impacts, regional asymmetries that would create benefits to some regions and costs to others. But, if as a consequence, if a group of countries decided investment on SRM, the resulting benefits would be excludable (which is not the same as for mitigation, whose benefits are common to all). Hence, the governance implications of this particular characteristic of SRM are particularly challenging since some countries may perceive advantages to be first-movers with SRM. Such unilateral action, however, might produce significant costs for others. Thus, some studies recommend that international governance be organized for SRM research and testing, to develop institutions to decide when to deploy them, how to maintain their capability, or to monitor and evaluate this research and its use. Nevertheless, several studies emphasize that SRM is not an alternative to emissions reductions, and that any agreements that might enable SRM would have to also continue to focus on emissions reductions. [13.2, 13.4.]

Numerous existing and proposed approaches to international cooperation could facilitate progress on climate change mitigation. A notable change since AR4 is that the number of climate policy approaches has increased. These approaches vary along several dimensions, including the degree to which they are centrally organized and managed (Figure TS.25). At one end of the spectrum is strong multilateralism, whereby countries and regions agree to a high degree of mutually binding rules or standards to guide their actions--for example, fixed targets and timetables for emission reductions. The Kyoto Protocol is an example of such an approach. A less-centralized approach would structure international cooperation around harmonized national policies, where national or regional policies are made compatible through, for example, harmonized carbon taxes, cap and trade schemes, or standards. Finally, at the other end of the spectrum of international cooperation, decentralized architectures may arise out of heterogeneous regional, national, and sub-national policies, which may vary in the extent to which they are internationally linked. [13.4]

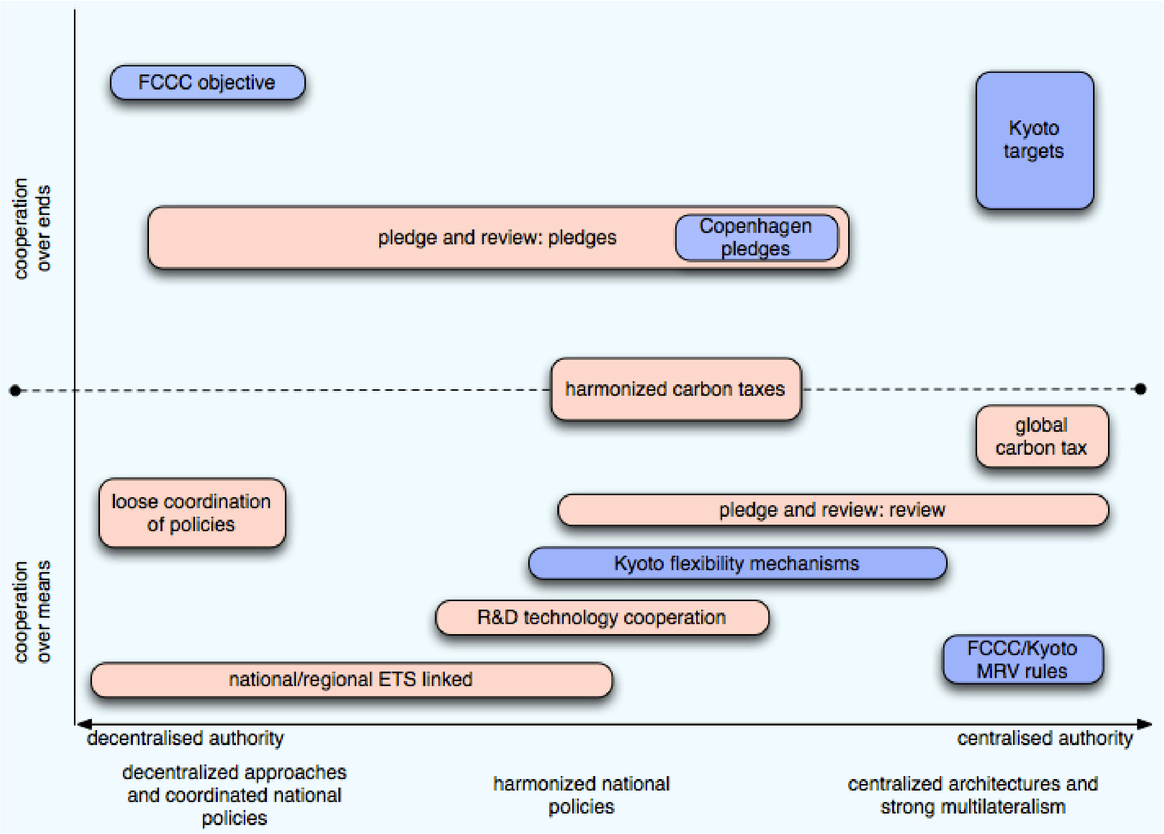


Figure TS.25. Degrees of centralized authority of existing (blue) and proposed (pink) approaches to international cooperation. [Figure 13.2]

