Meeting the 2 °C target From climate objective to emission reduction measures

Netherlands Environmental Assessment Agency

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Second print

The following changes have been made:
Figure 2.3. The original title has been changed to “Energy-related CO_2 emissions”
(to clarify that the data refer to energy-related CO2 emissions only)
Figure 3.4. The figure has been revised. Emissions are now in $GtCO_2$-eq
(instead of GtC-eq)

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The Netherlands Environmental Assessment Agency (PBL) is the national institute for strategic policy analysis in the field of environment, nature and spatial planning. We contribute to improving the quality of political and administrative decision-making by conducting outlook studies, analyses and evaluations in which an integrated approach is considered paramount. Policy relevance is the prime concern in all our studies. We conduct solicited and unsolicited research that is both independent and always scientifically sound.

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Foreword

International climate policy-making has entered a crucial phase. Over the last years, it has become clear that climate change may lead to severe impacts. In response, policymakers have expressed interest in a goal to avoid an increase in global mean temperature of more than 2 °C, as a means for operationalising the ambition of the UN Framework Convention on Climate Change (to 'avoid dangerous anthropogenic climate change'). This '2 °C' target has gained more support, but also raised several questions; is this target sufficient to avoid severe impacts? What is needed to achieve this target? When do emissions need to be reduced and to which level?

The Netherlands Environmental Assessment Agency (PBL) has published several analyses over the last few years that provide answers to some of these questions. In 2006, the publication 'From Climate Objective to Emission Reduction' combined a broad range of scientific information, to provide insight into the implications of various climate goals. The current publication provides not only an update including material that has become available since 2006, but also more explicitly focuses on the implication of such a 2 °C target. The publication has been systematically organised around the causal chain of climate change: from impacts to global emission reductions to regional emission reduction to implementation of various reduction measures and associated costs and, finally, to instruments to implement these measures.

Consistent with former publications, this report also shows that there is a large potential for reducing global greenhouse gas emissions to a level necessary for achieving the 2 °C target with high probability. The true challenge, however, lies not in the technical or economic aspects of emission reduction, but in agreeing upon and organising the institutional arrangements and policy instrumentation that would make these reductions feasible on both a worldwide and a local scale.

With this publication we aim to provide a useful point of reference to the current state of climate science for people interested in climate policy. As to the question of whether the 2 °C target will indeed be achieved, much will depend on the clarity with which climate strategies are introduced, and on the creativity of finding ways to make these commitments enduring and firm, in the years to come.

Maarten Hajer

Director of the Netherlands Environmental Assessment Agency

Contents

Summary

- Without additional policy, expected trends in greenhouse gas emissions are likely to lead to an expected increase in average global temperature of 2.5 to 6 °C, by 2100. Such a change in climate will lead to considerable risks, such as loss of valuable ecosystems, impacts on the global food supply, and large-scale disturbances of the current climate system.

- It is possible to change current trends in emissions. In the long term, atmospheric greenhouse gas concentration can be limited to 400 to 450 ppm CO_2 eq, corresponding to around 70 and 50% probability of staying below the 2 °C temperature increase above the pre-industrial level. This requires the implementation of policy packages aiming at zero-carbon energy options, energy efficiency, reducing non-CO_2 emissions, avoiding deforestation, and lifestyle changes. On a global level, the overall macroeconomic impacts are expected to be modest, although considerable investments are needed.

- In order to achieve this, it is necessary to halt the increase in global greenhouse gas emissions around 2020. This requires meaningful participation in climate policy by all major greenhouse gas emitting countries. By 2050, global greenhouse gas emission reduction would need to be between around 35 and 55%, compared to 1990 levels.

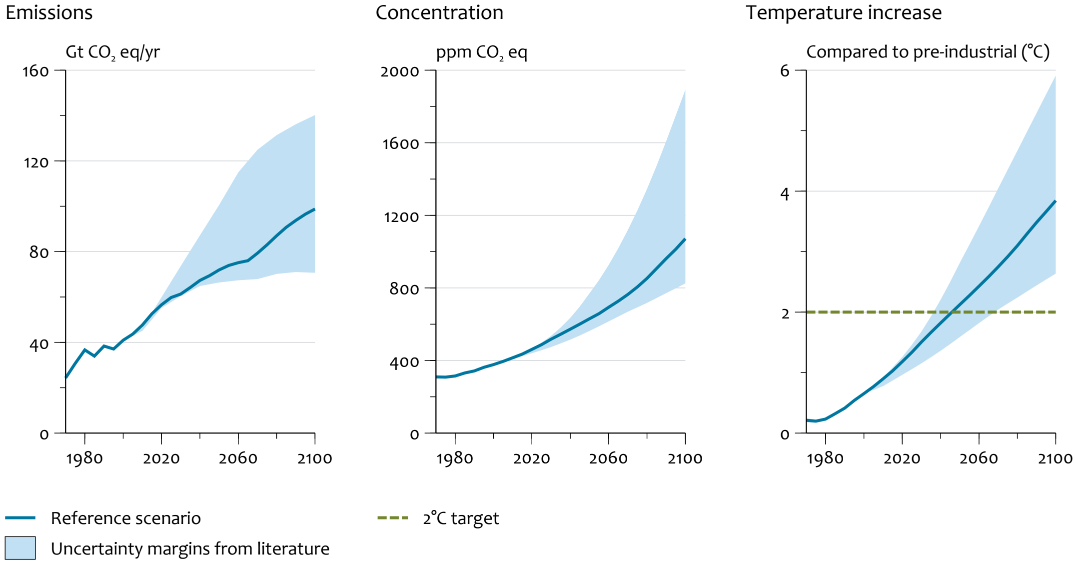
- The most significant challenges are to reach consensus on the contribution from different countries and sectors, and to put into place the right policies to spur off the shift to innovation and fundamental transitions that will help bring about the required emission reduction. Effective climate policies in this context require political ambition to meet the 2 °C target, long-term emission targets, and strict regulations to reach these. Integrated approaches are required to help harvesting the synergies between climate change mitigation, biodiversity protection, energy security and air pollution contol, and avoid trade-offs between these and other policy objectives.

The 2 °C target and climate impacts

Human society will face severe problems when global trends in climate change continue

The current increase in average global temperature is around 0.8 °C compared to pre-industrial levels. If left unchecked, anthropogenic greenhouse gas emissions are likely to cause an increase in average global temperature of 4 °C, by the end of this century, with a full range of 2.5 to 6 °C reflecting the uncertainty in emissions and climate sensitivity (Figure S1). Such an increase in average global temperature is likely to lead to serious climate risks, including the loss of valuable ecosystems, impacts on the global food supply, the risk of more than 1 metre sea level rise and large-scale disturbances of the current climate system. A significant temperature

Global greenhouse gas emissions, concentration and temperature change **Figure S1**



The uncertainty range for increases in concentration and temperature includes the uncertainty in the carbon cycle feedbacks and climate sensitivity (equilibrium temperature increase for a doubling of the pre-industrial CO_2 concentration levels). The range is slightly upward on the low side compared to IPCC, accounting for recent scenarios only. Source: van Vuuren et al. (2008; 2009b).

rise also increases the risk of critical thresholds being crossed in the climate system, such as the melting of the Greenland Ice Sheet, the release of methane in tundra, and the dieback of the Amazon forest.

A maximum increase in average global temperature of 2 °C, compared with pre-industrial levels, has been proposed as a limit to avoid dangerous anthropogenic climate change

The objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to avoid ‘dangerous anthropogenic climate change’. Limiting average global temperature increase to a maximum of 2 °C, compared to pre-industrial levels, has been proposed as an interpretation of this objective. The EU accepted this 2 °C target as the long-term objective of its climate policy. At the G8 Summit in July 2009, the major economies adopted the same target as a guideline for international climate policy. Setting long-term targets for climate change involves an interpretation of risks, valuation of different types of impacts and a valuation of future costs, elements that need (normative) societal and political choices, to which science can provide factual input. The 2 °C target has been mostly based on risk considerations, by considering the decrease in risks from a ‘business-as-usual’ situation to those associated with a 2 °C target. The 2 °C target may also be consistent with the outcome of cost-benefit analyses, but this strongly depends on choices in the discount rate (i.e. value attached to future losses), the value attached to different damages and the actual assessment of risks involved.

From the 2 °C target to emission reduction targets

In order to have a reasonably chance of achieving the 2 °C target, the increase in global emissions should be halted around 2020 and emissions should decrease afterwards

In the long run, greenhouse gas concentration levels of 400 to 450 ppm CO_2 eq, or less, are needed to keep a reasonable chance of staying below the 2 °C target. A 450 ppm CO_2 eq level corresponds to about 20 to 70% probability of staying below this target, a 400 ppm CO_2 eq level corresponds to a probability of between 40 and 90%. These concentration levels are consistent with CO_2-only concentration of 350 and 400 ppm. For comparison, the present CO_2 concentration is around 390 ppm and the pre-industrial level was 280 ppm.

Such low concentration levels can only be achieved after an initial overshoot to a peak concentration of around 500 ppm CO_2 eq. A temporary, limited overshoot of greenhouse gas concentrations has only limited environmental implications. However, a more sustained and larger overshoot, could lead to a more irreversible response. In order to achieve the 450 and 400 ppm CO_2 eq targets, the increase in global greenhouse gas emissions should be halted around 2020 and emissions should decrease afterwards. Some flexibility around the peak year exists, based on assumption of negative emissions in the second half of the century (using, for instance, bio-energy and carbon capture and storage), but this flexibility is not unlimited. Model calculations show that a 10 year delay in peaking would imply a substantial decrease in the probability of achieving the 2 °C target.

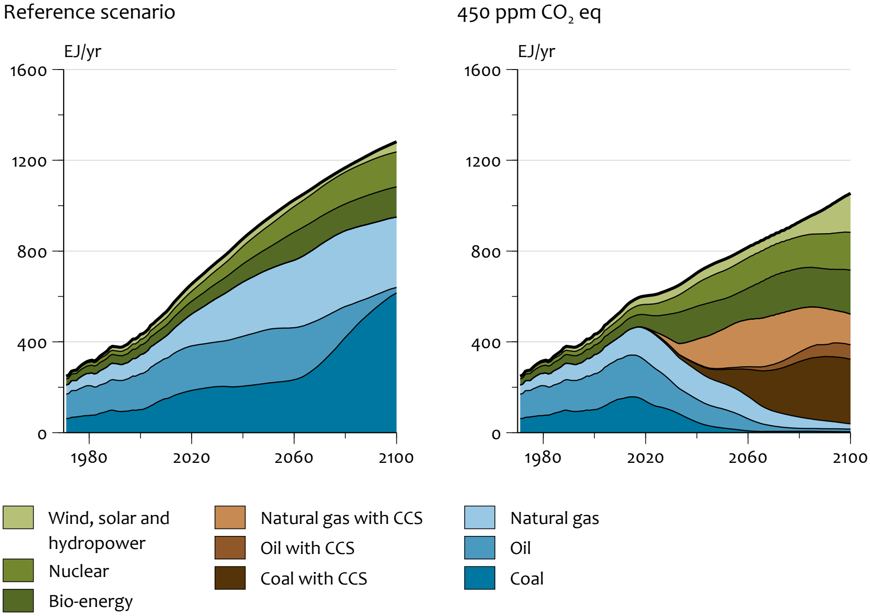
The 2 °C target corresponds to a reduction in global emissions of around 50%,by 2050, compared with 1990 levels

In the long term, emissions need to be reduced by around 35 to 55%, by 2050, compared with 1990 levels, to reach concentration levels of 400 to 450 ppm CO_2 eq. These reductions are allowing a limited overshoot of the concentration levels, based on costs considerations, and take advantage of inertia in the climate system. As such, the range is slightly lower than earlier numbers reported by IPCC (which were based on very few model runs). Further reduction in 2050 would be even more challenging – but to the benefit of increasing the probability of staying below the 2 °C target. Failure of meeting the reduction requirements by 2050 would imply that the overshoot in concentration levels more fundamentally determines the long-term temperature increase, significantly reducing the probability of staying below 2 °C.

Even with greenhouse gas concentrations of 400 or 450 ppm CO_2 eq, it might be useful to take the risk of 3 to 4 °C into account in adaptation policies

While a 400 or 450 ppm CO_2 eq scenario gives a reasonable chance of staying below 2 °C, the uncertainty in climate sensitivity implies that such a scenario could still result in a temperature increase of 3 °C or more. For policy-making, this implies that even if the 2 °C target is selected as an objective for mitigation policies, it might be

Global energy consumption by energy carrier **Figure S2**



Example of a reference scenario and a scenario leading to 2 °C. Source: van Vuuren et al. (2007)

useful to take the risk of 3 to 4 °C temperature increase into account in adaptation policies. Several uncertainties with respect to climate sensitivity need to be taken into account, such as the risk of a stronger impact of climate change on the carbon cycle, regional variations in climate effect, and time delays in society's adaptation to climate changes.

From emission reduction targets to mitigation measures

Reducing global greenhouse gas emission requires, above all, a rapid increase in energy efficiency, as well as a decarbonisation of power supply

The ambition to reduce greenhouse gas emissions by around 50%, by 2050, implies that, for the energy system, the annual rate of decarbonisation needs to be increased to 5%, up from the historical average of 2%. It is possible to achieve such a reduction by rapidly increasing energy efficiency, replacing fossil-fuel technologies by zero-carbon technologies, and by introducing carbon capture and storage (CCS) techniques (Figure S2). In addition, greenhouse gas emissions from agriculture and deforestation can be reduced. In other words, a broad portfolio of measures needs to be introduced – and the future energy supply will be very different from that of today.

The potential to increase energy efficiency is considerable, but its realisation requires ambitious standards for appliances, vehicles, and houses. There is also a large scope to reduce greenhouse gas emissions from power generation. Development of a connecting super grid on a continental scale, combined with a smart grid at local scale, would facilitate penetration of large-scale renewable power production, but also allow for a combination with decentralised power generation (by accommodating the variations in power production resulting from weather variations). This also requires the integration of storage systems, as well as the assurance of grid access. The important role of CCS in a shift towards a low-carbon society, even only as a 'transition technology', calls for experiments with this technology in the short term. Combined policies to reduce air pollution and climate change will lower costs and lead to considerable gains in life expectancy, especially in low-income countries.

The annual additional abatement costs for climate policy are likely to be between 1 and 2% of global GDP

A considerable and global effort is required to reduce greenhouse gas emissions by 50%, by 2050. Additional global investment needs for climate policy are estimated to average around 1,200 billion USD per year in the 2005-2050 period, which is, on average, about 1.4% of global GDP. In addition, estimated average costs for climate change adaptation range between 50 and 160 billion USD per year. To put these figures into perspective, these investments are similar to current spending on environmental protection and are lower than the expected expenditure on extension and renewal of the energy system that is required even in the absence of climate policy. It should be noted that these estimates are highly uncertain, but provide an indication of order of magnitude. Macroeconomic impacts are even more uncertain; typical values of around 0.1% reduction in annual economic growth are reported for ambitious climate policy scenarios.

From global to regional targets

In translating global climate targets into national and regional targets, agreements need to be made, among other things, with respect to short-term reductions, long-term ambitions and financing of adaptation measures in developing countries.

In 2020, on average, studies show a 25 to 40% reduction target, below 1990 levels (for a 2 °C target) for high-income countries. To achieve the 2 °C target, also meaningful participation of large emerging economies in international climate policy is required

The emission reductions required to reach the 2 °C target are large. First, it is necessary that all major emitting countries participate in a meaningful climate policy agreement. This not only includes today's high-income countries (OECD), but also Brazil, Russia, India and China. Studies that depart from the principle that high-income countries take the lead in reducing emissions, on average, come to a reduction target for this group of countries of 25 to 40% below 1990 levels, by 2020 (for 450 ppm CO_2 eq). It should be noted, however, that this strongly depends on the expected emission development without climate policy, and on the underlying concepts of what constitutes a fair distribution of efforts.

In addition, emissions for the group of low-income countries would need to be reduced. Corresponding to the above mentioned range for high-income countries would be a reduction of 15 to 30% for low-income countries, compared to business-as-usual emission projections for 2020. Within this group of countries, the burden of effort can be divided according to capacity; the more advanced low-income countries could reduce emissions more strongly than other low-income countries, while the lowest-income countries could be exempt from reductions until 2020. Part of the emission reductions might be financed through revenues from a Climate Fund, generated by a global greenhouse gas tax or trading system, or direct contributions from high-income countries.

In 2050, emission reductions for high-income countries would need to be around 80 to 90% below 1990 levels, according to most studies

By 2050, the emission reduction target for high-income countries should be around 80 to 90% below 1990 levels, by 2050, according to most studies that take into account different proposals to allocate future emissions (Figure S3 shows an example of 2 such proposals). For low-income countries, emission reduction allocations vary widely, from allowances for the lowest-income countries of far above the 1990 level, to about 20% below this level for more advanced low-income countries.

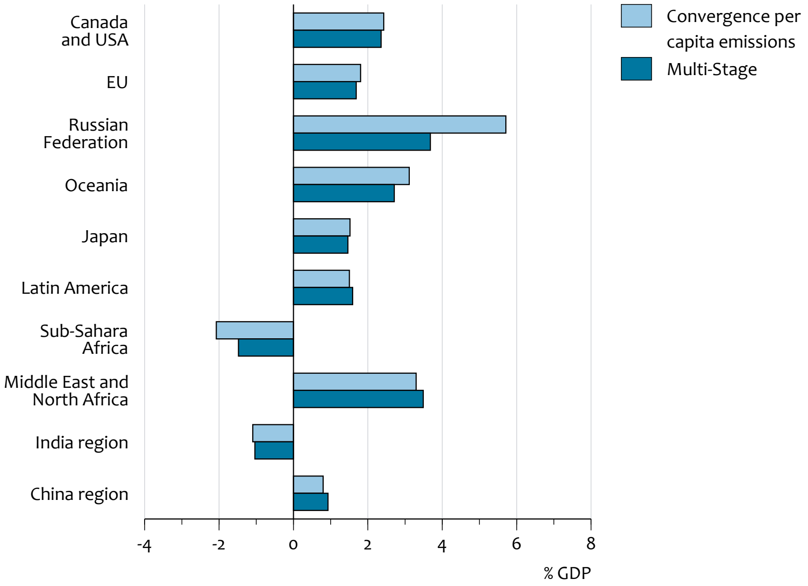
Abatement costs are relatively high for carbon-intensive and fossil-fuel exporting regions, while the lowest-income countries may even reap net benefits

Distribution of emission reduction costs is a highly sensitive issue. If emission reduction targets are allocated to regions based on convergence of per-capita emissions, high carbon-intensive and fossil-fuel exporting regions, such as Russia and the Middle East, are expected to bear higher costs, even when there participation in the climate regime starts at a later stage (Figure S3). However, the lowest-income regions, such as India and Sub-Saharan Africa, may benefit due to the sale of emission rights credits. Moreover, these regions are also most vulnerable to climate change impacts, and net benefits from reduced climate change would most likely surpass costs for these countries, in the long run.

The currently available funds for international financing of adaptation needs in low-income countries are far from their projected needs

Since the most severe impacts of climate change are projected to occur in the most vulnerable low-income countries, adaptation to climate change is especially important in those countries. The adaptation needs of low-income countries is estimated at 75 to 100 billion USD a year, which is far more than the current financing of the Adaptation Fund via a levy on CDM. A similar levy in all forms of emission trading would also not be able to create sufficient financing. Alternative proposals to finance adaptation have also been made, among other things, based on historic responsibility for climate change.

Figure S3 **Mitigation costs for different allocation approaches, 2050**



Average mitigation costs (2050) for two selected allocation approaches as illustration of possible outcomes. The Convergence approach involves a convergence of per-capita emissions by 2050. The Multi-Stage approach is an allocation method in which countries start to participate in emission reductions based on income or emission criteria. In the long run, also this allocation method leads to a convergence of per-capita emission credits. Negative costs result from the sale of emission credits through emission trading or the CDM. Source: den Elzen et al. (2008b).

Instrumentation and implementation

Effective climate policies require long-term targets that are translated into short-term goals that are predictable and strictly enforced

Long-term targets help to create a strategic focus in current policies and to increase policy predictability for stakeholders involved. Targets for 2050 provide the direction of policy implementation, thus indicating where investment needs and innovation efforts will need to be directed in the long run. This creates a level playing field for creative stakeholders to exploit the new possibilities of a society with low greenhouse gas emissions. A whole range of policy instruments are available to translate long-term targets into short-term goals. Putting a price on emissions constitutes an important measure of effective climate policy. In addition, standards can be useful to directly influence emissions and encourage innovation.

Realistic climate policies aims to find a balance with other public policy areas

Public policy weighs the requirements of climate policy against other objectives of public interest. For instance, energy policy balances climate change objectives against those on security of energy supply and cost issues. Similarly, climate policies interact with land-use and agricultural policies, industry and innovation policies, transport policies and energy security policies. There are considerable co-benefits between these different policy areas, such as the impacts of climate policy on air pollution, and the mitigation expansion of agricultural land (for climate and biodiversity). In some cases, there are also clear trade-offs (such as possibly around bio-energy). This calls for an integrated approach to domestic climate policy implementation.

The most significant political challenge is to decide on a joint and preferably global commitment to implement ambitious climate policies

The overview presented in this report shows that a low-carbon economy can be achieved with currently identifiable technologies, and with moderate economic costs. However, many other barriers exist: a key challenge is to achieve the right policy conditions and institutional settings to further significant emission reductions, and stimulate innovation. The challenge for finding solutions to these barriers is considerable, but it needs to be met in order for climate policies to succeed.

Introduction

1

The 2 °C target has been proposed as a reasonable limit to man-made climate change

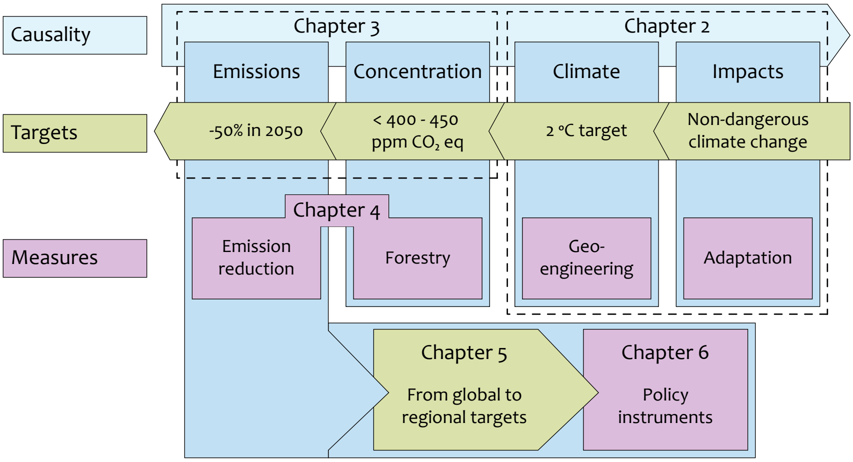
The earth's climate is changing, and while our understanding of the climate system is still far from complete, current knowledge is advanced enough for the Intergovernmental Panel on Climate Change (IPCC) to conclude with *very high confidence* that human activities are the main cause of the observed changes (IPCC, 2007a). Human activities that contribute to climate change include fossil-fuel combustion, agriculture and deforestation. These activities have significantly raised the concentration of greenhouse gases in the atmosphere and they are expected to lead to a further increase in the future, if current trends are left to go unchecked.

The activities that cause climate change can be influenced. However, this is not easy and requires taking difficult policy decisions. An important complication of climate policy-making is that the causes of climate change are separated from the consequences. First of all, greenhouse gas emissions from one country affect the climate of the whole world. Therefore, climate change policy can only succeed through an international approach. Second, most of the impacts of climate change occur far into the future as a result of the slow response time of the climate system. This implies that decision makers need to take account of impacts for future generations on the basis of uncertain scenarios.

The international community has acknowledged the threats posed by climate change and agreed on the United Nations Framework Convention on Climate Change in 1992 (UNFCCC, 1992). This convention aims to prevent dangerous anthropogenic interference in the climate system, in order to protect food production, biodiversity, and sustainable economic development. It is not possible, however, to unambiguously determine how much global warming can be tolerated without causing 'dangerous anthropogenic interference'. This is partly due to uncertainties in the climate system, but also because of differences of opinion on what should be protected, how much risk can be accepted and how much risk can be avoided by measures other than reducing greenhouse gas emissions (such as adaptation).

The EU has selected a maximum increase of 2 °C above pre-industrial levels as a practical target for international climate policy (EU, 2005). This 2 °C target may in fact be seen as a compromise between the risks of climate change and the required efforts to reduce greenhouse gas emissions. Several countries worldwide have endorsed the same target. The G8 Summit and major economies also adopted the 2 °C target as a guideline for international climate policy during their summit in July 2009, in L'Aquila, Italy (MEF, 2009).

