From climate objectives to emission reduction

Overview of the opportunities for mitigating climate change

Netherlands Environmental Assessment Agency

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MNP publications number 500114003/ 2006

ISBN: 978-90-6960-166-3

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reports@mnp.nl (please include the MNP publications number).

MNP publications number: 500114003/2006 Bilthoven.

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Contents

SUMMARY

The earth's climate is changing, and the latest assessments by the IPCC conclude that it is likely that humans have influenced this situation over the past 150 years (IPCC, 2001). In this context, in 1992 representatives from over 150 member countries of the United Nations signed an international Climate Change treaty in Rio de Janeiro (UNFCCC: UN Framework Convention on Climate Change). This convention forms the basis for international climate policy. The objective is to avoid dangerous anthropogenic changes to the earth's climate, in order to protect food production, biodiversity and sustainable development. The European Union (including the Netherlands) have translated this into a specific policy aim: to limit global temperature increases to a maximum of 2°C above pre-industrial levels.

- ***The European climate policy is based on the long-term objective of mitigating climate change to a maximum temperature increase of 2°C (p.14)***

It is not easy to translate this climate objective into specific long-term measures (i.e. after the 2008-2012 commitment period of the Kyoto Protocol). This requires scientific insight into the relationships between the causes and the consequences of climate change, which are still considerably uncertain. It requires making difficult and complex policy choices. For example, comparing the costs of climate policy and the risks of climate change. Limiting the temperature increase to 2°C requires a number of measures – not just by Europe, but also by the rest of the world – for which international agreement is required on the allocation of the efforts involved.

- ***Climate policy fits into a broader framework of sustainable development (p.16)***

The climate problem is not an isolated matter. When looking at this particular problem, many other policy objectives also need to be taken into consideration. Climate policy, both with respect to emissions reduction and with respect to adaptation to climate change, is part of a much broader context of policy objectives, such as international development, improving air quality and the security of energy supplies. Many of the measures taken in other policy areas also have a direct influence on the feasibility and costs of climate policy. It is therefore necessary to place climate policy within a broader framework of sustainable development. This also makes it possible to look for synergies between the various objectives, and thus also to widen the political and social levels of support for national and international climate policies.

This report aims to provide a useful and up-to-date overview of the latest scientific insights into the importance of, and opportunities for, reducing greenhouse gas emissions on both an international and national scale, based on a number of recent publications by the MNP (Netherlands Environmental Assessment Agency).

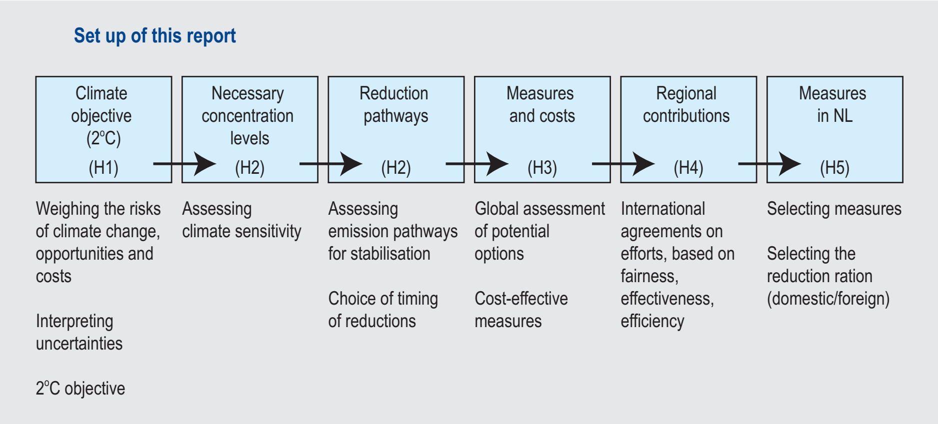

Figure A. From climate objectives to policy measures. Diagram showing relevant subjects and themes.

When translating the 2°C climate policy objective into possible measures, this report follows the steps shown in Figure A. It is important to realise that the decisions shown in Figure A concern various time frames. Clearly, the policy process itself is not as sequential, as indicated in Figure A.

From climate objectives to emissions reduction

- ***Only by stabilising the concentrations of greenhouse gases at low levels there is a reasonable chance of achieving the 2°C objective. With stabilisation at the level of 450 ppm CO_2-eq.[1] this chance is likely to be greater than 50% (p. 19)***
- ***If the world is not able to turn 'emissions growth' into 'emissions reduction' before 2025, the chances of achieving the 2°C objective will be significantly reduced (p. 24)***
- ***In order to stabilise greenhouse gas concentrations at 450 ppm CO_2-eq, emissions will need to be reduced by around 40% in 2050, compared to 1990 level (with a range from 25-60%). For 550 ppm CO_2-eq. the reduction rate compared to 1990 is around 10% (p. 24)***
- ***In climate policy, emissions reduction and adapting to climate change are complementary actions (p. 16)***

The EU's long-term objective of not allowing the average temperature on earth to increase by more than 2°C is based on a political assessment of the socioeconomic and ecological risks of climate change. The relationship between global temperature increases and the effects of climate change are discussed in a previous MNP report

1 The box in Chapter 2 explains the CO_2-equivalent (CO_2-eq.) concentrations.

(Limits to warming). Since the pre-industrial age, the average temperature on earth has risen by 0.6-0.7°C, with a much greater increase at the poles. The effects can be seen in various places on earth – including the Netherlands –, particularly in nature. Studies show that the effects of climate change will increase if the temperature continues to rise. Although there are still considerable uncertainties, it is expected that changes will initially concern sensitive ecosystems (such as coral reefs) and local effects (e.g. due to the increase in extreme weather events). Further climate change increases the risks of more radical (and large-scale) effects, such as the melting of Artic ice zones and parts of the Greenland ice sheet with related impacts on sea levels, negative effects on food production, or the collapse of the thermohaline circulation. The greatest effects of climate change are expected to take place in developing countries: they are also the most vulnerable due to their considerable dependence on climate-sensitive economic sectors.

In order to limit the temperature increase, the increasing concentrations of greenhouse gases in the atmosphere need to be stabilised. Recent studies have resulted in better insight into the relationship between the stabilisation level and the increase in temperature. Only when the concentration level is stabilised at less than 450 ppm (parts per million) of CO_2-eq. is there a more than 50% chance that the 2°C objective can be achieved. This level is much more ambitious than international politicians have taken into account previously, and is only slightly higher than the current concentration level. In order to achieve this level of 450 ppm, it is therefore inevitable that the concentration level will first rise above the 450 ppm level, before further emissions-reduction efforts can lead to a lower concentration (peak profile). It is of course also possible to evaluate emission profiles that result in a stabilisation and/or peaking of concentrations at higher levels, but this obviously reduces the chances of meeting a 2°C target.

The concentration levels that provide the best chance of achieving the 2°C objective can only be reached if greenhouse gas emissions are significantly reduced all over the world. In 2050 the total worldwide greenhouse gas emissions would need to be 25-60% below 1990 levels (depending on the timing and level of the peak in global emissions and emission reduction rates). This can only be achieved if all major countries make the necessary effort to reach this target. Even if the 2°C objective is achieved, it will still be necessary to adapt to changing climate conditions. This means taking measures such as changing agricultural and water-management techniques to take account of changing rainfall patterns, extreme weather events and rising sea levels. On the other hand, the success of adaptation policies will depend on limiting the temperature increase, to ensure that this policy is not faced with unmanageable problems. In other words, adaptation and reduction policies are to a large degree complementary approaches and, in many cases, not opposing choices.

From emissions reduction to a specific set of measures

- *Currently known technologies offer sufficient potential for realising the necessary reductions to achieve low stabilisation levels (p. 33)*
- *Achieving emissions reduction will require a broad portfolio of policy measures (p. 34)*
- *In addition to energy savings, CO_2 storage can be a very important technology in reducing greenhouse gas emissions (p. 28)*
- *Reducing non-CO_2 greenhouse gases over the next two decades is a sensible way of keeping costs down (p. 32)*
- *Reduction measures often also contribute to achieving other policy objectives (p. 36)*

The potential of currently known technologies is sufficient to achieve a global emissions reduction of 60% within five decades. The range of options is very wide: from nuclear energy to renewable energy sources, from energy saving through to enhancing carbon sinks. Energy saving is certainly an important option that can play a considerable role in the total reduction measures over the next few decades. In the longer term, the transition to carbon-neutral systems will play an increasingly greater role. Alongside renewable energy sources or nuclear energy, carbon capture and storage could be, worldwide, a very attractive technology. Limiting emissions of non-CO_2 greenhouse gases is also very attractive as the costs involved are often low.

Interestingly, these options are not just beneficial from a climate perspective, they also lead to less dependence on fossil fuels, improved access to modern energy, better air quality (and thus health), innovation, and new market opportunities for industry. The relative attractiveness of the various options will probably also be determined by the extent of these other advantages.

For reaching international agreements on taking measures, it is useful to look further than just the UN Framework Convention on Climate Change: particularly with respect to the synergy with other aspects of sustainable development, alternate frameworks (such as disaster alleviation, development funding, and trade) can also be very effective.

How much will climate change policies cost?

- *Stabilising at a level of 450 ppm CO_2-eq. is expected to lead to annual costs that average 1-2% of the worldwide GDP (p. 35)*
- *There is considerable uncertainty about the costs: these could amount to half of, or to double of the estimated levels (p. 38)*

In our calculations of the costs involved in achieving various stabilisation levels, we assumed a step-by-step expansion in the number of countries participating in emission reductions. The outcomes refer to direct costs, expressed as a percentage of the GDP (Gross Domestic Product), i.e. the size of the economy. These calculations show that the annual costs of an ambitious climate policy to stabilise emissions at 450 ppm CO_2-eq. in this century, would amount to around 1-2% of the global GDP. This means that, cumulated over the century and using a discount rate of 5%, the costs will be around 1% of the (cumulated) GDP. The extent of these costs is comparable to the current costs for the total environmental policy in Western countries.

These estimates are based on assumptions, for example, concerning the free exchange of technological knowledge, decreasing costs for new technologies, and an optimum-cost approach to emissions reduction via a significant growth in the international trading schemes for emissions rights (e.g. via the Clean Development Mechanism (CDM) under the Kyoto Protocol). However, there are considerable uncertainties surrounding these cost estimates. Calculations show that these vary from half the amount estimated, to around double this amount.

It should be noted that if the positive co-benefits of climate policies would be taken into account in the cost estimates, then the costs would be reduced. For example, when the positive effect on our health through less air pollution, as a side effect of climate policy, is expressed in terms of money, this can (in some cases) at least partly compensate for the aforementioned costs.

Differentiation of efforts between different countries

- ***Very ambitious reduction objectives can only be achieved if all large countries participate (p. 38)***
- ***Stabilisation at 450 ppm, under a multi-stage approach (in which the developing countries gradually join in), means emission reduction objectives for the richest countries in the order of 10-25% in 2020 and 60-90% in 2050 compared to 1990 levels (p. 43)***
- ***In order to achieve stabilisation at low levels, it is necessary to involve some developing countries in international emission agreements before the year 2020 (p. 44)***
- ***A system of worldwide emissions trading is a crucial instrument in limiting costs. This would need to take place on a far larger scale than at present (p. 45)***

Calculations show that all large countries must participate in this climate policy within a reasonable period, in order to achieve the necessary worldwide emissions reductions. Expanding the current coalition of countries with emissions objectives is therefore one of the most important priorities of international climate policy.

Many countries (both rich and poor) place the achievement of an acceptable diferentiation of efforts (burden-sharing) high on the agenda of international negotiations on climate policy. Rich countries are expected to take the lead, and to achieve greater

reductions than developing countries. However, not all industrialised nations are currently participating in international policies to reduce emissions. A high degree of certainty of reaching a 2ºC target can only be achieved if all industrialised countries, including the USA, participate. At the same time, the (larger) developing countries will also need to participate in a timely fashion if stabilisation at 450 ppm is to remain a realistic objective. Preferably, these contributions could be coupled to the realisation of sustainable development objectives (such as the access to energy, reducing air pollution, and energy security). This would slow the increase of greenhouse gas emissions in developing countries without damaging their economic development. It shows the urgency of developing strategies in which development and climate objectives are coupled, to remove the tension between climate and development wherever possible.
The system of emissions trading, including the Clean Development Mechanism (see main text) can play an important role in encouraging measures in developing countries, generating capital for developing countries, and keeping worldwide efforts at affordable levels.

Measures in the Netherlands up to 2020

Policy objectives eventually need to be translated into measures at a national level. The analyses presented below for the Netherlands can be seen as a case study showing this type of translation process.

- ***A national emissions reduction goal of 15-30% in 2020 is in line with the necessary international efforts to achieve the 2°C objective in the long term (p. 48)***
- ***The Netherlands has sufficient potential to achieve a domestic emissions reduction of 15% in 2020 (compared to 1990 levels), at a cost of € 1-2 billion per year. Technically, a 25% reduction is possible, but this would mean considerably higher costs (p. 49)***
- ***Using the technical potential for domestic emissions reduction will need to be assessed against the possibilities for reducing emissions (more cheaply) in other countries. Additional advantages of domestic climate policy should also be taken into consideration (p. 53)***

The Netherlands has recently made an inventory of options for climate measures up to the year 2020. This showed that, in theory, the Netherlands has sufficient reduction options available to achieve a substantive absolute reduction of greenhouse gas emissions in the medium term. A domestic reduction of 15% (compared to 1990 levels) is possible, at a cost € 1-2 billion per year. Technically, the potential is as high as 25%. However, the government has not considered policy instruments for implementing many of these options, and their feasibility. The study clearly showed that a 15% reduction would require considerable policy efforts.