Many interactions exist between climate change and other policies. In that sense, technology-oriented agreements may improve incentives for international cooperation. Agreements could cover activities for knowledge sharing, coordinated or joint research, technology transfer, and technology deployment policies. By lowering the cost of environmentally sound technologies relative to climate-damaging technologies, appropriate technology policies can increase incentives for countries to comply with international climate obligations. [13.9, 14.4]

Trade policy is also closely related to climate policy. However, there is no conclusive evidence regarding the impact of trade measures on the incentives for international climate cooperation. There are numerous and diverse unexplored opportunities for greater international cooperation in trade-climate policy interactions. While mutually destructive conflicts between the two systems have thus far been largely avoided, pre-emptive cooperation could protect against such developments in the future. Whether such cooperative arrangements can be most effectively devised within the existing institutional architectures for trade and for climate change or through new architectures is an open issue. [13.8, 14.2]

Current mitigation finance is estimated at USD 350 billion (2010/11 USD) per year using a mix of 2010 and 2011 data *(limited evidence, medium agreement)*. Governance of investment and finance for climate change mitigation and adaptation are also important foci of international climate negotiations. Availability of carbon funds can induce participation and compliance in international agreements. The estimate is based on a mix of instruments and a variety of sources and intermediaries. It covers full investment in mitigation measures, such as renewable energy power plants. Of the total, developing countries raised USD 120-41 billion of which 34-41% were public funds. Developed countries raised USD 213-255 billion including 17-23% from public sources. [16.2]

Climate finance reported under the UNFCCC accounts for less than 3% of current climate finance and about 15-25% of the public international climate finance flows to developing countries *(medium evidence, medium agreement)*. Annex II countries reported on an average of less than USD 10 billion per year from 2005-2010. From 2010- 2012, developed countries committed USD 28 billion (2012 USD) in Fast Start Finance. [16.2]

The private sector plays a central role in investing in low-carbon projects in industrialized and developing countries *(medium evidence, high agreement)*. Its contribution is estimated at USD 250-285 billion in 2010/2011, which represents around 75% of overall mitigation finance (2010/2011 USD). At present, a large share of private sector climate investments relies on low-interest and long-term loans as well as partial risk guarantees provided by public sector institutions to cover the incremental costs and risks of many mitigation investments. [13.12, 16.2]

There are important complementarities and trade-offs between financing mitigation and adaptation *(medium evidence, medium agreement).* Available estimates show that adaptation projects presently get only a minor fraction of international climate finance. However, economic analysis currently does not provide conclusive results on the most efficient temporal distribution of funding on adaptation vis-à-vis mitigation. Given that optimal balance of mitigation and adaptation actions and investments depends on the uncertain magnitude and pathways of climate change, it is important to emphasize that neither mitigation nor adaptation should be delayed. [13.11, 16.6]

The performance of existing international policies and institutions is mixed (Table TS.6). In the case of environmental effectiveness, assessments have examined the performance of the Kyoto Protocol and its market mechanisms. Significant emission reductions have taken place in Annex I countries, though relative reductions have been greater in economies in transition, where they were the result of economic factors, as well as the Kyoto Protocol. Overall, the Kyoto mechanisms, particularly the CDM, have demonstrated the institutional feasibility of carbon markets on a large scale, have contributed to reducing aggregate mitigation costs, and started to set a global price signal. Further, agreements inside and outside of the UNFCCC have been assessed, including the Major Economies Forum for Energy and Climate, the G20, and voluntary carbon markets; their performance remains unclear due to a lack of concrete action to date, with the exception of the Montreal Protocol—and the voluntary market to a smaller extent. Performance assessments of proposed architectures have included assessments of examples of strong multilateralism, harmonized national policies, and decentralized architectures and coordinated national policies. [13.13]

Table TS.6. Performance assessment of existing international cooperation. [Table 13.4]

