

4.1 Responding to climate change

Societies can respond to climate change by adapting to its impacts and by reducing GHG emissions (mitigation), thereby reducing the rate and magnitude of change. This Topic focuses on adaptation and mitigation options that can be implemented over the next two to three decades, and their inter-relationship with sustainable development. These responses can be complementary. Topic 5 addresses their complementary roles on a more conceptual basis over a longer timeframe.

The capacity to adapt and mitigate is dependent on socio-economic and environmental circumstances and the availability of information and technology²⁰. However, much less information is available about the costs and effectiveness of adaptation measures than about mitigation measures. {WGII 17.1, 17.3; WGIII 1.2}

4.2 Adaptation options

Adaptation can reduce vulnerability, both in the short and the long term. {WGII 17.2, 18.1, 18.5, 20.3, 20.8}

Vulnerability to climate change can be exacerbated by other stresses. These arise from, for example, current climate hazards, poverty, unequal access to resources, food insecurity, trends in economic globalisation, conflict and incidence of diseases such as HIV/AIDS. {WGII 7.2, 7.4, 8.3, 17.3, 20.3, 20.4, 20.7, SPM}

Societies across the world have a long record of adapting and reducing their vulnerability to the impacts of weather- and climate-related events such as floods, droughts and storms. Nevertheless, additional adaptation measures will be required at regional and local levels to reduce the adverse impacts of projected climate change and variability, regardless of the scale of mitigation undertaken over the next two to three decades. However, adaptation alone is not expected to cope with all the projected effects of climate change, especially not over the long term as most impacts increase in magnitude. {WGII 17.2, SPM; WGIII 1.2}

A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood. Some planned adaptation is already occurring on a limited basis. Table 4.1 provides examples of planned

adaptation options by sector. Many adaptation actions have multiple drivers, such as economic development and poverty alleviation, and are embedded within broader development, sectoral, regional and local planning initiatives such as water resources planning, coastal defence and disaster risk reduction strategies. Examples of this approach are the Bangladesh National Water Management Plan and the coastal defence plans of The Netherlands and Norway, which incorporate specific climate change scenarios. {WGII 1.3, 5.5.2, 11.6, 17.2}

Comprehensive estimates of the costs and benefits of adaptation at the global level are limited in number. However, the number of adaptation cost and benefit estimates at the regional and project levels for impacts on specific sectors, such as agriculture, energy demand for heating and cooling, water resources management and infrastructure, is growing. Based on these studies there is *high confidence* that there are viable adaptation options that can be implemented in some of these sectors at low cost and/or with high benefit-cost ratios. Empirical research also suggests that higher benefit-cost ratios can be achieved by implementing some adaptation measures at an early stage compared to retrofitting long-lived infrastructure at a later date. {WGII 17.2}

Adaptive capacity is intimately connected to social and economic development, but it is not evenly distributed across and within societies. {WGII 7.1, 7.2, 7.4, 17.3}

The capacity to adapt is dynamic and is influenced by a society's productive base, including natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance, national income, health and technology. It is also affected by multiple climate and non-climate stresses, as well as development policy. {WGII 17.3}

Recent studies reaffirm the TAR finding that adaptation will be vital and beneficial. However, financial, technological, cognitive, behavioural, political, social, institutional and cultural constraints limit both the implementation and effectiveness of adaptation measures. Even societies with high adaptive capacity remain vulnerable to climate change, variability and extremes. For example, a heat wave in 2003 caused high levels of mortality in European cities (especially among the elderly), and Hurricane Katrina in 2005 caused large human and financial costs in the United States. {WGII 7.4, 8.2, 17.4}

²⁰ Technology is defined as the practical application of knowledge to achieve particular tasks that employs both technical artefacts (hardware, equipment) and (social) information ('software', know-how for production and use of artefacts).

Table 4.1. Selected examples of planned adaptation by sector.

Sector	Adaptation option/strategy	Underlying policy framework	Key constraints and opportunities to implementation (Normal font = constraints; <i>italics</i> = opportunities)
Water {WGII 5.5, 16.4; Tables 3.5, 11.6, 17.1}	Expanded rainwater harvesting; water storage and conservation techniques; water reuse; desalination; water-use and irrigation efficiency	National water policies and integrated water resources management; water-related hazards management	Financial, human resources and physical barriers; <i>integrated water resources management; synergies with other sectors</i>
Agriculture {WGII 10.5, 13.5; Table 10.8}	Adjustment of planting dates and crop variety; crop relocation; improved land management, e.g. erosion control and soil protection through tree planting	R&D policies; institutional reform; land tenure and land reform; training; capacity building; crop insurance; financial incentives, e.g. subsidies and tax credits	Technological and financial constraints; access to new varieties; markets; <i>longer growing season in higher latitudes; revenues from 'new' products</i>
Infrastructure/ settlement (including coastal zones) {WGII 3.6, 11.4; Tables 6.11, 17.1}	Relocation; seawalls and storm surge barriers; dune reinforcement; land acquisition and creation of marshlands/wetlands as buffer against sea level rise and flooding; protection of existing natural barriers	Standards and regulations that integrate climate change considerations into design; land-use policies; building codes; insurance	Financial and technological barriers; availability of relocation space; <i>integrated policies and management; synergies with sustainable development goals</i>
Human health {WGII 14.5, Table 10.8}	Heat-health action plans; emergency medical services; improved climate-sensitive disease surveillance and control; safe water and improved sanitation	Public health policies that recognise climate risk; strengthen health services; regional and international cooperation	Limits to human tolerance (vulnerable groups); knowledge limitations; financial capacity; <i>upgraded health services; improved quality of life</i>
Tourism {WGII 12.5, 15.5, 17.5; Table 17.1}	Diversification of tourism attractions and revenues; shifting ski slopes to higher altitudes and glaciers; artificial snow-making	Integrated planning (e.g. carrying capacity; linkages with other sectors); financial incentives, e.g. subsidies and tax credits	Appeal/marketing of new attractions; financial and logistical challenges; potential adverse impact on other sectors (e.g. artificial snow-making may increase energy use); <i>revenues from 'new' attractions; involvement of wider group of stakeholders</i>
Transport {WGII 7.6, 17.2}	Realignment/relocation; design standards and planning for roads, rail and other infrastructure to cope with warming and drainage	Integrating climate change considerations into national transport policy; investment in R&D for special situations, e.g. permafrost areas	Financial and technological barriers; availability of less vulnerable routes; <i>improved technologies and integration with key sectors (e.g. energy)</i>
Energy {WGII 7.4, 16.2}	Strengthening of overhead transmission and distribution infrastructure; underground cabling for utilities; energy efficiency; use of renewable sources; reduced dependence on single sources of energy	National energy policies, regulations, and fiscal and financial incentives to encourage use of alternative sources; incorporating climate change in design standards	Access to viable alternatives; financial and technological barriers; acceptance of new technologies; <i>stimulation of new technologies; use of local resources</i>

Note:
Other examples from many sectors would include early warning systems.