In order to remain in line with the necessary global reductions for achieving the 2°C objective, alongside its domestic emissions reduction, the Netherlands is also considering realising emissions reductions in other countries, via international mechanisms such as CDM projects. The ratio between domestic and foreign emissions reductions will be an important discussion issue when determining post-2012 climate policy. The higher costs of domestic climate policy measures will therefore need to be weighed against the additional advantages, such as avoiding costs for attaining air pollution targets or advanced long term technological developments.

1. INTRODUCTION

The earth's climate is changing. Climate change, in itself, is a natural process, for example through changes in the sun's radiation. But since the pre-industrial era the climate has undergone some relatively fast changes. Although knowledge of the climate system is still far from complete, and surrounded by considerable uncertainties, there is less and less doubt that recent changes in our climate are the result of human activities, particularly through the emission of greenhouse gases by combustion of fossil fuels and deforestation. This has led to a strong increase in the concentrations of greenhouse gases in the atmosphere.

It is possible to change the activities that are causing human induced climate change, but it's not easy, and it requires some difficult policy choices. One important factor here is that, with climate change, there is a spatial separation between cause and effect: local emissions also cause effects elsewhere, while limiting local climate effects also require emissions reductions to take place elsewhere. This means that climate change policy can only succeed through an international approach. The time delay between the (mitigation of the) greenhouse gas emissions and the (reduction in) effects of climate change, particularly rises in sea level, forms an additional complication. This means that today's measures primarily reduce the risks for future generations. This requires policy makers to take account of the risks for future generations, based on still uncertain scientific knowledge concerning the causes and effects of climate change, and the possible solutions to this problem.

Scientific knowledge is developing fast. This report provides a handy overview of recent insights into the opportunities for mitigating climate change, based on a number of publications by the MNP (Netherlands Environmental Assessment Agency)[2], which also include an analysis of other new publications. Together these publications provide a renewed picture of the possibilities for climate policy, of the necessity for global measures, and of the contribution that the Netherlands can make to this situation. This information is a current topic, now that a new round of international negotiations has started concerning future climate policy, that focuses on new climate agreements for the period after 2012.

Science: from climate change to mitigation measures

The scientific understanding of the climate problem begins by studying changes to the climate over the course of time. Climatologists see a link between climate variables,

2 The articles on international climate policy are also included in the scientific assessment that is currently being prepared by the IPCC (Intergovernmental Panel on Climate Change). For the Netherlands, this report includes information from the so-called Option Document, written by ECN and MNP.

such as the average temperature on earth, regional rainfall patterns and environmental conditions, such as UV rays and concentrations of greenhouse gases in the atmosphere, with all their associated uncertainties.

Next, science helps to create an understanding of the risks of climate change. Ecosystems and society are expected to have the capacity to adapt to small, slow changes in the climate. But as the pace of climate change increases, adaptations become more difficult and the risk of irreversible processes and sudden changes occurring increases, with implications for the economy, nature and our social life. Examples include losing unique ecosystems such as coral reefs, regional threats to food production through changes in rainfall patterns and/or in glacial meltwater supplies, or the consequence of fast-rising sea levels for low-lying coastal areas and islands.

Finally, science can also contribute to knowledge of measures that can abate the human influence on our climate. Technologies to prevent climate change are usually available, although they sometimes need to be developed further, while the large-scale application of such technologies often requires important social and economic changes.

EU and Netherlands' objective: maximum 2°C temperature increase

In 1992 the international climate change treaty (UNFCCC) was signed in Rio de Janeiro (Brazil), . Its main objective is to prevent dangerous anthropogenic interference with the climate system, in order to protect food production, biodiversity and sustainable economic development. Which interferences are labelled as 'dangerous' is actually a social choice, where scientific knowledge concerning the risks plays an important role. The IPCC (Intergovernmental Panel on Climate Change), the most important international scientific platform for assessing the state of climate research, collates this knowledge and publishes periodic reports on its analyses. The third 'Assessment Report' (published in 2001) estimated that the temperature increase at the end of this century, without climate policy, would be between 1.5°C and 6°C, depending on the socio-economic developments and the uncertainties in the models used. The next IPCC report is due to be published in 2007.

According to the IPCC, the temperature on earth has risen by 0.6-0.7°C since the pre-industrial era. The effects thereof are already visible in different places in the world, including the Netherlands. Studies indicate that the consequences of climate change will increase with further temperature increases. An earlier MNP report[3] provided an overview of recent specialised knowledge, and Figure 1 provides a summary of that report. Although there are still considerable uncertainties, the expectation is that, ini-

3 B. Heij, B. Strengers, B. Eickhout, J. Van Minnen and M. Berk: 'Hoeveel warmer mag het worden? / Limits to warming?', MNP Report2005999.

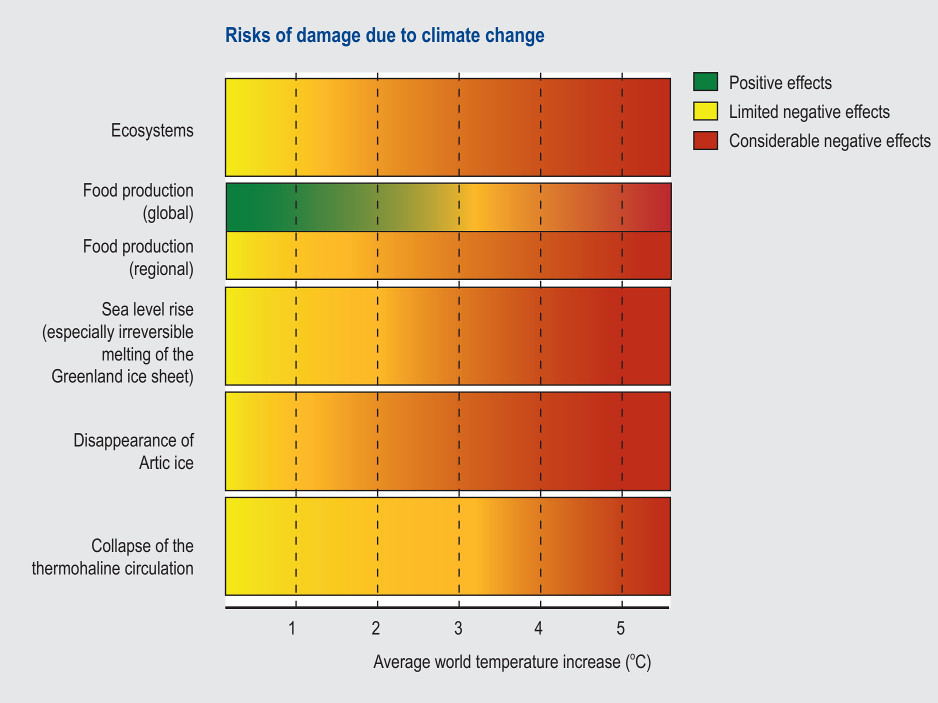

Figure 1. The risks of climate change on a global scale, for ecosystems, food production, rising sea levels, Arctic sea zones and the warm Gulf Stream, as a function of the global temperature increase compared to pre-industrial levels (MNP, 2005).

tially, sensitive ecosystems (such as coral reefs) or local systems (food supply) could be negatively affected. Further temperature increase is likely to lead to larger impacts, including the melting of Arctic sea ice and parts of the Greenland ice sheet with associated a significant rise in sea level, negative influences on worldwide food production, or the collapse of the thermohaline circulation.

Studies show that the greatest negative effects of climate change are to be expected in developing countries., These countries are the most vulnerable to climate change due to their high dependence on climate-sensitive economic sectors such as agriculture, the lack of facilities and structures to anticipate extreme weather situations, and the limited resilience as a result of low income levels.

Based partly on such insights, the EU has chosen to aim at limiting the average temperature increase on earth to a maximum of 2°C, compared to the pre-industrial revolution level. This objective should be seen as a political decision based on the risks of climate change and the opportunities for preventing climate change. Since 1996 this objective has formed the cornerstone of the climate policy undertaken by the EU and its Member States and, in 2005, was reconfirmed by the EU government leaders. This objective has therefore also been selected as a starting point for the analyses conducted for this report, i.e. which opportunities are available to ensure that the 2°C objective is met, both worldwide and at the regional level, and what are the costs/benefits of such a policy?

- ***The long-term objective of European climate policy is to limit climate change to a maximum 2°C temperature increase***

Climate policy in a wider context

Climate policy, both for reducing emissions and adaptation policy, falls within a much wider context of policy objectives, such as improving air quality, securing energy supplies, and international development objectives. Many of the measures that are included in other policy areas also have a direct influence on the feasibility and costs of climate policy. It is therefore necessary to set climate policy within a wider context of sustainable development. This makes it possible to search for synergies between the various objectives, and thus for opportunities to expand the political and social support for national and international climate policy.

Adapt to climate change, or further reductions?

Because unavoidable effects of climate change will occur, adaptation will need to be part of a strong climate policy. Adaptation policy is also important due to the many uncertainties in the system. In other words, even if greenhouse gas emissions are reduced on a global scale, the climate will still change (see also MNP report *Effects of climate change in the Netherlands*). The required adaptation depends on the global emissions-reduction efforts: if the worldwide concentrations of greenhouse gases are stabilised in time, there is a better chance that adaptation to climate change will be successful.

Thus, the extent to which the adaptation policy succeeds depends on limiting the temperature increase. Adaptation and reduction policies are complementary approaches. However, in practice, and at national level, choices between adaptation and mitigation will still be made, for example building higher dykes along waterways, and the contribution to the worldwide reduction of emissions. Considering the many scientific uncertainties it is not possible to substantiate an optimum division between mitigation and adaptation efforts. This is partly due to the differences in the sensitivity of countries to the effects (e.g. vulnerability to changes in sea levels and rainfall), and the widely varying contribution to emissions and opportunities for emissions reduction in these same countries.

Deciding between adaptation and emissions reduction remains fundamentally difficult due to the uncertainties concerning the risks of climate effects, the effectiveness of the (international) mitigation policy, and uncertainties with regard to the costs (and development thereof) within the time period (WRR, *Climate strategy between ambition and realism*, 2006). Another factor is the fact that costs and effects are not well known and, above all, the long-term effects (scientifically speaking) are still somewhat ambiguous.

Purpose of this report

This report aims to provide an up-to-date sketch of the current scientific knowledge concerning the implications of, and opportunities for, achieving the EU objective of keeping the global temperature increase to 2°C above pre-industrial levels. The report also provides insight into the choices that society needs to make in order to achieve this objective, and the effects that must also be considered. Crucial elements include the desired certainty of achieving this objective, which measures can be taken, the costs thereof, and the relationship to sustainable development, the necessary international cooperation and division of efforts, coordinating policies at various levels, and the content of the national climate policy.

Several subjects fall outside the scope of this publication. For example, the question of which policy instruments should be selected in order to implement the reduction options is not discussed. The text box in Chapter 5 mentions several options.

The report follows a step-by-step approach (see Figure 2). The global situation is discussed first, followed by possible ways to differentiate future commitments regionally, and finally it zooms in on mitigation options at the national level of the Netherlands . The information for the Netherlands can be seen as a case study that would also apply to other European countries. Chapter 2 shows the concentrations of greenhouse gases at which the temperature increase would probably be limited to 2°C or less, and which reductions of gas emissions would be required. Chapter 3 discusses the measures necessary to realise these (global) reductions. International measures appear to be both necessary and possible, but demand an acceptable division of efforts between the rich and poor countries (Chapter 4). Finally, Chapter 5 explains the opportunities for emissions reduction at national levels, e.g. the Netherlands.

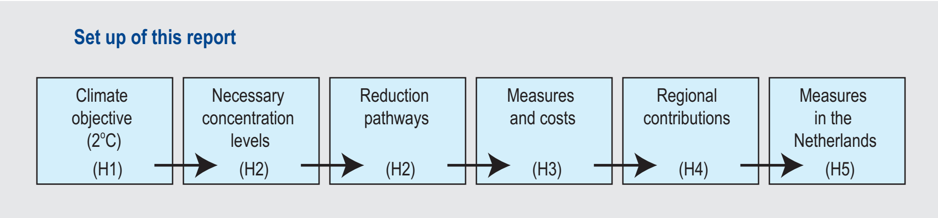

Figure 2. Set up of this report

2. CONCENTRATIONS AND EMISSIONS

When developing long-term climate strategies the first requirement is to define the relationship between the concentration of greenhouse gases in the atmosphere and temperature increase. More specifically for the EU target: which concentration level will ensure that the 2°C objective can be met? This chapter focuses on this aspect, while also answering the question: how much will greenhouse gas emissions need to be reduced in order to achieve this concentration level?

Scientists agree that the climate is changing. However, the exact relationship between greenhouse gas emissions, their concentrations in the atmosphere, and the resulting temperature is not yet clearly defined. There are a number of uncertain variables, such as the sensitivity of the climate system towards increased concentrations of greenhouse gases in the atmosphere (climate sensitivity), the relationship between greenhouse gas emissions and the resulting concentrations, the contribution of the various sources of greenhouse gases, and the speed with which the emissions can be reduced.