Policy		Assessment Criteria			
		Environmental Effectiveness	Aggregate Economic Performance	Distributional Impacts	Institutional Feasibility
Kyoto Protocol		Emission targets for Annex I countries only. Reductions occurred in countries in transition, but emissions increased in others due to surplus emissions allowances. Incomplete participation and non-compliance among Annex I countries. Not sufficient to reach 2°C.	Cost-effectiveness improved by flexible mechanisms and allowing for countries to choose policies to meet commitments. Efficiency subject to assumptions of discount rate and degree of participation, and evaluation of mitigation benefits and costs.	Commitments are progressive, but dichotomous distinction correlates only partly with historical emissions and evolving economic circumstances. Intertemporal equity affected by short term actions.	Ratified (or equivalent) by more than 190 countries. High participation partially due to recognition of responsibility, domestic sovereignty, limited efforts for developing countries, and flexible mechanisms.
Kyoto Mechanisms		1.15 billion tCO_2eq credits under the CDM, 0.6 billion under JI and 0.2 billion under IET. Additionality of CDM projects remains an issue but attempts at regulatory reform underway.	CDM mobilized low cost options, particularly industrial gases, reducing costs. Underperformance of some project types. Some evidence that technology is transferred to non-Annex I countries.	Limited direct investment from Annex I countries. Domestic investment dominates, leading to concentration of CDM projects in few countries. Limited contributions to local sustainable development.	Helped enable political feasibility of Kyoto Protocol. Has multi-layered governance. Largest carbon markets to date. Has built institutional capacity in developing countries.
Further Agreements under UNFCCC		Pledges made by all major emitters under Cancun Agreements, but unlikely sufficient to reach 2°C. Depends on treatment of measures beyond current pledges for mitigation and finance.	Efficiency not assessed. Cost-effectiveness might be improved by market-based policy instruments, inclusion of forestry sector, commitments by more nations than Annex I countries.	Depends on sources of financing, particularly for actions of developing countries.	COP decision; 80 countries agreed to emission targets or actions for 2020.
Agreements outside UNFCCC	G8, G20, MEF	May stimulate CO_2 reductions by phase out of fossil fuel subsidies, but implementation unknown. Otherwise not assessed.	Potential efficiency gains through subsidy removal. Too early to assess economic performance empirically.	Has not mobilized climate finance. Removing fuel subsidies would be progressive but have negative effects on oil-exporting countries.	Lower participation of countries than UNFCCC, yet covers 80% of global emissions. Opens possibility for forum-shopping of issues.
	Montreal Protocol	Stimulated emission reductions through ODS phase outs 5-6 times the magnitude of Kyoto FCP targets. Contribution may be negated by high-GWP substitutes.	[No literature cited.]	[No literature cited.]	Universal participation with different timing of phase-out.
	Voluntary Carbon Market	Covers 0.1 billion tCO_2eq, but certification remains an issue	Credit prices are heterogeneous, indicating market inefficiencies	[No literature cited.]	Fragmented and non-transparent market.

The institutional feasibility of international climate policies depends on agreement among national governments and so there is a two way link to domestic policies. On one side, international climate policy can shape domestic climate discourse. While, on the other side, domestic feasibility acts as a constraint for international agreements. Linkages among regional, national, and sub-national programs may complement international cooperation. While policy linkage can take several forms, linkage through carbon markets (Figure TS.26) has been the primary means of regional policy linkage due to the greater opportunities for trade as carbon markets expand. Such forms of regional agreements could then, in principle, form building blocks for greater global cooperation by linking these efforts across regions. The benefits of policy linkage may include lower mitigation costs, decreased emission leakage, increased credibility of market signals, and increased liquidity due to expanded market size. Linking national policies with international policies may also provide flexibility by allowing a group of parties to meet emissions reduction obligations in the aggregate. However, policy linkage may also increase transaction costs and raise the concern that the linked policies will be diluted (as enforcement in linked systems is only as stringent as the weakest among them), and that countries may be unwilling to accept an increase in mitigation costs that could result from linking with a more ambitious system. In the EU, although the EU Emissions Trading System has been successful as an instrument, cooperation has so far not been as successful as anticipated ; this is related to problems in the setting of targets of these measures, design issues, unanticipated economic events, new developments in the energy sector, and unanticipated interactions between policies. [13.6, 13.7, 14.4]