4.3 Mitigation options

Both bottom-up and top-down studies²¹ indicate that there is **high agreement and much evidence of substantial economic potential²¹ for the mitigation of global GHG emissions over the coming decades that could offset the projected growth of global emissions or reduce emissions below current levels.** {WGIII 11.3, SPM}

Figure 4.1 compares global economic mitigation potential in 2030 with the projected emissions increase from 2000 to 2030. Bottom-up studies suggest that mitigation opportunities with net negative costs²² have the potential to reduce emissions by about 6 GtCO₂-eq/yr in 2030. Realising these requires dealing with implementation barriers. The economic mitigation potential, which is generally greater than the market mitigation potential, can only be achieved when adequate policies are in place and barriers removed.²¹ {WGIII 11.3, SPM}

Sectoral estimates of economic mitigation potential and marginal costs derived from bottom-up studies corrected for double counting of mitigation potential are shown in Figure 4.2. While top-down and bottom-up studies are in line at the global level, there are considerable differences at the sectoral level. {WGIII 11.3, SPM}

No single technology can provide all of the mitigation potential in any sector. Table 4.2 lists selected examples of key technologies, policies, constraints and opportunities by sector. {WGIII SPM}

Future energy infrastructure investment decisions, expected to total over US\$20 trillion²³ between 2005 and 2030, will have long-term impacts on GHG emissions, because of the long lifetimes of energy plants and other infrastructure capital stock. The widespread diffusion of low-carbon technologies may take many decades, even if early investments in these technologies are made attractive. Initial estimates show that returning global energy-related CO₂ emissions to 2005 levels by 2030 would require a large shift in the pattern of investment, although the net additional investment required ranges from negligible to 5 to 10%. {WGIII 4.1, 4.4, 11.6, SPM}

Comparison between global economic mitigation potential and projected emissions increase in 2030

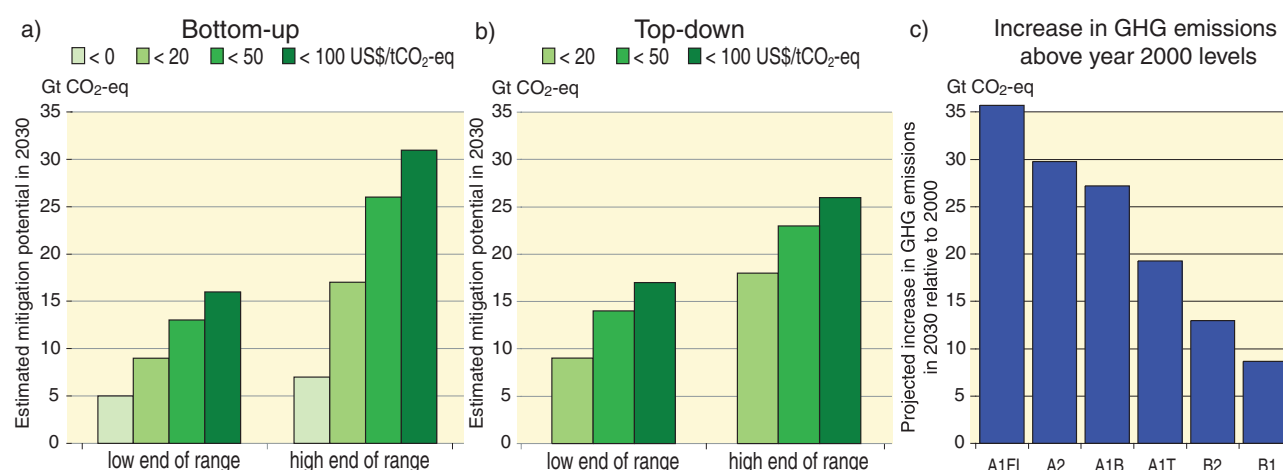


Figure 4.1. Global economic mitigation potential in 2030 estimated from bottom-up (Panel a) and top-down (Panel b) studies, compared with the projected emissions increases from SRES scenarios relative to year 2000 GHG emissions of 40.8 GtCO₂-eq (Panel c). Note: GHG emissions in 2000 are exclusive of emissions of decay of above-ground biomass that remains after logging and deforestation and from peat fires and drained peat soils, to ensure consistency with the SRES emissions results. {WGIII Figures SPM.4, SPM.5a, SPM.5b}

²¹ The concept of 'mitigation potential' has been developed to assess the scale of GHG reductions that could be made, relative to emission baselines, for a given level of carbon price (expressed in cost per unit of carbon dioxide equivalent emissions avoided or reduced). Mitigation potential is further differentiated in terms of 'market mitigation potential' and 'economic mitigation potential'.

Market mitigation potential is the mitigation potential based on private costs and private discount rates (reflecting the perspective of private consumers and companies), which might be expected to occur under forecast market conditions, including policies and measures currently in place, noting that barriers limit actual uptake.

Economic mitigation potential is the mitigation potential that takes into account social costs and benefits and social discount rates (reflecting the perspective of society; social discount rates are lower than those used by private investors), assuming that market efficiency is improved by policies and measures and barriers are removed.

Mitigation potential is estimated using different types of approaches. **Bottom-up studies** are based on assessment of mitigation options, emphasising specific technologies and regulations. They are typically sectoral studies taking the macro-economy as unchanged. **Top-down studies** assess the economy-wide potential of mitigation options. They use globally consistent frameworks and aggregated information about mitigation options and capture macro-economic and market feedbacks.

²² Net negative costs (no regrets opportunities) are defined as those options whose benefits such as reduced energy costs and reduced emissions of local/regional pollutants equal or exceed their costs to society, excluding the benefits of avoided climate change.

²³ 20 trillion = 20,000 billion = 20×10¹²

Economic mitigation potentials by sector in 2030 estimated from bottom-up studies

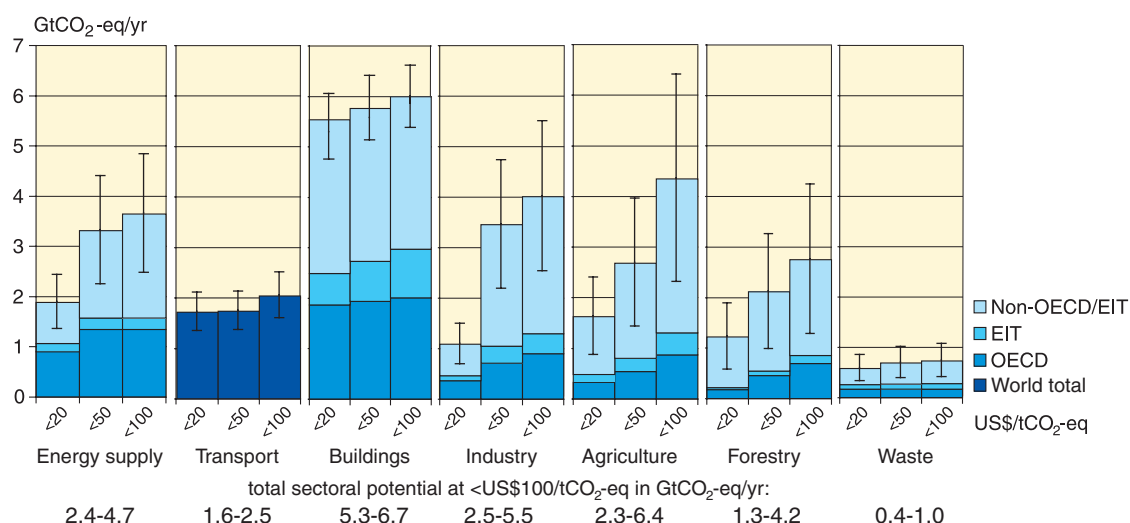


Figure 4.2. Estimated economic mitigation potential by sector and region using technologies and practices expected to be available in 2030. The potentials do not include non-technical options such as lifestyle changes. {WGIII Figure SPM.6}

Notes:

- The ranges for global economic potentials as assessed in each sector are shown by vertical lines. The ranges are based on end-use allocations of emissions, meaning that emissions of electricity use are counted towards the end-use sectors and not to the energy supply sector.
- The estimated potentials have been constrained by the availability of studies particularly at high carbon price levels.
- Sectors used different baselines. For industry the SRES B2 baseline was taken, for energy supply and transport the World Energy Outlook (WEO) 2004 baseline was used; the building sector is based on a baseline in between SRES B2 and A1B; for waste, SRES A1B driving forces were used to construct a waste-specific baseline; agriculture and forestry used baselines that mostly used B2 driving forces.
- Only global totals for transport are shown because international aviation is included.
- Categories excluded are non-CO₂ emissions in buildings and transport, part of material efficiency options, heat production and cogeneration in energy supply, heavy duty vehicles, shipping and high-occupancy passenger transport, most high-cost options for buildings, wastewater treatment, emission reduction from coal mines and gas pipelines, and fluorinated gases from energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10 to 15%.