Concentrations and temperature increase

Scientific literature includes various estimates of the relationship between the concentrations of greenhouse gases in the atmosphere and temperature increase, and thus the chance that the global temperature increase will not rise above 2°C. Figure 3 shows the ranges of estimates given for various stabilisation levels. This not only takes account of carbon dioxide (CO_2) levels, but also other greenhouse gases (see also the text box on 'CO_2 and CO_2-equivalents'). The chances of keeping the temperature increase under 2°C improve considerably at lower concentration levels. Figure 3 shows that at a stabilisation level of 550 ppm CO_2-eq. there is a significant risk (at least 66%) of exceeding the 2°C limit. However, at a concentration level of 450 ppm there is a reasonable chance (over 50%) of achieving the 2°C objective. It is also possible that, by choosing emission profiles carefully, emissions could be reduced even further after the concentration level has been reached (peaking), thus improving the chances, though this would not change the general conclusions.

- ***There is only a high degree of certainty for achieving the EU 2°C objective if concentrations of greenhouse gases are stabilised at low concentration levels. Stabilisation at 450 ppm CO2-eq.[4] or less is likely to lead to a chance of success above 50%***

4 See also text box ' CO_2 and CO_2-equivalents'.

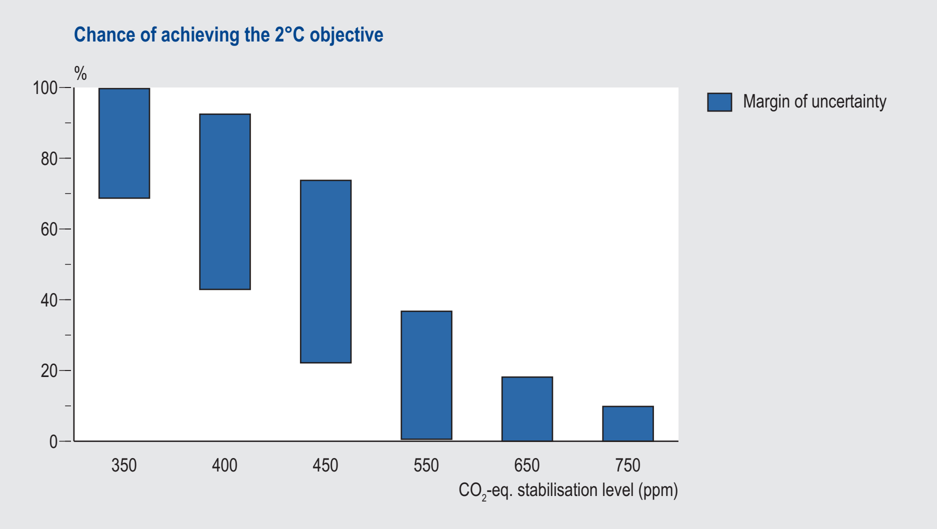

Figure 3. Estimates given in the scientific literature concerning the chances of achieving the European climate objective, at various stabilisation levels for greenhouse gas concentrations in the atmosphere.

This is a considerably lower level than was considered necessary several years ago in order to achieve the 2°C objective. The 1996 EU Council decision assumed that concentrations of CO_2 would need to be stabilised at a level of less than 550 ppm (or 650 ppm CO_2-eq.). The difference is caused by new insights and a better interpretation of the uncertainties.

CO_2 and CO_2-equivalents

Carbon dioxide (CO_2) is an important waste product of combustion, and is also the most important greenhouse gas in the atmosphere. But it is not the only gas that causes global warming. According to current insights, other greenhouse gases account for around 25% of emissions. These other greenhouse gases include, for example, methane (CH_4), laughing gas (N_2O), and fluorinated gases such as HFCs, PFCs, and SF_6. The atmospheric concentrations of some of these gases are low, but their impact per weight unit on increasing the greenhouse effect is sometimes thousands of times greater than that of CO_2.

In order to create one indicator for all gases combined, the concept of CO_2-equivalents has been created. This concept aims to convert the effects of other greenhouse gases into the equivalent of CO_2. This report presents all figures as CO_2-equivalents – unless explicitly shown otherwise. Emissions are expressed in tons CO_2-eq. (tCO_2-eq.), and concentrations in parts per million CO_2-eq. (ppm, or the number of molecules of CO_2 per million parts of air). The CO_2 concentrations correspond to the CO_2-eq. concentrations shown in Table 1 (p. 23).
[end box]

What will happen if there is no climate policy?

Emission developments over the coming century are uncertain. How will the world's population develop? How strongly will the world economy grow? What will happen to energy stocks, prices and energy technologies? How will consumption patterns develop? How much deforestation will there be? Strong economic growth, high population growth and energy-intensive consumption patterns are all factors that can lead to higher emissions. On the other hand, strong technological development can lead to lower emissions.

Scientific studies try to gain insights into potential emission development by developing various reference projections or scenarios. The analyses described in this report are based on a so-called 'medium scenario', developed by MNP. This scenario is based on trend estimates, such as those also used in the IEA (International Energy Agency) reference scenario, and the so-called B2 scenario used by the IPCC.

According to the reference scenario, over the next century the world population will expand to 9-10 billion (in the middle of the century) and will fall slightly thereafter. Combined with a worldwide economic growth of around 2% per year, it is expected that the global demand for energy will increase considerably: doubling by 2050, and reaching three times the current use in 2100 (see Figure 4). This growth primarily

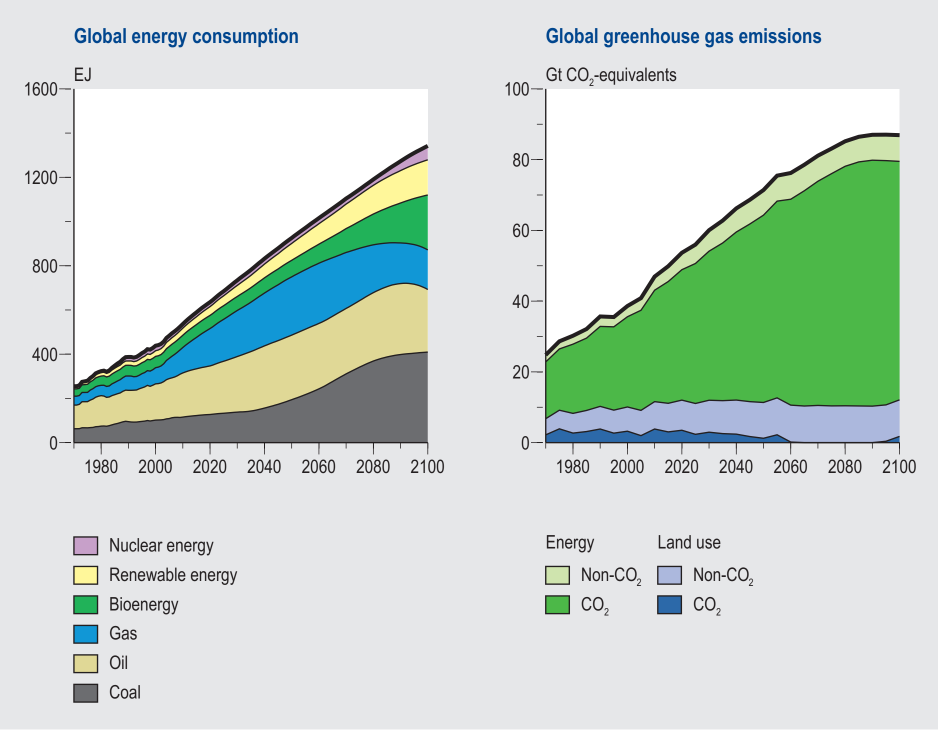

Figure 4. Development of total energy primary energy supply and greenhouse gas emissions in the baseline scenario.

occurs in the current developing countries, which thus partially make up their huge arrears in energy consumption per person.

Without climate policy the expectation is that the world's energy demand will primarily be met by conventional combustion of fossil fuels, as a result of which CO_2 emissions will increase accordingly. In this baseline, the total greenhouse gas emissions increase from around 30 billion tons (=Gt) CO_2-eq. in 2000, to 50 billion tons in 2050, and 70 billion tons in 2100. The projections of alternative reference scenarios are sometimes higher, and sometimes lower (often between 40 and 90 billion tons). While most emissions have, up to now, been caused by the rich nations (around 80%), as with energy consumption, emissions are now rising fastest in the less developed countries: in the reference scenario it is expected that their contribution increases from around 50% today, to 65% in 2100. At the same time, per capita, emissions from the current OECD (Organisation for Economic Cooperation and Development) countries remain higher than those from developing countries.

Under these trends, the greenhouse gas concentrations are in 2100 more than doubled, from current levels of around 425 ppm CO_2-eq. to over 900 ppm CO_2-eq., and the concentrations continue to increase further. With an average estimate of uncertainties the temperature increase in 2100 will be far higher than 2°C.

Clusters of reduction pathways

As previously mentioned, low greenhouse gas concentration levels cannot be achieved without substantial climate policy action. The question is: how much reduction is required to achieve low concentrations? There is of course a certain amount of uncertainty involved. This uncertainty in the outcome has several causes:

- The reductions, measured in CO_2-equivalents, can be achieved via various combinations of greenhouse gases.
- The reference development influences the speed with which emission increases can be reversed and the extent of the necessary reductions.
- Starting climate policies early leads to different emission routes than those needed if climate policy is started later. Postponing emissions reduction can even lead to some concentration levels no longer being achievable.
- There is no general consensus on future technological development, including the costs of new techniques.

Exploring the possible emissions reduction needed to stabilise greenhouse gas concentrations in the atmosphere does not result in a single emission pathway, but in 'clusters' of interrelated sets of emission pathways (see Figure 5). These clusters show the bandwidths within which emissions must remain in this century in order to achieve the various stabilisation levels for greenhouse gases (being high within the band early in the century, allows one to be low in the band in the second part of the century – and vice versa).

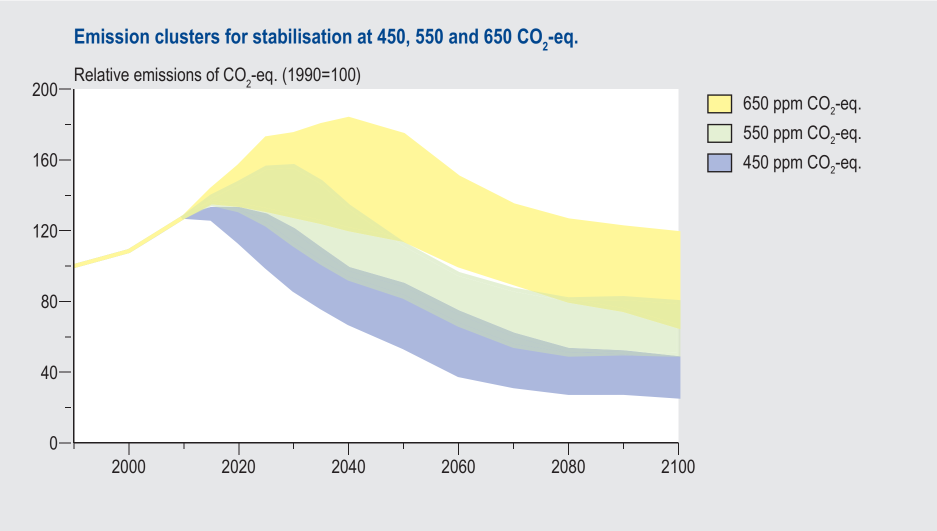

Figure 5. Clusters of emission-reduction pathways. These clusters originate from various uncertainties in baseline developments and various differences in timing climate policy.

The top of the cluster is primarily determined because postponing measures further means that the desired stable concentration levels in the atmosphere can no longer be achieved. The lower edge is primarily limited by the available potential of mitigation measures, which cannot be implemented at indefinite rate. Based on literature survey, we assume that annual global emissions cannot be reduced over 2-3% per year over a long time period, irrespective of the ambitious climate policy used. Emission-reduction pathways that start off along the top of the cluster will later move to the lower side, and vice versa (see also text box 'Intermezzo: Models').

More reductions, and faster

Current scientific insights have important consequences for global climate policy. The 'emission clusters' indicate that urgency is required for achieving low stabilisation targets. If the world does not succeed in turning emissions growth into a considerable emissions reduction before 2025, then low concentration levels will no longer be achievable, in the timeframe required.

Table 1. Summary of reduction pathways.

CO_2 Equivalent Concentration	Corresponding CO_2 concentration	Emission reductions		Equilibrium temperature	
		2000-2100 reduction (from baseline):	Emissions 2020 (% above 1990)	Range	Best estimate
ppm	ppm	$GtCO_2$-eq.		°C	°C
650	540 - 575	2600	-	1.7 -5.0	3.2
550	475 - 500	3600	19-41	1.4 - 4.1	2.6
450	400 - 420	4300	7-24	1.0 - 3.0	1.8

- ***If the world does not succeed in turning the growth in emissions into an emission reduction before 2025, then the chance of achieving the 2°C objective is considerably reduced***

The need to turn the current emissions increase into an emissions reduction is naturally greatest for the 450 ppm CO_2-eq. profile. If this turnaround does not occur in the next 10-20 years then this profile will become almost impossible to reach. It is important to note that the current profile already allows for a temporary overshoot above the targeted level (to around 500 ppm), given the fact that current concentration levels are already close to the desired 450 ppm CO_2-eq. level. This type of overshoot profiles can still lead to high changes of achieving a 2ºC (or other) temperature target if the 'overshoot' period is very short. Overshoot profiles can also be developed for other concentration levels, but are not discussed further here.