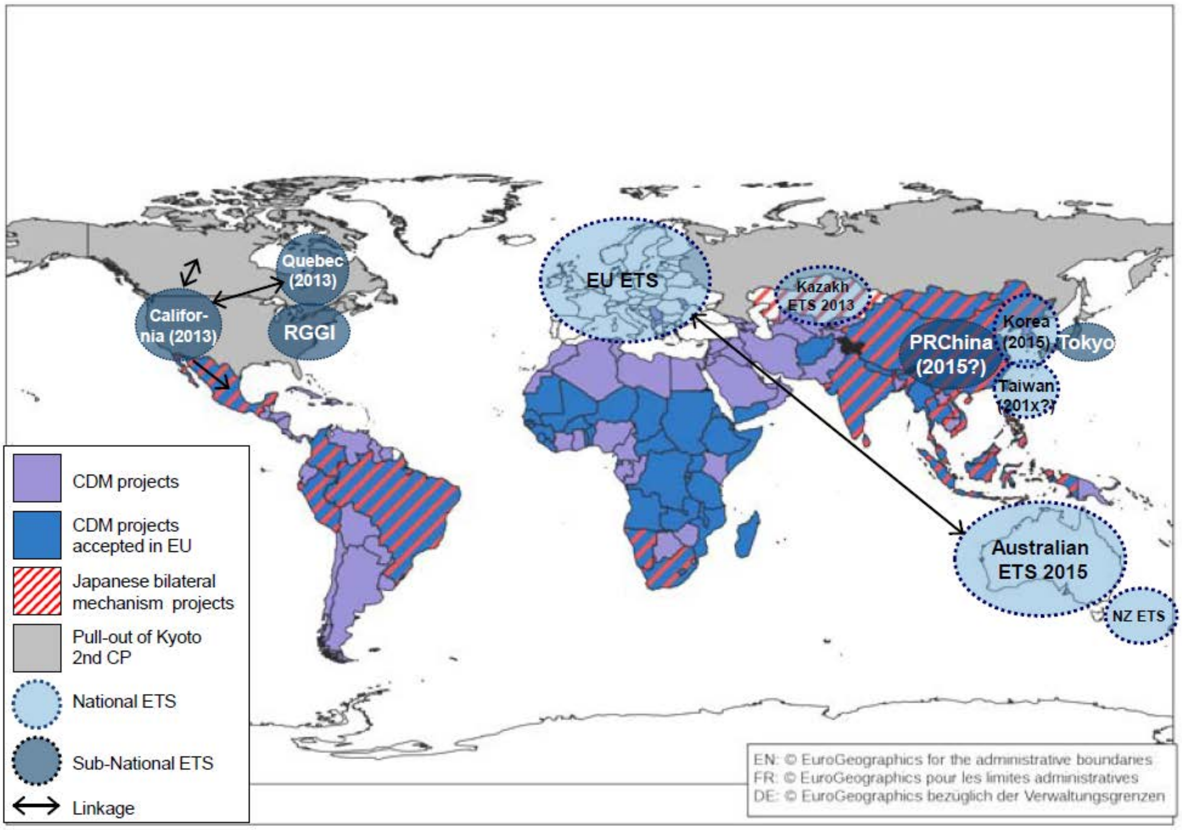


Figure TS.26. Cap and trade schemes with existing linkages. [Figure 13.3]

Interaction of the EU ETS with other mitigation policies impede policy performance. Tradable permit policies, unlike taxes and other policies, cancel the emission reduction of other policies within the capped sectors. (In case the other policies are more stringent, a tradable permit policy is rendered redundant with the carbon price being driven to zero.) For example, the additional emission reduction from carbon taxes in the UK may be offset by increased emission in the rest of the EU due to the EU ETS, and this may be true of many other national and subnational policies in the EU. One possible way of addressing this problem in cap-and-trade schemes is to create an institutional mechanism to tighten the cap in response to other policies so that their effects are not offset by permit trading. [14.4, 15.7]

TS.5.3 National and sub-national policies

There is no best policy for mitigating climate change *(high confidence)*. Different policies play different roles, typically to 1) provide a price signal; 2) remove barriers; or 3) promote long-term investments. A combination of policies that addresses all three roles (detailed in Table TS.7) is most effective. Policies should be designed and adjusted so as to complement rather than substitute for other policies in the same and other jurisdictions. Appropriate designs depend on national and local circumstances and institutional capacity. These categories are complementary when policy packages are designed to take advantage of synergies and avoid negative interactions. If there is no coordination within an integrated perspective then results in one area may be undone by results in another area for instance through the rebound effect. [15.5, 15.6, 15.8]

The institutional environment of each setting constrains policy choices. Countries that lack market institutions and security of property rights cannot in any obvious way enjoy all the efficiency benefits associated with economic instruments. Similarly optimal policy design in an economy with a high degree of concentration will involve some modification in instrument design. Also the degree of openness, the scale, and the maturity of institutions are important. [15.2]