Causality, targets and measures of climate change **Figure 1.1**



Meeting the 2 °C target; from climate objective to reduction measure

This report responds to increasing political support for the 2 °C target, by picturing its implications in terms of risks of climate change, emission reductions, mitigation measures and costs. The report does so, mostly by discussing recent publications of the Netherlands Environmental Assessment Agency (PBL). The report also indicates the societal choices that will need to be made to achieve such a target. Crucial topics include the probability of reaching the target, the type of measures that could be taken, the required international cooperation, and agreements on burden-sharing.

For this report, we followed a step-wise approach, organised around the causal chain of climate change (see Figure 1.1). This chain runs from emissions via greenhouse gas concentration to climate change and, finally, to impacts. As indicated above, we assume that the overall goal of international climate policy (to avoid 'dangerous anthropogenic interference in the climate system') is translated into an ambition to limit global temperature increase to a maximum of 2 °C. Deriving more concrete reduction measures starting from the 2 °C target implies going in the reverse direction of the causal chain as indicated in the figure (targets). First, Chapter 2 discusses the implications of accepting the 2 °C target, in relation to the ambition to avoid (non-dangerous) climate change impacts. Moreover, it also indicates how 'business-as-usual' trends compare to the 2 °C target. In translating the 2 °C target to implications for emission reductions, it is important to account for the uncertainties that play an major role in the causal chain, such as the response of the terrestrial biosphere to climate change, and the so-called 'sensitivity' of the climate system to greenhouse gas concentrations. This is the topic of Chapter 3. Next, Chapter 4 presents what would be required to achieve these emission reductions from a global perspective. There are different categories of possible measures, related to the two main emission sources: land-use and the energy sector. Emissions can be reduced in both categories by changes in demand and production. It should be noted, however, that climate policies will need to be formulated on a regional or national level.

As a result, actual policies depend on the allocation of emission reduction efforts to different regions, countries and/or sectors. Chapter 5 provides the available information on this issue. Lastly, Chapter 6 indicates what further issues could arise if policies are finally formulated on a national level.

Summarising, the following questions are specifically addressed:

- How does the 2 °C target relate to expected impacts of climate change? (Chapter 2)
- How much do emissions need to be reduced to achieve the 2 °C target? (Chapter 3)
- How and at which costs can these emission reductions be reached? (Chapter 4)
- How can global emission reductions be translated into regional reductions? (Chapter 5)
- What are the policy instruments available? (Chapter 6)

Abbreviations and terms used in this report are defined after Chapter 6 (see Appendix). This mainly concerns the references to two main country groupings (low and high-income countries) and the naming of scenarios.

2

The 2 °C climate target in relation to expected impacts

- Business-as-usual is expected to lead to an increase in global mean temperature of 2.5-6 °C by 2100, with further increase thereafter. This would lead to serious climate risks, including the loss of valuable ecosystems, impacts on the global food supply and large-scale disturbances of the current climate system.
- A maximum increase in average global temperature of 2 °C has been proposed as a reasonable limit for managing climate risks.
- It seems more useful to regard mitigation and adaptation as complements rather than substitutes. As there are limits to what adaptation can achieve, mitigation can help to keep adaptation strategies realistic. At the same time, as mitigation will only reduce the level of climate change and not prevent it, adaptation will be needed under each scenario.

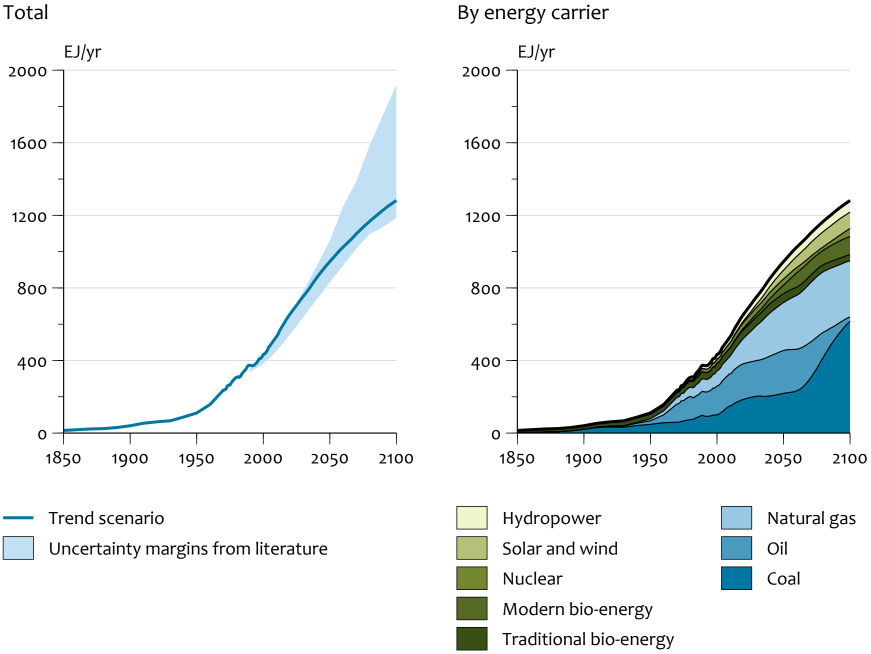
What constitutes the ambition to prevent ‘dangerous anthropogenic interference with the climate system’ depends on the risks involved in climate change and their appraisal. Climate change impacts occur not only in the absence of climate policy, but also with ambitions climate policy. This chapter first presents possible developments assuming no international climate policy (as a reference) and next indicates how the 2 °C target compares to different ways of looking at the impacts of climate change.

2.1 Temperature increase and climate impacts without climate policy

Population growth and economic growth are expected to lead to rapid growth in energy use

Emission developments over the coming century are uncertain. High economic and population growth and energy-intensive consumption patterns are factors that can lead to higher emissions. However, fast technological development, depletion of fossil fuels or less energy-intensive consumption patterns can lead to lower emissions. Scientific studies try to gain insights into the potential development of emissions by developing various reference projections or scenarios. The main

Global energy consumption, Reference scenario **Figure 2.1**

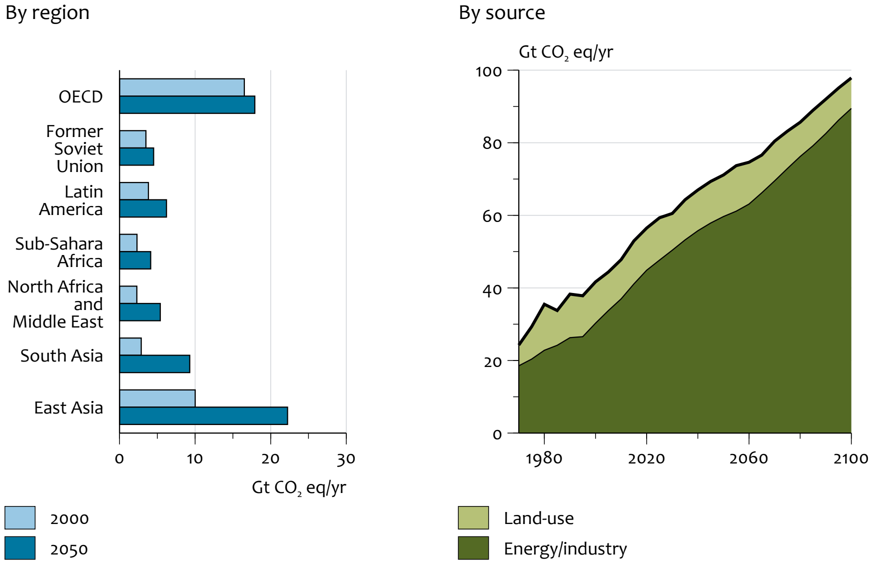


Source: van Vuuren et al. (2009b) and Nakicenovic et al. (2006).

reference scenario used in this report is representative for the medium range of scenarios in the literature (van Vuuren et al., 2009b). Population in the reference scenario reaches 9.1 billion by 2050, after which it stabilises at about 9.2 billion, up to 2100 (UN, 2008). Typical reference projections, such as the one used in this report, assume high economic growth in low-income regions: this is especially the case in Asia and Latin America early on in the scenario period, followed later by Africa. Despite these rapid growth rates, the current high-income economies are projected to remain the richest in per-capita terms. In terms of total economic activity, however, the economies of current low-income regions (based on their large contribution to the world population) will dominate the world economy for most of the century.

This increase in economic activity will also lead to an increase in energy use, again mostly in low-income regions. A typical projection of world energy consumption shows an increase by a factor of 2 to 3, over the 21st century (Figure 2.1; Fisher et al., 2007). Assuming no change in current policies, it is expected that fossil fuels continue to hold a large market share, as their average prices will remain below those of alternative fuels. In the reference scenario used for this report, in the coming decades, the consumption of oil, natural gas and coal will all increase. Depletion and resulting price increases, however, would lead to a stabilisation of oil and natural gas usage around the middle of the century. For coal, resource

Figure 2.2 **Greenhouse gas emissions, Reference scenario**



By region

By source

Source: van Vuuren et al. (2009b).

scarcity is not expected to limit usage or lead to increasing costs in the foreseeable future. As a result, coal use may strongly increase in the absence of climate policy. Although non-fossil energy production – including nuclear, biomass and other renewables – is likely to increase substantially, as well, their share will remain limited.

The growth in energy use will contribute to increasing greenhouse gas emissions

At this moment, most greenhouse gas emissions can be attributed to fossil-fuel combustion and industrial emissions. Therefore, the expected increase in fossil-fuel use will lead to increasing greenhouse gas emissions (Figure 2.2). Typically, scenarios without climate policy project roughly a doubling of greenhouse gas emissions by the end of the century – including the reference scenario used here (see also Figure 2.4 and Box 2.1). The contribution from land-use change and agriculture is expected to drop somewhat, mostly because of decreasing emissions from deforestation. The latter is a result of a declining growth rate in agricultural area. Although most of the increase in greenhouse gases occurs in low-income countries, per-capita emissions remain highest in the OECD countries. The impact of the current economic crisis is believed to be mostly a short-term one (see Box 2.2).

The 2 °C target is already likely to be exceeded by the middle of the century in the reference case

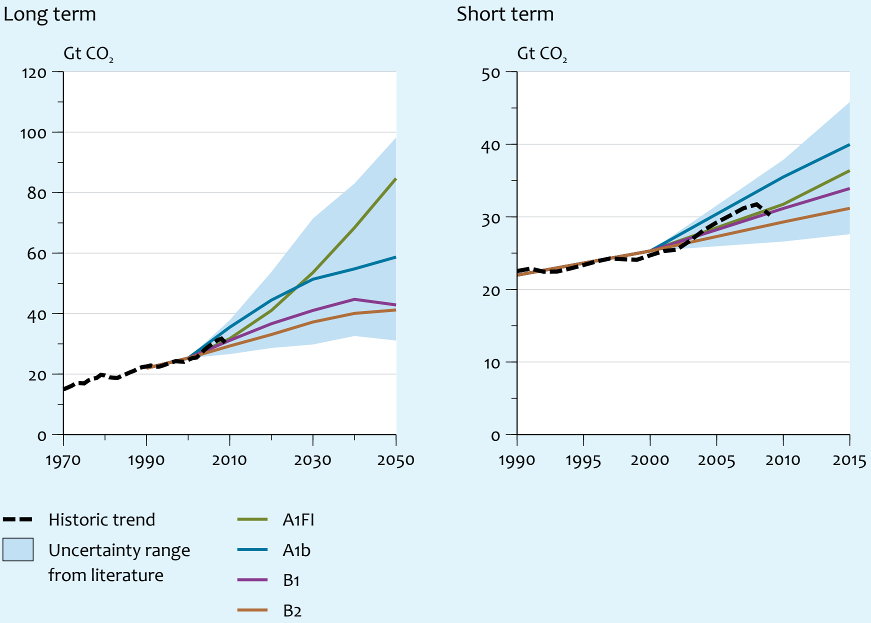
As a consequence of these emission trends, greenhouse gas concentration will continue to rise throughout the 21st century (Figure 2.4). Values for reference scenarios vary over a rather wide range, given the uncertainty in emission development and carbon cycle feedbacks. Typical values are in the order of 800 to 1800 ppm CO_2 eq, by 2100. After 2100, concentrations will continue to rise. Despite these uncertainties, scientific knowledge leaves little doubt that a consequence of an increase in atmospheric greenhouse gas concentration would be a steady

Box 2.1: What do current emission trends imply for the long term

The rapid growth of CO_2 emissions since 2000, at a rate of above 3% annually, has recently attracted considerable scientific and policy attention. Raupach et al. (2007) and Sheehan (2008), for example, suggest that the rapid growth may indicate a trend reversal and thus postulate the beginning of a significant break, away from the long-term historic trends of improving carbon and energy intensities. Comparing short-term trends with long-term scenarios, however, needs to be done with care. After looking at current trends, van Vuuren and Riahi (2008) concluded that there is no reason to believe that emissions will remain outside the (wide) range of long-term projections drawn up in the IPCC-SRES scenarios. Since their publication, the financial crisis in 2008 has slowed down emissions so much that by now emissions are again well within the SRES range

Energy-related CO_2 emissions, IPCC scenarios and historic trend

Figure 2.3



Historic trends based on CDIAC, extended up to 2008 by data of the EDGAR database and projection for 2009 (IMAGE/TIMER). Source: van Vuuren and Riahi (2008).

increase in global mean temperature. The 2 °C target is likely to be exceeded by the middle of this century, after which temperature levels increase further. Based on the uncertainty in emissions and the relationship between greenhouse gas concentration and temperature increase (the so-called climate sensitivity), the temperature increase may be 2.5 to 6 °C near the end of the century, relative to pre-industrial levels. The uncertainty is especially large at the high-end range of this estimate, so that even higher values cannot be excluded (van Vuuren et al., 2008). Temperature levels of all reference scenarios are still rapidly increasing by the end of the century: in other words, temperature is expected to increase further after the end of the century.

2.2 From the ambition to avoid dangerous impacts to the 2 °C target

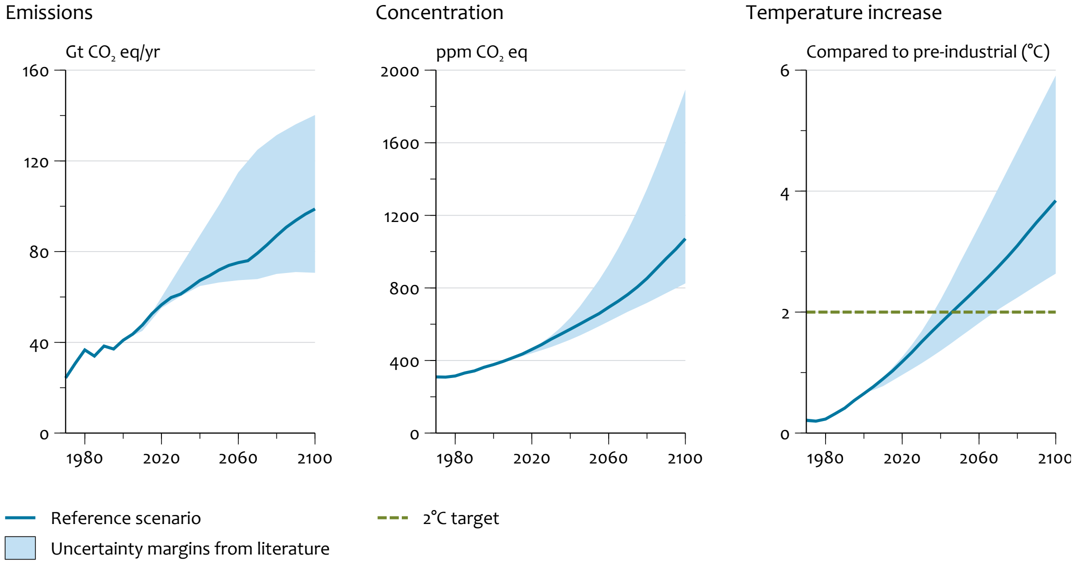
Higher temperatures mean higher risks of a whole range of adverse effects

The risks of climate change can be mapped as a function of global mean temperature increase. IPCC recently updated its earlier assessment of the risks of climate change (Figure 2.5). Although there are still considerable uncertainties, it is expected that at a low increase of global mean temperature, impacts will mostly concern sensitive ecosystems, such as coral reefs, and mainly will have local effects (for example, the effects on coastal systems from the increase in extreme weather events). Further climate change increases the risks of more radical and large-scale effects, such as the melting of Arctic ice, negative effects on food production, or the collapse of the thermohaline circulation. For the 21st century, unchecked climate change may lead to a sea level rise of 50 centimetres to over 1 metre; in the long run, it may even lead to an increase of more than 6 metres. Moreover, there is

Box 2.2: The impact of the 2008/2009 economic crisis

The present economic recession not only features a downturn in worldwide economic activity, but also has strong environmental impacts. Emissions in high-income regions have declined, while emissions increase less strongly than expected in most low-income regions. The net result has been a significant decrease in global emissions between 2007 and 2009 (see Figure 2.3). PBL calculations show, however, that if the economy recovers, greenhouse gas emissions are expected to rise again. As such, the crisis on a global scale mainly causes a few years delay in emission growth and a related impact on concentration and temperature. By itself, this impact would make short-term targets (e.g. 2020) slightly easier to achieve –with little long-term impacts. However, some evidence exists that the crisis also has negatively impacted private investments in clean energy (PBL, 2009c). Worldwide, in 2008, about 111 billion euros was invested in renewable energy; a modest annual rise of 5%, compared to annual growth rates of over 50% in previous years (Science for Environmental Policy, 2009). Investments in greenhouse gas emission reduction in sectors within the European Emission Trading Scheme (EU ETS) are also likely to decline due to very significant drops in CO_2 prices.It is important to prevent that the economic crisis would make long-term targets more difficult to achieve due to reduced investments, in the short-term.

Global greenhouse gas emissions, concentration and temperature change **Figure 2.4**



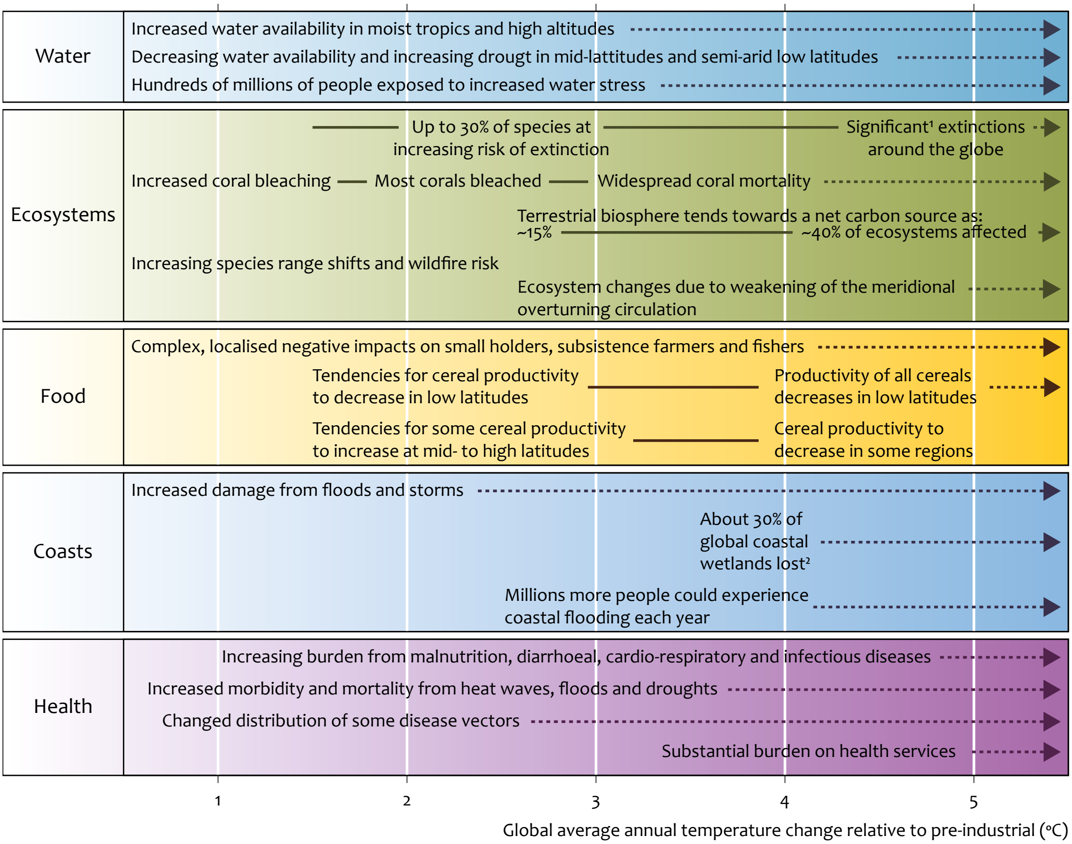
The literature range refers to scenarios without climate policy; for concentration and temperature, the indicated range includes the uncertainty in emissions, carbon cycle feedback and climate sensitivity. Source: van Vuuren et al. (2008; 2009b).

considerable risk of passing critical thresholds for survival of the Amazon forest, the release of methane from tundra/permafrost, and for the stability of the Greenland and west Antarctic ice sheets. The largest effects of climate change are expected to take place in low-income countries. The reason for this is not only because the most severe impacts often occur in these countries (changes in precipitation or impacts on yields), but also because they are the most vulnerable due to their considerable dependence on climate-sensitive economic sectors, such as agriculture. By comparing the projected 21st century temperature increase in Figure 2.4 with the impacts in Figure 2.5, insight on possible impacts during this century can be obtained.

Impacts of climate change, to a certain extent, can be reduced by adaptation measures

Where mitigation aims to reduce the above-mentioned risks by reducing climate change, adaptation aims to reduce vulnerability by adjusting to higher temperatures or changes in precipitation patterns. Ecosystems and society, to some extent, have the capacity to adjust to climate change. Adaptation can be stimulated by policies. Some forms of adaptation are relatively cheap and can be introduced rapidly without much difficulty. These measures, such as changes in heating and cooling practices in buildings, are introduced mostly by a large number of private actors (and thus require little government action). Other examples include changes in crops and improving irrigation systems. An important feature of

Figure 2.5 **Examples of impacts associated with global average temperature change**



[1] Significant is defined here as more than 40%

[2] Based on average rate of sea level rise of 4.2mm/year from 2000 to 2080

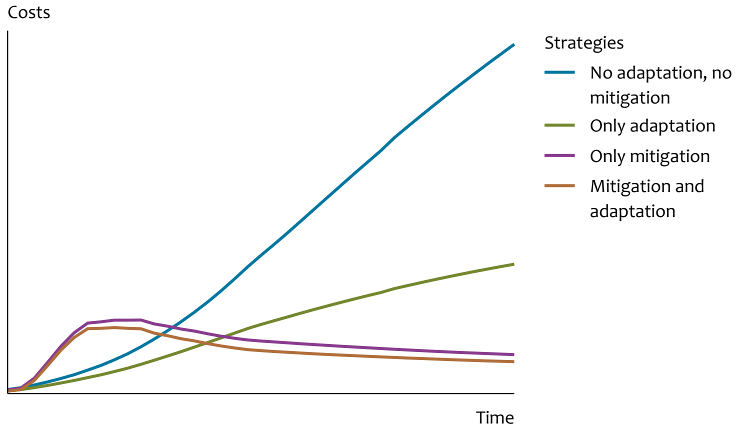
Impacts will vary by extent of adaptation, rate of temperature change and socio-economic pathway. Source: IPCC (2007a).

this type of adaptation measures is that they can reduce the risks of climate change in the near future. Mitigation, in contrast, reduces long-term climate risks, due to the slow response time in the climate system.

The relation between adaptation and mitigation is shown schematically in Figure 2.6. The figure introduces 4 hypothetical strategies in response to climate change: 1) doing nothing, 2) only adapt, 3) only mitigate and 4) mitigate and adapt. The figure shows, in qualitative terms, the results of these strategies in terms of total climate costs, which consists of the costs of damage from climate change, the adaptation costs and the costs of mitigation. As shown in Figure 2.6, the cost level and the time profile varies depending on the type of climate policy. If no action is taken (neither mitigation nor adaptation), in the long run, climate damages will be

Costs of climate change **Figure 2.6**

Sum of mitigation, adaptation and impacts



Relation between adaptation and mitigation strategies shown schematically. Source: Hof et al. (2010).

high and as a result, so will the total costs. If society would choose to adapt only to climate change, and not to mitigate emissions, costs would obviously be reduced significantly. However, as there are limitations to adaptation, certainly at high temperature levels, climate damage would still increase over time, as would the total costs. Introducing mitigation now leads to a very different profile. The costs of mitigation are borne early in time – therefore, total costs are high early on, as well. However, as mitigation measures prevent climate change and, as a result, reduce long-term climate impacts, this finally leads to low long-term costs. Combining mitigation with adaptation strategies will lead to the lowest costs, in the long run.