In 2050: 40% (25-60%) less emissions than in 1990

The current commitments under the Kyoto Protocol continue only up to 2012, and basically require around 3% emissions reductions by the richest nations (excluding USA and Australia). These commitments thus are only a beginning for the reductions required to stabilise greenhouse gas concentrations. Depending on the desired certainty of achieving the 2°C objective, in 2050 worldwide reductions will be necessary in the

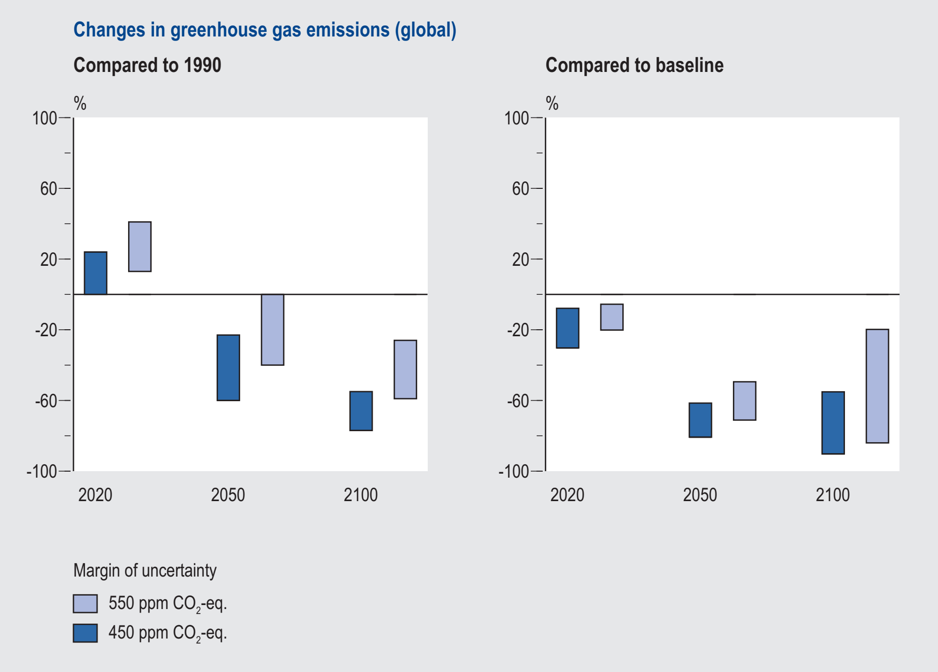

Figure 6. Necessary worldwide reductions of greenhouse gases in order to achieve stabilisation of emissions, compared to both 1990 levels and the baseline.

order of 10% for 550 and 40% for 450 ppm compared to 1990 (under the reference scenario and central reduction pathways). Taken all uncertainty into account with respect to reference scenarios emissions (in particular deforestation) and timing of emission reductions these numbers van vary over a range of 0-40% for 550 ppm and 25-60% for 450 ppm.

These reductions mentioned so far are relative to emissions in 1990. In practice, the trend since 1990 has been a continued growth in worldwide emissions. Compared to the reference scenario, reductions will need to be even greater: in that case the change to achieve stabilisation at 450 ppm is already an estimated 10-30% in 2020 and 60-80% in 2050, depending on the assumed growth in the baseline.

Intermezzo

Models

The calculations in Chapters 2, 3 and 4 of this report are based on various models that calculate global energy and land use, climate change, and the costs of climate policy. All calculations basically consist of two main elements:
- Initially, 'clusters' of emissions pathways are defined that match the concentration objectives.
- Then a set of measures is sought that, from a global viewpoint, achieve the emission reductions required to keep emissions within these clusters at the lowest expense.

Both elements run in parallel. The reduction pathways take into account the availability of reduction options. A number of essential assumptions are made for both elements. The reduction pathways must ensure that the concentration objective is exceeded only for a limited period of time. Above all, the pathways take into account that technical limitations mean that the speed of the reduction can never be higher than 2-3% per year. At the same time, it is assumed that emissions can be reduced in all sectors, for all greenhouse gases and in all regions. This optimistic assumption (which can be achieved via international emission trading) leads to a possibly rose-coloured outcome with respect to the costs involved. Limiting the measures per sector can lead to significantly higher costs, for example, by 30% if non-CO_2 reduction options are excluded.

All calculations have been performed for 17 world regions. For calculating regional reductions and costs (see Chapter 4), the global reduction objectives are first divided between these regions using a pre-defined differentiation of commitments. The resulting regional reduction objectives can then be realised via measures both inside and outside the region. Emissions trading systems allow these reductions to be 'traded' between the various regions.

In general the models used provide insights into the chances of achieving the temperature-increase objectives, the contributions made by the various measures, and the (regional) costs involved (assuming that measures are implemented in all regions). The costs always concern the direct costs of climate policy. No macroeconomic impacts of these costs are calculated. For such feedback effects, such as for example the moving of industrial activity or the loss of fossil fuel exports, reference is made to the existing analyses. The co-benefits, such as lower costs for air pollution policy, are not included in the calculations.

3. MEASURES AND COSTS OF EMISSIONS REDUCTION

The previous chapter showed that the 2°C objective requires considerable reductions in greenhouse gas emissions. An important question, certainly for policy makers, is: are there sufficient opportunities to achieve the reductions mentioned, and which measures will help to achieve this aim? This chapter discusses this question on the basis of data concerning reduction potentials in all sectors, and of models that allow for defining cost-optimal strategies to achieve far-reaching emissions reductions.

The model calculations result in portfolios of measures with which the required emission levels can be achieved. In addition to the total reduction costs, cost implications for various sectors – such as the energy sector – are also dealt with. The way in which such a policy is executed, and the societal efforts required, fall outside the scope of this report. The certainties and uncertainties arising from these studies are important in considering risks and costs.

Individual options

The scientific literature provides descriptions of various options that can be used to achieve significant emission reductions. Table 2 contains an overview of typical values for the technical potential of individual option, as given in the literature (the table concentrates on minimum values; note that these cannot be easily summed up). In comparison, the emissions in the baseline scenario in the 2000-2100 period are almost 7000 Gton CO_2-eq. (this is within the range of 5000-8000 Gton CO_2-eq. used in IPCC scenarios). As previously mentioned, Table 1 shows the necessary emission reductions for stabilisation at 650, 550 and 450 ppm, which are 2600, 3600, and 4300 Gton respectively, compared to the baseline scenario.

Table 2. Literature estimates of the cumulative technical potential to reduce greenhouse gas emissions during the period 2000-2100 (in billion tons CO_2-equivalents).

Option	Cumulative technical potential (Gton CO_2-eq.)
Energy savings	>1000
Carbon capture and storage	>2000
Nuclear energy	>300
Renewable	>3000
Carbon sinks	>350
Non-CO_2 greenhouse gases	>500

The various options that can be used to reduce greenhouse gas emissions are discussed below. The WRR report 'Climate strategy between ambition and realism' also provides an overview of reduction options and their contribution. The figures presented here are in the same size range, though slightly lower: these are estimates for an earlier point in time (2050), which give greater consideration to possibilities for applying the measures. The importance of the various options is generally comparable.

Saving energy

Saving energy is an important part of all climate policy strategies. Compared to the current situation, studies show that saving energy over the next century could achieve emission reductions of 50-70%, although the effect decreases after the first decades of this century. Even in the absence of climate policy, equipment becomes more efficient as a result of technological improvements. This implies that the actual additional potential is somewhat reduced. The IPCC estimates that, compared to the baseline, saving energy can achieve a 25% emissions reduction over the next 30 years. Using this as a basis, a conservative estimate for the entire century results in a reduction potential of around 1000-1500 billion tons CO_2-eq.

The costs of saving energy vary enormously, from benefits of around several dozen euro per ton of CO_2 avoided, to costs of around € 50 per ton (compared to other options this is relatively low). Saving energy is also an attractive option because it has so many other advantages. Efficient use of energy reduces the dependence on energy imports. Energy cost reductions also reduce the sensitivity to energy price variations, and may improve the competitiveness of companies. However, it is difficult to substantially accelerate the energy-saving tempo, due to the wide range of sectors and applications involved, and due to the fact that many parties would need to cooperate. This is particularly valid for options concerning households and the transport sector.

CO_2 storage

In addition to saving energy, storing the CO_2 that is released by the energy sector and elsewhere in industry could form an important technology in the fight against climate change. The costs of this new technology (CCS: Carbon Capture and Storage) are estimated at around € 20-80 per ton CO_2-eq., with the possibility of further cost reduction. The global storage potential is estimated as being at least 2000 Gton CO_2-eq.

- ***In addition to saving energy, CO_2 storage could become a very important technology for reducing greenhouse gas emissions***

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. Coal-rich countries, in particular, could use this technology to achieve both security of energy supplies and to meet climate objectives. Large-scale application at power plants still needs to be proven, and the costs and risks 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. The CCS technology competes for emissions reductions in the electricity sector with both nuclear energy and renewable energy. Future cost estimates for these three options overlap. Over the past 10 years the knowledge of CO_2 storage has been disseminated internationally, and demonstration projects have proven that this is a viable option.

Nuclear energy

It is not clear whether there will be a considerable increase in the worldwide use of nuclear energy, partly due to the limited social acceptance in many countries, but also due to the high investment costs involved and the long construction period required. If drastic emissions reduction is required then expanding the use of nuclear energy could be a viable option. This is partly due to the difficulty of integrating a large share of alternative energy sources (such as wind and solar energy) into national electricity grids. However, nuclear energy also has disadvantages such as the risks of accidents and proliferation and long-term storage of radioactive waste. Cost estimates for the direct costs of nuclear energy (excluding the complete storage costs and risks mentioned) vary over the coming decades from € 15-100 per ton CO_2 emissions reduction. The potential until 2100 depends on social factors as well as technical factors. Based on the current technology and proven stocks, this potential is limited to 300-400 billion tons CO_2. But new techniques and reserves could increase this potential considerably. Nuclear energy could reduce the dependence on oil and gas imports, but also means that nations are again dependent on a limited number of suppliers.

Sun, wind and other energy sources

The literature provides assessment of the possible role for hydropower, solar and wind energy, with extremely diverse results: from a fairly limited role to the production of many times our current energy consumption. The large variation in results largely depends on whether economic and markets considerations are included and how this is done. However, it is clear that the amount of electricity produced by the 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. Important challenges for further expansion would be cost reductions (particularly for solar energy), spatial impacts and nuisance factors (wind energy), and the integration of these intermittent sources into national electricity grids. Further technological breakthroughs, better integration into the electricity grid, and the public's acceptance of renewable resources – in competition, for example, with nuclear energy and CO_2 storage – are essential, but there is certainly a huge potential.

In general, renewable sources are currently among the relatively more expensive options (from € 50 per ton CO_2-eq.), but substantial cost reductions are predicted. Wind energy (both onshore and offshore) is economically the most attractive option, but has less potential than solar energy.

Renewable sources can reduce the dependency on fossil energy imports. They can also play an important role in providing electricity in rural areas, and thus creating extra jobs.

Bioenergy

Among the renewable sources, bioenergy (energy from crops or other biological waste material) deserves special attention. Studies of the potential confirm that the production of liquid fuels from biomass could meet the total demand in the global transport sector (see Figure 7). Bioenergy can also be used to produce electricity and heat.

Part of the bioenergy can be derived from waste products. However, large-scale application will mean that bioenergy will primarily be derived from specific crops that are cultivated for energy production. The eventual contribution from biomass greatly depends on the expectations for future land use. The large-scale cultivation of biomass for energy applications could mean a considerable change in future land use, and could compete with the use of this land for food production. Other aspects of sustainability, such as maintaining biodiversity and clean production methods, also play a role here. Bioenergy is expected to profit considerably from agricultural land that will become available, initially in developed areas, but also in developing countries during the latter part of this century. If there is a rapid shift towards wood and grassy crops (cellulose-based processes), this option offers greater CO_2 reduction options and less land use per unit of energy, although technical breakthroughs are still required to achieve this.

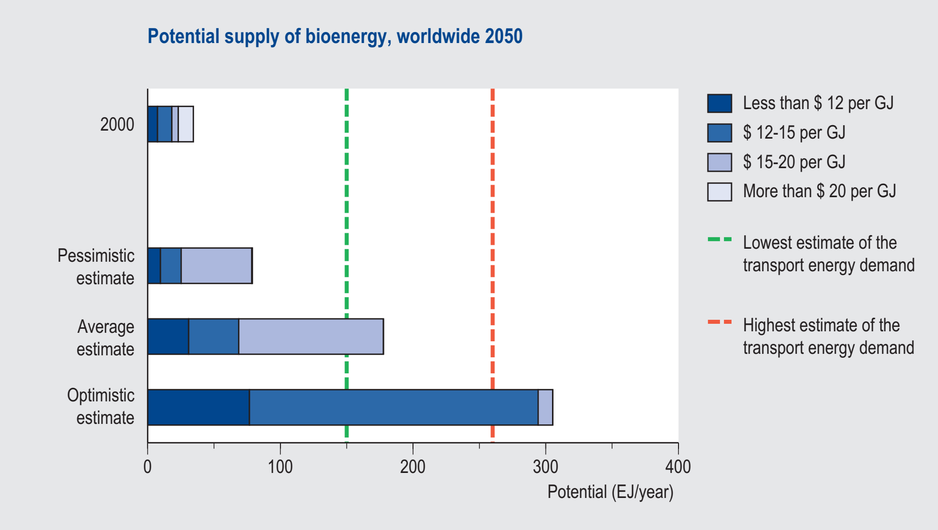

Figure 7. Worldwide potential of bioenergy supplies (estimates are based on the elaboration of four IPCC scenarios).