While studies use different methodologies, there is **high agreement and much evidence** that in all analysed world regions near-term health co-benefits from reduced air pollution, as a result of actions to reduce GHG emissions, can be substantial and may offset a substantial fraction of mitigation costs. {WGIII 11.8, SPM}

Energy efficiency and utilisation of renewable energy offer synergies with sustainable development. In least developed countries, energy substitution can lower mortality and morbidity by reducing indoor air pollution, reduce the workload for women and children and decrease the unsustainable use of fuelwood and related deforestation. {WGIII 11.8, 11.9, 12.4}

Literature since the TAR confirms with **high agreement and medium evidence** that there may be effects from Annex I countries' action on the global economy and global emissions, although the scale of carbon leakage remains uncertain. {WGIII 11.7, SPM}

Fossil fuel exporting nations (in both Annex I and non-Annex I countries) may expect, as indicated in the TAR, lower demand and prices and lower GDP growth due to mitigation policies. The extent of this spillover depends strongly on assumptions related to policy decisions and oil market conditions. {WGIII 11.7, SPM}

Critical uncertainties remain in the assessment of carbon leakage. Most equilibrium modelling supports the conclusion in the TAR of economy-wide leakage from Kyoto action in the order of 5 to 20%, which would be less if competitive low-emissions technologies were effectively diffused. {WGIII 11.7, SPM}

There is also **high agreement and medium evidence** that changes in lifestyle and behaviour patterns can contribute to climate change mitigation across all sectors. Management practices can also have a positive role. {WGIII SPM}

Examples that can have positive impacts on mitigation include changes in consumption patterns, education and training, changes in building occupant behaviour, transport demand management and management tools in industry. {WGIII 4.1, 5.1, 6.7, 7.3, SPM}

Policies that provide a real or implicit price of carbon could create incentives for producers and consumers to significantly invest in low-GHG products, technologies and processes. {WGIII SPM}

An effective carbon-price signal could realise significant mitigation potential in all sectors. Modelling studies show that global carbon prices rising to US\$20-80/tCO₂-eq by 2030 are consistent with stabilisation at around 550ppm CO₂-eq by 2100. For the same

Table 4.2 Selected examples of key sectoral mitigation technologies, policies and measures, constraints and opportunities. (WGIII Tables SPM.3, SPM.7)

Sector	Key mitigation technologies and practices currently commercially available. Key mitigation technologies and practices projected to be commercialised before 2030 shown in <i>italics</i> .	Policies, measures and instruments shown to be environmentally effective	Key constraints or opportunities (Normal font = constraints; <i>italics</i> = opportunities)
Energy Supply (WGIII 4.3, 4.4)	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower; solar; wind; geothermal and bioenergy); combined heat and power; early applications of carbon dioxide capture and storage (CCS) (e.g. storage of removed CO ₂ from natural gas); <i>CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and wave energy; concentrating solar; and solar photovoltaics</i>	Reduction of fossil fuel subsidies; taxes or carbon charges on fossil fuels Feed-in tariffs for renewable energy technologies; renewable energy obligations; producer subsidies	Resistance by vested interests may make them difficult to implement <i>May be appropriate to create markets for low-emissions technologies</i>
Transport (WGIII 5.4)	More fuel-efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning; <i>second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries</i>	Mandatory fuel economy; biofuel blending and CO ₂ standards for road transport Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport	Partial coverage of vehicle fleet may limit effectiveness Effectiveness may drop with higher incomes <i>Particularly appropriate for countries that are building up their transportation systems</i>
Buildings (WGIII 6.5)	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycling of fluorinated gases; <i>integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar photovoltaics integrated in buildings</i>	Appliance standards and labelling Building codes and certification Demand-side management programmes Public sector leadership programmes, including procurement Incentives for energy service companies (ESCOs)	Periodic revision of standards needed <i>Attractive for new buildings. Enforcement can be difficult</i> Need for regulations so that utilities may profit Government purchasing can expand demand for energy-efficient products <i>Success factor: Access to third party financing</i>
Industry (WGIII 7.5)	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO ₂ gas emissions; and a wide array of process-specific technologies; <i>advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture</i>	Provision of benchmark information; performance standards; subsidies; tax credits Tradable permits Voluntary agreements	<i>May be appropriate to stimulate technology uptake. Stability of national policy important in view of international competitiveness</i> Predictable allocation mechanisms and stable price signals important for investments Success factors include: clear targets; a baseline scenario; third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry
Agriculture (WGIII 8.4)	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH ₄ emissions; improved nitrogen fertiliser application techniques to reduce N ₂ O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency; <i>improvements of crop yields</i>	Financial incentives and regulations for improved land management; maintaining soil carbon content; efficient use of fertilisers and irrigation	<i>May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation</i>
Forestry/forests (WGIII 9.4)	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use; <i>tree species improvement to increase biomass productivity and carbon sequestration; improved remote sensing technologies for analysis of vegetation/soil carbon sequestration potential and mapping land-use change</i>	Financial incentives (national and international) to increase forest area, to reduce deforestation and to maintain and manage forests; land-use regulation and enforcement	Constraints include lack of investment capital and land tenure issues. <i>Can help poverty alleviation.</i>
Waste (WGIII 10.4)	Landfill CH ₄ recovery; waste incineration with energy recovery; composting of organic waste; controlled wastewater treatment; recycling and waste minimisation; <i>biocovers and biofilters to optimise CH₄ oxidation</i>	Financial incentives for improved waste and wastewater management Renewable energy incentives or obligations Waste management regulations	<i>May stimulate technology diffusion</i> Local availability of low-cost fuel Most effectively applied at national level with enforcement strategies

stabilisation level, studies since the TAR that take into account induced technological change may lower these price ranges to US\$5-65/tCO₂-eq in 2030.²⁴ {WGIII 3.3, 11.4, 11.5, SPM}

There is high agreement and much evidence that a wide variety of national policies and instruments are available to governments to create the incentives for mitigation action. Their applicability depends on national circumstances and an understanding of their interactions, but experience from implementation in various countries and sectors shows there are advantages and disadvantages for any given instrument. {WGIII 13.2, SPM}

Four main criteria are used to evaluate policies and instruments: environmental effectiveness, cost effectiveness, distributional effects including equity, and institutional feasibility. {WGIII 13.2, SPM}

General findings about the performance of policies are: {WGIII 13.2, SPM}

- **Integrating climate policies in broader development policies** makes implementation and overcoming barriers easier.
- **Regulations and standards** generally provide some certainty about emission levels. They may be preferable to other instruments when information or other barriers prevent producers and consumers from responding to price signals. However, they may not induce innovations and more advanced technologies.
- **Taxes and charges** can set a price for carbon, but cannot guarantee a particular level of emissions. Literature identifies taxes as an efficient way of internalising costs of GHG emissions.
- **Tradable permits** will establish a carbon price. The volume of allowed emissions determines their environmental effectiveness, while the allocation of permits has distributional consequences. Fluctuation in the price of carbon makes it difficult to estimate the total cost of complying with emission permits.
- **Financial incentives** (subsidies and tax credits) are frequently used by governments to stimulate the development and diffusion of new technologies. While economic costs are generally higher than for the instruments listed above, they are often critical to overcome barriers.
- **Voluntary agreements** between industry and governments are politically attractive, raise awareness among stakeholders and have played a role in the evolution of many national policies. The majority of agreements have not achieved significant emissions reductions beyond business as usual. However, some recent agreements, in a few countries, have accelerated the application of best available technology and led to measurable emission reductions.
- **Information instruments** (e.g. awareness campaigns) may positively affect environmental quality by promoting informed choices and possibly contributing to behavioural change, however, their impact on emissions has not been measured yet.