Mitigation and adaptation measures need to be combined for successful climate change policies

Describing the impacts of climate change as a function of mitigation and adaptation (as done in the previous section) may suggest that the costs and benefits of mitigation and adaptation and the residual damages can be easily weighed against each other. However, the appraisal of long-term mitigation and adaptation strategies is being complicated by several fundamental factors. One of these factors is the aforementioned difference in temporal scale of mitigation and adaptation. Another complication involves the many uncertainties (and thus risks) that are involved in the appraisal. Mitigation has the advantage that it reduces these uncertainties, since – in contrast to adaptation – it reduces climate change itself.

It seems more useful to regard mitigation and adaptation as complements rather than substitutes. As there are limits to what adaptation can achieve, mitigation can help to keep adaptation strategies realistic. Likewise, as mitigation will only be able to reduce the level of climate change but not prevent it, adaptation will always be needed. In a combined strategy, adaptation reduces short-term risks, and mitigation reduces risks in the long term.

Sometimes, also geoengineering is proposed as another form of response to climate change. The impacts of these measures, however, are still largely unknown. Therefore, at this stage, it is not useful yet to consider these measures as part of a realistic response strategy (see Box 2.3).

Risk assessment constitutes one way to determine long-term climate targets

In exploring a preferred mix of mitigation, adaptation and impacts, two main approaches exist: (i) the risk-based approach, which bases the preferred level of mitigation on the potential impacts of different levels of climate change, and (ii) cost–benefit analysis, which compares the same impacts to the costs of mitigation, but in monetary terms.

The first approach uses the relationships between global mean temperature increase and possible impacts such as depicted in Figure 2.5. From such an overview of possible impacts, it is possible to derive a maximum temperature increase that would correspond to avoiding impacts that are not ‘acceptable’. It should be noted that such impacts can be direct (e.g. costs of reduced agricultural production), as well as indirect (possible societal impacts, such as refugees). As indicated in Chapter 1, the objective of the EU is to prevent an increase in global mean temperature of more than 2 °C above the pre-industrial level, based on risk considerations (EU, 1996, 2005). Several scientists have provided similar considerations (Azar

Box 2.3: Geoengineering

In addition to mitigation and adaptation, it is also possible to reduce climate risks by using large-scale engineering of our environment, in order to counteract changes induced by increasing greenhouse gas concentrations. There are two basic categories of geoengineering options: removing greenhouse gases from the atmosphere, and managing the radiative forcing balance (that is, the difference between incoming and outgoing radiation energy). An example of the first category includes direct capture of CO_2 *from the atmosphere by absorption and subsequent storage. Options for the second category include the deliberate introduction of aerosols – fine particles – in the stratosphere and altering the planet’s reflection by white cloud formation. In general, the impacts of most forms of geoengineering are still relatively unknown, several measures are very expensive and others involve important risks. Further research is needed before it would be useful to consider these measures as part of climate response strategies (if it all). Moreover, most authors consider geoengineering only as an ultimate response to immediate climate risks – and not as alternative for other forms of climate policy responses. In terms of governance, it is important to note that international legislation that would provide a context for geoengineering is currently lacking. There is an urgent need (also if geoengineering is not pursued) to formulate international agreements on the use of geoengineering techniques (TRS, 2009).*

and Rodhe, 1997; O'Neill and Oppenheimer, 2002; WBGU, 1995). Some scientists explicitly argue in favour of more stringent targets (Hansen et al., 2007; Rockström et al., 2009) while others argue for less stringent ones. As shown further in this publication, short-term measures required to reach the 2 °C target can already be regarded as the maximum feasible response. In that light, it is unlikely that strategies for even more stringent targets will diverge much from a 2 °C target in the short-term, so that there is room for re-evaluation in 1-2 decades.

The outcome of cost-benefit analyses strongly depends on critical uncertainties and policy choices, in particular regarding the discount rate

Another way to compare different climate strategies is by exploring their monetary impacts using cost-benefit analysis. This approach is often presented as determining optimal emission reductions – but the outcomes critically depend on all kinds of uncertainties and normative assumptions. As a result, the outcomes of cost-benefit studies presented in the literature vary widely. The Stern Review (Stern, 2006), for instance, indicates on the basis of a cost-benefit approach that a 2 °C target is optimal, while other economists advocate much higher optimal targets (Nordhaus, 2008; Tol, 2002). Hof et al. (2008) showed that the differences can be

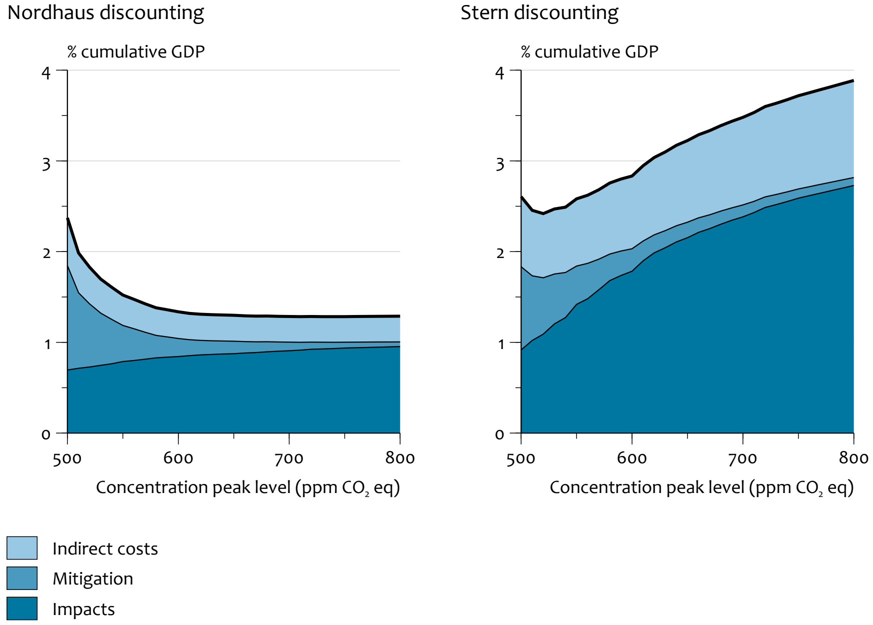
Box 2.4: Models used for this publication

The calculations in this report are based on the IMAGE integrated assessment modelling framework, consisting of various interlinked models that calculate global energy and land-use (TIMER/IMAGE), climate change (MAGICC), and the costs of climate policy (FAIR). The combination of models can be used to explore trends in the absence of climate policy, and to develop mitigation scenarios that show which combination of emission reductions would be required in order to reach different climate targets. The framework can also be used to analyse specific climate policy regimes, including different allocation rules for international emission permits.

All calculations have been performed for 24 or 26 world regions. The models cover all major emission sources and greenhouse gases, including CO_2, methane, nitrous oxide, halogenated gases, air pollutants and aerosols. The emission reduction pathways require assumptions on different reduction options as described in various publications (MNP, 2006; van Vuuren et al., 2007). In developing reduction pathways, reductions are bound by the available potential, capital turnover rates and requirements on the time period for which the concentration objective may be exceeded. As most scenarios discussed in this report assume international emission trading, emissions can be reduced in all sectors, for all greenhouse gases, and in all regions.

For calculating regional reductions and costs, the global reduction objectives are first divided between these regions based on allocation rules. The resulting regional reduction objectives can then be realised both via domestic measures and via emission trading. In general, the models provide insights into the chances of achieving the climate objectives, the contributions of the various measures, and the (regional) costs involved. The costs indicate the direct costs of climate policy.

Figure 2.7 **Total cumulative discounted consumption loss, 2001-2250**



The x-axis plots the concentration peak level and not the final stabilisation level (see Chapter 3). A 510 ppm CO_2 eq peak level corresponds to a final stabilisation level of 450 ppm CO_2 eq. Source: based on Hof et al. (2008).

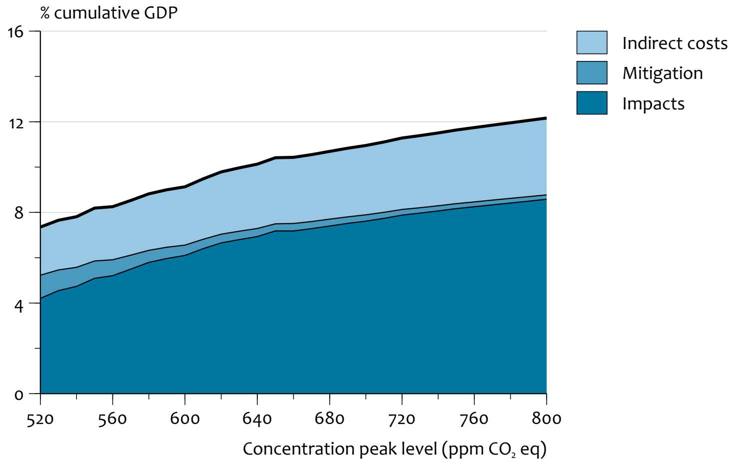
fully understood on the basis of underlying assumptions, in particular with respect to:

1. differences in importance attached to the welfare of future generations (‘discount rate’);
2. differences in the monetary estimates of climate change impacts.

The relative importance attached to costs for future generations can be easily shown by looking at Figure 2.6 again. The costs of mitigation are mainly incurred by the current generation, whereas potential climate change impacts (and thus also the benefits of mitigation) take place in the distant future. Studies which attach relatively more importance to the current generation (high discount rate), therefore, recommend less stringent climate targets than studies that award relatively more importance to future generations (low discount rate). This factor is ultimately a subjective choice, but it strongly determines the preferred outcome of cost-benefit analyses, as illustrated in Figure 2.7. This figure shows at which greenhouse gas concentration level the lowest costs occur for two discount rates: one used in the Stern report and one used by Nordhaus (all other factors such as mitigation costs and climate damages are kept equal). Depending on the choice of the discount rate, each having their supporters, greenhouse gas concentration peak levels in the whole range of 500 to 800 ppm CO_2 eq can be easily justified as

Total cumulative discounted consumption loss, 2001-2250 **Figure 2.8**

Worst case approach



Total climate cost assuming worst-case assumptions for all major uncertainties, reflecting a precautionary approach. Discount rate according to UK green book (UK Treasury, 2003). The x-axis plots the concentration peak level and not the final stabilisation level (see Chapter 3). A 510 ppm CO_2 eq peak level corresponds to a final stabilisation level of 450 ppm CO_2 eq. Source: Hof et al. (2009d).

leading to the lowest costs (more on concentration peak levels and CO_2 eq see Chapter 3).

Apart from the discount rate, the monetary estimates of climate change impacts strongly influence the results of cost-benefit analysis. These estimates differ widely, both because the effects of climate change are surrounded by large uncertainties and because scientists use different methods to value these effects. Many of the benefits of climate change mitigation, such as a reduction in the number of people exposed to health risks or loss of biodiversity, are not easily expressed in monetary terms.

Explicitly taking a precautionary approach would lead to lower preferred targets, such as the 2 °C target

Standard cost-benefit analysis focuses on best-guess values for the sensitivity of the climate system, the costs of mitigation and climate change impacts and has been criticised for this (e.g. Weitzman, 2009). An alternative monetary approach would start from the precautionary principle – and therefore focus on minimising the risks of very high climate change costs. In this approach, instead of using best-guess values, assumptions that represent the worst case are deliberately used – and the strategy that is most robust in such a situation is identified. Under this approach, lower temperature targets become more attractive, as can be seen in Figure 2.8. However, the discount rate can still play an important role (Hof et al., 2009d).

The 2 °C target as goal for climate policy

Both science and economic considerations can advise on best targets for climate policy, but the final choice depends fully on what risks society is willing to accept. Given limitations in valuating impacts and risks, it is important to always consider a more physical description of impacts as well. In selecting a target for climate policy, the importance attached to future generations and valuation of climate impacts and risks involve important value judgments. Differences in opinion on how to deal with these value judgments lead to widely different recommendations for climate change policy. The 2 °C target is not contrasted by available information on risks, nor by cost-benefit analysis, especially if a precautionary approach is chosen.

3

From climate objective to emission reduction targets

- The 2 °C target needs a statement on the certainty with which it should be achieved to make it an operational target.
- In the long run, a greenhouse gas concentration level of 400 to 450 ppm CO_2 eq is needed to keep a reasonable chance of meeting the 2 °C target. A 450 ppm level corresponds to about 20 to 70% probability of remaining below 2 °C; a 400 ppm level corresponds to 40 to 90%.
- Most emission scenarios leading to 2 °C have a peak in global emissions around 2020, at the latest.
- Global emission reductions compared to 1990 would need to be around 35 to 55% by 2050 and continue to decline thereafter.

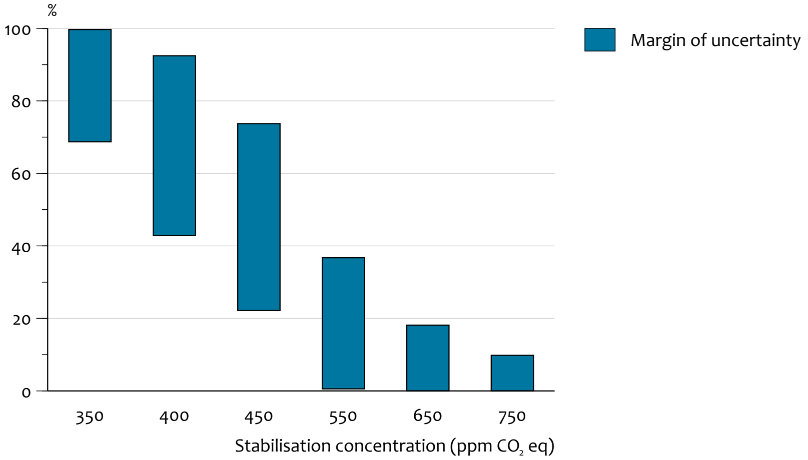
The translation of the 2 °C target into proposed emission reductions, over time, requires three fundamental steps. First, it has to be determined which greenhouse gas concentration levels correspond to a maximum increase in global mean temperature of 2 °C. This depends on the relationship between greenhouse gas concentrations in the atmosphere and temperature increase. Second, an emission trajectory has to be defined that leads to these concentration levels. Finally, the difference between this emission reduction trajectory on the one hand, and the expected emission trajectory in the absence of climate policy on the other hand, determines the necessary reduction in emissions.

3.1 From temperature target to concentration level

Given the large uncertainties in the relationship between greenhouse gas concentration and temperature, the 2 °C target needs to be accompanied with a statement on the certainty with which it should be achieved

The relationship between greenhouse gas concentrations in the atmosphere and temperature change is beset with uncertainty. This uncertainty is usually expressed in terms of the so-called climate sensitivity, which is defined as the increase in global mean temperature resulting from a doubling of the greenhouse

Chance of achieving the 2°C target **Figure 3.1**



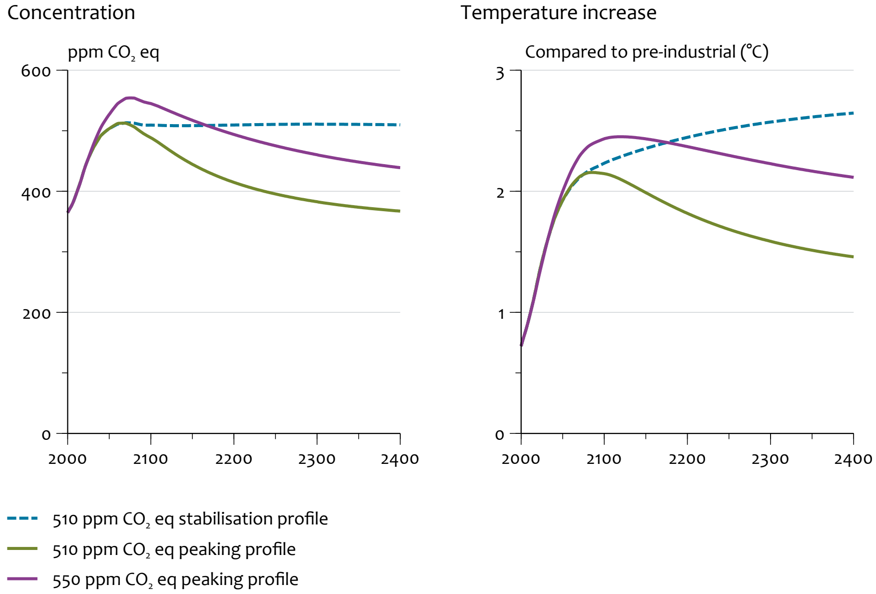
Relationship between greenhouse gas concentration and the chance of staying below 2 °C.
Source: Meinshausen et al. (2006).

gas concentration in the atmosphere. A large number of scientific studies have been published on the value of climate sensitivity, often expressing this in probabilistic terms (e.g. the value is very likely to be above 1.5 °C and below 4.5 °C). Recent research has often shown the climate to be more sensitive to increases in concentrations than was assumed earlier, although the uncertainty range remains large (IPCC, 2007a). The uncertainty in climate sensitivity implies that it is not useful to only talk about the 2 ° C itself, but that also some statement needs to be made on the certainty of meeting the target.

In the long run, a greenhouse gas concentration level of 400 to 450 ppm CO_2 eq or lower is needed to have a reasonable chance of meeting the 2 °C target. A 450 ppm level corresponds to about 20 to 70% probability of remaining below 2 °C; for a 400 level, this is 40 to 90%

On the basis of studies on climate sensitivity, the likelihood of achieving a 2 °C target for specific concentration levels can be expressed. Figure 3.1 shows the probability of achieving a certain temperature target for different concentration stabilisation levels. The concentration in the figure is expressed in so-called CO_2 eq. This means that it does not only take into account CO_2, but also other greenhouse gases and aerosols (see text box 3.1). In general, higher concentration levels provide less chance of reaching 2 °C. Interestingly, the chances of remaining below 2 °C increase rather rapidly at declining levels from 550 to 400 ppm CO_2 eq. The chance of reaching the 2 °C target is less than 40% if concentrations are stabilised at 550 ppm CO_2 eq, 20 to 70% for stabilisation at 450 ppm, and 40 to 90% for stabilisation at 400 ppm. A 400 ppm CO_2 eq level corresponds to a concentration of 350 ppm CO_2 only (see Appendix).

Figure 3.2 **Peaking versus stabilisation profiles**



Source: Based on den Elzen and van Vuuren (2007).

Concentration peaking profiles may be preferred to stabilisation profiles, as the former can achieve a better environmental performance at lower costs than the latter

There are different strategies for achieving long-term temperature targets. Traditionally, researchers have looked at the equilibrium temperature associated with a greenhouse gas concentration. However, as part of the temperature increase occurs only slowly, it takes centuries before the equilibrium temperature is reached. Therefore, part of the increase can be prevented by not allowing the temperature to reach this equilibrium level (den Elzen and van Vuuren, 2007). This can be done by reducing concentrations after an initial peak (so-called peaking profiles), instead of stabilising concentrations at a certain level. This is illustrated in Figure 3.2, by comparing a 510 ppm CO_2 eq stabilisation profile with a profile that peaks concentration at this level. The 510 ppm stabilisation scenario will most likely lead to an increase in temperature of about 2.2 °C by the end of the century, with steadily increasing temperatures afterwards (to almost 2.7 °C in 2400). If the concentration level would be reduced after stabilisation, temperature increase would peak at about 2.2 °C and be reduced afterwards. Obviously, in the peak scenario more effort is needed after 2080, leading to more costs. However, because costs are usually discounted, the costs difference so-far out in time are not so important (even for low discount rates). This makes the peaking profile the more attractive strategy of the two. It provides a much higher likelihood of staying below the 2 °C target, at only little additional costs (den Elzen and van Vuuren, 2007).

This leads to consideration of alternative peaking profiles that would allow an (very limited) overshoot of the ultimate concentration target. This is illustrated in Figure 3.2 by a peaking pathway at 550 ppm CO_2 eq. This profile leads to less long-term climate change than the 510 ppm stabilisation profile. The costs are also considerably less, because the 550 ppm peaking case avoids some additional action early-on in the scenario. Therefore, the conclusion is that, using peaking profiles, a limited and brief overshoot of the ultimate target can be allowed, benefiting from the inertia in the climate system. For meeting the

Box 3.1: CO_2 and CO_2 equivalents

Carbon dioxide (CO_2) is the most important contributor to human-induced climate change. But it is not the only gas that causes global warming. According to current insights (IPCC 2007), other greenhouse gases, such as methane (CH_4), laughing gas (N_2O), and fluorinated gases, such as HFCs, PFCs, and SF_6, together are responsible for slightly less than 60% of the warming that CO_2 causes. While the atmospheric concentrations of some of these gases are low, their impact per weight unit *on global warming is sometimes thousands of times greater than that of CO_2. As a group, aerosols (such as sulphate, organic carbon, black carbon and nitrate aerosols) are expected to have a net cooling effect – but uncertainties are large. In order to express the contribution of various gases and other factors that influence climate in one collective number, the concept of CO_2 equivalent emissions and concentrations have been created.*

The total in greenhouse gas emissions can be expressed in tonnes CO_2 equivalents (tCO_2 eq), which is commonly done by weighing emissions using Global Warming Potentials (GWPs). Current climate policies, such as the Kyoto Protocol, use GWPs to allow substitution across the different gases, as such benefiting from the increased flexibility under a multi-gas approach (van Vuuren et al., 2006). Alternative metrics have also been proposed, such as metrics that directly focus on reaching a chosen temperature target. If a substitution metric was chosen that would focus only on the long term, the value attached to short-lived gases, such as methane, would be set at a lower level. The economic impact of using alternative metrics appears to be relatively small. A change in substitution metric, if any, should preferably be introduced smoothly and in a predictable way, so that previous economic decisions do not become uneconomic.

The concept of equivalent concentrations expresses the total contribution to greenhouse gas forcing of all different greenhouse gases in the atmosphere in one collective number, by directly converting it into an equivalent concentration of CO_2 that would cause the same forcing. The equivalent concentration is measured as parts per million CO_2 equivalents (or ppm CO_2 eq). This report presents all figures in ppm CO_2 eq – unless stated otherwise. It should finally be noted that scenarios are generally named after either the peak concentration during the 21st century, the 2100 concentration, or the ultimately achieved target. In this publication, numbers usually refer to the intended ultimately achieved target – unless stated otherwise (for numbers see Appendix).

2 °C target, slightly lower concentration levels need to be considered than in the example presented in Figure 3.2. Here, the conclusions are even more obvious as for these very low targets some overshoot cannot be prevented, given inertia in reducing emissions. It is important to note that the considerations above only apply to limited overshoot scenarios. If more overshoot is allowed, the peak concentration starts to determine the temperature outcomes, and risks occur as a result of irreversible behaviour of the climate system. As shown by Solomon et al. (2009), once a certain temperature level is achieved, it takes centuries to bring temperature down again.

3.2 From concentration level to emission reduction targets

The 2 °C target requires an emission reduction, across the century, of about 60 to 65%, compared to the reference case

Many studies have been performed relating concentration targets to emissions. These studies can be divided into so-called emission profiles and emission scenarios. Emission profiles concentrate on biophysical factors only, while emission scenarios explicitly take into account societal constraints. Such societal constraints, for instance, could imply that it is unlikely that emissions will be reduced by more than 5%, annually (see also text box 3.2).

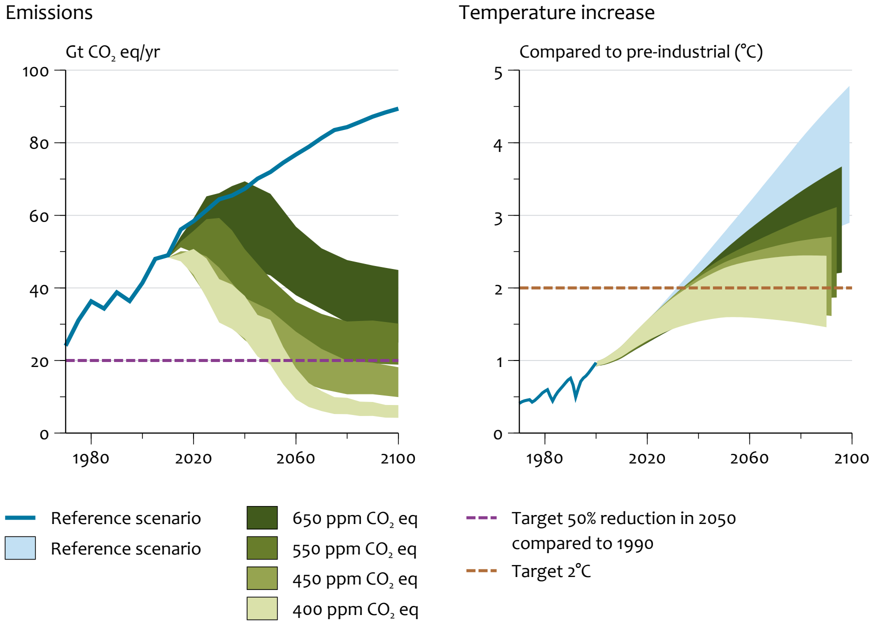
Figure 3.3 shows the bandwidth of emission scenarios leading to various concentration targets (and, thus, indicating the probability of achieving the 2 °C target). The figure illustrates that there is some flexibility in timing the emission reductions. Early emission reductions allow for a more smooth reduction over time and stimulate technology development. However, such a strategy benefits less from autonomous technological change and, in the short term, leads to higher mitigation costs. For target concentrations below 450 ppm CO_2 eq, flexibility in the timing of emission reductions is limited. If concentrations are allowed to peak at higher levels, there is slightly more room in the next decades, but relatively steep reductions are necessary, later in the century (which could even make targets unattainable) (den Elzen et al., 2007). On average, the emission scenarios leading to 400 and 450 ppm CO_2 eq need to reduce the cumulative emissions in the 21st century by 60 to 65%, compared to those in the reference scenario.