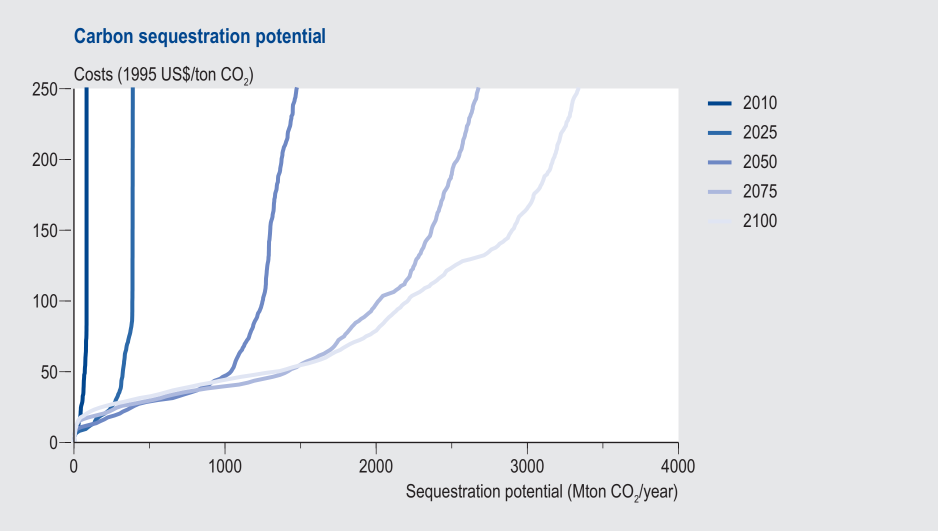

Figure 8. Sequestration potential for carbon plantations at different cost levels. The potential is based only on abandoned agricultural land. The total available (technical) potential has been reduced to 40% to account for implementation barriers.

Carbon sinks and other land use

Reducing deforestation can also contribute to limiting the concentrations of greenhouse gases in the atmosphere. The reference scenario of this study already assumes less deforestation (without extra climate policy). A further step would be reforestation: planting new trees or other vegetation that absorbs relatively more carbon from the atmosphere. Since such forests absorb more carbon than, for example, agricultural crops or natural vegetation, such applications are known as 'carbon sinks' (see Figure 8). Carbon sinks have a limited potential compared to the current annual greenhouse gas emissions, around a maximum of 4-7 billion tons CO_2-eq. per year, which would result in a conservative estimate of 350 billion tons over the coming century.

Over the next few decades Southern Africa and the former Soviet Union will be the main focus for carbon sinks, although South America and China will also contribute later this century. The costs are estimated as relatively low: € 10-50 per ton CO_2-eq.

Fuel substitution

Emissions can also be reduced by using alternative, lower-carbon, fossil fuels in power plants. The CO_2 emissions from burning natural gas, for example, are 40% lower than when burning coal. The conversion efficiency in gas-fired plants is also considerably higher than for coal-fired plants, certainly if natural gas is used in combined heat and power plants.

The costs of this option largely depend on developments in the relationship between oil, gas and coal prices. However, this option does have consequences for the security of supply, because Europe becomes dependent on imports of natural gas. The potential is relatively limited: ambitious emission-reduction objectives would replace this option with others that can achieve far greater reductions.

Hydrogen

Combustion of hydrogen in end-use sectors does not produce CO_2. Whether or not hydrogen can also contribute to reducing greenhouse gas emissions depends on the way it is produced. Hydrogen can be produced from renewable resources or by using nuclear energy, hence without greenhouse gas emissions or it can be produced from fossil fuels. In the latter case, hydrogen is only a climate-neutral source if the carbon from the fuel is stored, rather than being released into the atmosphere.

Based on costs alone, hydrogen is not expected to play an important role in the energy supply system before the middle of the 21^{st} century.This could, however, happen in the second half of this century, with the transport sector playing a key role in large-scale application. Other factors too, like security of supply or air quality, could encourage the use of hydrogen in the short term. Coal and natural gas (even with CO_2 capture) are economically the most attractive raw materials, and are currently also used in commercial hydrogen production in the petrochemical industry. 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 will then be produced from fossil fuels; with climate policy, it allows for greater flexibility for the energy system to respond more effectively.

Non-CO_2 greenhouse gases

- ***Reducing emissions of non-CO_2 greenhouse gases is a good way of keeping costs down***

Reducing the emissions of non-CO_2 greenhouse gases is a particularly attractive option for the next few decades, since it is less expensive than some CO_2-reduction options. Some options are reducing emissions of methane gas from coal mines and gas extraction, landfill waste sites, animal husbandry and rice fields (see Figure 9). Emissions of laughing gas (N_2O) could also be significantly reduced.

Besides industrial sources, emissions from non-CO_2 greenhouse gases primarily come from the agricultural sector. In total, emissions of non-CO_2 greenhouse gases are expected to be around 1000-1500 billion tons CO_2-eq. during this century, of which at least 500 billion tons can be prevented. The costs of this option are largely estimated as relatively low (€ 0-50 per ton). Using this option would result in the costs (in 2050) being 30-40% lower than without this option.

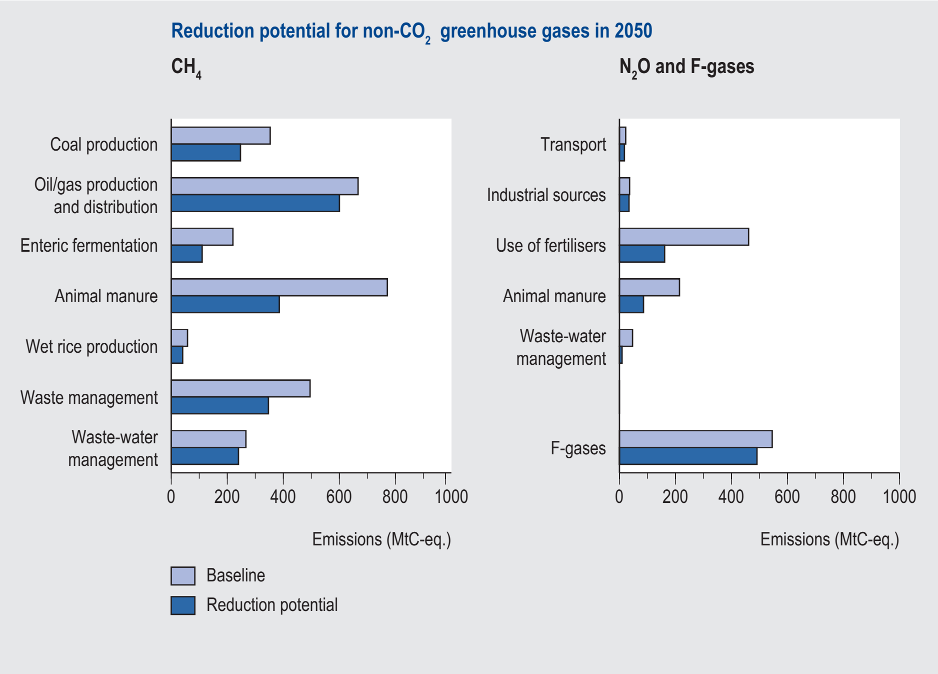

Figure 9. Worldwide potential for reducing non-CO_2 greenhouse gases in 2050.

Sets of policy measures

Chapter 2 shows that a worldwide change of direction is necessary over the next few decades, from an upward emissions trend into a downward trend, in order to achieve low concentrations of greenhouse gasses. The previous section showed that on basis of estimates for individual technologies, there is theoretically sufficient potential available to realise this objective. But how could such technologies be combined in a cost-effective way, how much would this cost, and would there be other advantages or disadvantages? This section discusses these possibilities (without discussing the policies that would be required to implement these measures).

- ***Currently known technologies have sufficient potential to achieve the reductions needed for low stabilisation levels***

In the past many scientific analyses focused on the opportunities for achieving stabilisation at 650 and 550 ppm CO_2-eq. However, model studies and data from this chapter lead us to conclude that, from an average emissions baseline, stabilisation at 550, 450 ppm and (under certain circumstances) even 400 ppm could be achieved using currently known technologies. Realistic assumptions are made with respect to learning curves of technologies, cost reductions and the implementation of new techniques. New technologies, for example, are not implemented until the old installations have been fully depreciated.

For the the 450 and 400 ppm stabilisation level, it is not possible to develop scenarios that do not exceed these values temporarily. However, if this period of temporary overshoot is short enough, it results in few extra risks. It is possible to reach the target concentrations shortly after the 21st century.

- ***A broad portfolio of technologies is required to produce drastic emissions reductions***

The main conclusion from our integrated scenario analyses is that searching for a cost-effective approach to emissions reduction does not lead to any single option, but to broad portfolios of policy options (see Figure 10). This is primarily due to the fact that the potential contribution by each individual option is limited, for technical or other reasons. But there are other causes. Technologies can sometimes only be used in certain areas or sectors. A broad portfolio approach can be detrimental due to the fragmentation of research and development, or through limited scale advantages for individual options. But there are clear advantages too. To ensure resilience in the face

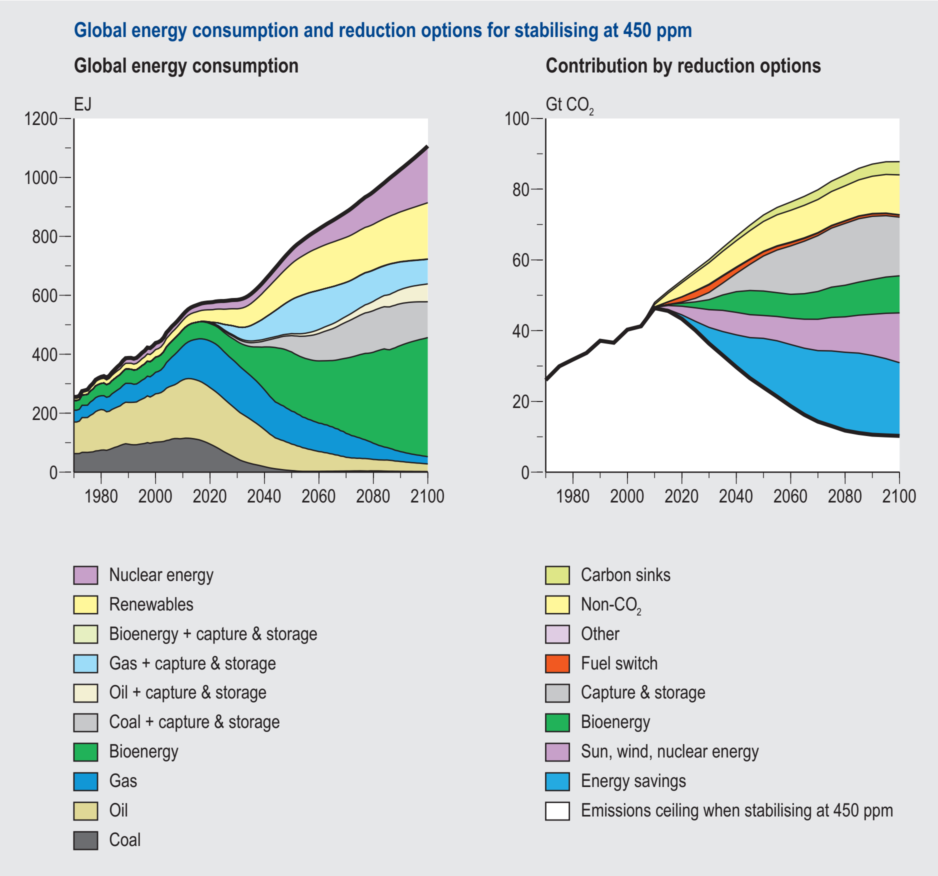

Figure 10. Developing the fuel mix and contribution of reduction options to the energy supply in the 21st century for stabilisation at 450 ppm.

of the uncertainties in the climate system and the possible underperformance of certain options, it is advisable to spread the risks. This advantage counteracts the disadvantages of fragmentation.

Excluding certain options can lead to extra costs. This applies less to the electricity sector, which has many options (at comparable costs) that can be used to replace each other: nuclear energy, renewable energy sources and CO_2 storage. This gives a considerable freedom of choice, and the eventual mix may depend on technological developments that influence the competition between these options (such as electricity storage or lower costs), as well as acceptance by society as a whole. Other sectors have less interchangeable options.

Costs: Early action can pay off

The direct costs of the mitigation scenarios are expressed as fraction of world GDP, and include the annual costs to the energy sector and other costs for climate policy. In comparison: the current direct costs of the energy sector amount to around 8% of GDP worldwide, while the costs for environmental policy in Western Europe amount to around 2% of GDP. The costs of the climate measures calculated here vary considerably, and also vary over time[5]. One way of expressing the costs is as 'net present value', or the cumulated factored costs throughout the 21st century. Achieving a concentration level of 650 ppm leads to a net present value of 0.1-0.3% of the net present value of the global GDP. Maximum costs amount to around 0.4-0.7% of GDP. Achieving a concentration level of 550 ppm requires an average net present value of around 0.4-0.6%, and 450 ppm will cost around 0.9-1.2% (see Table 3). The maximum cost levels (around 2030-2050) are again higher, and amount to 0.9-1.3%, and 1.6-2-6% respectively (see the previous section for an estimate of the uncertainties).