- **Research, development and demonstration (RD&D)** can stimulate technological advances, reduce costs and enable progress toward stabilisation.

Some corporations, local and regional authorities, NGOs and civil groups are adopting a wide variety of voluntary actions. These voluntary actions may limit GHG emissions, stimulate innovative policies and encourage the deployment of new technologies. On their own, they generally have limited impact on national- or regional-level emissions. {WGIII 13.4, SPM}

4.4 Relationship between adaptation and mitigation options and relationship with sustainable development

There is growing understanding of the possibilities to choose and implement climate response options in several sectors to realise synergies and avoid conflicts with other dimensions of sustainable development. {WGIII SPM}

Climate change policies related to energy efficiency and renewable energy are often economically beneficial, improve energy security and reduce local pollutant emissions. Reducing both loss of natural habitat and deforestation can have significant biodiversity, soil and water conservation benefits, and can be implemented in a socially and economically sustainable manner. Forestation and bioenergy plantations can restore degraded land, manage water runoff, retain soil carbon and benefit rural economies, but could compete with food production and may be negative for biodiversity, if not properly designed. {WGII 20.3, 20.8; WGIII 4.5, 9.7, 12.3, SPM}

There is growing evidence that decisions about macro-economic policy, agricultural policy, multilateral development bank lending, insurance practices, electricity market reform, energy security and forest conservation, for example, which are often treated as being apart from climate policy, can significantly reduce emissions (Table 4.3). Similarly, non-climate policies can affect adaptive capacity and vulnerability. {WGII 20.3; WGIII SPM, 12.3}

Both synergies and trade-offs exist between adaptation and mitigation options. {WGII 18.4.3; WGIII 11.9}

Examples of synergies include properly designed biomass production, formation of protected areas, land management, energy use in buildings, and forestry, but synergies are rather limited in other sectors. Potential trade-offs include increased GHG emissions due to increased consumption of energy related to adaptive responses. {WGII 18.4.3, 18.5, 18.7, TS.5.2; WGIII 4.5, 6.9, 8.5, 9.5, SPM}

²⁴ Studies on mitigation portfolios and macro-economic costs assessed in this report are based on top-down modelling. Most models use a global least-cost approach to mitigation portfolios, with universal emissions trading, assuming transparent markets, no transaction cost, and thus perfect implementation of mitigation measures throughout the 21st century. Costs are given for a specific point in time. Global modelled costs will increase if some regions, sectors (e.g. land use), options or gases are excluded. Global modelled costs will decrease with lower baselines, use of revenues from carbon taxes and auctioned permits, and if induced technological learning is included. These models do not consider climate benefits and generally also co-benefits of mitigation measures, or equity issues. Significant progress has been achieved in applying approaches based on induced technological change to stabilisation studies; however, conceptual issues remain. In the models that consider induced technological change, projected costs for a given stabilisation level are reduced; the reductions are greater at lower stabilisation level.

Table 4.3. Integrating climate change considerations into development policies – selected examples in the area of mitigation. {WGIII 12.2.4.6}

Selected sectors	Non-climate change policy instruments and actions	Potentially affects:
Macro-economy	Implement non-climate taxes/subsidies and/or other fiscal and regulatory policies that promote sustainable development	Total global GHG emissions
Forestry	Adoption of forest conservation and sustainable management practices	GHG emissions from deforestation
Electricity	Adoption of cost-effective renewables, demand-side management programmes, and transmission and distribution loss reduction	Electricity sector CO ₂ emissions
Petroleum imports	Diversifying imported and domestic fuel mix and reducing economy's energy intensity to improve energy security	Emissions from crude oil and product imports
Insurance for building, transport sectors	Differentiated premiums, liability insurance exclusions, improved terms for green products	Transport and building sector GHG emissions
International finance	Country and sector strategies and project lending that reduces emissions	Emissions from developing countries

4.5 International and regional cooperation

There is *high agreement and much evidence* that notable achievements of the UNFCCC and its Kyoto Protocol are the establishment of a global response to the climate change problem, stimulation of an array of national policies, the creation of an international carbon market and the establishment of new institutional mechanisms that may provide the foundation for future mitigation efforts. Progress has also been made in addressing adaptation within the UNFCCC and additional initiatives have been suggested. {WGII 18.7; WGIII 13.3, SPM}

The impact of the Protocol's first commitment period relative to global emissions is projected to be limited. Its economic impacts on participating Annex-B countries are projected to be smaller than presented in the TAR, which showed 0.2 to 2% lower GDP in 2012 without emissions trading and 0.1 to 1.1% lower GDP with emissions trading among Annex-B countries. To be more environmentally effective, future mitigation efforts would need to achieve deeper reductions covering a higher share of global emissions (see Topic 5). {WGIII 1.4, 11.4, 13.3, SPM}

The literature provides *high agreement and much evidence* of many options for achieving reductions of global GHG emissions at the international level through cooperation. It also suggests that successful agreements are environmentally effective, cost-effective, incorporate distributional considerations and equity, and are institutionally feasible. {WGIII 13.3, SPM}

Greater cooperative efforts to reduce emissions will help to reduce global costs for achieving a given level of mitigation, or will improve environmental effectiveness. Improving and expanding the scope of market mechanisms (such as emission trading, Joint Implementation and Clean Development Mechanism) could reduce overall mitigation costs. {WGIII 13.3, SPM}

Efforts to address climate change can include diverse elements such as emissions targets; sectoral, local, sub-national and regional actions; RD&D programmes; adopting common policies; implementing development-oriented actions; or expanding financing instruments. These elements can be implemented in an integrated fashion, but comparing the efforts made by different countries quantitatively would be complex and resource intensive. {WGIII 13.3, SPM}

Actions that could be taken by participating countries can be differentiated both in terms of when such action is undertaken, who participates and what the action will be. Actions can be binding or non-binding, include fixed or dynamic targets, and participation can be static or vary over time. {WGIII 13.3, SPM}

5

The long-term perspective: scientific and socio-economic aspects relevant to adaptation and mitigation, consistent with the objectives and provisions of the Convention, and in the context of sustainable development

5.1 Risk management perspective

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. {WGII 20.9, SPM; WGIII SPM}

Risk management techniques can explicitly accommodate sectoral, regional and temporal diversity, but their application requires information about not only impacts resulting from the most likely climate scenarios, but also impacts arising from lower-probability but higher-consequence events and the consequences of proposed policies and measures. Risk is generally understood to be the product of the likelihood of an event and its consequences. Climate change impacts depend on the characteristics of natural and human systems, their development pathways and their specific locations. {SYR 3.3, Figure 3.6; WGII 20.2, 20.9, SPM; WGIII 3.5, 3.6, SPM}