Figure 3.3 shows the implications for all greenhouse gases together. There are major differences between the gases, as is described in Chapter 4 in more detail. In general terms, some of the non-CO_2 gases will be reduced less than proportionally by the end of the century, due to lack of emission reduction options. Therefore, for CO_2, some scenarios in fact show net negative emissions – brought about by a combination of bio-energy and carbon capture and storage (CCS) or reforestation measures (see Chapter 4).

Most emission scenarios leading to 2 °C have a peak in global emissions around 2020, at the latest

For the 400 and 450 ppm CO_2 eq scenarios, analyses show that the peak in global emissions needs to be around 2020. This is illustrated by Figure 3.4, which represents an update of emission scenarios in the lowest categories leading to 400

Global emissions and temperature increase for various concentration levels **Figure 3.3**



Emission corridors and temperature consequences. For temperature, the indicated range includes the uncertainty in climate sensitivity. Source: Den Elzen et al. (2007) and van Vuuren et al. (2008).

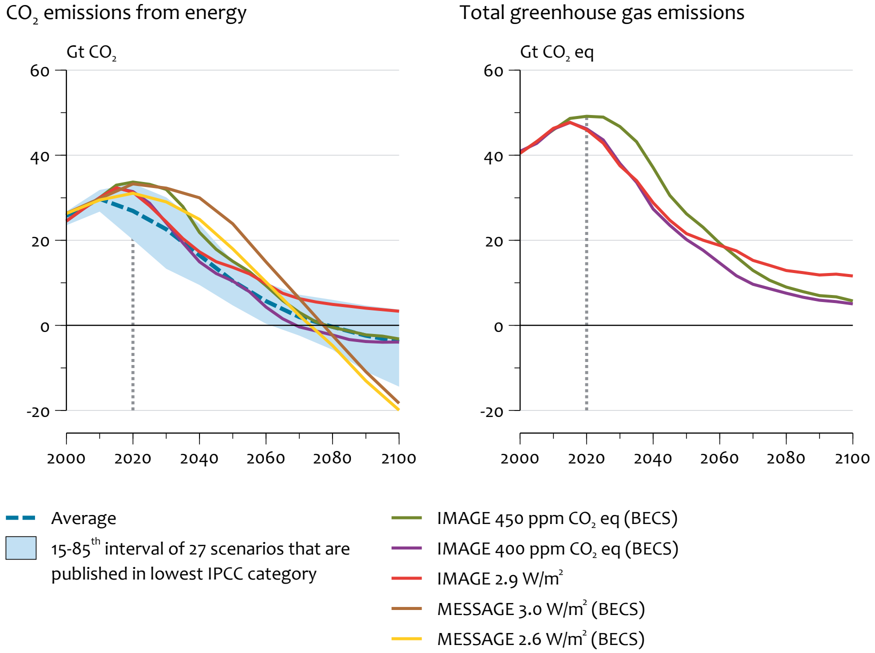
and 450 ppm CO_2 eq. The same data is also summarised in Table 3.2. In the 2015-2020 period, the IMAGE scenarios show more-or-less stable emissions so that it may be safely concluded that the peak could easily be shifted between these years. This is confirmed by the position of other scenarios in the literature that fall into this category. Clearly, there are very little scenarios that achieve low concentration targets and that have a peak in emissions far later than 2020.

The implications of a global peak in emissions as early as 2020 implies that, by that time, all major emitting countries, including the emerging economies, need to be actively involved in climate policy. This issue is presented in more detail in Chapter 5.

Global emission reductions, from 1990 levels, would need to be around 35 to 55% in 2050

Table 3.1 provides the summary of the emission reduction, over time, which corresponds to achieving the 2 °C target with a probability of 50% or more. By 2020, global emissions should be reduced by about 20 to 40%, compared to the reference scenario. By 2050, substantial emission reductions of 65 to 75%, compared to the reference scenario, are necessary. Comparing these reduction levels to the 1990

Figure 3.4 Global emissions in lowest IPCC category


CO$_2$ emissions from energy

Total greenhouse gas emissions

Source: New scenarios as summarised in Knopf et al. (2009) and Clarke et al. (2009) and new IMAGE and MESSAGE scenarios (van Vuuren et al. (2009b) and Rao et al. (2009)).

Note that the IMAGE concentration levels indicate the ultimately achieved stabilisation level (peak scenarios). The two MESSAGE scenarios represent scenarios with a comparable level of ambition. BECS indicates that the scenario includes the technology bio-energy combined with CCS.

Table 3.1 Summary of emission reductions necessary to achieve the 2 °C target

	2020	2050	2100
Emissions reduction compared to 1990	Increase 15-30%	35-55%	70-85%
Emissions reduction compared to reference scenario	20-40%	65-75%	90-95%

Table 3.2 Description of scenario literature on medium to low mitigation scenario

	Peak year	Emission reduction in 2050	Cumulative CO$_2$ emissions 2000-2050
IMAGE	~2020	35-55%	1150-1350
Literature range	~2015-2020	50% (40-85%)	1200 (825-1350)

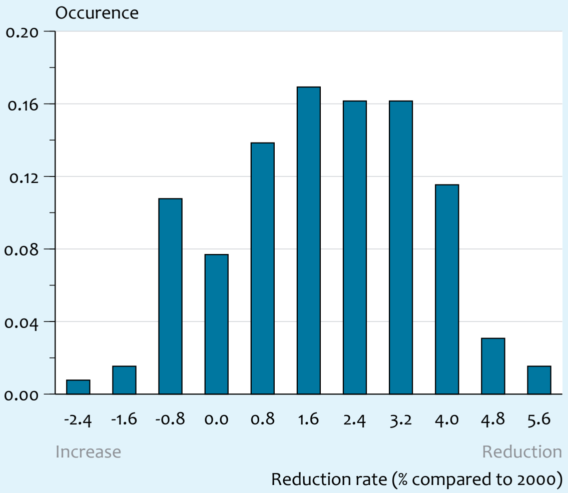
Box 3.2: The scope for delayed action

Policymakers have raised the question of whether there is flexibility in designing global emission pathways to allow for a slightly slower start in 2020. The answer critically depends on the maximum rate at which emissions can be reduced (and thus whether any delay can be undone). This is determined by factors, such as the lifetime of different technologies, and the speed at which new policies can be agreed upon and introduced. Models can provide some insight. To illustrate this, Figure 3.5 shows the occurance of different reduction rates over decadal periods within the set of scenarios that fall within the lowest category (Nakicenovic et al., 2006). The average reduction rate is 2.8% per year. Only in a very few cases, the rate of reduction over a 10 year period exceeds a value of 4 to 5% per year. In fact, models that achieve such a rate would often need to include all conceivable mitigation options.

Taking this maximum rate into account, it is easy to show that too much delay will make the 2 °C target much less likely to achieve. Focussing on the question of whether it is possible to delay the proposed 2020 emission reduction until 2030, it can be easily shown that taking the 3-4% maximum reduction rate into account, it is not possible to fully compensate for a delayed start by reducing emissions faster between 2030 and 2050. It would still be possible, however, to reach a 40% emission reduction by 2050, but with higher cumulative emissions in the 2000-2050 period. Another consequence is higher costs in 2050, but lower cumulative costs in the preceding period. In other words, a 10-year delay would make achieving the 2 °C less probable.

Greenhouse gas emission reduction rate within a set of scenarios, 2010-2100

Figure 3.5



Emission reduction rates in ten-year periods in scenarios that meet low greenhouse gas concentration targets. The numbers on the x-axis represent lower bounds. Source: Based on same references as Figure 3.4.

level implies that, by 2020, a small increase in emission could be allowed. The reduction by 2050 would need to be of the order of 35 to 55%.

This is slightly less stringent than the numbers quoted in the Fourth Assessment Report of the IPCC, or the average reduction numbers in the literature (around 50%). Regarding the former, for the assessment of the lowest category of scenarios, the numbers in the IPCC were not very representative as, at that time, only three models had explored such low targets (among which the PBL IMAGE model). Since then, many more models have followed suit and explored the low concentration ranges. The slightly lower numbers of the literature range, among other things, were caused by the question of whether models account for the possibility of negative carbon emissions in the second half of the 21st century. Another major uncertainty is the carbon uptake by ecosystems and oceans. Given these uncertainties, a necessary reduction of 50% by 2050 can be seen as a reasonable median estimate.

4

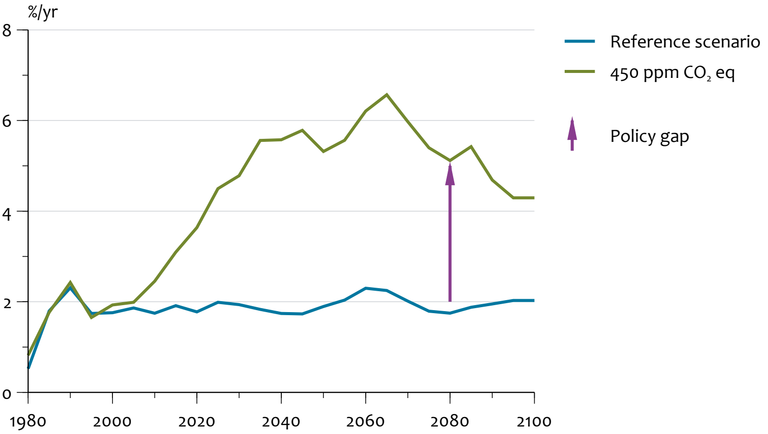
From emission reduction targets to reduction measures

- Currently, known technologies have sufficient potential to achieve emission reductions needed for reaching a greenhouse gas concentration level of the order of 450 ppm CO_2 eq by the end of the century.
- A strategy for reaching the 2 °C target will be based on a broad portfolio of mitigation measures. Important contributions may come from energy efficiency improvement, carbon capture and storage (CCS), bio-energy, renewable energy, nuclear power, and reducing non-CO_2 greenhouse gases.
- The additional costs of climate policy are likely to be around 1 to 2% of GDP.

Reaching the 2 °C target requires substantial reductions in greenhouse gas emissions (see Chapter 3). Important questions are: is there sufficient potential to realise these reductions, which mitigation measures could contribute to such reductions, and what would be the costs involved? To answer these questions, this chapter presents the possibilities of significantly reducing greenhouse gas emissions, from a global perspective. This is done by using information on reduction potentials in all sectors, and by defining cost-optimal strategies to achieve far-reaching emissions reductions. Models were used to identify such strategies.

The enormous challenge involved in achieving the emission reductions required for reaching greenhouse gas concentrations of around 450 ppm CO_2 eq can also be illustrated by looking at the ratio between income and greenhouse gas emissions. Historically, there has been a clear relationship between economic activity and greenhouse gas emissions – although there has been a constant improvement in the ratio of these two factors of around 2% per year. As shown in the figure, the ratio would need to improve by 5% per year in order to stabilise greenhouse gas concentrations at 450 ppm CO_2 eq (Figure 4.1). The unprecedented '5% rate' needs to be sustained for many decades. Therefore, the question of whether this could be achieved is very relevant.

Rate of improvement of ratio between greenhouse gases and GDP **Figure 4.1**



Required change in carbon intensity improvement to reach '2 °C' scenarios. Source: Based on van Vuuren et al.(2009b).

4.1 The potential of various emission reduction categories

Greenhouse gas emissions can be reduced in the energy sector, in the agricultural sector and by changed land-use. In addition to changes in the economic structure, there are three major ways of reducing emissions:

1. increasing energy efficiency
2. changing energy supply (using zero-carbon energy options) and implementing end-off pipe measures (CCS)
3. other reduction measures (non-CO_2, land-use change)

Various assessments have been made of the potential for reducing emissions. The IPCC's Fourth Assessment Report provides an overview of these options for different sectors (see Table 4.1). Obviously, the importance of each sector in reducing emissions depends on the relative reduction potential – but also on the size of the sector. For each sector, Figure 4.2 provides a possible projection of future emissions (reference scenario). Given the high contribution to the total in emissions, reducing emissions from energy supply is of crucial importance, followed by agriculture, transport, industry, buildings and process emissions. Below, the potential for reducing emissions is briefly described, per reduction option.

4.1.1 Increasing energy efficiency

Energy efficiency improvement is an important contribution to reducing emissions, in all scenarios

Saving energy is an important element in all climate policy strategies. Studies show that increasing the improvement rate of energy efficiency to above the projected rate, in the reference case, could achieve substantial emission reductions over the

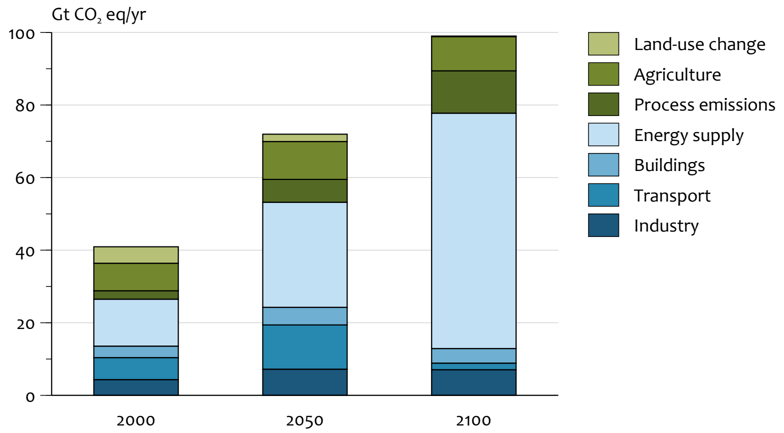
Table 4.1 Important technologies for decreasing greenhouse gas emissions

	Important emission reduction technologies and measures that are now commercially available	Important emission reduction technologies and measures expected to be commercially available by 2030
Industry	Efficient electrical devices, heat and electricity recovery, recycling and replacement of materials, management of greenhouse gases other than carbon dioxide, various process technologies	Advanced energy saving; carbon capture and storage in cement, ammonia and steel production, inert electrodes for aluminium production
Transport	More efficient vehicles; hybrid vehicles; clean diesel; biofuels; 'modal shift' to rail and public transport and to non-motorised transport; improved spatial planning and transport planning	Second generation biofuels, high-efficiency aircraft; advanced electric and hybrid vehicles
Buildings	Efficient lighting, appliances and heating and cooling; improved boilers and insulation, passive and active applications of solar energy for heating and cooling; alternative refrigerants and recycling of conventional refrigerants	Integrated design of utility buildings with intelligent energy management; integrated photovoltaics
Energy supply	Improved efficiency in production and distribution; switching from coal to gas; nuclear energy; renewable heat and electricity (water, sun, wind, geothermal and bio-energy); Combined Heat & Power units; first applications of carbon capture and storage	Carbon capture and storage for electricity generation from gas, biomass and coal; advanced nuclear energy; advanced renewable energy, including tidal and wave energy, concentrated solar energy and photovoltaics
Process emissions	Reduce N_2O emissions from acidic and apidic acid production; reduce HFC emissions	
Agriculture and waste management	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 fertilizer application techniques to reduce N_2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency; land fill methane recovery; waste incineration; recycling and waste minimization; controlled waste water treatment	Improvement of crop yields
Land -use change	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bio-energy to replace fossil fuels	Tree species improvement to increase biomass productivity and carbon sequestration; improved remote sensing techniques for analysis of vegetation/soil carbon sequestration potential and mapping land-use change.

Source: Based on IPCC (2007a)

next century, although the effect decreases after the first decades of this century. Saving energy is an attractive option, because it has many other advantages: it reduces the dependence on energy imports, it reduces the sensitivity to energy price variations, and it helps to improve the competitiveness of companies or whole sectors. Substantial acceleration in the rate of energy efficiency improvement, however, is not easy to realise through policy, because of the wide range of sectors and applications and the large number of actors involved. This is particularly valid for options concerning households and the transport sector. Moreover, improving energy efficiency may lead to lower prices of certain products, in turn, leading to increased use, thereby partly counteracting the emission reduction.

Greenhouse gas emissions by sector, Reference scenario **Figure 4.2**



In this figure, emissions are allocated to the sector in which they occur. The increase in energy supply emissions in the second half of the century, therefore, is caused by an increase in secondary energy carriers, such as electricity and hydrogen in the transport and buildings sector. Source: van Vuuren et al. (2009b).

4.1.2 Changes in energy supply

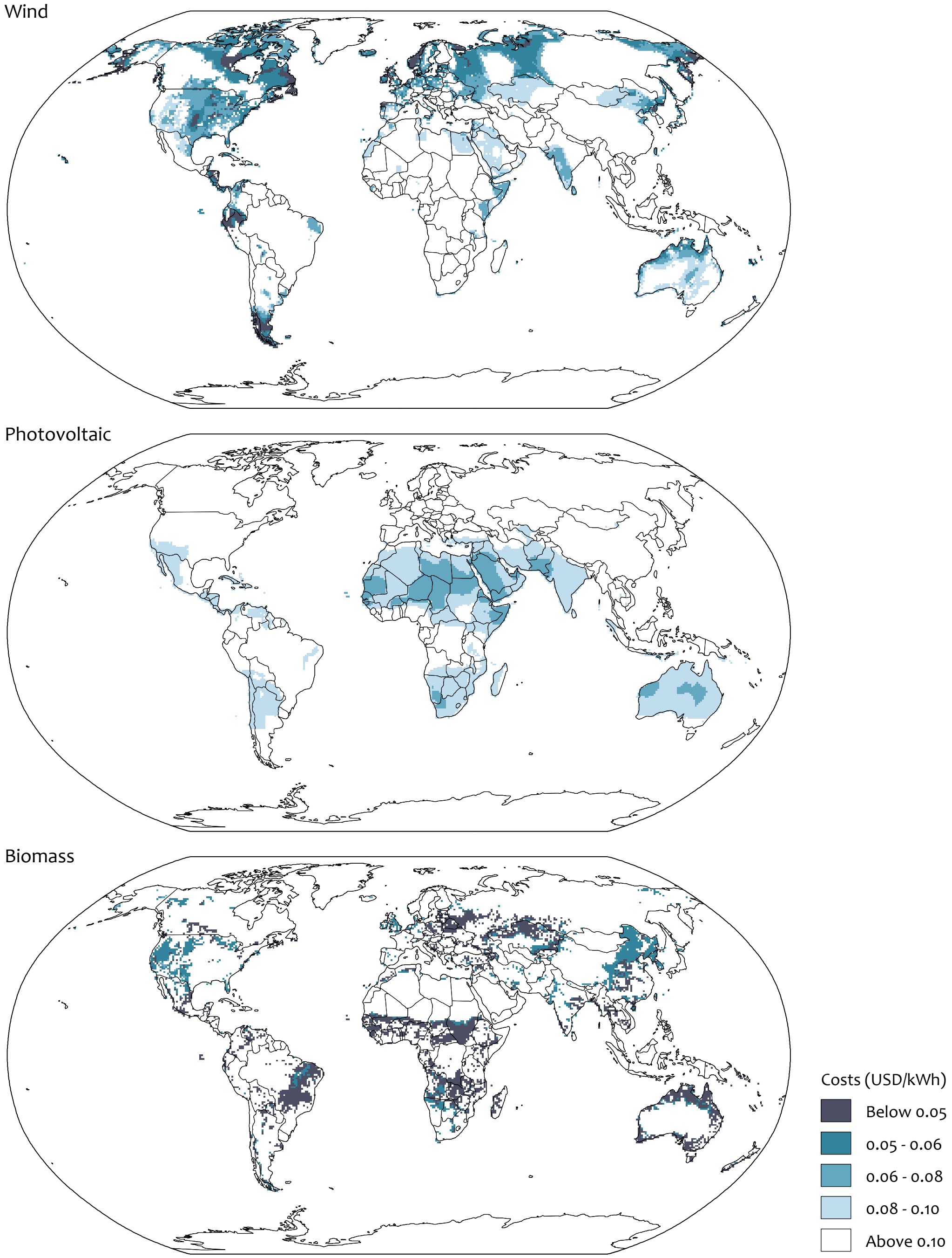
One of the most attractive forms of climate policy is to decarbonise the centralised power system

Decarbonising the central power system is attractive, because of the relatively low costs and ease of implementation. Decarbonisation can be achieved by using large-scale renewable power production, such as wind power, hydropower or concentrated solar power, bio-energy, nuclear power and/or fossil-fuel fired plants in combination with CCS. This makes stimulating the transformation to an all-electric energy system attractive, with electricity being produced – at least partly – in centralised units and distributed through a well-developed grid. For passenger transport, a transition to electric vehicles, charged from grid power points, fits into such a strategy, as well. The same argument in principle also applies to an increased use of hydrogen as secondary energy-carrier, although at the moment electricity seems to be somewhat more attractive based on costs and existing infrastructure (see Box 4.1).

In most regions, there is considerable potential for renewable energy

The potential for renewable energy is considerable in almost all world regions (Figure 4.3). For some renewable technologies, such as photovoltaics, however, costs are still considerably higher than using fossil fuels, and substantial cost reductions are required to make them economic. In the recent past, rapid cost reductions have been observed. A side benefit of renewable sources is that they can play a role in providing electricity to rural areas, where power-grid expansion is relatively expensive. According to mitigation studies, however, integration of

Figure 4.3 **Potential for renewables, 2050**



Wind

Photovoltaic

Biomass

Illustration of costs under IPCC B2 scenario. Source: de Vries et al. (2007).

renewable energy into the national power grid is likely to be more constraining for large-scale use of renewables than their potential and costs.

As a result, estimates on the future use of hydropower, solar and wind energy vary from a fairly limited role to an extensive role in future energy supply. The crucial question hereby is whether the system integration barriers can be solved. In any case, it is very likely that the amount of electricity produced by sun and wind will increase considerably, over the next few decades. Hydropower currently has the greatest share, but the potential for further expansion is relatively small. Apart from the integration problem, important challenges for further expansion would be cost reductions (particularly for solar energy) and spatial impacts and nuisance factors (the 'not in my backyard' problem of wind energy). Further technological breakthroughs, a major expansion of current grids (a super grid to connect parts of continents, and smart grids to allow dealing with intermittency) to facilitate better integration into the power grid, and public acceptance of renewable resources – in competition, for example, with nuclear energy and CCS – are essential.

Increased nuclear energy reduces emissions, but there is a trade-off with other environmental considerations

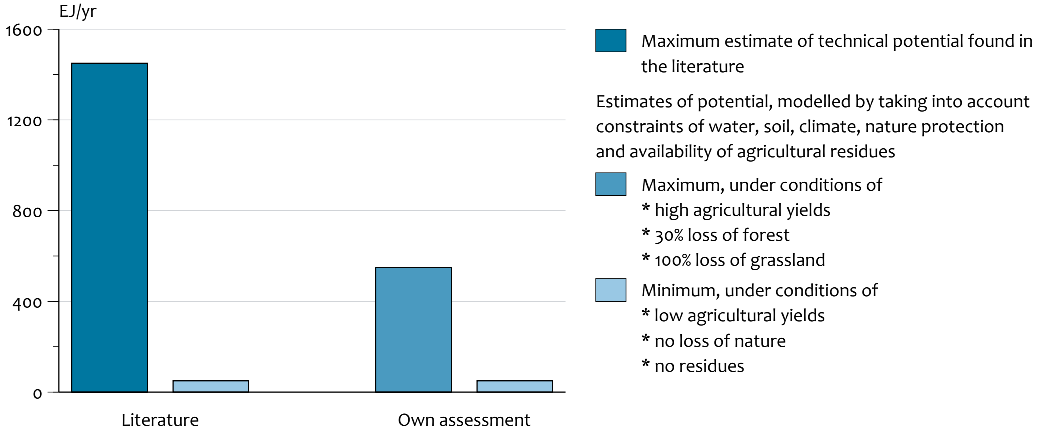
The scope for a strong increase in nuclear energy worldwide is uncertain. This is partly due to the limited social acceptance in many countries, but also because of the high investment costs involved and the long construction period required. The use of nuclear energy could be a viable option, if emissions need to be reduced drastically. This is partly due to the above-mentioned difficulty of integrating alternative energy sources (such as wind and solar energy) into national power grids. Moreover, nuclear energy could reduce dependency on oil and gas imports. It also has disadvantages, such as the risks of accidents, proliferation, and long-term storage of radioactive waste. Therefore, the potential until 2100 depends on social factors, as well as on technical ones. Current technology and proven stocks suggest that the potential is limited to 300 to 400 Gt CO_2. But new techniques and reserves could increase this potential considerably.