- ***In order to keep the temperature increase to less than 2°C, an extra annual expenditure of 1-2% of worldwide GDP seems necessary.***

The phasing of climate policy is also important to these calculations. An important question here is: is it worthwhile to act early, or is it cheaper to wait until later before responding? For the next few decades the answer to this question is very clear. Postponing measures also means relatively low costs, but the bill for that will need to be paid later this century. Comparing the total costs (until 2100) between an early and a late start of climate policy depends on the uncertainties and societal perspective, such as weighing the costs in the distant future. However, according to MNP analyses, there are good arguments for acting quickly. The main reasons are that technological deve-

5 The macroeconomic effects on the economy and welfare are not included in these calculations, and the local effects thereof can be either positive or negative. An example: a new industrial sector for low-carbon technologies exists, which benefits the local economy. In addition, the cost estimates assume full international cooperation.

Table 3. Comparing climate risks with the costs of measures for stabilising at 450, 550 and 650 ppm CO_2-eq. The cumulative costs are expressed as a percentage of cumulative GDP across the century (based on a 5% bank rate).

Stabilisation level (ppm CO_2 -eq.)	**Probability (%) of remaining within the 2°C target** Range	**Cumulative costs (% of GDP)**	**Maximum costs in any year (% of GDP)**
450	14-67	0.9-1.2	1.6-2.6
550	1-40	0.4-0.6	0.9-1.3
650	1-21	0.1-0.3	0.4-0.7

lopment can be encouraged earlier, that the signal for change is given earlier to the energy supply system, and that high peaks in the percentage reduction required are avoided. Above all, early action results in more possibilities in the future to respond to new information on climate change.

Additional advantages and disadvantages

Significantly reducing CO_2 emissions not only has positive effects on the climate, but can also have co-benefits in other areas. Important related policy areas include air quality, security of supply and land use (see also the following chapter). In general, one can speak of positive relationships: when reducing CO_2 or other greenhouse gases, most options also result in reduced emissions of fine particles or acidifying substances such as sulphur oxides and nitrogen oxides. The total set of measures thus also results in clear advantages for the regional air quality (see Figure 11). A few options require

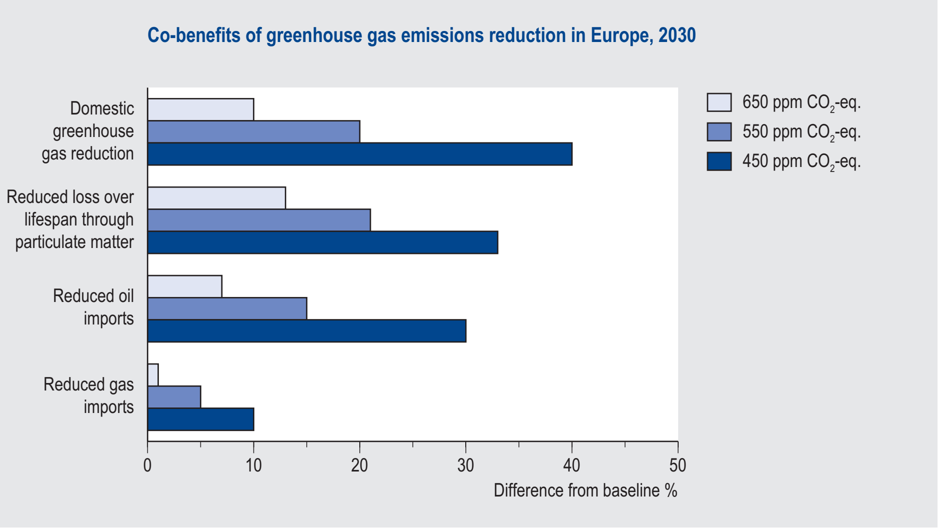

Figure 11: Co-benefits of climate policy for energy security, climate and air quality in 2030 (percentage difference from baseline).

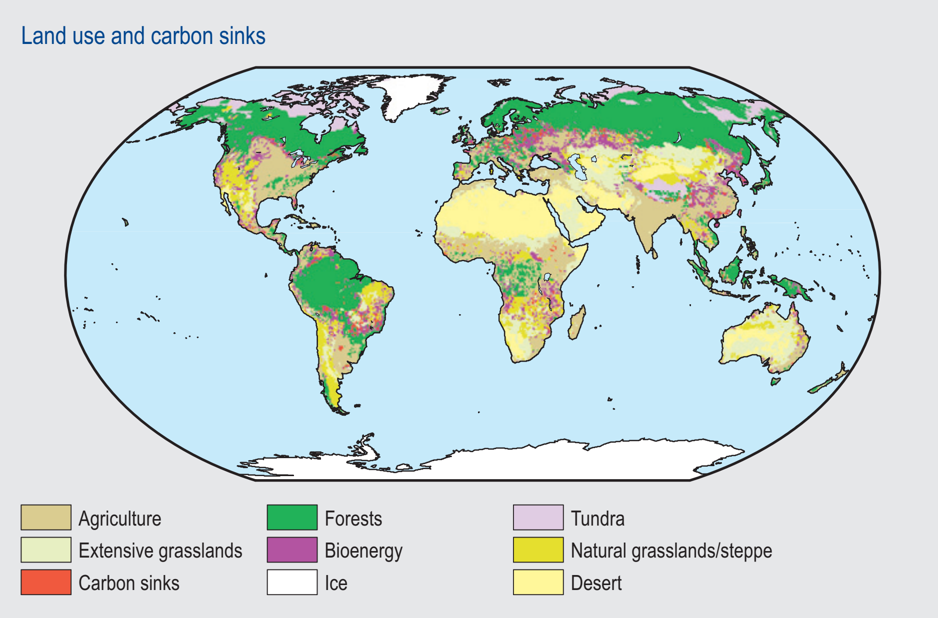

Figure 12. Possible implications of stabilisation at 450 ppm for global land use in 2100 (carbon sinks and bioenergy). The figure provides a basic sketch of the implications; details are not relevant, given the many uncertainties.

a choice (e.g. certain forms of biofuel). Another additional advantage of many climate measures for fossil-fuel importing regions is that the use of fossil energy is reduced, and thus the dependence on imports. The positive effects for the total portfolio are also shown in Figure 11.

One disadvantage of a stringent climate policy concerns the potential extra demand for land. Both carbon plantations, bio-energy and to a lesser extend wind and solar power require land. Figure 12 shows the possible consequences in terms of land use, illustrated for the most stringent climate scenario (450 ppm). Both bioenergy and carbon fixation in plantations lead to a significant land requirement. This extra land use means, for example, that there is less room for expanding nature areas.

Necessary conditions

Having the right technologies available is one thing, but creating the right socio-economic and institutional conditions in order to actually implement them is a another, and a difficult policy challenge. All calculations assume that the world will find a mechanism whereby the technologies described can be used wherever they form the cheapest reduction option. This is an important, but also an optimistic assumption. Many reduction options, in both developed and developing countries, are not yet being used. In particular, the participation of large industrialised countries (such as the USA), or developing countries (such as China), is a precondition for the outcomes presented to be realised. Delayed participation leads to increased overall costs and possibly to losing the possibility of stabilising greenhouse gas concentrations.

- ***A global climate policy can only succeed if all relevant countries participate***

Achieving the desired reductions begins with governments and citizens all over the world realising that a transition to a low-emission society is a fundamental necessity. This 'sense of urgency' forms the basis for several necessary preconditions. The dynamic application of new technologies in all countries of the world demands a much more efficient transfer of knowledge and technologies than existed in the past. Information and opportunities for attracting cheap capital are also crucial factors in the transition process. In addition to increased awareness of possible damage due to climate change, changes in perspective can also help to achieve these necessary conditions. This primarily concerns placing climate policy in a broader context of development objectives. For example, the Lisbon Agenda for the EU (which aims to strengthen the competitiveness of the EU economy through innovation) and the Millennium Development Goals (MDG) in developing countries. The following section provides more details.

Handling uncertainties

Between the political reality of long-term climate objectives and the translation into sets of policy measures and the calculation of associated costs, there are a large number of uncertainties in the climate system, but also in the technological development and potential of the various techniques involved. Other factors are also involved, such as social acceptance of, for example, nuclear energy and wind turbines. When all uncertainties are combined this leads to a broad spectrum of results that range roughly from halving the costs to doubling the costs of the various stabilisation scenarios. The increase in temperature is also uncertain. Since the scientific community cannot currently reduce this uncertainty any further, climate policies will need to have a certain amount of 'resilience' against these uncertainties. This could be achieved by using several portfolios of measures, and allowing for policy adjustment ('hedging'), by keeping policy options open.

- ***Uncertainties concerning the costs are considerable: estimates could be either halved, or doubled***

4. GLOBAL DIFFERENTIATION OF EFFORTS AND COSTS PER REGION

A climate policy that focuses on stabilising greenhouse gases requires eventual participation by all nations of the world. An important question here is: how can countries that are not yet actively participating (such as the USA and developing countries) become involved in international climate policy? How can the efforts, and thus the associated costs, be divided (in a reasonable way) among the various countries?

In order to stabilise greenhouse gas concentrations at low levels, the Kyoto agreements up to 2012 will need to be followed by new climate agreements, as shown in the previous chapters. However, negotiating these agreements is an extremely complicated affair, due to the existing widely differing visions and interests with respect to the approach taken regarding the climate problem and the priority given to this problem.

New agreements will need to take account of these differing visions and interests. It will probably be necessary to use another approach than that taken in the Kyoto Protocol, certainly if developing countries are also asked to make certain efforts. Although this report does not detail the opportunities and costs of adapting to climate change, agreements on this subject will probably also play a role in the new agreements. This chapter discusses the opportunities for international agreements, the (regional) division of efforts and costs, and the role played by the international trade in emission rights. The situation in Western Europe is also discussed, before focusing on the Netherlands in Chapter 5.

Expanding climate policy is necessary for ambitious objectives

The Kyoto Protocol includes agreements on the division of emission-reduction tasks between the industrialised nations, up to the year 2012. This means that only a limited number of countries have agreed to limit their emissions of greenhouse gases. Moreover, the USA and Australia have decided not to participate in the Kyoto Protocol.

Future international climate policy must be broadened, i.e. the number of participating countries must be increased. The reason for this is that the share of developing countries in global emission is growing fast. Although most energy-related greenhouse gas emissions (particularly CO_2) are currently still produced by the developed nations (see Table 4), within a few decades this balance will tip towards the developing countries. At the same time, the per capita emissions from the developing countries will still remain lower than those of the developed nations, even in 2050. Stabilisation at low concentration levels will be impossible if countries that are responsible for large

Table 4. CO_2 emissions from energy and industrial sources.

		Industrialised nations	Asia	Rest	World
2000	**CO_2 emissions ($Gt\ CO_2$)**	15	8	2	26
	Emissions per capita (tCO_2/head)	11.9	2.3	1.8	4.2
2050	**CO_2 emissions ($Gt\ CO_2$)**	23	22	9	53
	Emissions per capita (tCO_2/head)	17.1	4.3	3.3	5.9

amounts of emissions, such as the USA, but also large developing countries, do not participate in new international climate agreements.

Increasing the number of countries involved in international climate policy can be arranged in different of ways, but must in any case take account of the positions of the various countries. Scientists and policy advisors have already made many proposals and evaluations on the format of new agreements. Important questions here include: how to differentiate reduction commitments? How can the USA become involved in climate policy? In addition to new commitments for industrialised nations, how can agreements also be made with developing countries? Can agreements be formulated on the basis of other factors than emissions reduction, such as technology standards – and can such agreements be effective? One important factor here is that nations are independent and cannot be compelled to make international agreements. They can thus compare the costs and benefits of climate policy, and even try to shift the costs to other parties (so-called 'free riders'). There are few examples of countries being effectively forced to cooperate. As previously mentioned, it is important that there be sufficient parties, particularly large countries, experiencing a sense of urgency and that solutions be available (see previous chapter). An effective global climate policy does not require all countries to participate immediately in emissions reduction, but for the credibility and stability of an international climate regime it is necessary that there is at least the prospect of them participating at some point. This certainly applies to countries with considerable existing and fast-growing emissions, such as the large developing countries. This perspective is lacking in the Kyoto Protocol. In order to reach agreement on contributions it is important that countries feel that the division of the required contributions is fair and that it takes account of their interests. It can then be helpful to combine several policy agendas and to search for solutions that serve more than one purpose or interest (see following section).

Climate policy in a wider context

The fear of many policy makers in industrialised and developing countries is that both climate change and climate policy will form a threat to (further) development.

As indicated in the previous chapter, climate policy largely concerns adapting the energy system, and the energy system plays an important role in efforts to achieve sustainable development. This means that climate policy needs to be considered in an integrated manner that accounts for the availability of sufficient and affordable energy as the main driving force behind economic development, the need for security of supply, and the mitigation of regional and local air pollution.

Combining development priorities and options for adaptation and mitigation policy can create opportunities for strategies that result in climate-friendly development (thus with lower emissions) and in a less vulnerable society (climate-safe development). These options need not be selected just from a climate perspective, but are also attractive because they lead to reduced dependence on fossil fuels, improved access to modern energy, improved indoor and urban air quality (and thus health), technological innovation and new market opportunities for industry. Integrated analyses can provide an overview of the pros and cons of policy options for various policy areas, in order to explore synergies and to consider the 'trade-offs' in the policy.