5.2 Key vulnerabilities, impacts and risks – long-term perspectives

The five ‘reasons for concern’ identified in the TAR are now assessed to be stronger with many risks identified with higher confidence. Some are projected to be larger or to occur at lower increases in temperature. This is due to (1) better understanding of the magnitude of impacts and risks associated with increases in global average temperature and GHG concentrations, including vulnerability to present-day climate variability, (2) more precise identification of the circumstances that make systems, sectors, groups and regions especially vulnerable and (3) growing evidence that the risk of very large impacts on multiple century time scales would continue to increase as long as GHG concentrations and temperature continue to increase. Understanding about the relationship between impacts (the basis for ‘reasons for con-

cern’ in the TAR) and vulnerability (that includes the ability to adapt to impacts) has improved. {WGII 4.4, 5.4, 19.ES, 19.3.7, TS.4.6; WGIII 3.5, SPM}

The TAR concluded that vulnerability to climate change is a function of exposure, sensitivity and adaptive capacity. Adaptation can reduce sensitivity to climate change while mitigation can reduce the exposure to climate change, including its rate and extent. Both conclusions are confirmed in this assessment. {WGII 20.2, 20.7.3}

No single metric can adequately describe the diversity of key vulnerabilities or support their ranking. A sample of relevant impacts is provided in Figure 3.6. The estimation of key vulnerabilities in any system, and damage implied, will depend on exposure (the rate and magnitude of climate change), sensitivity, which is determined in part and where relevant by development status, and adaptive capacity. Some key vulnerabilities may be linked to thresholds; in some cases these may cause a system to shift from one state to another, whereas others have thresholds that are defined subjectively and thus depend on societal values. {WGII 19.ES, 19.1}

The five ‘reasons for concern’ that were identified in the TAR were intended to synthesise information on climate risks and key vulnerabilities and to “aid readers in making their own determination” about risk. These remain a viable framework to consider key vulnerabilities, and they have been updated in the AR4. {TAR WGII Chapter 19; WGII SPM}

- **Risks to unique and threatened systems.** There is new and stronger evidence of observed impacts of climate change on unique and vulnerable systems (such as polar and high mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase further. An increasing risk of species extinction and coral reef damage is projected with higher confidence than in the TAR as warming proceeds. There is *medium confidence* that approximately 20 to 30% of plant and animal species assessed so far are *likely* to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C over 1980-1999 levels. Confidence has increased that a 1 to 2°C increase in global mean temperature above 1990 levels (about 1.5 to 2.5°C above pre-indus-

Key Vulnerabilities and Article 2 of the UNFCCC

Article 2 of the UNFCCC states:

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

Determining what constitutes “dangerous anthropogenic interference with the climate system” in relation to Article 2 of the UNFCCC involves value judgements. Science can support informed decisions on this issue, including by providing criteria for judging which vulnerabilities might be labelled ‘key’. {SYR 3.3, WGII 19.ES}

Key vulnerabilities²⁵ may be associated with many climate-sensitive systems, including food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets and modes of oceanic and atmospheric circulation. {WGII 19.ES}

More specific information is now available across the regions of the world concerning the nature of future impacts, including for some places not covered in previous assessments. {WGII SPM}

²⁵ Key Vulnerabilities can be identified based on a number of criteria in the literature, including magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and ‘importance’ of the impacts.

trial) poses significant risks to many unique and threatened systems including many biodiversity hotspots. Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1 to 3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatisation by corals. Increasing vulnerability of Arctic indigenous communities and small island communities to warming is projected. (SYR 3.3, 3.4, Figure 3.6, Table 3.2; WGII 4.ES, 4.4, 6.4, 14.4.6, 15.ES, 15.4, 15.6, 16.ES, 16.2.1, 16.4, Table 19.1, 19.3.7, TS.5.3, Figure TS.12, Figure TS.14)

- **Risks of extreme weather events.** Responses to some recent extreme climate events reveal higher levels of vulnerability in both developing and developed countries than was assessed in the TAR. There is now higher confidence in the projected increases in droughts, heat waves and floods, as well as their adverse impacts. As summarised in Table 3.2, increases in drought, heat waves and floods are projected in many regions and would have mostly adverse impacts, including increased water stress and wild fire frequency, adverse effects on food production, adverse health effects, increased flood risk and extreme high sea level, and damage to infrastructure. (SYR 3.2, 3.3, Table 3.2; WGI 10.3, Table SPM.2; WGII 1.3, 5.4, 7.1, 7.5, 8.2, 12.6, 19.3, Table 19.1, Table SPM.1)
- **Distribution of impacts and vulnerabilities.** There are sharp differences across regions and those in the weakest economic position are often the most vulnerable to climate change and are frequently the most susceptible to climate-related damages, especially when they face multiple stresses. There is increasing evidence of greater vulnerability of specific groups such as the poor and elderly not only in developing but also in developed countries. There is greater confidence in the projected regional patterns of climate change (see Topic 3.2) and in the projections of regional impacts, enabling better identification of particularly vulnerable systems, sectors and regions (see Topic 3.3). Moreover, there is increased evidence that low-latitude and less-developed areas generally face greater risk, for example in dry areas and megadeltas. New studies confirm that Africa is one of the most vulnerable continents because of the range of projected impacts, multiple stresses and low adaptive capacity. Substantial risks due to sea level rise are projected particularly for Asian megadeltas and for small island communities. (SYR 3.2, 3.3, 5.4; WGI 11.2-11.7, SPM; WGII 3.4.3, 5.3, 5.4, Boxes 7.1 and 7.4, 8.1.1, 8.4.2, 8.6.1.3, 8.7, 9.ES, Table 10.9, 10.6, 16.3, 19.ES, 19.3, Table 19.1, 20.ES, TS.4.5, TS.5.4, Tables TS.1, TS.3, TS.4, SPM)
- **Aggregate impacts.** Compared to the TAR, initial net market-based benefits from climate change are projected to peak at a lower magnitude and therefore sooner than was assessed in the TAR. It is *likely* that there will be higher damages for larger magnitudes of global temperature increase than estimated in the TAR, and the net costs of impacts of increased warming are projected to increase over time. Aggregate impacts have also been quantified in other metrics (see Topic 3.3): for example,

climate change over the next century is *likely* to adversely affect hundreds of millions of people through increased coastal flooding, reductions in water supplies, increased malnutrition and increased health impacts. (SYR 3.3, Figure 3.6; WGII 19.3.7, 20.7.3, TS.5.3)

- **Risks of large-scale singularities.**²⁶ As discussed in Topic 3.4, during the current century, a large-scale abrupt change in the meridional overturning circulation is *very unlikely*. There is *high confidence* that global warming over many centuries would lead to a sea level rise contribution from thermal expansion alone that is projected to be much larger than observed over the 20th century, with loss of coastal area and associated impacts. There is better understanding than in the TAR that the risk of additional contributions to sea level rise from both the Greenland and possibly Antarctic ice sheets may be larger than projected by ice sheet models and could occur on century time scales. This is because ice dynamical processes seen in recent observations but not fully included in ice sheet models assessed in the AR4 could increase the rate of ice loss. Complete deglaciation of the Greenland ice sheet would raise sea level by 7m and could be irreversible. (SYR 3.4; WGI 10.3, Box 10.1; WGII 19.3.7, SPM)

5.3 Adaptation and mitigation

There is *high confidence* that neither adaptation nor mitigation alone can avoid all climate change impacts. Adaptation is necessary both in the short term and longer term to address impacts resulting from the warming that would occur even for the lowest stabilisation scenarios assessed. There are barriers, limits and costs that are not fully understood. Adaptation and mitigation can complement each other and together can significantly reduce the risks of climate change. (WGII 4.ES, TS 5.1, 18.4, 18.6, 20.7, SPM; WGIII 1.2, 2.5, 3.5, 3.6)