Bio-energy may play a key role in emission reduction, but given the potential implications for food supply and biodiversity it needs to be introduced carefully

Bio-energy – energy produced from organic materials – could be an important option in climate policy, because of its relatively low costs and ease of implementation. An important advantage of bio-energy is that it can help to reduce emissions in sectors where relatively few alternative options for emission reduction are available, such as in aviation and shipping. Moreover, bio-energy combined with CCS, in the power sector, creates net negative CO_2 emissions, as CO_2 is absorbed during the crop growth and subsequently stored.

While bio-energy, partly, can be derived from waste products, large-scale application implies that it must be derived from crops, specifically cultivated for energy production. This means that bio-energy production might become an attractive alternative in the agricultural sector. Up to now, policymakers have particularly focused on stimulating the use of biofuels in the transport sector. This overwhelming push for biofuels caused a scientific and political debate over whether they are indeed a sustainable solution. The risk of biodiversity loss

Figure 4.4 **Estimates of global bio-energy potential, 2050**



Source: van Vuuren et al. (2009c).

and the increase in food prices have dominated recent debates on biofuels. The sustainability effects of so-called second-generation biofuels, which are based on cellulosic material, are probably less severe but nevertheless largely uncertain (Eickhout et al., 2008). In order to avoid negative impacts, it seems sensible to set any ambitious bio-energy or biofuel target with great care.

The potential for bio-energy depends strongly on future developments. The potential can be high for strongly increasing agricultural yields, low meat dietary patterns, a low population, and the acceptance of natural areas being used for bio-energy production. If agricultural yields increase at a relatively low pace and strict biodiversity and sustainability criteria are applied, bio-energy potentials may be much smaller (Figure 4.4). Summarising, it can be said that despite the potential role of bio-energy use in greenhouse gas reduction, it will be important to monitor its impacts closely, given the potential negative impacts on biodiversity.

Switching between fossil fuels can reduce emissions, but its scope is very limited

Emissions can also be reduced by switching from high-carbon fuels, such as coal, to lower carbon fuels, such as natural gas. However, for many world regions, this option has consequences for the security of supply, as they would then become dependent on imported natural gas. Moreover, the potential is relatively limited: ambitious emission reduction objectives cannot be achieved without options generating far greater reductions.

If combined with CCS, the use of fossil fuel in the energy system could fit within a '2 °C policy'

Storing the CO_2 that is released by the energy supply sector and elsewhere in industry, could prove very important in the fight against climate change. This option is particularly attractive for so-called 'point sources' with large emissions, such as power plants and several industrial sectors. An important advantage of this technology is that it seems easy to integrate into the current energy infrastructure. However, large-scale application at power plants still needs to be proven, and the costs and risks of CCS are not yet entirely known, and depend on local circumstances. Worldwide, there are currently several large projects operational in the gas and oil extraction sector, and various demonstration and pilot projects are being carried out.

For emission reductions in the energy supply sector, CCS competes with both nuclear energy and renewable energy. Future cost estimates for these three options overlap, so it is uncertain how attractive CCS will be, compared to these other options. Model studies, such as those of the PBL, often find CCS to be relatively attractive – therefore, this technology may account for up to a third of the emission reductions in energy-related CO_2 emissions. In this case, large amounts of CO_2 need to be stored. This means that there would be a need for very

Box 4.1: Large scale introduction of hydrogen could also make mitigation easier

Hydrogen and electricity are both energy carriers that do not emit CO_2 at end-use (but may emit CO_2 during the production stage). Electricity already has a considerable market share – and its use is expected to grow in the future. Potentially, also hydrogen could play an important role. Based on the current costs, hydrogen is not expected to play an important role in the energy supply system before the middle of the 21st century (van Ruijven et al., 2007). However, costs may decrease considerably. By then, the transport sector may play a key role in large-scale application (important alternatives are electricity and biofuels). Other factors than costs, such as air quality, and slow development of batteries for electric cars, could potentially facilitate large-scale hydrogen use.

Whether or not hydrogen can contribute to reducing greenhouse gas emissions depends on the way it is produced. Hydrogen can be produced from renewable resources, using nuclear energy, or fossil fuels. In the latter case, hydrogen would only be a low-carbon option if the carbon from the fuel would be stored, rather than released into the atmosphere. Based on costs, without climate policy, coal and natural gas seem to be the most attractive feedstocks for hydrogen production. With climate policy, fossil-fuels with CCS seem to be attractive. Production from renewable sources is also possible, but at much higher costs. In short, hydrogen use is not likely to contribute to emission reductions without climate policy, as it would then be produced from fossil fuels; with climate policy it would allow for greater flexibility in the response of the energy system (van Ruijven et al., 2007).

large investments in infrastructure to transport CO_2. In the longer run, bio-energy combined with CCS might be an essential technology, as it allows for creating net negative emissions, which might be required to reach ambitious targets (van Vuuren et al., 2009b).

4.1.3 Other ways of reducing emissions

Reducing emissions from deforestation seems to be a low-costs mitigation measure

Deforestation, mostly in tropical countries, accounts for about 20% of greenhouse gas emissions. Expansion of agricultural area is the main driver of tropical deforestation. The costs of reducing deforestation rates are relatively low, compared to other mitigation options. Kindermann et al. (2008) estimated that, especially in the tropics, costs of avoided deforestation could be as low as 10 or 20 USD per tonne of CO_2. They estimated that reducing deforestation emissions by 50% would reduce global emissions by around 2 Gt CO_2. This implies that reducing deforestation can decrease global mitigation costs substantially. In the short term (up to 2020), the cost reduction might even by 25 to 40%.

Apart from reducing climate change, avoiding deforestation has important advantages for preserving biodiversity and related ecosystem services. The major downside of reducing deforestation is that effectuation is rather complicated, partly as a result of different interests of stakeholders (e.g. governments, local communities and timber companies). Previous attempts to reduce deforestation rates for biodiversity purposes have had a very mixed result. In addition, there is no guarantee that carbon stored by forests is permanent. It must also be ensured that deforestation and associated emissions are not merely shifted from one region to another. Hence, at the national level, well-performing governance structures, a clear definition of land ownership, as well as monitoring and enforcement mechanisms, are prerequisites for effectively reducing deforestation.

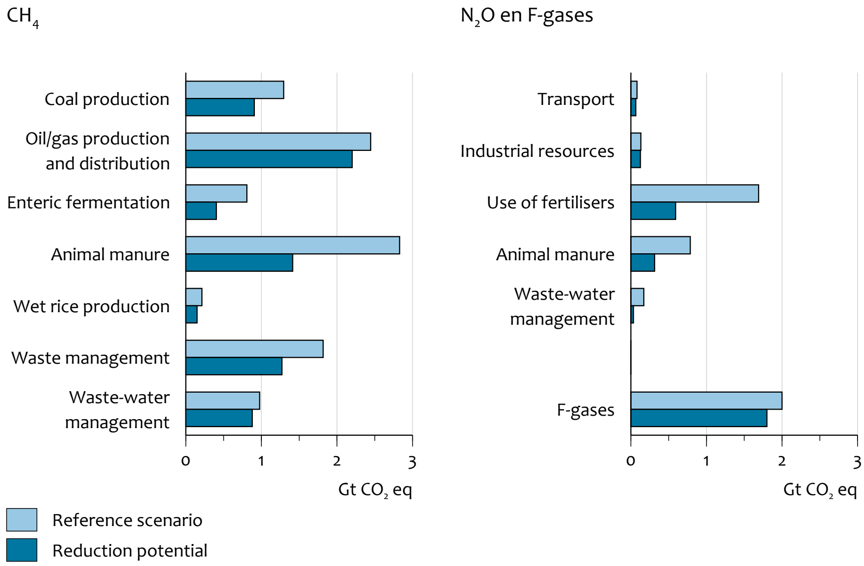
Reducing non-CO_2 greenhouse gas emissions could contribute significantly to reducing climate change at relatively low costs

Non-CO_2 greenhouse gas emissions currently account for about a quarter of all greenhouse gas emissions. This includes methane emissions from animals, rice cultivation, waste management, fossil-fuel operations, nitrous oxide emissions from fertiliser use, animals and adipic and nitric acid production, and emission of fluorinated substances. A substantial number of these emissions could be avoided at relatively low costs (Lucas et al., 2007), such as most fugitive emissions from energy production, emissions associated with waste management, industrial emissions, and part of the agricultural emissions. Reducing these last emissions is challenging, as a significant amount originates from activities of a very large number of farmers in low-income countries, making implementation of reduction measures more difficult. Still, studies indicate that, by 2050, at least half of the non-CO_2 emissions could be avoided (van Vuuren et al., 2007).

The impact of lifestyle changes is often overlooked, but can be considerable

Behaviour and lifestyle are key determinants of greenhouse gas emissions and, therefore, changes in these two areas can contribute substantially to emission reduction. Examples of such adjustments are the changing of transport modes and

Reduction potential for non-CO_2 greenhouse gas emission, 2050 **Figure 4.5**

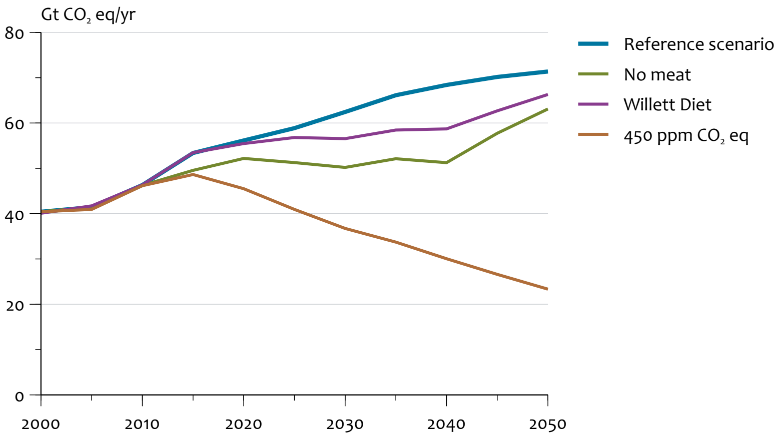


Source: Lucas et al. (2007).

using energy more efficiently. In many cases, lifestyle changes can reduce several environmental pressures at the same time. One clear example of how lifestyle changes can contribute to achieving multiple sustainability targets is through reducing the consumption of meat.

Currently, 80% of agricultural land is utilised in meat production, but accounts for only 15% of caloric intake. The most land-intensive form of meat production is that of beef. Reduced meat consumption (specifically of beef) can contribute substantially to reducing greenhouse gas emissions, both directly (by reducing methane and nitrous oxide emissions associated with animal husbandry) and indirectly by re-growth of vegetation on abandoned agricultural land. Stehfest et al. (2009) evaluated the consequences of dietary shifts, by looking at illustrative cases, in which 1) meat consumption is replaced by a vegetarian diet based on crops (using pulses and soy to replace protein intake) and 2) meat consumption is reduced to the level recommended from a health viewpoint. The latter was based on the fact that studies also show that current diets in rich countries contain too much red meat to be healthy. As such, the second illustrative case is based on the so-called Willett diet, advocated by the Harvard School of Public Health, which is based on an average daily consumption of around 10g of beef, 10g of pork, 47g of chicken and eggs, and 23g of fish. Model calculations show that adoption of these illustrative cases could theoretically achieve as much as 20 to 30% of the emission reduction required to achieve the 2 °C target (Figure 4.6). In reality, the effect may be somewhat lower than shown here, as re-growth of forests might be slower than modelled and reduced land scarcity could also lead to less price incentives to

Figure 4.6 **Impact of diet on greenhouse gas emissions**



The figure shows the impact on emissions of 2 illustrative scenarios that assume global adoption of a no-meat and healthy-diet consumption pattern. Source: Stehfest et al. (2009).

improve crop yields. Nevertheless, the effects may be substantial and decrease the costs of more traditional measures to reduce greenhouse gas emissions described in the previous chapter.

The question remains whether these lifestyle changes could be achieved. Financial stimuli (such as a meat tax) could have some effect, but considerable societal resistance can be expected. Consumer preferences have proven difficult to change.

4.2 Integrated analysis of mitigation strategies

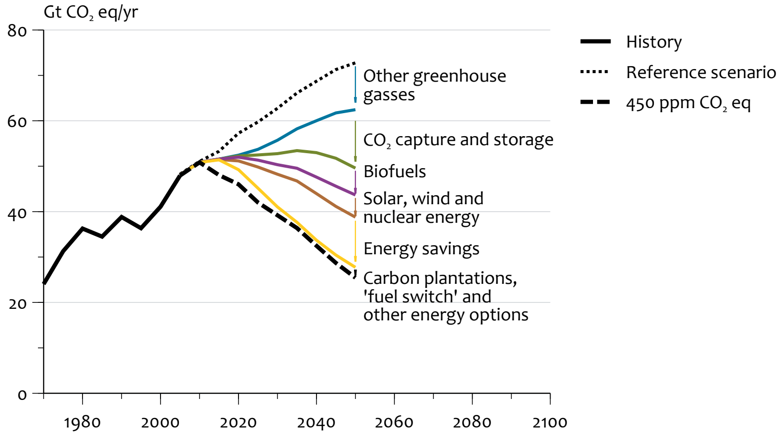
Model-supported scenario analysis allows exploring different mitigation strategies

The overview of different options suggests that, in principle, sufficient emission reduction potential is available to achieve the required emission reductions. The main question is whether these can be combined into viable reduction strategies. Models can be used to explore such strategies on the basis of different sets of assumptions. While the assessment in this report was mostly based on model calculations, it should be noted that in reality also other factors than costs play a role. This includes, for instance, the public preferences for certain measures (also see Chapter 6).

Currently known technologies have sufficient potential to achieve emission reductions needed to maintain at least a 50% chance of meeting the 2 °C target

The PBL has developed a range of different scenarios that explore the implications of low stabilisation targets under various assumptions. This includes, for instance, different reference scenarios, participation rules for different regions, and the

Contribution by reduction options to stabilise global greenhouse gas emissions **Figure 4.7**



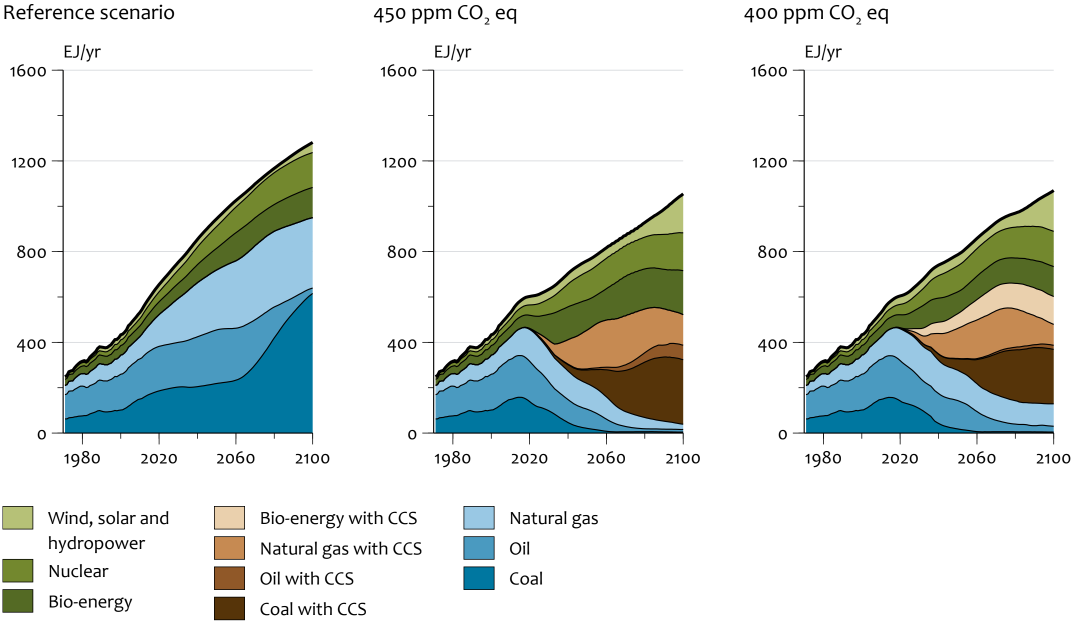
The option of reducing deforestation has not been assessed as part of this study. It could contribute to emission reductions, especially in the short-run. Source: van Vuuren et al. (2007).

costs and potential of individual reduction options. Above all, these scenarios show that, assuming global participation in climate policy, long-term greenhouse gas stabilisation levels at 450 and 400 ppm CO$_2$ eq can be achieved. Figure 4.7 illustrates, for one of the main scenarios, which mitigation options are used to bring about the required emission reductions, based on cost minimisation. Energy efficiency, CCS, large-scale bio-energy use, reduction of non-CO$_2$ greenhouse gases, and increased use of renewables and nuclear power all contribute significantly to total emission reductions. The contribution of various options changes over time: while early-on energy efficiency, reduction of non-CO$_2$ greenhouse gases and forestry options are attractive, based on their relatively low costs; in the longer run, most reductions come from changes in energy supply.

A strategy to reach the 2 °C-target will be based on broad portfolio of mitigation measures

The emission reductions are achieved by implementing a wide range of different technologies. In other words, there is no silver bullet. The wide range results from the fact that the potential of individual technologies is limited. Moreover, some technologies are confined to certain sectors or regions. A broad portfolio approach has some drawbacks, in terms of the diffusion of research investments, but the main advantage is that it leads to a more resilient policy, in case some of the technologies achieve less than promised or cannot be implemented at all.

Figure 4.8 **Global energy consumption by energy carrier**



The shown distributions are indicative examples. In the 400 ppm CO_2 eq scenario, it is assumed that bio-energy combined with CCS is available, while this is not the case in the 450 ppm CO_2 eq case. Source: van Vuuren et al. (2009b).

Excluding emission reduction options may lead to additional costs or even the inability to implement mitigation strategies that would be consistent with 2 °C target

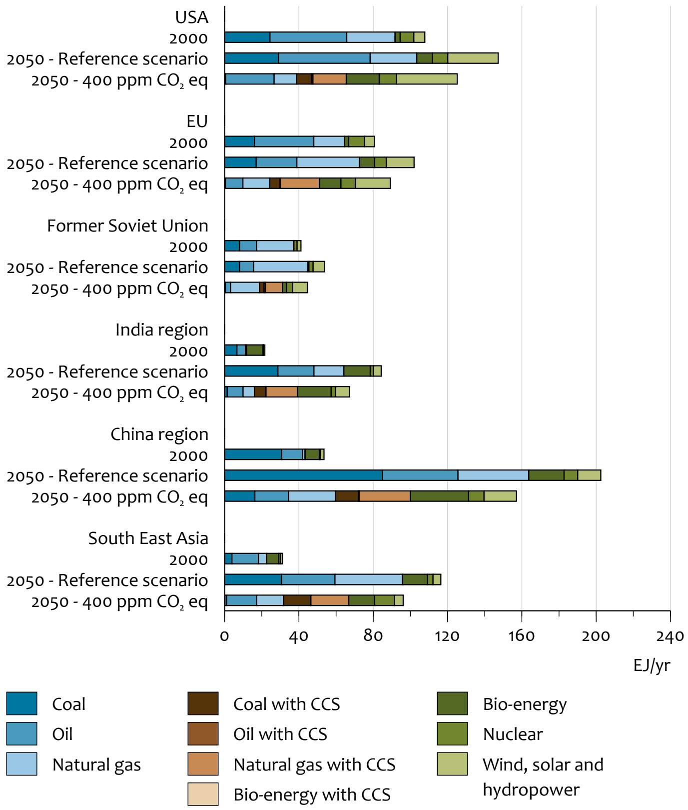
Excluding certain specific options might entail that the 2 °C target becomes very costly or even infeasible. A target of 400 ppm CO_2 eq, for instance, cannot be achieved without the availability of bio-energy in combination with CCS. Reaching a 450 ppm CO_2 eq target critically depends on a drastic improvement in energy efficiency and the availability of CCS. Other technologies are less critical for achieving the reduction targets. In the power sector, for instance, different mitigation techniques are available at relatively low costs. As a result, technologies that are not available can at least partly be substituted, with limited financial consequences.

The energy system will need to be changed totally

The energy system consistent with the 2° C targets looks very different than today's system and the one under the reference scenario (Figure 4.8). Unabated use of coal, oil and natural gas will need to be replaced by fossil-fuel use in combination with CCS, bio-energy, nuclear power and renewables. Moreover, also total energy consumption decreases significantly as a result energy-efficiency improvement. The exact contribution of different options depends strongly on technologic

Energy supply under various scenarios

Figure 4.9



Source: van Vuuren et al. (2009b).

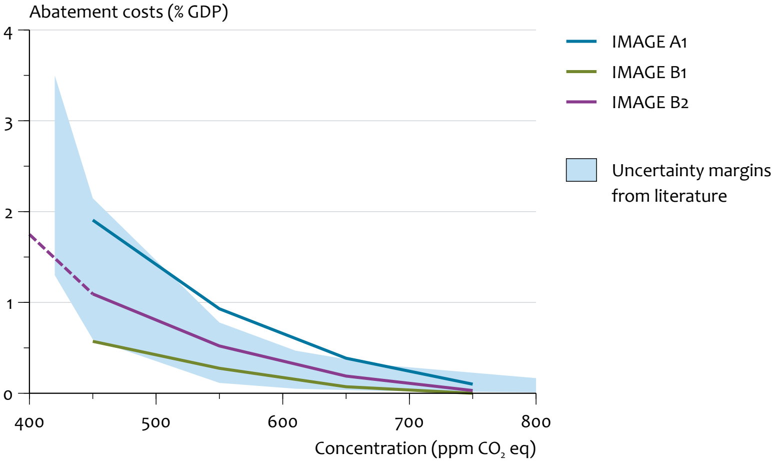
development and societal choices – therefore, the figure should be mainly interpreted as an illustration.

As shown in Figure 4.9, a similar pattern can be observed in most regions – although there are some noticeable regional characteristics that depend on the local availability of different forms of energy.

The additional costs of climate policy are likely to be around 1 to 2% of GDP per year

Investments in the energy system in the next 50 years will be considerable, with or without climate policy. Even in the absence of climate policy, the world would need to spend around 60,000 billion USD on energy supply up to 2050, to meet global energy demand. This figure amounts to about 1.5% of cumulative GDP over this period. Expenditures on the demand side are more difficult to determine, as it is hard to distinguish them from other investments (e.g. the costs of heating and

Figure 4.10 **Costs of reaching different concentration levels**



Source: Fisher et al. (2007); Nakicenovic et al. (2006) and van Vuuren et al. (2007).

insulation in a building), but they are estimated to be at least of the same order of magnitude.

Implementing climate policy measures would require a shift in existing investments, as well as considerable additional investments. Most of the *additional* expenditures (mostly in investments) would be in energy efficiency. In energy supply, there would be a shift towards investments in low-carbon options, with additional costs – at least partly – being offset by reduced energy demand. Compared to the standard reference scenario, the additional costs, in the 2010-2050 period, of reaching a long-term greenhouse gas concentration at 450 ppm CO_2 eq are estimated to be around 50,000 billion USD. This, however, strongly depends on the reference emission development, technology assumptions and the effectiveness of global climate policy. Estimates of other studies range from 20,000 to 90,000 billion USD, all assuming global participation in climate policy (see Chapter 5 for the additional costs when not all regions participate in climate policy). A central estimate of reaching a 400 ppm CO_2 eq concentration, in the long run, is about 60,000 to 65,000 billion USD in the period up to 2050 (most additional costs would be in the second half of the century). This implies that, on average, global climate policy costs in the coming decades are estimated around 1 to 2% of world GDP (Figure 4.10). This would imply a 25 to 50% increase in aggregate costs for the energy sector. The costs are in fact comparable to the current expenditures on environmental policy in OECD countries, which is also around 2% of GDP (mostly for water treatment and waste management).

The associated carbon price of meeting a 2 °C target would increase rapidly, over time. Typical values would be around 10 USD/tCO_2 in 2010, slightly above 60 USD/tCO_2 in 2020, around 80 USD/tCO_2 in 2030 and up to 150 to 200 USD/tCO_2 in 2050.

The high carbon price is particularly necessary to reduce emissions from the less-responsive sources, such as CO_2 emissions from transport or some of the non-CO_2 emissions from agricultural sources. The average costs of emission reduction is much lower, as the power sector can already reduce their emissions to virtually zero at carbon prices of 'only' 100 USD USD/tCO_2 eq. From 2050 onwards, the carbon price might stabilise around 200 to 250 USD/tCO_2 (obviously strongly depending on technology assumptions) (van Vuuren et al., 2009b).