Encouraging energy efficiency, for example, contributes directly to all objectives mentioned, but this also applies to encouraging renewable energy in rural areas, or using coal-fired plants with CCS. In particular, the possibility to use CDM (Clean Development Mechanism), JI (Joint Implementation) and emissions trading to ensure investments that contribute both to a cost-effective climate policy and sustainable development, offer considerable opportunities. Various developing countries, such as China and India, are also showing a great interest and already are implementing many activities in this area.

Multi-stage approach as an example of international differentiation of efforts

The international approaches proposed for post-Kyoto agreements vary enormously and can be assessed according to a large number of criteria (environmental effectiveness, possibility for acceptance and the associated reasonableness, opportunities for implementation, flexibility levels). One of the proposals to achieve an international differentiation of efforts concerns the so-called 'multi-stage approach' (see text box), in which an increasing number of countries accept commitments that, over a period of time, become increasingly more ambitious as the countries become more developed. Alternative approaches, which do not assume specific agreements on emissions reductions, include making agreements concerning the development and application of technologies, and agreements on objectives per sector. Such agreements generally offer less certainty of the environmental benefits, but can certainly contribute to technological innovation. Possibly a combination of elements from the various proposals could help to break through deadlocks in climate negotiations.

Compared to other proposals, the multi-stage approach scores well, due to its flexibility, links to existing policy and the possibility of linking to sustainable development. The following section shows a possible differentiation of efforts/commitment to meet an intended worldwide emissions reduction, based on this multi-stage approach. This differentiation of commitments consists of a system in which countries with comparable levels of development have comparable commitments to contribute to reducing greenhouse gas emissions (see Figure 13). Although other allocation rules are possible, the outcome can be considered indicative for various other proposals.

Developing a global climate policy: a multi-stage approach

The so-called multi-stage regime for global climate policy plays an important role in many studies concerning the differentiation of future commitments. In its simplest form, this regime differentiates between three stages of participation in international climate policy:

1. No commitments / baseline: this is for the least-developed nations that are not yet required to make a climate commitment.

2. Relative reduction objectives: this is for the more-developed (developing) countries, and means that the emissions do not increase as fast as the growth in the economy (relative decoupling). Integrating climate aspects into development policy offers considerable opportunities to make development more sustainable.

3. Absolute reductions: this applies to the industrialised nations, as per the Kyoto Protocol, and leads to reduced greenhouse gas emissions, although they still show economic growth (absolute decoupling).

This last stage includes the countries currently listed in Annex I of the Kyoto Protocol and that have ratified the Protocol. For example, this includes all countries in Western Europe, but not the developing countries (non-Annex I). Up to 2012 the USA (listed in Annex I, but not ratified) is not included in this stage.

Various criteria can be defined to determine which stage applies to which country. The calculations underlying Figure 13 are based on emissions per capita. but average welfare levels (GDP per capita) are also taken into consideration.

The first conclusion is that stabilisation at 450 or 550 ppm can only be achieved if the developed nations are committed to significant reduction targets for the period after 2012 (compared to 1990 levels). For these countries (including the EU), stabilising at 550 ppm requires in 2020 an emissions reduction of 10%, and in 2050 a reduction of 60%. A greater chance of achieving the 2°C objective, by stabilising at 450 ppm, would require even greater reductions: 25% in 2020, and 60-90% in 2050 (note that these reduction do not necessarily need to be implemented domestically, but may also be achieved via international trading mechanisms).

Figure 13. Regional emission ceilings for developed and developing regions, under a multi-stase approach, and global emission scenarios for stabilisation at 450 ppm and 550 ppm.

- ***Stabilisation at 450 ppm could mean, under a multi-stage approach, that the richest nations have an emissions reduction target of 10-25% in 2020, and 60-90% in 2050, compared to 1990 levels***

Under the multi-stage approach, various developing countries also participate after 2012, although they are in first instance simply required to limit the growth of emissions. Without the early involvement (in whatever form) of several developing countries with significant emissions (such as China, India, South Africa and Brazil), the objectives for stabilising concentrations at a low level, e.g. 450 or 550 ppm, will not be attainable. The more-developed developing countries will need to start reducing their emissions growth before 2020, at least to well below their baseline (10-30% in 2020, and 70-85% in 2050). The least-developed countries with relatively low incomes (South Asia, West and East Africa) may continue up to 2050 with a significant emissions growth that is just under their baseline.

Unless the USA and the developing countries participate, a stabilisation level of 450 ppm could only be kept within reach if the EU realised very high reductions in 2020. In fact, even with a very limited participation by the USA (but with participation by developing countries) the emissions-reduction objectives for the EU could already become unrealistically high. If new global climate agreements after 2012 do not directly follow up the Kyoto Protocol this could result in costly sharp emissions reductions in order to compensate for this delay.

- ***Achieving stabilisation at low levels requires that some developing countries become involved in international emissions agreements before 2020***

For several reasons, contributions by developing countries can also be beneficial for the developed nations, as well as for developing countries. If the opportunities for emissions trading improve, costs for the developed nations will be lower – even with additional reductions. At the same time, emissions trading can result in lower costs for developing countries, or even a net gain.

Costs: winners and losers

Depending on the economic, social and natural circumstances, the costs of climate policy per region can deviate considerably from the global average (see Chapter 3). For all 17 world regions that are considered, it would appear that the non-CO_2 measures offer an attractive and relatively inexpensive option that works well, particularly in the short term. The rest of the portfolio of measures varies specifically per region, and therefore the costs vary also.

In general, the OECD countries pay around 1.5 times as much for climate measures as the global average. For the former Soviet Union and the Middle East, the costs (compared to their GDP) can be considerably higher due to the high carbon intensity of these economies. The somewhat richer developing countries in Southeast Asia, East Asia (including China) and South America can expect limited costs for most climate regimes. The poorer countries in South Asia and Africa could possibly even profit from stringent climate policy, through income from emissions trading.

Emissions trading expands

The reductions mentioned in this report are targets that countries can also partially achieve outside their national borders. This can ensure a certain levelling out of the cost levels in the various regions, because the cheapest measures can be implemented first, in whatever country, sector or region. The buyer then gains extra emission permits at a relatively low price, and the seller can use this external funding to implement emissions-reduction measures.

Emissions trading, e.g. via the so-called ‘Kyoto mechanisms’ (CDM and JI), allows developed nations to (partially) achieve their climate targets by financing measures in poorer countries, in exchange for extra emissions permits. Systems for direct trade in emissions rights, such as the European emissions trading system, also allow companies to trade in the same way.

Studies concerning the division of climate measure costs over the various regions assume that the emissions trading methods will be refined and expanded over the coming decades. Such trade can therefore be implemented on a much larger scale that is currently the case. Creating situations that allow emissions trading therefore remains an important aspect of a cost-effective climate policy.

- ***Worldwide emissions trading is likely to occur on a much larger scale than exists at present***

In addition to relatively high costs for climate policy, some regions (Middle East, former Soviet Union) can also be affected by significantly lower incomes due to reduced (growth in) exports of fossil fuels. Other regions (South America, former Soviet Union) could, in contrast, receive extra income, for example, through the large-scale production of biofuels. Moreover, the reduction in fossil fuel trade also means reduced dependence by importing countries. In order to achieve international agreements it will probably be necessary to spare the regions with relatively high cost levels.

EU measures

Under the current Kyoto Protocol, the EU is committed to emitting an average of 8% less greenhouse gases per year (for the period 2008-2012), compared to 1990 levels. For the period after 2012 the EU Council of Ministers has proposed an emissions reduction by industrialised nations of 15-30% in 2020, as a basis for negotiations on agreements after 2012. This is based on the 2°C temperature limit for targeted environmental quality. In the longer term (up to 2050 and beyond), some countries have already selected an indicative target. For example, Germany, France and the UK already aim at (at least) halving their emissions by 2050.

Calculations based on the multi-stage approach described in the previous section show that, in order to make it possible to stabilise concentrations at low levels, countries within the EU, like other Annex I countries in the Kyoto Protocol, must make a relatively high contribution to global emissions reduction. In 2020, emissions reduction in the EU-25 countries will be at least 10-25% (for 550 and 450 ppm respectively), and will increase to 60-90% in 2050. It can therefore be concluded that the intended European proposal lies, for 2020, within the ‘range’ of emission-reduction pathways, which lead to the stabilisation of greenhouse gas concentration levels at 550 or 450 ppm.

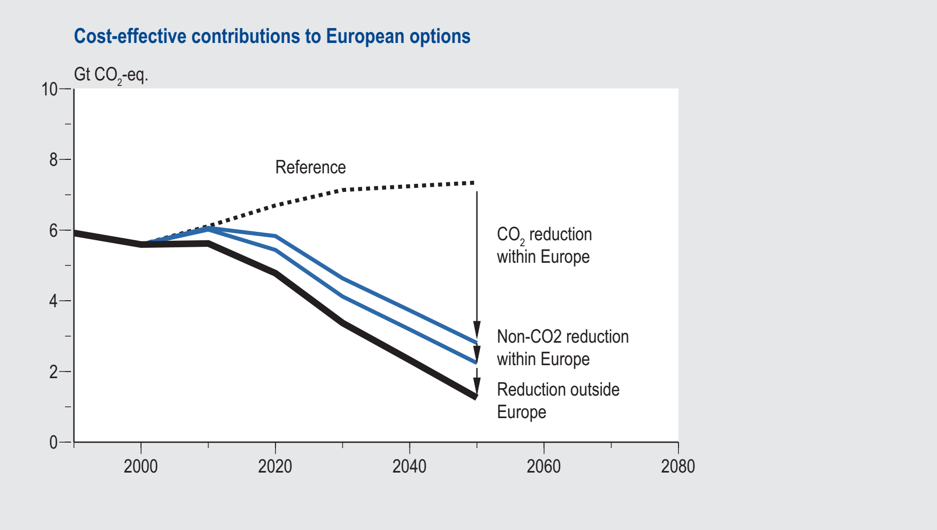

Figure 14. Percentage of domestic and foreign emissions reductions for the EU, at a cost-effective climate policy, to stabilise concentrations 450 ppm.

It is expected that it will be cost effective to realise a significant part of this reduction objective by funding measures outside Europe (see Figure 14). However, this will reduce the co-benefits of climate policy in Europe, such as energy security, air quality and technological innovation. The policy will therefore need to consider both the direct costs of climate policy and the co-benefits within the region.

5. OPTIONS FOR THE NETHERLANDS

The previous chapters show that, worldwide, there are potentially sufficient measures available to stabilise the concentration of greenhouse gases in the atmosphere at low levels. Given the regional differences in economic development, size etc., it is interesting to look at the situation for the Netherlands.

This chapter discusses the measures that the Netherlands could take in the short term (in the period up to 2020), under the assumption that drastic emissions reductions will be required in the 21st century. The basis for this chapter is the " Options document" and reference estimate, in which the MNP and ECN (Energy research centre of the Netherlands) provide an overview of the costs and potentials of all domestic reduction measures, up to 2020.

The analysis for the Netherlands can be seen as a case study for implementing post-2012 climate policy in European countries. Within this context it is important to realise that the Netherlands has a fairly efficient energy supply; and that the Kyoto objective (-6% emissions compared to 1990 levels) is considered to be relatively stringent. Many inexpensive measures have already been taken in the Netherlands.

One important conclusion is that climate policy in the Netherlands cannot be viewed separately from international climate policy. This generally applies to agreements on emissions-reduction targets, but an international context is also important for many specific measures. For example, many measures concerning transport are effective and cost efficient only if applied at the EU level. The Netherlands, as one of the 25 Member States, can influence such decisions. Individual national measures sometimes produce little effect unless incorporated into European implementation schemes and, for industry, a level playing field within the EU is often a precondition for measures.

The main question is to what extent the current policy in the Netherlands, and the country's reduction opportunities, match the possible targets for the EU, as discussed at the end of the previous chapter (10-25% reduction in 2020, and 60-90% reduction in 2050).

Like in the Options Document, this chapter does not discuss the necessary policy instruments, sustainability aspects, the innovative power of Dutch industry, or the public support for wind or nuclear energy.

Climate policy up to 2020

Within the European target setting (to achieve 8% lower emissions in 2008-2012, compared to 1990 levels), the Netherlands has agreed to a target of 6% emissions reduction, compared to 1990 levels. Part of this objective is currently being realised by projects in other countries, on the basis of the so-called Kyoto mechanisms. For the period after 2012, the Netherlands continues to follow EU policy (for a description of EU policy, see the end of the previous chapter). This means that, although options are being considered for achieving reductions up to 2020, there is no strategy for the longer term.

- ***A national emissions reduction of 15-30% in 2020 is in line with the necessary international efforts to achieve the 2°C objective in the longer term***

Measures in the Netherlands

A joint research project by ECN and MNP studied the opportunities for reducing domestic greenhouse gas emissions in the Netherlands. The study looked in detail at three specific levels of domestic emission reduction in 2020 (thus excluding emission reductions from projects in other countries (see Figure 15).

- Stabilisation of national emissions at 2010 levels, or at a level of 220 million tons[6] CO_2-eq. emissions per year. This level is slightly higher than the annual emissions in 1990 (214 Mton).
- A reduction of 6% compared to the 1990 emission level (200 Mton per year).
- A reduction of 15% compared to 1990 (180 Mton per year).

The last optional target best meets the emission reduction targets from the previous chapter: rich countries, such as the Netherlands, will need to achieve a relatively larger emission reduction over the next few decades, in order to realise a worldwide stabilisation at less than 550 ppm. The 15% target falls just within the indicative EU objective of 15-30% emission reduction in 2020. For additional emission reduction the Netherlands can always use emissions trading options with developing countries.