Adaptation will be ineffective for some cases such as natural ecosystems (e.g. loss of Arctic sea ice and marine ecosystem viability), the disappearance of mountain glaciers that play vital roles in water storage and supply, or adaptation to sea level rise of several metres²⁷. It will be less feasible or very costly in many cases for the projected climate change beyond the next several decades (such as deltaic regions and estuaries). There is *high confidence* that the ability of many ecosystems to adapt naturally will be exceeded this century. In addition, multiple barriers and constraints to effective adaptation exist in human systems (see Topic 4.2). (SYR 4.2; WGII 17.4.2, 19.2, 19.4.1)

Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. Reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation is not possible, or will only be available at very high social, environmental and economic costs. (WGII 18.1, SPM)

²⁶ See glossary

²⁷ While it is technically possible to adapt to several metres of sea level rise, the resources required are so unevenly distributed that in reality this risk is outside the scope of adaptation. (WGII 17.4.2, 19.4.1)

Efforts to mitigate GHG emissions to reduce the rate and magnitude of climate change need to account for inertia in the climate and socio-economic systems. {SYR 3.2; WGI 10.3, 10.4, 10.7, SPM; WGIII 2.3.4}

After GHG concentrations are stabilised, the rate at which the global average temperature increases is expected to slow within a few decades. Small increases in global average temperature could still be expected for several centuries. Sea level rise from thermal expansion would continue for many centuries at a rate that eventually decreases from that reached before stabilisation, due to ongoing heat uptake by oceans. {SYR 3.2, WGI 10.3, 10.4, 10.7, SPM}

Delayed emission reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. Even though benefits of mitigation measures in terms of avoided climate change would take several decades to materialise, mitigation actions begun in the short term would avoid locking in both long-lived carbon intensive infrastructure and development pathways, reduce the rate of climate change and reduce the adaptation needs associated with higher levels of warming. {WGII 18.4, 20.6, 20.7, SPM; WGIII 2.3.4, 3.4, 3.5, 3.6, SPM}

5.4 Emission trajectories for stabilisation

In order to stabilise the concentration of GHGs in the atmosphere, emissions would need to peak and decline thereafter.²⁸ The lower the stabilisation level, the more quickly this peak and decline would need to occur (Figure 5.1).²⁹ {WGIII 3.3, 3.5, SPM}

Advances in modelling since the TAR permit the assessment of multi-gas mitigation strategies for exploring the attainability and costs for achieving stabilisation of GHG concentrations. These scenarios explore a wider range of future scenarios, including lower levels of stabilisation, than reported in the TAR. {WGIII 3.3, 3.5, SPM}

Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels (Table 5.1 and Figure 5.1). {WGIII 3.5, SPM}

Table 5.1 summarises the required emission levels for different groups of stabilisation concentrations and the resulting equilibrium

CO₂ emissions and equilibrium temperature increases for a range of stabilisation levels

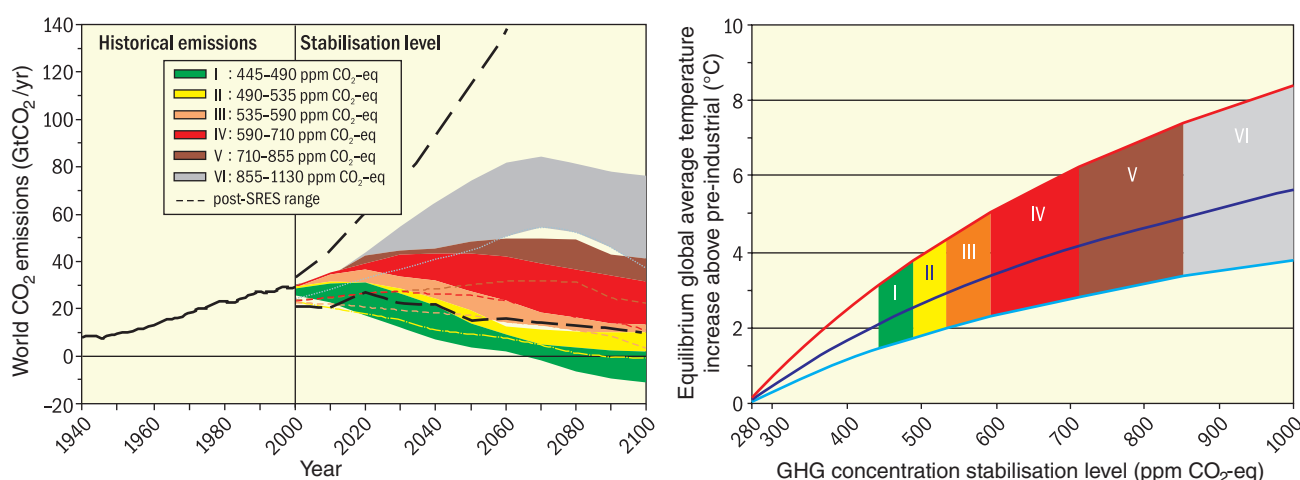


Figure 5.1. Global CO₂ emissions for 1940 to 2000 and emissions ranges for categories of stabilisation scenarios from 2000 to 2100 (left-hand panel); and the corresponding relationship between the stabilisation target and the likely equilibrium global average temperature increase above pre-industrial (right-hand panel). Approaching equilibrium can take several centuries, especially for scenarios with higher levels of stabilisation. Coloured shadings show stabilisation scenarios grouped according to different targets (stabilisation category I to VI). The right-hand panel shows ranges of global average temperature change above pre-industrial, using (i) 'best estimate' climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of likely range of climate sensitivity of 4.5°C (red line at top of shaded area) (iii) lower bound of likely range of climate sensitivity of 2°C (blue line at bottom of shaded area). Black dashed lines in the left panel give the emissions range of recent baseline scenarios published since the SRES (2000). Emissions ranges of the stabilisation scenarios comprise CO₂-only and multigas scenarios and correspond to the 10th to 90th percentile of the full scenario distribution. Note: CO₂ emissions in most models do not include emissions from decay of above ground biomass that remains after logging and deforestation, and from peat fires and drained peat soils. {WGIII Figures SPM.7 and SPM.8}

²⁸ Peaking means that the emissions need to reach a maximum before they decline later.

²⁹ For the lowest mitigation scenario category assessed, emissions would need to peak by 2015 and for the highest by 2090 (see Table 5.1). Scenarios that use alternative emission pathways show substantial differences on the rate of global climate change. {WGII 19.4}

Table 5.1. Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only.^a {WGI 10.7; WGIII Table TS.2, Table 3.10, Table SPM.5}

Category	CO ₂ concentration at stabilisation (2005 = 379 ppm) ^b	CO ₂ -equivalent concentration at stabilisation including GHGs and aerosols (2005=375 ppm) ^b	Peaking year for CO ₂ emissions ^{a,c}	Change in global CO ₂ emissions in 2050 (percent of 2000 emissions) ^{a,c}	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity ^{d,e}	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only ^f	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Notes:

- The emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed here might be underestimated due to missing carbon cycle feedbacks (see also Topic 2.3).
- Atmospheric CO₂ concentrations were 379ppm in 2005. The best estimate of total CO₂-eq concentration in 2005 for all long-lived GHGs is about 455ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375ppm CO₂-eq.
- Ranges correspond to the 15th to 85th percentile of the post-TAR scenario distribution. CO₂ emissions are shown so multi-gas scenarios can be compared with CO₂-only scenarios (see Figure 2.1).
- The best estimate of climate sensitivity is 3°C.
- Note that global average temperature at equilibrium is different from expected global average temperature at the time of stabilisation of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150 (see also Footnote 30).
- Equilibrium sea level rise is for the contribution from ocean thermal expansion only and does not reach equilibrium for at least many centuries. These values have been estimated using relatively simple climate models (one low-resolution AOGCM and several EMICs based on the best estimate of 3°C climate sensitivity) and do not include contributions from melting ice sheets, glaciers and ice caps. Long-term thermal expansion is projected to result in 0.2 to 0.6m per degree Celsius of global average warming above pre-industrial. (AOGCM refers to Atmosphere-Ocean General Circulation Model and EMICs to Earth System Models of Intermediate Complexity.)