The costs of reaching the required emission reduction will not be disruptive to the economy

The macroeconomic impacts of the changes in investments are uncertain and as a result, estimates of these impacts vary widely. Most studies show a (limited) reduction in economic growth, but a small number of studies projects a more rapid growth as a result of higher investments in research and development and high employment rates (for an overview, see Fisher et al., 2007; Stern, 2006). The macroeconomic impacts strongly depend on the way climate policy is implemented. Bollen et al. (2005), for instance, showed that macroeconomic impacts strongly depend on the size of the global coalition in climate policy, with larger coalitions and little restriction on international flexibility schemes (such as the Clean Development Mechanism (CDM)) leading to lower costs. To illustrate this, if emissions can be reduced in a large coalition, the macroeconomic impact of a 2 °C scenario could be as low as a 0.2% loss of global GDP in 2020; if, instead, the same emission reductions would need to be achieved by high-income countries, alone, costs are estimated to be around 1% of GDP (see also Chapter 5 for the impacts of broadening participation in global climate policy). Other crucial factors are the way climate policy is implemented (carbon tax, and how potential revenues of such a tax are used; cap-and-trade; regulation).

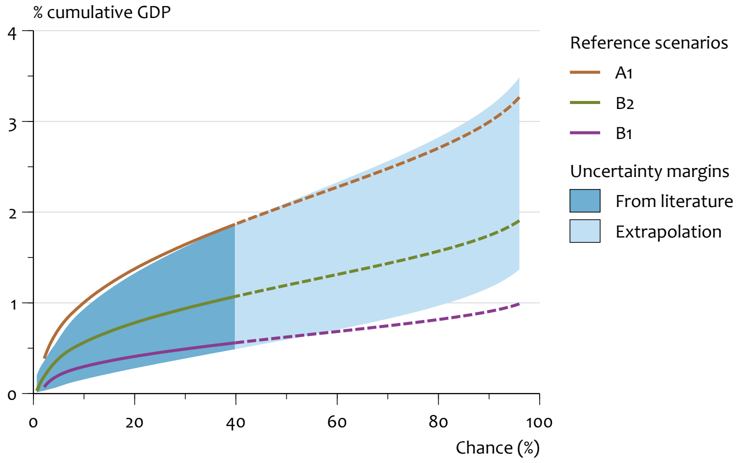
Limited by the small number of available studies, the IPCC did not provide average macroeconomic costs from the literature, but only indicated a maximum GDP loss according to the available literature of 5.5% by 2050, in order to stabilise concentrations at 450 ppm CO_2 eq (IPCC, 2007a). These studies are based on the assumption of global cooperation in reducing emissions. Some studies claim that lower losses (2 to 3%) would be conceivable when larger technological progress is taken into account (Knopf et al., 2009). As described in Chapter 5, it needs to be noted that economic costs are not equally distributed.

Increased mitigation expenditure proportionally increases the probability of meeting a 2 °C target

Figure 4.11 shows the mitigation costs for different probabilities of reaching the 2 °C target. Interestingly, the figure shows that additional investments in climate mitigation increase the probability of achieving the 2 °C target almost proportionally. In the central estimate, reaching the 2 °C target with a probability of 40% will cost about 1% of GDP; with a probability of 60% about 1.3% of GDP, and with a probability of 80% about 1.6% of GDP (Schaeffer et al., 2008). This implies that if policymakers are seeking more certainty in limiting climate change, the economic consequences would not increase exponentially – but more moderately.

Figure 4.11 **Costs versus chance of achieving the 2°C target, 2005-2100**

Cumulative discounted mitigation costs



Source: Schaeffer et al. (2008)

4.3 Synergies and trade-offs in climate policy

Many technical measures in the energy sector have an effect on various other environmental and development themes

Replacing conventional energy technologies with alternative ones can have positive impacts (co-benefits), such as improving air quality and enhancing energy security. However, certain options, such as biomass and nuclear energy, carry new risks for adverse impacts. Table 4.2 lists some of the main interactions between climate change, air pollution, security of supply, and access to clean energy services. While co-benefits can provide an important incentive in implementing emission reduction measures, associated risks could slow down implementation. Developing a broad technology portfolio is of key importance to limit known risks and hedge against uncertainties.

Climate policy can improve global security of energy supply through reduced oil dependency, although dependency on natural gas and bio-energy imports may increase

Without climate policy, oil production is expected to be concentrated further in the Middle East (while similar trends occur for natural gas). Climate policy is expected to lead to lower oil use, causing a reduction in oil imports and, thus, improved energy security for net energy importing regions, such as the United States, Western Europe, India and China. In contrast, global natural gas trade may, in fact, increase with climate policy, as it is a relatively clean alternative to coal. Also the dependency on bio-energy imports may increase, although bio-energy production is likely to be less concentrated. The net result would be that climate policy is likely

Interaction between measures to promote sustainable energy supply **Table 4.2**

	Effect on climate change	Effect on air pollution	Effect on security of energy supply	Effect on access to clean energy services
Climate change		Often positive, for example, less use of fossil fuels due to energy saving and renewable energy sources. Exceptions - some bio-energy applications (NO_x and emissions of particulate matter)	Often positive (especially with stringent climate policy) - energy savings, renewable energy, some negative impacts from switching to gas and reduction in coal use (without CCS)	The energy system could become more expensive;
Air pollution	Often little effect, because of many 'end of pipe' measures; sometimes positive, but can also be negative, such as decrease in aerosols, diminishing the regional cooling effect that partially counteracts global warming		Often little effect; limited negative effect, as a result of less use of coal and more of gas	Restrictive for electrification on the basis of fossil fuels
Security of supply	Possibly negative: use of coal and exploitation of unconventional oil and gas sources; positive - renewables, bio-energy, energy-efficiency.	Possibly negative - use of coal, less use of clean fossil fuels; positive - renewable energy		Slight
Access to clean energy services	Very little Impact; neutral/ positive if based on renewable energy	Positive, if renewable energy is used to replace traditional biomass; negative, if based on fossil fuels	Negative, if based on fossil fuels; positive, if based on local energy sources and renewable energy	

Source: Adapted from IPCC (2007a)

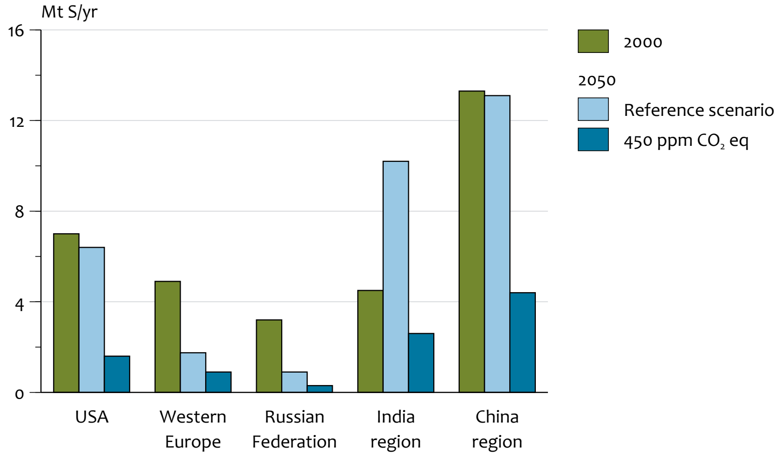
to improve energy security in countries with low coal use and high oil consumption, but worsen energy security in countries with high coal use.

Climate policies can contribute significantly to the reduction of air pollution, specifically in low-income countries

Greenhouse gas emissions and emissions of air pollutants, such as sulphur dioxide, nitrous oxides, and particulate matter, largely originate from the same activities. This implies that there could be important links between climate change policies and air quality policies. Co-benefits of air quality and climate policies depend on the type of technologies that are introduced. In transport, for instance, introduction of hydrogen and electricity would reduce the emission of air pollutants to virtually zero. Use of bio-energy, however, would only have a limited effect on nitrous oxide and particulate matter emissions. In the power sector, most climate options reduce a range of emissions, but some important exceptions exist, such as carbon capture, which leads to an increase in nitrous oxide emissions as a result of efficiency loss, and the earlier mentioned bio-energy.

Overall, however, the co-benefits of air quality and climate policies are significant. This is illustrated in Figure 4.12 that compares the emissions of SO_2 in the reference scenario with the 2 °C climate policy scenario. It shows that climate policy helps to improve air quality significantly, especially in low-income countries. From a health perspective, reducing local air pollution in these countries often has a much higher priority than reducing greenhouse gas emissions. The benefits from reduced air

Figure 4.12 SO_2 emissions, Reference and mitigation scenarios



Source: van Vuuren et al. (2009a).

pollution due to climate policy are mainly at a local level and in the short term, which would give them a higher priority for many low-income countries.

It needs to be stressed, however, that although the indirect benefits of climate policy – improved air quality and public health – could be an additional incentive for countries to participate in a future climate convention, they are too small to outweigh the costs of climate policy. Bollen et al. (2009) illustrated this for China, where they estimated the value of reduced air pollution control to be around 25% of the costs of climate policy.

There is, in fact, also one important trade-off: sulphur-based aerosols have a cooling effect: therefore, reducing sulphur emissions is likely to lead to increased warming.

Energy access is a crucial condition to improve human development indicators

Improved access to energy is a necessary condition for raising the standard of living for 1 to 2 billion people, especially in rural areas. Although there is no formal Millennium Development Goal (MDG) formulated for energy, it has been shown that other MDGs cannot be achieved without increasing access to modern energy (Modi et al., 2006). Use of traditional forms of biomass does not only limit economic prospects, but also has a negative impact on human health (due to high emissions of particulate matter) and climate change (so-called black carbon emissions are thought to be important for an additional increase in temperature in Asia). Calculations have shown that providing access to modern energy would only increase CO_2 emissions from fossil fuels by around 1 to 2%. The impact on total greenhouse gas emissions might even be negative if reduced emissions from traditional biomass use are also accounted for.

Land-use and carbon sinks, 2100 **Figure 4.13**

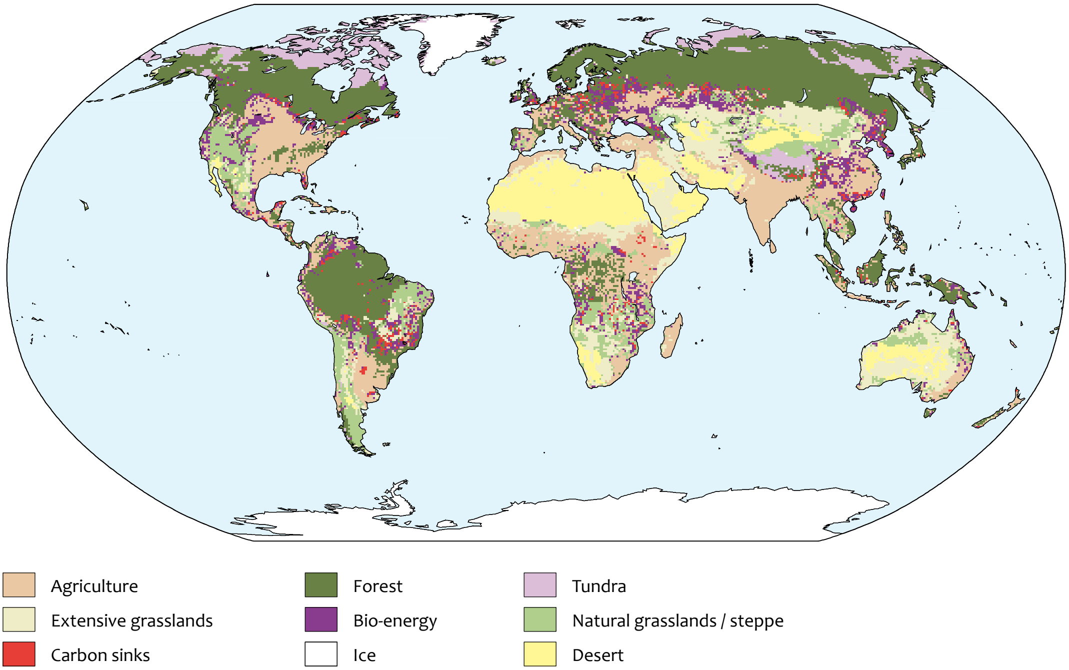


Illustration of possible impacts of climate policy on land-use. Source: van Vuuren et al. (2007).

Interactions between land-use and climate policy call for an integrated approach in protecting biodiversity, mitigating climate change and promoting human development

There are several linkages between land-use and climate policy. First of all, land-use change (i.e. deforestation) represents a major cause of emissions. Ecosystems tend to be more carbon dense and biologically diverse in their natural state, so degradation of many ecosystems significantly reduces their carbon storage and sequestration capacity. The most important driver of deforestation constitutes the expansion of agricultural land (although other drivers are important as well). Measures that decrease the demand for additional agricultural land, such as a further increase in agricultural yields, a reduction of post-harvest losses and a dietary change towards less meat-intensive diets, would contribute both to protecting biodiversity and avoiding climate change.

Several climate change mitigation strategies, most noteworthy bio-energy and reforestation policies, require land, thus, potentially further increasing competition over land. As indicated earlier in this chapter, especially bio-energy can have important consequences for land-use. Figure 4.13 illustrates this relationship by showing the land used for bio-energy and carbon sinks (reforestation) in 2100 under a 450 ppm CO_2 eq scenario. Here, bio-energy is mostly concentrated on abandoned agricultural land. In order to avoid negative impacts, it seems prudent to be cautious about setting ambitious bio-energy or biofuel targets. Monitoring impacts and adjusting policies accordingly, remains important.

5

From global to regional targets

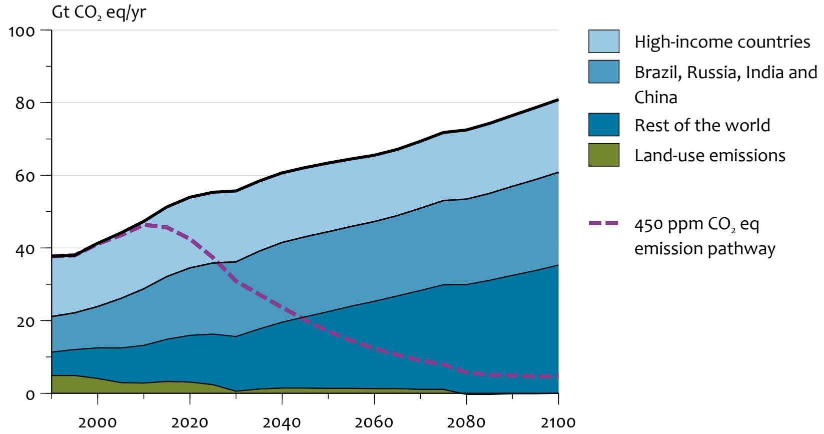
- Broadening participation in international climate policy is a key priority to keep a 2 °C target within reach.
- In order to meet the 2 °C target, high-income countries as a group should reduce emissions by 25 to 40% below 1990 in 2020, while low-income countries as a group should reduce 15-30% below their reference emissions.
- The lowest-income regions like India and Sub-Sahara Africa may benefit from participating in a climate agreement through financial revenues from selling carbon credits to high-income countries.

Climate policies need to be implemented at the regional, national or local level. For this, the global emission reductions discussed in Chapter 3 and Chapter 4 need to be translated into emission reduction targets at lower geographical scales. In this chapter, we look into regional efforts and costs that are consistent with the 2 °C target (the scale of large countries and regions is chosen for practical reasons – but the same rules and conclusions apply also for all countries). Specifically, we look into the following questions: How can a global emission reduction target be translated into regional targets? What could be reasonable ranges of reduction targets for high- and low-income countries that are consistent with the 2 °C target? What are the indicative regional costs of these reduction targets? What are the likely costs of adaptation – and can this be financed via a levy on emission trading?

Climate policy aimed at limiting global warming to 2 °C will require participation of practically all countries worldwide

The necessary emissions reductions to reach the 2 °C target can not be achieved by high-income countries alone. This is clearly shown by Figure 5.1. Reaching the 450 ppm CO_2 eq profile becomes impossible by 2025, if high-income countries reduce emissions only. And, even if all high-income countries and Brazil, Russia, India and China would reduce their emissions to zero by mid-century, remaining emissions would still exceed those that are consistent with the 2 °C target (van Vliet et al., 2009). In line with this, Boeters et al. (2007) and several other studies (for an overview, see Hof et al. (2009b)) showed that the cheapest way to reduce emissions is by a global agreement. Still, cooperation among all countries to transform the global energy system is very difficult to achieve. Negotiations are complicated by large differences between countries with respect to their historical contribution to global warming, their current levels of economic development, expected emission trends, and different regional impacts of climate change. Furthermore, international climate negotiations suffer from the free-rider problem, as the emission reductions of a single country only have a small effect on global emission reductions.

Global greenhouse gas emissions, Reference and mitigation scenarios **Figure 5.1**



Source: van Vliet et al. (2009).

5.1 Regional efforts and costs: 2020

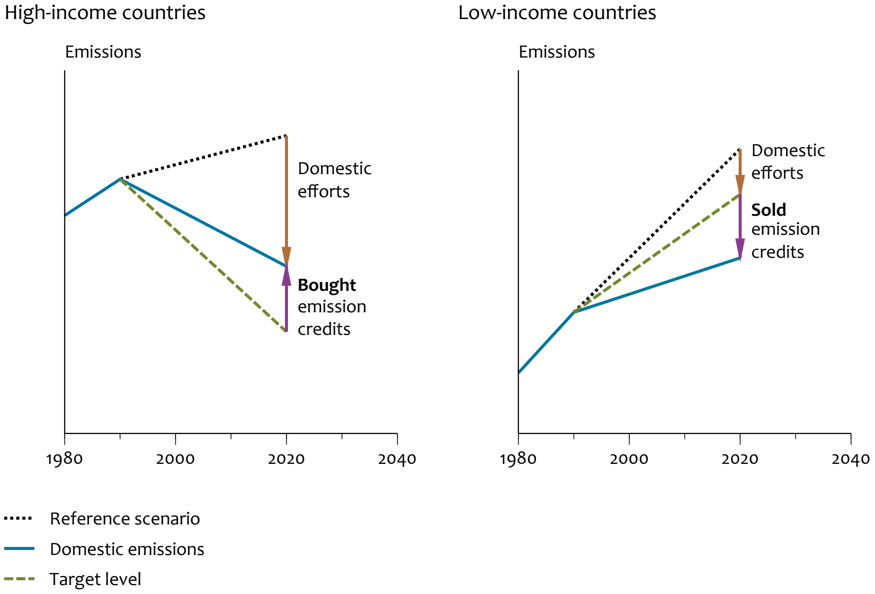
In this section we briefly discuss the emission reduction among high- and low-income countries as a group. Next, we specifically look into different proposals how to allocate reduction targets across high-income countries to meet the overall aggregated reduction target.

In order to meet the 2 °C target, high-income countries as a group should reduce emissions by 25 to 40% below 1990 in 2020, while reductions for low-income countries need to be around 15-30% in 2020 relative to their reference emissions

Chapter 3 showed that global emissions in 2020 should be less than 30% above the 1990 level to meet 450 ppm CO_2 eq in the long-term. Many studies have looked into the question how the required emission reductions should be divided across countries and different groups of countries. It should be noted that there is an important difference between the emission reduction target (assigned amount) and the actual, domestic, emissions. The use of flexible instruments (emission trading and the Clean Development Mechanism or CDM) is likely to result in a net flow of carbon credits from low-income to high-income countries. Emission reduction potential in high-income countries is thought to be more restricted than in low-income countries, while targets are often more stringent in high-income countries (see below). Figure 5.2 shows that high-income countries should be able to achieve their reduction targets in part through domestic action and in part by using credits resulting from emission reductions in low-income countries. In the short-term, the role of surplus emission allowances could still complicate the picture (see Box 5.1).

The discussion about attributing emission reductions in 2020 can be simplified by first focussing on only two groups of countries: high-income and low-income

Figure 5.2 Difference between target and actual greenhouse gas emission

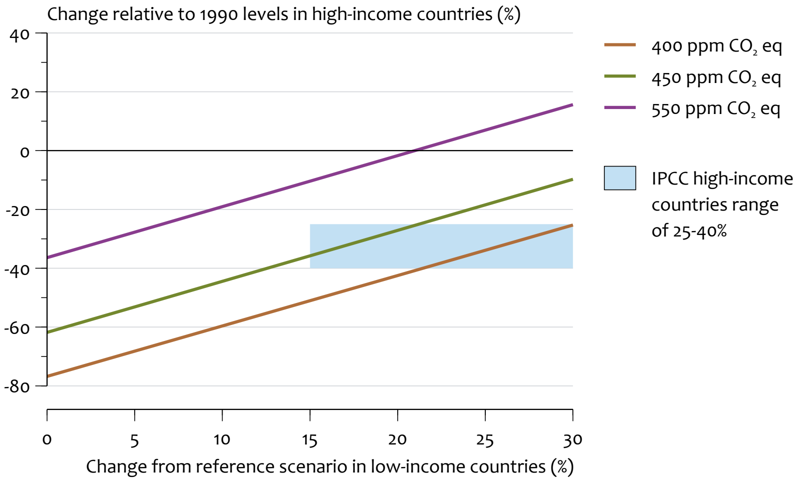


Source: den Elzen and Höhne (2009).

countries. Several papers have been published that report emission reductions for these two groups. Both IPCC (Gupta et al., 2007) and den Elzen and Höhne (2008; 2009) looked into these studies. Den Elzen and Höhne (2008; 2009) reviewed 10 and den Elzen and Höhne (2009) reviewed 19 studies for a 450 ppm CO_2 eq pathway. The reviewed studies differed with respect to assumptions regarding baseline emissions, allocation method, and global emission reduction target. The assumptions strongly influence the outcomes for high-income reduction targets in 2020. As shown by den Elzen and Höhne (2008), the 50% interval of all reported values across these studies for emission reduction targets for high-income countries equals 25 to 40% reduction compared to 1990 in 2020 (with an average of 30%). Although the specific reduction target needs to be based on an interpretation of what is fair (possibly based on specifically preferred allocation methods), this range does provide a ball-park estimate of what the literature currently suggests. Den Elzen and Höhne (2009) have analysed the effect of the assumption on the global emissions target in more detail, and considered two groups of studies: 1) ‘lower-range’ studies assuming global emissions in the order of 5 to 15% above 1990 and 2) ‘higher range’ studies assuming global emissions in the order of 20 to 30% above 1990. They concluded that the original range of 25 to 40% reduction in 2020 for high-income countries is still in the middle of all studies, but do not cover the full range. The ‘lower range’ studies generally lead to more stringent reduction targets than this range, whereas the ‘higher range’ studies generally lead to less stringent reduction targets than this range.

Trade-off between emission reductions of high and low-income countries, 2020

Figure 5.3



Source: den Elzen and Höhne (2008)

The emission reduction target for low-income countries in these studies is obviously related to those for the high-income countries. Assuming that the allocation has little impact on the global emission reduction target, there is in fact a direct trade-off, as illustrated by the straight lines in Figure 5.3. Based on their literature review, den Elzen and Höhne concluded that for a 450 ppm CO_2 eq stabilisation target, studies suggest that low-income countries together would need to reduce their emissions by 15 to 30% in 2020 relative to their reference emissions. As this target is formulated vis-à-vis the reference scenario, this means that they can still increase emissions compared to current levels. The target is less stringent than the one for high-income countries. These reduction targets are based on studies that report targets *before* the use of the flexible mechanisms like emission trading and the CDM (den Elzen and Höhne, 2009).

More stringent targets for high-income countries than for low-income countries is in line with the UNFCCC principle of common but differentiated responsibilities

The difference in emission reduction targets between the high-income and low-income countries quoted above could be seen as consistent with the UNFCCC principle of 'common but differentiated responsibilities and respective capabilities' (Article 3.1). The principle implies that high-income countries should take the lead in reducing emissions.

In this report, we assume a total reduction target for high-income countries of 30% below 1990 in 2020 and for low-income countries of 16% below their reference scenario in 2020. The total reduction target for low-income countries could be differentiated according to different equity principles, like ability to pay or potential to mitigate, so that the more advanced low-income countries reduce emission more strongly than the other low-income countries, while the lowest-income countries are exempt from reductions. There are different proposals on how to organise a meaningful contribution of low-income countries to the global emission reductions. In some cases, it might be useful to consider full participation in the international regime (allowing low-income countries possibly to take credit of their ability to sell emission credits). In most cases, alternative methods such as the use of domestic action plans seem more adequate. As the emission reduction targets for high-income countries are more stringent and will probably have a more binding character, we will below limit the focus on differentiation of commitments for 2020 on high-income countries only.

Ensuring comparable efforts among reduction commitments of high-income countries is a key issue in climate negotiations

Given the overall target of 30% below the 1990 level for high-income countries, the main question is what would be a fair distribution of efforts across these countries. One policy principle that already was supported by all countries that are parties to the Kyoto protocol is that every country should contribute based on ‘shared but differentiated responsibilities’. Ensuring such ‘comparable efforts’ among high-income countries’ commitments to reduce greenhouse gas emissions is a key issue in the current negotiations towards a post-2012 agreement on climate change. Below, we explore different ways of interpreting this term.