The factors influencing the actions of market actors—including firms, households, and individuals—are numerous and often poorly understood; and yet their relative importance can dictate the degree to which policy-driven changes in one factor, such as the price signal, results in behavioural change *(high confidence)*. Individuals, operating as decision-makers for households and for firms, often display myopic behaviour, ignoring particular sets of outcomes of their decisions. They exhibit non-linear behavioural responses to changes in the assessed likelihood or magnitude of assessed risks. They place disproportionate emphasis on some risks based on psychological factors such as dread or feelings of control. All of these factors make their responses to climate policy instruments difficult to predict, and in many cases have been found to account for differences between theory-driven prediction and ex-post observations of policy effectiveness. [2.2, 2.4]

The extent to which policy instruments introduce or manage regulatory risk differs, and this has an effect on their effectiveness and efficiency *(high confidence).* Many market instruments, such as carbon taxes and tradable permits, create an incentive for low-carbon investment by influencing actors' expectations of long-term operating costs, and yet a number of factors can render these expectations, in response to the policy, highly uncertain. The effect of this uncertainty in most cases is to reduce the extent of behavioural change in response to the magnitude of the carbon price signal. Some subsidy instruments, such as investment tax credits, do not alter long-term expectations, but create an immediate incentive to shift investments. Other subsidy instruments, such as feed-in tariffs, have the effect of stabilizing long-term expectations, a feature that has been found to stimulate the level of investment relative to the magnitude of the subsidy. [2.4]

Table TS.7. Three roles of climate policy instruments. [Table 15.1]

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

The use of economic instruments is not always sufficient to encourage mitigation by firms and individuals because their behaviour is often hampered by "barriers" such as the costs of acquiring and processing information. A range of barrier-removal policies for energy efficiency improvement including regulations, information measures, energy management systems, energy audits and so forth, often bring about energy efficiency improvement and greenhouse gas emission cuts at negative to low cost to society when assessed at individual policy instrument level. [15.5]

Instruments that promote long-term investment are an essential part of an adequate policy mix *(high confidence)*. The main reason for this is that there are other market failures in addition to the failure to internalize damages from GHGs. One additional failure is that of the market for protection of intellectual property rights (for example the patent market). As a result, private investments in research and development (R&D) of low-carbon technologies and energy efficiency technologies often are lower than socially optimal. In other contexts, technology policy can extent beyond R&D activities to the support of commercialization and technology transfer. [15.6, 13.9]

Elimination or reduction of subsidies for fossil energy can result in major emission reductions at negative cost. In most countries (particularly low and middle-income countries), carbon and fuel taxes are progressive or neutral with the rich paying an equal or greater proportion of their income than the poor. Kerosene in low-income countries is an exception, with taxation being regressive. [15.5]

Rebound effects can offset some of the emission reductions from energy efficiency improvements. Direct rebound effects are in the range of 10-30% of projected technical energy savings in developed countries. Direct rebound effects will tend to be greater in developing economies and also appear to be more significant in the productive sectors of economy, where direct rebound may range from 20-60% or higher, particularly for energy intensive sectors where energy services are easily substituted for other factors of production. Some argue that macro-economic rebound effects are larger and can exceed 100% (called backfire) in some cases *(limited evidence, low agreement).* [5.6, 15.5]

National policies often have the effect of favouring particular technologies or technological pathways; yet many technologies have been met with substantial public opposition, based on the perceived risks to health and welfare that they create. Nuclear power is the most visible example of a low-carbon technology that has engendered high levels of public opposition in proportion to demonstrated risk levels, but wind turbines, high-voltage power lines, and carbon dioxide transport and storage facilities have all elicited similar reactions, with substantial effects on the pace of investment. A number of factors have been found to influence levels of public support or opposition, including the transparency of permitting processes, degree of local ownership and control, and national political culture *(very high confidence)*. [2.4]

IPCC reports are addressed to governments; however some have argued that each individual has an ethical duty to play a part in a collective effort to mitigate climate change. Some private individuals take climate change into account in their decision-making which raises the question of private ethical duties with respect to climate change. First, many individuals have a civic duty to influence their governments and support them when they act rightly. Voting is one influence they have. Moreover, by reducing her carbon footprint, a person can demonstrate that she is willing to make sacrifices in order to reduce emissions, which may induce others to follow suit and may encourage her government to take more effective action. Second, since emissions of GHG do harm, it seems that an individual does harm to others by her own emissions. Some argue that harming others for one’s own benefit is unjust except in certain special circumstances. Should such emissions be unjust, then it may be argued that each individual has an ethical duty not to emit GHG. Some philosophers deny that an individual’s emissions always do harm. Indeed, even after a pollutant has been strictly regulated, typically emissions still occur and most economists would argue that such Pareto-irrelevant externalities are justified. [3.2]