global average temperature increases, using the 'best estimate' of climate sensitivity (see Figure 5.1 for the *likely* range of uncertainty). Stabilisation at lower concentration and related equilibrium temperature levels advances the date when emissions need to peak and requires greater emissions reductions by 2050.³⁰ Climate sensitivity is a key uncertainty for mitigation scenarios that aim to meet specific temperature levels. The timing and level of mitigation to reach a given temperature stabilisation level is earlier and more stringent if climate sensitivity is high than if it is low. {WGIII 3.3, 3.4, 3.5, 3.6, SPM}

Sea level rise under warming is inevitable. Thermal expansion would continue for many centuries after GHG concentrations have stabilised, for any of the stabilisation levels assessed, causing an eventual sea level rise much larger than projected for the 21st century (Table 5.1). If GHG and aerosol concentrations had been stabilised at year 2000 levels, thermal expansion alone would be expected to lead to further sea level rise of 0.3 to 0.8m. The eventual contributions from Greenland ice sheet loss could be several metres, and larger than from thermal expansion, should warming in excess of 1.9 to 4.6°C above pre-industrial be sustained over many centuries. These long-term consequences would have major impli-

cations for world coastlines. The long time scale of thermal expansion and ice sheet response to warming imply that mitigation strategies that seek to stabilise GHG concentrations (or radiative forcing) at or above present levels do not stabilise sea level for many centuries. {WGI 10.7}

Feedbacks between the carbon cycle and climate change affect the required mitigation and adaptation response to climate change. Climate-carbon cycle coupling is expected to increase the fraction of anthropogenic emissions that remains in the atmosphere as the climate system warms (see Topics 2.3 and 3.2.1), but mitigation studies have not yet incorporated the full range of these feedbacks. As a consequence, the emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed in Table 5.1 might be underestimated. Based on current understanding of climate-carbon cycle feedbacks, model studies suggest that stabilising CO₂ concentrations at, for example, 450ppm³¹ could require cumulative emissions over the 21st century to be less than 1800 [1370 to 2200] GtCO₂, which is about 27% less than the 2460 [2310 to 2600] GtCO₂ determined without consideration of carbon cycle feedbacks. {SYR 2.3, 3.2.1; WGI 7.3, 10.4, SPM}

³⁰ Estimates for the evolution of temperature over the course of this century are not available in the AR4 for the stabilisation scenarios. For most stabilisation levels global average temperature is approaching the equilibrium level over a few centuries. For the much lower stabilisation scenarios (category I and II, Figure 5.1), the equilibrium temperature may be reached earlier.

³¹ To stabilise at 1000ppm CO₂, this feedback could require that cumulative emissions be reduced from a model average of approximately 5190 [4910 to 5460] GtCO₂ to approximately 4030 [3590 to 4580] GtCO₂. {WGI 7.3, 10.4, SPM}

5.5 Technology flows and development

There is *high agreement* and *much evidence* that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place for development, acquisition, deployment and diffusion of technologies and addressing related barriers. {WGIII SPM}

Worldwide deployment of low-GHG emission technologies as well as technology improvements through public and private RD&D would be required for achieving stabilisation targets as well as cost reduction.³² Figure 5.2 gives illustrative examples of the contribution of the portfolio of mitigation options. The contribution of different technologies varies over time and region and depends on the baseline development path, available technologies and relative costs, and the analysed stabilisation levels. Stabilisation at the lower of the assessed levels (490 to 540ppm CO₂-eq) requires early investments and substantially more rapid diffusion and commercialisation of advanced low-emissions technologies over the next decades

(2000-2030) and higher contributions across abatement options in the long term (2000-2100). This requires that barriers to development, acquisition, deployment and diffusion of technologies are effectively addressed with appropriate incentives. {WGIII 2.7, 3.3, 3.4, 3.6, 4.3, 4.4, 4.6, SPM}

Without sustained investment flows and effective technology transfer, it may be difficult to achieve emission reduction at a significant scale. Mobilising financing of incremental costs of low-carbon technologies is important. {WGIII 13.3, SPM}

There are large uncertainties concerning the future contribution of different technologies. However, all assessed stabilisation scenarios concur that 60 to 80% of the reductions over the course of the century would come from energy supply and use and industrial processes. Including non-CO₂ and CO₂ land-use and forestry mitigation options provides greater flexibility and cost-effectiveness. Energy efficiency plays a key role across many scenarios for most regions and time scales. For lower stabilisation levels, scenarios put more emphasis on the use of low-carbon energy sources, such as renewable energy, nuclear power and the use of CO₂ capture and storage (CCS). In these scenarios, improvements of carbon intensity of energy supply and the whole economy needs to be much faster than in the past (Figure 5.2). {WGIII 3.3, 3.4, TS.3, SPM}

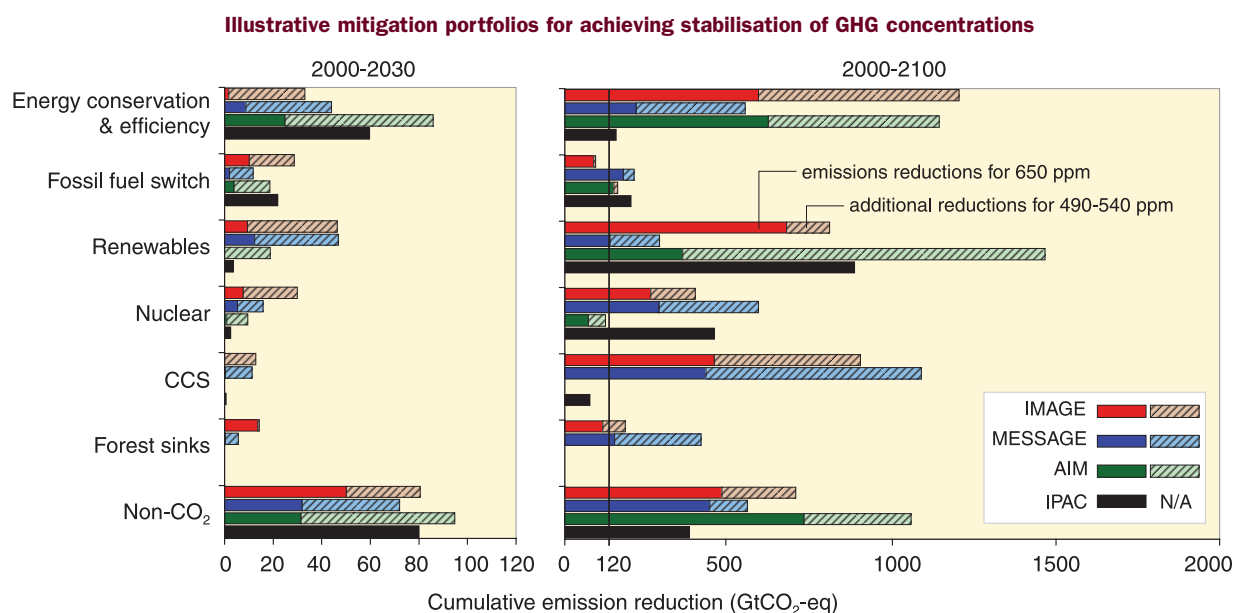


Figure 5.2 Cumulative emissions reductions for alternative mitigation measures for 2000-2030 (left-hand panel) and for 2000-2100 (right-hand panel). The figure shows illustrative scenarios from four models (AIM, IMAGE, IPAC and MESSAGE) aiming at the stabilisation at low (490 to 540ppm CO₂-eq) and intermediate levels (650ppm CO₂-eq) respectively. Dark bars denote reductions for a target of 650ppm CO₂-eq and light bars denote the additional reductions to achieve 490 to 540ppm CO₂-eq. Note that some models do not consider mitigation through forest sink enhancement (AIM and IPAC) or CCS (AIM) and that the share of low-carbon energy options in total energy supply is also determined by inclusion of these options in the baseline. CCS includes CO₂ capture and storage from biomass. Forest sinks include reducing emissions from deforestation. The figure shows emissions reductions from baseline scenarios with cumulative emissions between 6000 to 7000 GtCO₂-eq (2000-2100). {WGIII Figure SPM.9}