There are two main interpretations to comparable efforts: Equal future burden and Equal endpoint approaches

Den Elzen et al. (2009) evaluated the strengths and weaknesses of six selected allocation approaches that were selected based on the advice from senior climate negotiators and policy advisors (Table 5.1). These six approaches can be divided into two main groups: “Equal future burden” and “Equal endpoint”. All of these approaches could be interpreted as resulting in comparable efforts, but the approaches do result in different emissions reduction targets and costs, as analysed below. As already noted above, for 2020 these approaches are only applied to high-income countries.

Equal future burden approaches are based on uncertain projections and do not give credits to past actions

The equal future burden approach defines the problem as a burden that needs to be shared between the countries. The efforts to be compared relate to the level of change from the current state or from a likely reference development. The simplest example of the equal future burden approach is that all countries should reduce emissions equally relative to their reference scenario (equal reduction below reference emissions). The equal future burden approaches seem attractive as they are closest to distributing costs equally across all parties. There are, however, also disadvantages. The calculations required for these approaches are based on uncertain future reference scenarios. These scenarios will be the source of major disagreement, and there will be an incentive to inflate projected assumptions. Furthermore, they generally do not consider efforts that have been made in the past.

Strengths and weaknesses of several allocation approaches **Table 5.1**

Allocation approach	Strengths	Weaknesses
Equal future burden approaches		
Equal reduction below reference: emissions have to be a certain equal percentage below the emission level in a reference scenario	Relatively simple	Requires agreement on a reference scenario Does not take into account past efforts Leads to less stringent reductions for countries reporting high reference emissions
Equal marginal mitigation costs: countries should invest in mitigation measures up to a certain cost level per unit of emissions reduction	Widely used concept	Requires agreement on marginal abatement costs per country Ignores possible changes of lifestyle and behaviour Indicator for the effort of the last saved ton, but not for total reductions
Equal mitigation costs: same mitigation costs for all countries as share of their income	Richer nations bear more costs	Requires agreement on reference scenario and marginal abatement costs per country Ignores possible changes of lifestyle and behaviour
Equal end-point approaches		
Converging per capita emissions: countries need to reach equal levels of per capita emissions by a predefined target year (here 2050)	No reference scenario needed Simple	Not taking into account national circumstances
Sectoral approach: emission reductions are allocated based on technological standards or targets at the sector level (den Elzen et al., 2008a)	National circumstances are explicitly accommodated for Explicitly allows for economic growth at improving efficiency in all countries Aims to put internationally competitive industries on same level	Complexity of the approach requires many decisions and sectoral data, making global application a challenge, and it may be perceived as not being transparent Agreement on required projections of production growth rates for heavy industry and electricity may be difficult

Source: Adapted from den Elzen et al. (2009)

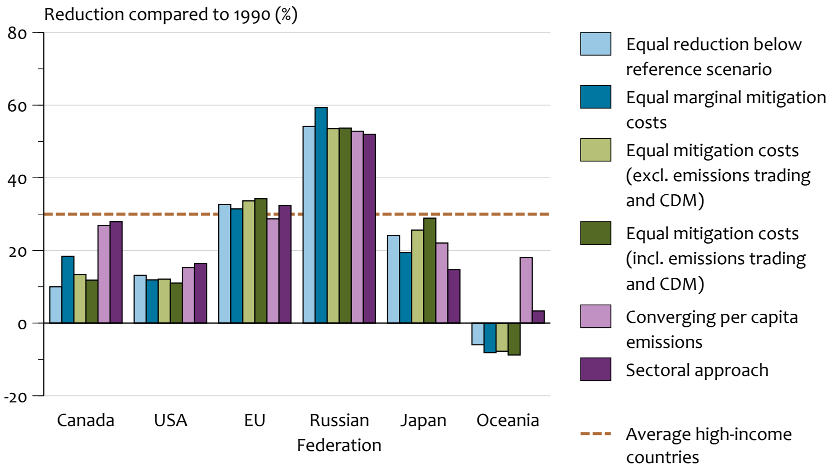
Equal endpoint approaches do take past actions into account, but are either more complex or do not completely account for structural differences in national circumstances

The equal endpoint approach looks at reduction efforts needed to reach the same state in the future. A simple common example is the converging per capita emissions approach, which requires countries to reach equal levels of per capita emissions by a predefined target year. The major advantages of these approaches are that the results do not primarily depend on a reference scenario and past actions are taken into account. This implies that countries already closer to the endpoint, including those that are closer due to efforts already undertaken in the past, need less effort to reach the target. However, disadvantages are that equal endpoint approaches do not always account for all structural differences in national circumstances. Indicators need to be defined for their implementation, and common endpoints need to be chosen. The results also depend on assumptions about reaching or missing the Kyoto targets by 2010.

Reductions by the EU of at least 30% below 1990 in 2020 could be consistent with aiming for concentrations at 450 ppm CO_2 eq, provided that other parties take on comparable effort reduction targets

The reduction targets resulting from these allocation rules are shown in Figure 5.4, assuming that high-income countries on average reduce their emissions by 30% compared to 1990. For all approaches, the reduction targets below 1990 levels are high for Russia, due to its high carbon intensity.

Figure 5.4 **Greenhouse gas emission reduction targets for different allocation approaches, 2020**



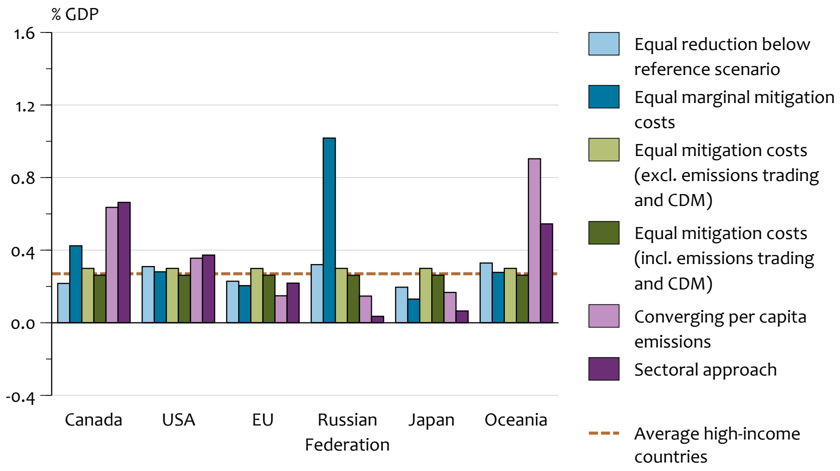
Source: den Elzen et al. (2010).

The EU would need to reduce their emissions by about 30% below 1990 levels in 2020 and the USA by about 10-15%. The reason that the targets relative to 1990 are more ambitious for the EU than for the USA is that the current (2007) emission level of the EU is already below the 1990 level, whereas the current emission level of the USA is 17% above the 1990 level (partly as a result of efforts in the past period). The targets for the EU resulting from the allocation approaches are all very similar to the EU's multilateral 30% reduction target.

Box 5.1: Surplus allowances and climate policy in the coming years

An important issue for future climate policy is how to deal with surplus of emission allowances from the Kyoto period, which is estimated to amount to more than 10 Gt CO_2 *eq. Most of the surplus originates from the economic transition in Eastern Europe and the Former Soviet Union, but currently the economic recession also has contributed to the surplus. Moreover, new surpluses could be created during the next commitment period, if again countries are given targets above their expected emission levels. Banking and subsequent use of these allowances, in the coming years, could threaten the environmental effectiveness of post-2012 climate policy. Moreover, these allowances may have a substantial impact on the price on the carbon market and, therefore, will lower the price of CDM credits, which results in decreasing revenues for low-income countries. When designing new climate policy, negotiators not only need to consider how environmental effectiveness can be guaranteed, but also how proposals affect the position of different countries. Two main options, which are currently being discussed, are 1) increasing the reduction targets of al high-income countries, including Former Soviet Union, at the end of the next commitment period to absorb current surplus allowances, and 2) reducing the use of surplus allowances.*

Mitigation costs for different allocation approaches, 2020 **Figure 5.5**



The estimated costs take into account the consequences of the economic crisis on future emissions. Source: den Elzen et al. (2010).

For Japan, the equal marginal mitigation cost approach and sectoral approach lead to the lowest reductions because of the relatively few low cost options available. For Canada and Oceania, convergence per capita emissions leads to high reductions, due to their current high per capita emissions.

Figure 5.5 shows the mitigation costs as share of income resulting from the allocation approaches. The average cost level is about 0.25% of national income in 2020. The cost differences between the approaches are particularly large for Russia and Oceania. The mitigation costs of the EU and Japan tend to be relatively small in most approaches due to their below-average emissions per capita.

5.2 Regional efforts and costs: 2050

Chapter 3 showed that in 2050, global emissions should be reduced between 35 to 55% below 1990. It is obvious that practically all countries should contribute significantly to reducing emissions (also see Figure 5.1 and Box 5.2). We discuss the potential regional reductions and costs by focussing on two alternative well-known allocation approaches: 1) convergence per capita emissions (see also last section) and 2) the multi-stage approach (den Elzen et al., 2008b).

In the multi-stage approach, targets become more ambitious as countries get richer

The multi-stage approach is based on the idea that countries can be grouped into “stages” that define different levels of commitment, ranging from “no commitment” to “fully participating in emission reduction”. The position of each country is determined by criteria that either reflect the capability in reducing emissions (measured by income per capita) or the responsibility for reducing emissions (measured by per capita emissions). Gradually, more-and-more countries would fully participate in climate policy as the countries become more developed.

As the multi-stage approach is very comparable to the current Kyoto approach and allows for defining the stages in different ways, the approach scores well on issues like flexibility, links to existing policy and the possibility of linking to sustainable development, compared to other proposed allocation schemes. The multi-stage approach looked at here consists of three stages for commitments. In stage 1, there are no commitments; in stage 2, countries adopt emission intensity targets, and in stage 3, countries adopt absolute reduction targets. Both per capita income and per capita emissions determine the stage of a country; higher per capita income and per capita emissions imply a higher stage and therefore more stringent targets.

The converging per capita emissions approach is the most commonly used allocation approach, as it is simple and transparent

The converging per capita emissions approach assumes that in a selected convergence year, the allocation across countries is such that all countries have equal per capita emissions. Over time, allocation would slowly converge from

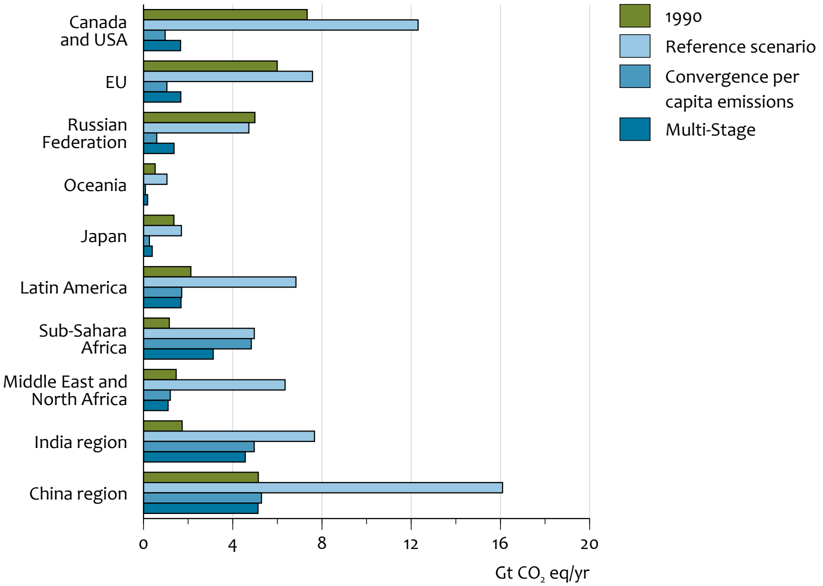
Box 5.2: Global participation is crucial for reaching ambitious climate targets

In the introduction of this chapter, we indicated that global participation in emission reductions is important for reaching ambitious climate targets. Recently, the EMF-22 study (with 10 leading models participating in the study) investigated delayed participation specifically (Clarke et al., 2009). The study analyses two extreme participation scenarios:

1. *A scenario assuming immediate global participation from 2012 onwards;*
2. *A delayed participation scenario with immediate participation of high-income countries, with Brazil, Russia, India and China commencing participation by 2030 and fully participating in 2050 and the other regions by 2050.*

The study shows that in such a delayed participation scenario, ambitious climate targets of 450 ppm CO_2 eq by the end of the century are not attainable. A less ambitious target of 500 ppm CO_2 eq is attainable under delayed participation, but at much higher costs (25 to 90%) as compared to the full participation scenario. In other words, scenarios that explore costs implications of delayed participation show considerable higher costs compared to global cooperation (such as those in Chapter 4). In the interpretation of these results, however, it should be noted that the delays explored so-far are only illustrative and in fact rather extreme (very long delay). Also, for those regions that do not participate in a global agreement, there are other mechanisms that would enhance deviation from baseline emissions projections, such as reducing deforestation. Therefore, a more general conclusion might be that some delay in participation of low-income countries will increase the costs of reaching the 2 °C target. This confirms the earlier finding that broadening participation in global climate policy is a key priority to keeping the 2 °C target within reach.

Greenhouse gas emission reduction targets for different allocation approaches, 2050 **Figure 5.6**



Source: den Elzen et al. (2008b).

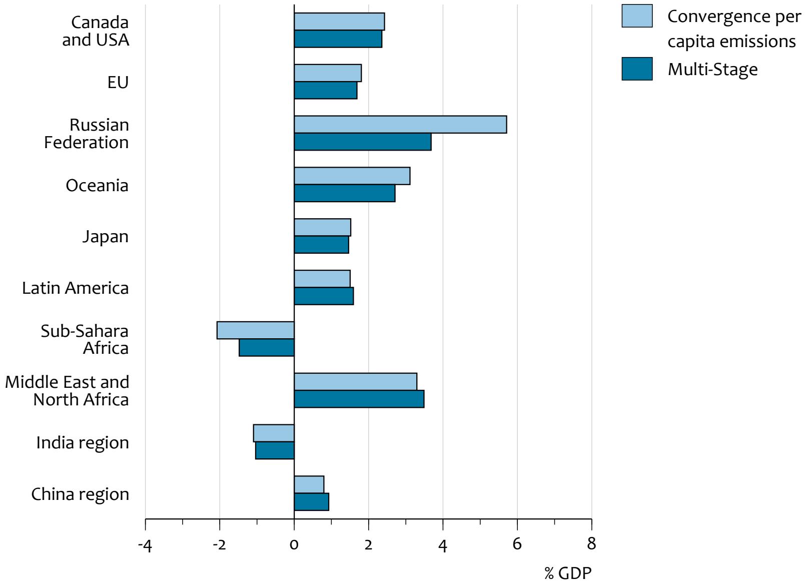
the present shares of countries in global emission to equal emissions per capita. An attractive part of this proposal is its simplicity and its direct link to fairness principles. Partly as result of this, this allocation principal has been explored most often in literature (Hof et al., 2009b). The disadvantage of this approach is that it can lead to unbalanced outcomes, as it does not take into account national circumstances, like low potential to reduce emissions.

Sub-Sahara Africa and India can increase their emissions relative to 1990 until 2050 for both allocation approaches, while all high-income regions need to reduce emissions by 80 to 90%

Figure 5.6 compares the emission reduction targets in 2050 of these two approaches for several world regions. Global emission reductions in this case are 40% below 1990 levels.

Interestingly, differences between the two allocation approaches are only small with some noticeable exceptions. In general, low-income countries have slightly more stringent targets with the multi-stage approach compared to the convergence per capita emissions approach. The general picture is the same across the regimes: emission targets are very stringent for high-income countries, while the lowest-income regions Sub-Sahara Africa and South Asia can increase their emissions substantially relative to their 1990 level. These regions have to reduce emissions relative to reference as well. For the more advanced low-income regions,

Figure 5.7 **Mitigation costs for different allocation approaches, 2050**



Note that negative costs result from the sale of emission credits either by emission trading or CDM. Source: den Elzen et al. (2008b).

such as Latin America, the Middle East/North Africa and the China region, emission targets in 2050 are almost equal to their emission levels in 1990.

Interestingly, the lowest-income regions like South Asia and Sub-Sahara Africa may actually benefit from participating in climate policy, as a result of emission trading

The regional mitigation costs in 2050 are depicted in Figure 5.7. For most high-income regions, mitigation costs are about 2% of regional income. The notable exception is Russia, for which mitigation costs are especially high according to the convergence per capita emissions approach. The reason is a combination of high emissions per capita and low income levels in this region.

The differences in mitigation costs between low-income regions are large. Interestingly, the lowest-income regions in our analysis clearly benefit from the flexible instruments used in climate policy (the CDM and emission trading), and therefore experience net gains from both approaches. For other regions, costs are around average in China and Latin America – but very high in the Middle East and North Africa, where costs will be between 3% and 4% of regional income (higher than the average of high-income regions). The main reason is the high carbon intensity of the economy in this region, combined with relatively low income levels.

The results indicate that broadening participation can be attractive for various parties, as it can reduce mitigation costs for high-income countries and can be a source of income, through the sale of emission rights, for low-income countries.

5.3 Financing adaptation costs in low-income countries

Adaptation costs are especially high for the lowest-income countries, who are particularly vulnerable to climate change

A post-2012 global climate agreement will need to pay special attention to adaptation, i.e. measures aiming at reducing the vulnerability to climate change. The importance of adaptation, especially for low-income regions, is depicted in Figure 5.8. This figure shows the impacts, measured in monetary terms as share of national income, for a scenario that is based on the 2°C target. Impacts are expressed in different ways. Residual damages indicate the remaining climate impacts after adaptation. Adaptation costs indicate the investments costs for adaptation measures. Finally, the category “extra costs without adaptation” indicates the climate change impacts, assuming that no adaptation would take place (in other words, it shows the reduction in total costs due to adaptation action).

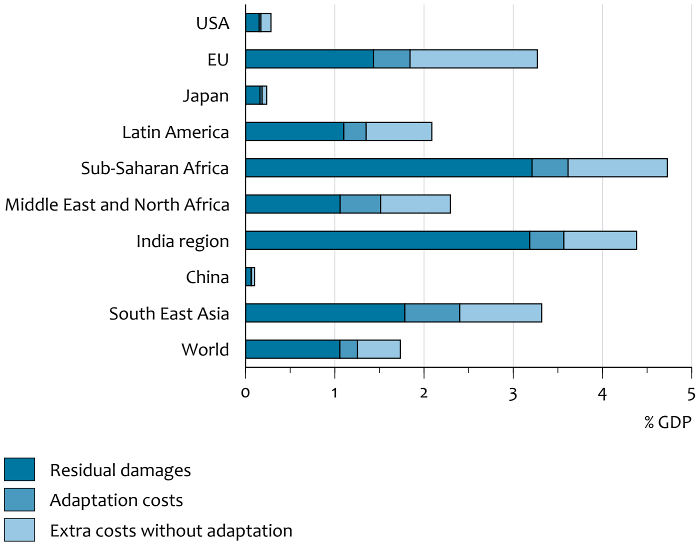
Uncertainties in impact estimates are large (also see Chapter 2). Still, models consistently project the highest climate change damages in low-income regions such as the India region and Sub-Sahara Africa. Here, costs might be in the order of 4-5% of GDP. In most cases, adaptation costs are assumed to be considerably less than the impacts themselves – but associated costs are still considerable. At the global level, investment costs for adaptation measures are estimated at between USD 40 and 170 billion, in 2030 (UNFCCC, 2007), or on average around USD 50 billion for the period from 2000 to 2050 (Hof et al., 2009a). A recent study by Parry (2009) indicated that adaptation costs could be up to three times higher.

Neither a 2% levy on CDM projects, nor a 2% levy on all emission trading, would create enough funds to substantially finance adaptation in low-income countries

The fact that the most severe impacts of climate change occur in low-income countries has led to the proposal that an Adaptation Fund needs to be established in order to help low-income countries especially vulnerable to climate change finance their investments in adaptation measures. Currently, the Adaptation Fund is financed by setting aside 2% of emission rights granted for CDM project activities. These emission rights are then sold; the revenues of which are used to finance the Adaptation Fund. It can be shown that the funds created by this mechanism are insufficient to finance even a small share of adaptation needs in low-income countries (Hof et al., 2009a). Therefore, additional financing mechanisms seem necessary.

Hof et al. (2009a) analysed the effect of broadening the scope of the financing mechanism. Instead of setting aside 2% of emission rights granted for CDM project activities only, a 2% levy is applied to all emission trading from high-income to low-income countries. The funds raised by this mechanism are shown in Figure 5.9. The funds raised in the next decade are in the order of a few billion USD, which could increase (under an ambitious climate policy scenario) to around USD 20 billion in 2050. Estimates on the adaptation costs in low-income countries by that time are

Figure 5.8 **Climate change impacts and adaptation costs, 2100**



Regional impacts are based on Nordhaus and Boyer (2000), while adaptation costs and benefits are based on de Bruin et al. (2009). Source: Hof et al. (2009a).

in the order of USD 75 to 100 billion a year (World Bank, 2009). This indicates that broadening the scope of the 2% levy to include emission trading still does not suffice to finance a substantial share of adaptation needs in low-income countries.

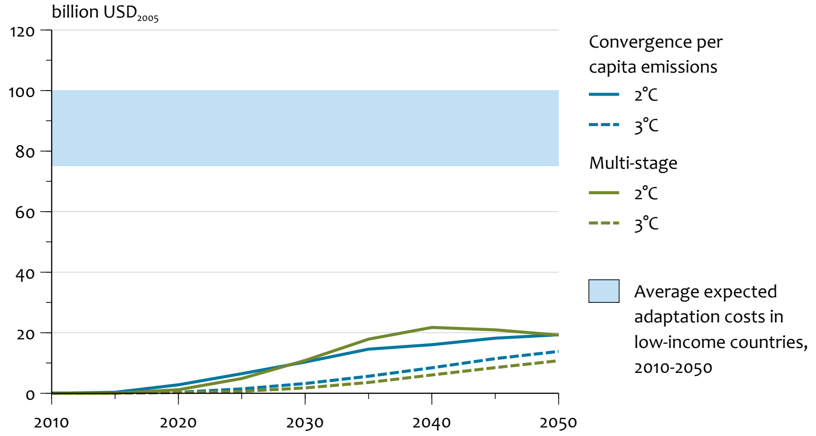
It should be noted that mitigation costs and adaptation costs need to be evaluated at the same time. Earlier, we showed that for some regions emission trading might even result in net economic gains from international climate policy. One may argue that in such a situation, gains would be weighted against the costs of climate policy discussed here (Hof et al., 2009c).

There are also alternative proposals on financing an Adaptation Fund

An alternative method of financing adaptation is to base a country's contribution to financing on the principles of (historical) responsibility and capacity to pay (measured as national income). Dellink et al. (2009) have analysed the distributional effects of this method. Figure 5.10 shows the burdens for several countries and world regions if an allocation approach would be based on both responsibility (measured either as historical contribution to warming since 1750, historical contribution to warming since 1900 and present emissions) and capacity to pay (measured as GDP). Following such a proposal, about 55% of the burden would fall on high-income countries. The difference between the indicators of responsibility is rather small: if annual adaptation costs of low-income countries are USD 100 billion, the EU and the USA would have to contribute about USD 20 billion each, Japan and Russia USD 5 billion each, and China USD 12-15 billion.

Funds raised by 2% levy on emission trading

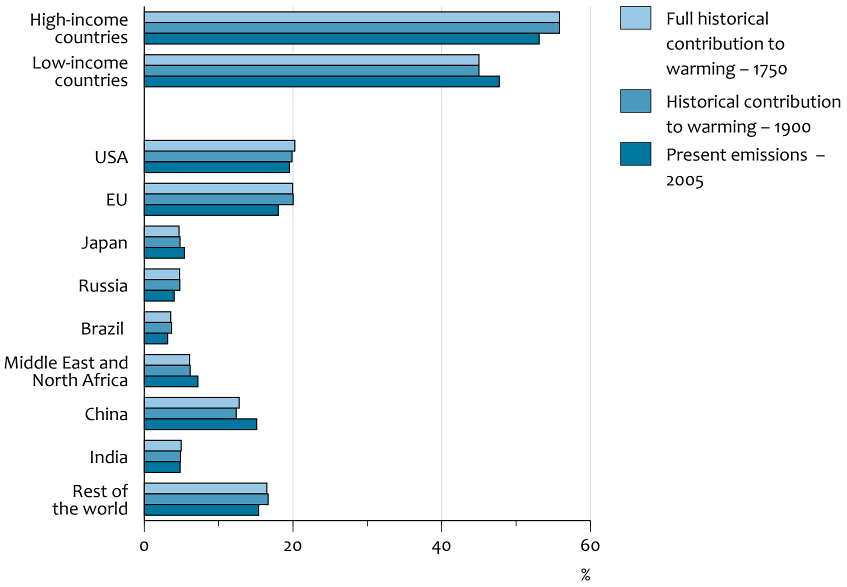
Figure 5.9



Source: Hof et al. (2009a).

Contribution of adaptation finance

Figure 5.10



Source: Dellink et al. (2009).

6

Policy instruments and implementation

While climate policy objectives are partly formulated at the international level, policies need to be implemented on a national, subnational or even local scale. The translation of emission reduction targets into national and sectoral (e.g., transport, energy, housing) policy is often specific for the national institutional context of a country. In Europe, for instance, both the European Union and national governments are the key actors, who after agreeing on a framework of climate policies have to implement these policies. Ultimately, climate policy needs to be merged with policies and ambitions in other areas. This section presents some of the lessons that can be drawn from translating climate objectives into action on a national level .

6.1 Possible policy instruments and strategies

Effective environmental policies require long-term targets, preferably strictly enforced and predictable

Given the long-term character of climate change, targets should also be formulated for the long term, creating consistent policies to achieve these targets. Such targets must define the level playing field for creative and innovative stakeholders, stimulate research and development and ensure that long-term considerations are taken into account while making short-term decisions. Many of the decisions made over the coming years will have an impact far into the future. Infrastructure takes a significant amount of time to design, to deploy and, moreover, has a long lifetime. Replacing infrastructure thus often determines the pace of development. For example, power stations and buildings that are designed and built today, are likely to still be standing in 2050. This means that restructuring the energy and agricultural systems by the middle of the 21st century, would require strong political action, in the short term. Since it is not possible to prescribe what would be the optimal technological configuration of the economic system, or the energy system in particular, a sound long-term policy would indicate the general direction, identify and invest in robust measures, and preclude unwanted outcomes, while keeping options open for a variety of technical and political solutions (PBL, 2009b). Key is to prevent a lock-in with technology that is at odds with the long-term target. For instance, energy security considerations for the 2020-2030 period, when taken in isolation, could easily lead to investment in coal-based technology that would be long-lived and incompatible with the vision for a low-carbon economy, by 2050.

Similarly, replacing carbon-intensive fossil fuels (e.g. coal) by less carbon-intensive ones (natural gas) provides some reductions, but in the long-term these are not enough to reach the ambitious reduction targets.

Interlinkages between the climate system, land-use, agriculture, energy and biodiversity, make it important to consider co-benefits and trade-offs: integrated approaches are required

There are many relationships between climate policy and other policy coals, making it important to consider co-benefits and trade-offs. In Chapter 4, we identified several of these relationships, such as the role of deforestation (causing both greenhouse gas emissions and loss of biodiversity), expansion of agricultural area (important for biodiversity, greenhouse gas emissions but also for available land for climate mitigation options) and, related to this, changes in yields and diets, the role of bio-energy (possibly reducing greenhouse gas emissions but often leading to competing land claims), emissions of non-CO_2 greenhouse gases from agriculture, and the impacts of climate change of biodiversity and agriculture. The relationships imply that there are several important trade-offs and co-benefits for climate policy and biodiversity policy. A key condition for any policy strategy is to use the synergy, not only between environmental themes, but also between the environment and energy security. This implies that integrated policy-making is needed.

A balance between market-based and regulatory instruments is needed to ensure environmental effectiveness

Various policy instruments are available in the policymaker's toolbox; for example, public procurement, tax measures, standards and regulation, and mobilisation of the private sector through subsidies or engagement in public-private partnerships (Table 6.1). In environmental policies of the last decades, a mix of market-based and regulatory instruments has been used. The effectiveness of these policy instruments depends on local and sometimes cultural characteristics of a country. A number of instruments, listed in Table 6.1, have been further explored and are described in this section. A balance between market-based and regulatory instruments is needed. While policy choices in the past have alternately favoured any of these instruments, their combined effect could harvest 'the best of both worlds', when applied in a sensible way.

Putting a price on emissions can be effective if the price is high enough to change behaviour and if it is broadly applied

Putting a price on greenhouse gas emissions is an economic standard prescription for addressing the negative externalities of greenhouse gases. A price on greenhouse gas emissions discourages the use of carbon-intensive technologies and stimulates investments and research in low-carbon technologies. Price-based instruments can contribute to reaching emission reduction objectives, while economising on the need of information gathering: policymakers do not need to pick certain technologies as 'winners', as greenhouse gas prices are inherently technology-neutral. Both a tax on greenhouse gas emissions, and a cap-and-trade system such as the EU ETS, are examples of putting a price on greenhouse gas emissions (see Box 6.1). Preconditions for the effectiveness of pricing are a broad implementation (to avoid leakage), and having a pricing level that is high enough to stimulate changes in behaviour. A major disadvantage of price instruments is that

Table 6.1 Overview and evaluation of climate policy instruments

Instrument	Criteria			
	Environmental effectiveness	Cost-effectiveness	Sharing benefits and burdens	Institutional feasibility
Putting a price on emissions	Only if the level of the charge or emission ceiling leads to changes in behaviour	Better if broadly applied; higher administrative costs if institutions are weak	Can be improved by recycling income	Often politically unpopular; difficult to introduce where the institutions are underdeveloped
Environmental standards and regulation	Emission levels are directly influenced; depends on exceptions and maintenance	Depends on design; uniform application often leads to better enforcement	Depends on a 'level playing field'; smaller, as well as new players are sometimes disadvantaged	Depends on the technical capacity of institutions
Research and development	Depends on consistent financing; long-term benefits are possible	Depends on the design of the support and the amount of risk	Advantage primarily for participants; probability of bad funding allocation	Requires many different decisions; depends on research and development capacity and long-term financing
Information provision	Depends on acceptance by users; most effective in combination with other measures	Potential for low costs, but this depend on design	Can be less effective for particular groups that have no access to information (such as those on low incomes)	Depends on cooperation with the business community and social actors
Removing perverse subsidies	Only if the level of the removed subsidy leads to changes in behaviour	Could be very high, as it reduces government spending	Disadvantageous for the affected	(Very) unpopular among the affected

Source: Based on IPCC (2007b)

the focus is on efficiency rather than environmental effectiveness; in other words, it does not always guarantee that environmental objectives will be reached.

Standards directly influence emissions and can encourage innovation

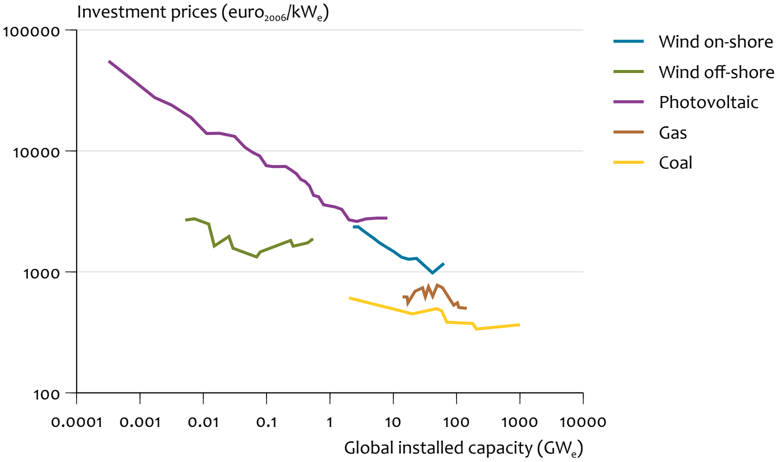
Progressive environmental standards for products help to clear the market of products that do not meet these standards (PBL, 2009a). Such standards can be applied to a broad range of products. For instance, the EU applies emission criteria to cars and electric appliances. Strict and long-term standards define the economic playing field and ensure distributional equity, while market forces would help to ensure that these conditions are met with maximum efficiency and innovative creativity within this playing field. Such a strategy would encourage experimentation, learning and innovation, rather than by 'picking (technological) winners'. This leaves enough creativity in the market and civil society to find appropriate solutions.

Direct regulation of consumption is a sensitive issue, but could force fundamental changes in consumption patterns

Directly influencing consumption patterns by means of consumer quota (e.g., the phasing out of all inefficient incandescent light bulbs in Australia), is in most countries a rather sensitive issue (PBL, 2009a), but it could help to force a change in regular routines and to bring about fundamental changes rather than incremental improvements. Governments can also increase their spending on public procurement, that is, on items that show up directly on their balance sheets, such as government buildings and infrastructure. Such spending could also be part of a green recovery package, if priority is given to measures which bring about direct

Experience curves of energy supply technologies

Figure 6.1



Source: Junginger et al. (2008).

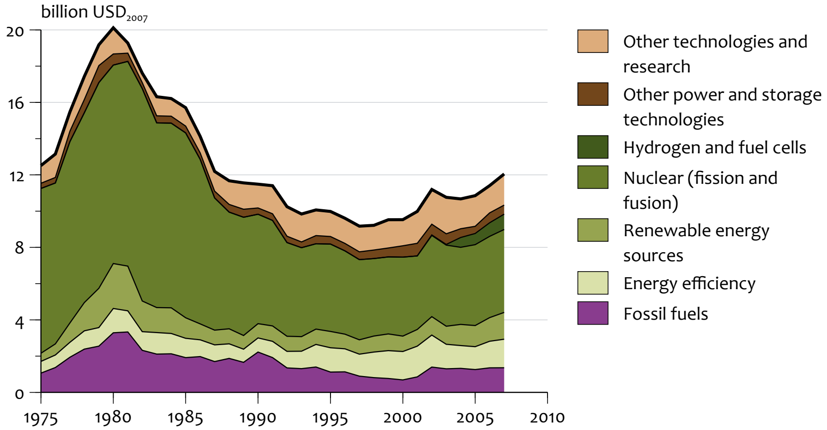
or indirect climate benefits or reduction of land-use, such as investments in public transport, power grids and energy efficiency (Edendorfer and Stern, 2009).

R&D can especially be worthwhile in early stages of technology development and in complex and large-scale technologies

There is considerable potential to decrease greenhouse gas emissions through the application of a range of technologies that are already known and available, but the rate of implementation has to be stepped up, considerably, if important pilot technologies are to play a significant role, by 2050. In order to stimulate technology development, policies may be targeted at different stages within the innovation chain, ranging from basic research and development to market introduction and the set-up of suitable infrastructure. In general, the more advanced the stages of development and deployment, the larger the role of private investors and the impact of greenhouse gas pricing. During the early stages of technology development, public R&D funding plays an important role. The knowledge created by R&D exhibits the characteristics of a public good, and thus tends to be underfunded. For complex and large-scale approaches, such as CCS or centralised power production using concentrated solar power, demonstration projects can prove their viability and reduce risks, thus being an important intermediate step towards commercialisation.

Many renewable technologies are presently still relatively expensive, but generally show fast learning curves (Figure 6.1). Learning curves allow for an investigation into the necessity for learning investments, that is the expenditures required to bridge the gap between power production costs of new technology and baseline costs of the incumbent technology, until a competitive break-even point is reached. Although there is no proof of policy accelerating technology learning processes through public R&D investments, financial policy measures could stimulate extra

Figure 6.2 **Public research and development energy investments**



Source: IEA, 2009.

market volume, which in turn drives down production costs (Junginger et al., 2008). However, while general R&D levels in OECD countries have slowly increased over the last decades, public investments in energy R&D have decreased for more than two decades, only modestly recovering in the last years (Figure 6.2). Moreover, the spending on research hardly seems to reflect model results on key technologies that will reduce emissions in the future (compare Chapter 4). For instance, while analysis of successful mitigation strategies generally finds an important role for improving energy efficiency, expenditure on energy efficiency R&D is relatively low.

Providing information might help voluntary changes in lifestyles and can play an important role in reducing the perceived costs of ambitious mitigation policy

Providing information could help achieving voluntary changes in lifestyles and values (e.g. changes in dietary patterns, choices in transport modes), which could have a significant impact, as well. Changes in lifestyles and values may also increase public acceptance of the necessary changes implied by a low-carbon society, in a more general sense, for example, including the large-scale introduction of new technologies, or political acceptance of costs resulting from ambitious climate policies. To make the necessary lifestyle changes, consumers need to be aware of the emission contents of the products they consume (e.g. via product labelling), willing to reduce these emissions, and have alternatives at hand. Product labelling, campaigns to raise awareness, and public discussions, are policy instruments to achieve voluntary lifestyle changes. While voluntary lifestyle changes would not be sufficient to achieve low stabilisation, they can play an important role in reducing the perceived cost of the ambitious mitigation programmes that will be required.

Removing perverse subsidies provides room for a sustainable development strategy

Many subsidies for fossil-fuel use and for resource depletion through mining, forestry and fishing, are embedded in national policy architectures. Such subsidies have been named perverse given the fact that they work against government objectives to reduce greenhouse gas emissions. Examples of this situation are tax exemptions for aeroplane kerosene or state support systems for fishing fleets. It has been estimated that annual global costs of public subsidies in the energy and industry sectors amounted to about 520 billion euros in the 1990s, accounting for 2% of world GDP. Close to half this amount went to the energy sector, mostly targeting production in industrialised countries, while supporting consumption in low-income countries (van Beers and de Moor, 2001). Currently, price and production subsidies for fossil fuels amount to over 200 billion USD per year, globally (UNEP, 2009). For a global sustainability agenda, such subsidies clearly require reform to fully take into account the global commons.

Large investments in energy infrastructure will be required in the future, in any case, providing a window of opportunity for including renewable energy technologies

Investments in the energy infrastructure will be considerable, even in the absence of climate policy. IEA, for instance, estimated global investments for development and replacement of energy infrastructure at 200-300 billion euros per year in the coming decades (IEA, 2003, 2008). The promotion of renewable electricity requires a grid infrastructure that is adapted for this. A key issue, in this respect, is the large and hard to control fluctuation in power production, which requires additional storage and grid capacity or back-up production facilities. This can be solved on the local scale by so-called smart grids, which allow for a rapid balance between electricity supply and demand. At the same, time, providing better large-scale connections across (or even between) continents (sometimes called super grid) also allow for a much better penetration of renewables as it allows for connecting areas with high renewable energy potential to load centres, and a better absorption of fluctuations in demand. Governments can play a key role in this, by investing or actively promoting investments in these new grids.

Text box 6.1 Cap-and-trade schemes versus international carbon taxes

Market based instruments, such as carbon taxes and cap-and-trade systems, have been advocated as cost-effective instruments for reducing emissions. In principle, both instruments allow involved stakeholders to identify options for reduction at the lowest costs possible. The effort sharing is independent of the instrument chosen. With a tax system, it is the redistribution of tax revenues that determines the costs for stakeholders; in a cap-and-trade system the allocation of emission rights is crucial. There are some differences, however. Carbon taxes provide more certainty about the mitigation costs, and caps are a better guarantee for a specific emission outcome (Newell and Pizer, 2003). Both systems have passionate advocates and opponents, depending on the preference for more certain economic outcomes or more certain environmental outcomes. In the short term, it makes sense to build on already existing systems, most notably the cap-and-trade systems in the EU and the United States. In future arrangements, more hybrid systems may be considered, for instance, a cap-and trade system that allows for banking of emissions, or a trading system with minimum and maximum emission permit prices as safety valves (Jacoby and Ellerman, 2004).

It should be noted that incorporating decentralised power production in the energy infrastructure is not only a technological issue, but also an institutional challenge to allow for power feedback mechanisms, and to elaborate coordination and grid control mechanisms (Faber and Ros, 2009). In Germany, an advanced feedback system for renewable energy production has been institutionalised, including pre-determined tariffs that are secured for the long term, and the gearing down of regular production facilities at times when sustainable power production is high. Also here, governments can play a leading role by setting up such systems.

6.2 Implementing policies on different scales

The previous section provided a list of possible policy instruments to achieve the ambitious emission reductions necessary to meet the 2 °C target. This section provides a concrete example of climate policy, focused on the EU and, more specifically, on the Netherlands (as an example of the national level).

European-wide policies imply a more limited role for domestic policy-making

In December 2008, the Council of the European Union and the European Parliament agreed on a substantial policy package on energy and climate change. This package aims at realising the European energy and climate targets. It includes guidelines for i) adjusting the European emission trading scheme (ETS), ii) renewable energy, iii) CO2 capture and storage, and iv) CO2 standards for passenger vehicles. Some sectors are not included in the European emission trading scheme. For these sectors, the package contains a decision on emission reduction targets for each Member State, separately. Below, these guidelines have been explained further.

Sectors included in the ETS are the energy-intensive industry and the energy sector, covering about 50% of total European emissions. These sectors have to reduce their emissions by 21% between 2005 and 2020, with possibly more stringent targets based on international agreements. This emission cap is set at the EU level, without distribution over the Member States. The trade in emissions, combined with limited availability of emission rights, means that emissions in the ETS sectors are reduced Europe-wide. This implies that the possibility of domestic climate policy for the ETS sectors is very limited.

Sectors not included in the ETS have a Europe-wide reduction target of 10%, between 2005 and 2020, which, again, may become more stringent dependent on international agreements. Agriculture, transport, and the built environment are sectors not included in the ETS. For the Netherlands, the reduction target for these sectors is 16%. For sectors not included in the ETS, Member States will have to implement measures on a national scale to reach their targets. This is supported EU-wide through measures, such as for housing, appliances, cars, and labelling systems. Moreover, Member States can buy a limited amount of CDM emission rights to fulfil their requirements.

The European target for renewable energy is 20% of total final energy demand, in 2020. There is a specific binding target for each Member State. For the Netherlands this is 14%. For the transport sector, there is a separate target for renewable energy of 10% of total energy demand, in 2020. These national targets imply that domestic climate policy plays an important role for renewable energy.

EU policy is also promoting the use of CCS. New power plants with a capacity of 300 MWe or more have to be 'capture ready'. Furthermore, power companies have to identify possible locations for storage, possibilities for transporting CO2, and options for making current power plants suitable for the capture and storage (retrofitting). Finally, a maximum of 300 million emission rights will be available for financing up to 12 large-scale demonstration projects (both for CCS and renewable energy).

Having separate national targets for renewable energy and energy savings may be useful, in view of implementation and promoting other goals than climate policy, but could also increase costs

In order to achieve the above-mentioned targets, a variety of measures have been planned. These include standards for biofuels in transport, (voluntary) agreements between government and sectors, subsidies (e.g. for renewable energy) and research. A recent evaluation of these planned policy measures showed that the domestic targets are difficult to achieve in the Netherlands (PBL, 2009c). While the European target, for the Netherlands, for the non-ETS sectors (16% below 1990 levels, by 2020) is within reach, achieving the national target of 30% below 1990 levels, by 2020, seems more complicated. This also applies to the domestic targets for renewable energy and energy savings. Moreover, achieving these separate targets for renewable energy and energy savings, can only succeed with additional policy measures at relatively high costs (ECN, forthcoming).

The above discussion shows that setting different target levels (global, European and national) may complicate climate policy and increase costs. However, some targets, set by national governments, aim to realise more than mere emission reduction (e.g., energy security) and, therefore, may be preferred. The cost-optimal strategy for reducing emissions which is often assumed in models, will thus not be realised in reality. This may lead to higher costs, but also to additional benefits.

Long-term targets and synergies with other policy domains seem to be the most important success factors for implementation of climate policy

Concluding, one of the most important aspects of climate policy seems to be long-term targets to create predictable policies. Several policy instruments are available to achieve a transition to a low-carbon society, each with their own advantages and disadvantages. For the EU, specifically, there is a shift from national policies to policies at EU level. Implementation of policy instruments needs tremendous attention, because of:

- Prevention of technology lock-in;
- Improving support for ambitious policy;
- Keeping costs manageable;
- Moving away from existing interests.

A well articulated set of long and short-term targets can contribute to ensure these issues. The necessary changes require awareness and acceptance of the urgency of the problems.

Furthermore, synergies with other policy targets should be sought. For governments, climate policy is only one of many. For energy, for instance, which is one of the most important policy domains for climate change, often a triangle of policy targets is used. Apart from climate change targets, and other environmental targets, security of energy supply and reasonable costs for end-users are the most pronounced targets for policymakers. Another example is stimulation of domestic innovation, which is often applied to increase (future) employment. Targets of energy policies vary per country. Climate policies also interact with land-use and agricultural policies, with industrial and innovation policies, with transport policies and with energy security polcies. Hence, realistic climate policies should aim to balance national policies of all countries involved, and to balance all policy areas. This is a huge challenge – which needs to be accomplished in order for climate policies to succeed. It is important to realise, however, that important synergies exists between climate policy and other policy areas, in particular air pollution and energy security.

Climate policy requires all stakeholders, governments, businesses and citizens to realise and accept that the thrust of policy-making will be one of tough, and in the future probably even tougher, standards aimed at achieving ambitious targets. The joint, clearly marked, political choices would have to translate into regulation, which would be the sign for many to reinvent their businesses, and to reconsider choices and demands. While much will depend on environmental policy standards in the strict sense, it is conceivable that climate policies will have another effect, as well. They may spark off creative competition to invent the technologies, the planning arrangements and all that will help to achieve these targets.

This report shows that the potential exists to diverge from current trends in the coming decades. Much will depend on the clarity with which climate strategies are introduced, and on the creativity of finding ways to make these commitments enduring and firm, in the years to come.

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Appendix
Abbreviations and definitions

CCS
Carbon Capture and Storage

CDM
Clean Development Mechanism

CH_4
Methane

CO_2
Carbon dioxide

CO_2 eq
CO_2 equivalent (either emissions or concentrations)

EJ
Exajoule = 10^{18} Joules

ETS
Emission Trading Scheme

EU
European Union

FAIR
Framework to Assess International Regimes for differentiation of future commitments (model)

GDP
Gross domestic product

Gton
Giga ton = 10^{12} kg

IEA
International Energy Agency

IMAGE
Integrated Model to Assess the Global Environment (model)

IPCC
Intergovernmental Panel on Climate Change

N_2O
Nitrous oxide; dinitrogen oxide

OECD
Organisation for Economic Co-operation and Development

PBL
Netherlands Environmental Assessment Agency

ppm
parts per million (concentration metric)

R&D
Research and Development

RIVM
National Institute for Public Health and the Environment (Netherlands)

SRES
Special Report on Emission Scenarios, set of scenarios published by IPCC

TIMER
Targets/Image Energy Regional Model (model)

UN
United Nations

UNEP
United Nations Environment Programme

UNFCCC
United Nations Framework Convention on Climate Change

USD
United States dollars (US$)

Relationship between final, 2100 and peak concentrations

Table A1

Total greenhouse gases (ppm CO_2 eq)		
Final concentration	**2100 concentration**	**Peak value (mid 21st century)**
400	440-470	500-520
450	480-500	510-550

Relationship between concentrations and radiative forcing, 2100

Total greenhouse gas		CO_2 only
ppm CO_2 eq	**W/m²**	**ppm CO_2**
350	1.2	~315
400	1.9	~355
450	2.6	~400
500	3.1	~435
550	3.7	~470

Definitions

Most of this publication uses the terms “high-income” regions and “low-income” regions to denote two large groups of countries. The term “high-income” regions roughly refers to the countries and regions that have emission targets under the Kyoto Protocol, i.e. USA, European Union, Japan, Australia and New Zealand, and the Economies in Transition (countries of the Former Soviet Union and Eastern Europe). The term “low-income” regions refers to all other regions. The terms are used in similar way as the terms “developed” and “developing countries” or “industrialised” and “industrialising” regions in other publications.

Indication of scenarios

Scenarios can be named in different ways. As most of the scenarios reported here are so-called peaking scenarios, they can be referred in terms of their peak concentration value, their concentration in 2100 and/or the intended final concentration level. Generally, this publication uses the final concentration level for naming the scenarios, as this corresponds best to stabilisation concepts that have been used mostly in the literature. In Table A1, some of the scenario characteristics are indicated as points of reference.

Some of the literature is expressing the concentration of greenhouse gases in terms of the radiative forcing of these gases in W/m2. As equivalent concentration levels are in fact also based on radiative forcing levels, there is a unique relationship between these two units (Table A2). The relationship between CO_2 eq concentration and CO_2 concentration is not unique. It depends on the concentration of other greenhouse gases and aerosols in the atmosphere. By the end of the century, it is likely that aerosols have been reduced significantly – as a result of which the relationship becomes somewhat more clearly defined. In Table A2 we have indicated some typical values for CO_2 concentrations corresponding to different equivalent concentration levels across a wide range of scenarios reported in the literature.

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Colophon

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‘Meeting the 2 °C target: From climate objective to emission reduction measures’

Limiting temperature increase to a maximum of 2 °C has been proposed to avoid dangerous anthropogenic climate change. Without additional policy, trends in greenhouse gas emissions will result in a temperature far above this target. In order to have at least a 50% chance of staying below 2 °C, atmospheric greenhouse gas concentrations need to be limited to between 400 and 450 ppm CO_2 eq, or lower, in the long run. For this, the increase in global greenhouse gas emissions will need to be halted by around 2020. In 2050, global emissions would need to be reduced by 35 to 55%, compared to 1990. Meeting such targets requires considerable emission reductions in high-income countries, but also early involvement of other major economies in climate policy. The emission reductions can be achieved with known techniques. The overall macro-economic impacts of stringent climate policy are expected to be modest on a global level, although considerable investments are needed. The most significant challenges are to reach consensus on the contributions from different countries and sectors, and to put into place the right policies that lead to innovation and fundamental transitions.

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