³² By comparison, government funding in real absolute terms for most energy research programmes has been flat or declining for nearly two decades (even after the UNFCCC came into force) and is now about half of the 1980 level. {WGIII 2.7, 3.4, 4.5, 11.5, 13.2}

5.6 Costs of mitigation and long-term stabilisation targets

The macro-economic costs of mitigation generally rise with the stringency of the stabilisation target and are relatively higher when derived from baseline scenarios characterised by high emission levels. {WGIII SPM}

There is *high agreement* and *medium evidence* that in 2050 global average macro-economic costs for multi-gas mitigation towards stabilisation between 710 and 445ppm CO₂-eq are between a 1% gain to a 5.5% decrease of global GDP (Table 5.2). This corresponds to slowing average annual global GDP growth by less than 0.12 percentage points. Estimated GDP losses by 2030 are on average lower and show a smaller spread compared to 2050 (Table 5.2). For specific countries and sectors, costs vary considerably from the global average.³³ {WGIII 3.3, 13.3, SPM}

5.7 Costs, benefits and avoided climate impacts at global and regional levels

Impacts of climate change will vary regionally. Aggregated and discounted to the present, they are *very likely* to impose net annual costs, which will increase over time as global temperatures increase. {WGII SPM}

For increases in global average temperature of less than 1 to 3°C above 1980-1999 levels, some impacts are projected to produce market benefits in some places and sectors while, at the same time, imposing costs in other places and sectors. Global mean losses could be 1 to 5% of GDP for 4°C of warming, but regional losses could be substantially higher. {WGII 9.ES, 10.6, 15.ES, 20.6, SPM}

Peer-reviewed estimates of the social cost of carbon (net economic costs of damages from climate change aggregated across the

globe and discounted to the present) for 2005 have an average value of US\$12 per tonne of CO₂, but the range from 100 estimates is large (-\$3 to \$95/tCO₂). The range of published evidence indicates that the net damage costs of climate change are projected to be significant and to increase over time. {WGII 20.6, SPM}

It is *very likely* that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts. It is *virtually certain* that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries and populations. In some locations and amongst some groups of people with high exposure, high sensitivity and/or low adaptive capacity, net costs will be significantly larger than the global average. {WGII 7.4, 20.ES, 20.6, 20.ES, SPM}

Limited and early analytical results from integrated analyses of the global costs and benefits of mitigation indicate that these are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilisation level where benefits exceed costs. {WGIII SPM}

Comparing the costs of mitigation with avoided damages would require the reconciliation of welfare impacts on people living in different places and at different points in time into a global aggregate measure of well-being. {WGII 18.ES}

Choices about the scale and timing of GHG mitigation involve balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay. {WGIII SPM}

Many impacts can be avoided, reduced or delayed by mitigation. {WGII SPM}

Although the small number of impact assessments that evaluate stabilisation scenarios do not take full account of uncertainties in projected climate under stabilisation, they nevertheless provide indications of damages avoided and risks reduced for different

Table 5.2. Estimated global macro-economic costs in 2030 and 2050. Costs are relative to the baseline for least-cost trajectories towards different long-term stabilisation levels. {WGIII 3.3, 13.3, Tables SPM.4 and SPM.6}

Stabilisation levels (ppm CO ₂ -eq)	Median GDP reduction ^a (%)		Range of GDP reduction ^b (%)		Reduction of average annual GDP growth rates (percentage points) ^{c,e}	
	2030	2050	2030	2050	2030	2050
445 – 535 ^d	Not available		<3	<5.5	< 0.12	< 0.12
535 – 590	0.6	1.3	0.2 to 2.5	slightly negative to 4	< 0.1	< 0.1
590 – 710	0.2	0.5	-0.6 to 1.2	-1 to 2	< 0.06	< 0.05

Notes:

Values given in this table correspond to the full literature across all baselines and mitigation scenarios that provide GDP numbers.

a) Global GDP based on market exchange rates.

b) The 10th and 90th percentile range of the analysed data are given where applicable. Negative values indicate GDP gain. The first row (445-535ppm CO₂-eq) gives the upper bound estimate of the literature only.

c) The calculation of the reduction of the annual growth rate is based on the average reduction during the assessed period that would result in the indicated GDP decrease by 2030 and 2050 respectively.

d) The number of studies is relatively small and they generally use low baselines. High emissions baselines generally lead to higher costs.

e) The values correspond to the highest estimate for GDP reduction shown in column three.

³³ See Footnote 24 for further details on cost estimates and model assumptions.

amounts of emissions reduction. The rate and magnitude of future human-induced climate change and its associated impacts are determined by human choices defining alternative socio-economic futures and mitigation actions that influence emission pathways. Figure 3.2 demonstrates that alternative SRES emission pathways could lead to substantial differences in climate change throughout the 21st century. Some of the impacts at the high temperature end of Figure 3.6 could be avoided by socio-economic development pathways that limit emissions and associated climate change towards the lower end of the ranges illustrated in Figure 3.6. {SYR 3.2, 3.3; WGIII 3.5, 3.6, SPM}

Figure 3.6 illustrates how reduced warming could reduce the risk of, for example, affecting a significant number of ecosystems, the risk of extinctions, and the likelihood that cereal productivity in some regions would tend to fall. {SYR 3.3, Figure 3.6; WGII 4.4, 5.4, Table 20.6}

5.8 Broader environmental and sustainability issues

Sustainable development can reduce vulnerability to climate change, and climate change could impede nations' abilities to achieve sustainable development pathways. {WGII SPM}

It is *very likely* that climate change can slow the pace of progress toward sustainable development either directly through increased

exposure to adverse impacts or indirectly through erosion of the capacity to adapt. Over the next half-century, climate change could impede achievement of the Millennium Development Goals. {WGII SPM}

Climate change will interact at all scales with other trends in global environmental and natural resource concerns, including water, soil and air pollution, health hazards, disaster risk, and deforestation. Their combined impacts may be compounded in future in the absence of integrated mitigation and adaptation measures. {WGII 20.3, 20.7, 20.8, SPM}

Making development more sustainable can enhance mitigative and adaptive capacities, reduce emissions, and reduce vulnerability, but there may be barriers to implementation. {WGII 20.8; WGIII 12.2, SPM}

Both adaptive and mitigative capacities can be enhanced through sustainable development. Sustainable development can, thereby, reduce vulnerability to climate change by reducing sensitivities (through adaptation) and/or exposure (through mitigation). At present, however, few plans for promoting sustainability have explicitly included either adapting to climate change impacts, or promoting adaptive capacity. Similarly, changing development paths can make a major contribution to mitigation but may require resources to overcome multiple barriers. {WGII 20.3, 20.5, SPM; WGIII 2.1, 2.5, 12.1, SPM}