The starting point for the *Options Document* are the MNP/ECN reference estimates, based on economic scenarios from the Netherlands bureau for economic policy analysis (CPB) for socioeconomic developments in the Netherlands up to the year 2020. The so-called Global Economy scenario forms the central reference development, which includes a relatively high economic and population growth in the Netherlands. This results in high energy consumption and thus in associated high emissions levels. Based on this reference/background scenario, the research institutes studied baskets of options that could meet the emission targets at the lowest total cost.

6 The baseline in the Global Economy scenario should lead to a domestic emissions level of 250 Mton CO_2

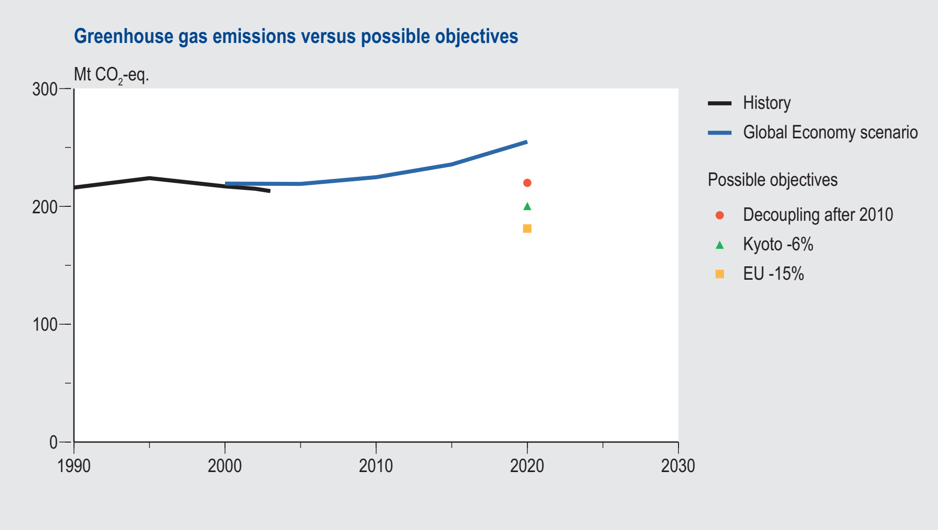

Figure 15. Greenhouse gas emissions in the reference scenario (Global Economy) and possible national (domestic) emission-reduction targets.

Portfolios of options

An important conclusion from analysing the potential of these options compared to the reference development, is that the Netherlands has sufficient technical potential to achieve a domestic emission reduction of 15% in 2020, compared to 1990 levels.

- ***The Netherlands has sufficient potential to achieve a 15% reduction of domestic emissions in 2020, compared to 1990 levels, at a cost of € 1-2 billion per year. Technically, a greater reduction is possible, but at considerably higher costs and increased effort***

A basket of options was defined for each of the three aforementioned indicative emissions objectives, at the lowest possible national costs[7]. Compared to the baseline, an objective of 15% lower emissions in 2020 will cost around € 1.4 billion per year (see Table 5).

These options also include measures that do not cost any money, but can (from a national point of view) even yield revenues, for instance through specific energy saving measures or through the so-called road pricing option. In all cases, these measures, despite their profitability, are not easily taken – for example, because they require a change in behaviour or because there are social costs involved (which are both outside the scope of this analysis).

7 Excluding the costs associated with implementing this policy.

Table 5: Annual costs of sets of options whereby, in addition to climate objectives, future air quality objectives (NEC ceilings, particulate matter) are also achieved.

Objective for 2020 (in Mt CO_2-eq.)	Required emissions reduction in 2020 (in Mt CO_2-eq.)	Annual costs of optional measures in 2020 (in billion euro/year)		
		Balance	Negative costs	Positive costs
220 (= stabilisation compared to 2010)	31	-0.0	-0.6	0.6
200 (= -6% compared to base year)	51	0.3	0.6	0.9
180 (= 15% reduction compared to base year)	71	1.4	-0.6	2.0

For this reason these measures are not included in the reference development, but are considered options: they cannot be achieved without additional policies. The most expensive measures in the basket that achieves the 15% target reduction cost around € 81 per ton of avoided CO_2-eq. In other words, achieving 15% emissions reduction would require all possible reduction measures that cost up to € 81 per ton. For a 6% reduction this upper limit is around € 23 per ton, and for stabilising at 2010 levels this would cost up to € 8 per ton.

Options up to 2020

Analysis of the *Options Document* highlights three relatively important measures that have a high emissions-reduction potential at relatively low costs (see Figure 16. For all three options see also the considerations in Chapter 3, including the assessment of the costs).

- Energy savings.
- Nuclear energy.
- CO_2 storage.

It appears that two sectors (industry and the energy supply sector) could make a considerable contribution to the basket of options analysed. This relates to both the relatively high greenhouse gas emissions in both sectors, but also to relatively low reduction costs. As previously stated, a more stringent reduction target would make it necessary to introduce more expensive measures, including for example certain renewable energy sources and certain energy savings options, such as ‘wall insulation’ in homes and offices. It should be noted that the reference scenario (i.e. without climate policy) already includes a significant contribution to energy saving and renewable energy.

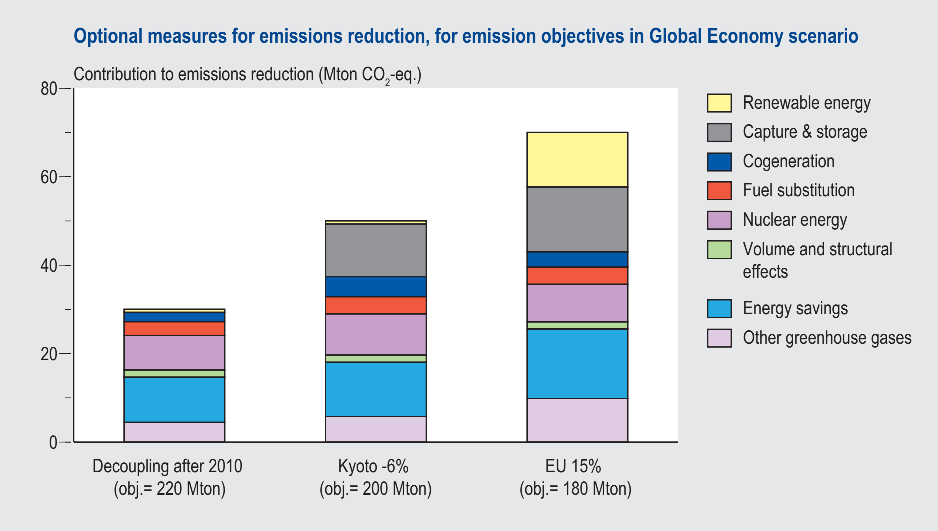

Figure 16. Optimum-cost sets of options to achieve various national reduction objectives.

Whether or not measures can really be implemented, or are feasible within the desired time period, primarily affects the total costs of the particular portfolio of measures. Similar to the global level, here too it is clear that excluding certain options costs money. If, for whatever reason, nuclear energy or CO_2 storage options cannot be realised, this will result in significantly increased costs, because the alternatives are more expensive. In the case of the 15% objective, the costs could increase by almost € 2.9 billion per year. If only nuclear energy is excluded, annual costs of future climate policy would be € 590 billion higher; if CO_2 storage is excluded then costs would rise by € 1.8 billion per year.

An interesting question concerns the way options that are attractive for the Netherlands relate to those at global level (Chapter 3). Generally, there are clear similarities. Globally speaking, saving energy and CO_2 capture and storage are also identified as options that can make the greatest contribution to emissions reduction. The contribution from renewable energy in the Netherlands is generally similar to the global situation. In the options for 15% emissions reduction in 2020, offshore wind farms provide the greatest contribution. Bioenergy and wind are already included in the background scenario, due to the presumed government policy.

One remarkable difference concerns bioenergy – which plays an important role in the worldwide portfolio of measures, but which is almost entirely lacking from Dutch policies. There are two reasons for this. Firstly, the background scenario for the Netherlands already assumes that a lot of biomass will be used to produce electricity, including stimulation by subsidies. Secondly, options concerning transport biofuels are more expensive, so that they are not included in the options portfolio for the Netherlands in 2020. In the longer term, using more expensive options (such as biofuels for transport) will be necessary for the global reduction pathways associated with the 2°C objective. Due to the limited availability of land for energy crops in the Netherlands, a significant portion of the bioenergy is imported. This limited availability of land is also the reason that carbon sinks (land) make a smaller contribution in the Netherlands than worldwide. The contribution from non-CO_2 gases in the Netherlands is less than at the global level, due to the fact that the Netherlands has already achieved a great deal with the industrial sector, and the options in the agricultural sector in developing countries are more important than in developed countries. On the other hand, nuclear energy plays a smaller role in the solutions mix at global level (due to the greater use of other sources).

Saving energy

The *Option Document* calculates a maximum technical savings rate of 2.3% per year, for the years 2010-2020. However, due to the high costs of certain savings measures this maximum is not reached for the 15% target in the option portfolios. If the goal is to keep national costs as low as possible, then the savings rate to achieve this target needs to be increased: from 1% in the baseline package, to 1.7% per year. The current savings rate is around 1% per year.

From options to implementation

Table 6 provides a few examples of policies that need to be implemented in order to achieve a 15% emissions reduction in 2020. These examples clearly show that, considering the short timeframe available in which to achieve the desired effects (2020), the use of policy measures cannot be delayed for long. From the current policy point of view, 15% domestic emissions reduction in the Netherlands is thus an ambitious target. In addition to domestic emissions reduction, there is also room to realise part of the objective via projects in countries where emissions-reduction measures are less expensive. The choice between taking domestic measures or using projects in other countries not only depends on the direct costs. Other aspects, such as development cooperation, social support, innovation opportunities for Dutch industry and institutional barriers, all play a role here.

In addition, emissions trading schemes also transfer the co-benefits, such as less emissions of sulphur and nitrogen oxides, or of particulate matter, to other countries. Ambitious European objectives exist that require additional measures – and synergy can thus be attractive in minimising national environmental costs.

Table 6: Examples of implications of the target level (180 Mt) in 2020.

Options to achieve an emissions level of 180 Mton CO_2-eq. in 2020	**Examples of implications**
New nuclear power plants (capacity: 1600 MW_e)	- Specific investment plan for 2010 by private parties - Government intervention, as the sector will not/ cannot carry the risks itself
5500 MW_e offshore wind energy	- Modifying policy for renewable energy (current policy assumes 2000 MW_e)
Minimum 12 Mton CO_2 capture	- Specific investment plans for around 2013 - Harmonising with the operation of suitable natural gas fields, so that timely storage capacity is available - Apply for permits and install infrastructure for capture, transport and storage within six years (from 2013) - Via emissions trading: structural CO_2 price of at least € 50/ton CO_2-eq. from 2011. Requires European harmonisation
3 Mton reduction in industry via energy savings and cogeneration	- Via emissions trading: structural CO_2 price of at least € 80/ton CO_2-eq. from 2011. Requires European harmonisation

- ***Using the technical potential for domestic emissions reduction needs to weighed against the opportunities for reducing emissions more cheaply in other countries. Co-benefits from domestic climate policy should be included in the considerations***

Option Document and oil price

The most recent analyses of measures in the Netherlands assume a relatively low oil price. The price of oil, and thus the price of natural gas (which is usually coupled to the oil price), have no effect on the technical potential of reduction options, but are certainly important parameters when calculating the costs of emissions reduction. Roughly speaking: the higher the assumed oil price, the lower the extra costs for climate policy.

The *Option Document* includes two scenarios, with prices of around 25 US$ and of 40 US$ per barrel.

Using the higher oil price, the reference scenario will achieve more energy savings, but more coal will also be used, and the market situation for gas-fired (cogeneration) plants will be less good. The net result is that in the scenario with a higher oil price emissions are around 4 million tons CO_2-eq. lower. The costs of the options for 15% emissions reduction thus fall by around €400 million per year. An oil price that remains structurally high will ensure that these costs are reduced even further.

Policy measures to implement these options

This report focuses on reduction options rather than on the possible policy instruments that would be required in order to implement these options. There is a wide range of policy measures that could encourage the application of each technological option: regulations, duties and subsidies, emissions trading, research, information campaigns, and strengthening infrastructure. It is often necessary to consider effectiveness, policy costs and flexibility with respect to technology choice, and thus usually the cost effectiveness. The most compelling instrument is the setting of (technical) criteria and specifications. Initially this offers considerable certainty of the effectiveness, but it also leads to high policy costs and offers little flexibility. Duties and subsidies offer more flexibility, but also limited certainty. The EU has chosen emissions trading as an important part of the European climate policy. The advantage of this instrument is that it offers both certainty of the environmental effectiveness as well as a high degree of flexibility and thus cost efficiency.

Technological innovation forms a crucial part of the long-term climate policy aimed at achieving low concentrations. Studies show that innovation works best with policies that offer long-term certainty for the market. Economic instruments alone do not seem to offer sufficient certainty. Thus, a climate policy that tries to encourage both efficiency and innovation will need a greater number of instruments. The Netherlands has established an energy transition policy to try and offer market parties sufficient certainty so that they will initiate the required technological innovation.

Another example of policies with a binding objective aimed at innovation, is the Californian approach using the ‘zero emission car’. Comparable technology-based norms on a European scale could contribute to more certainty at a high scale level (European market). However, market parties would need the freedom to choose for themselves the best techniques with which to comply with this norm.

Uncertainties versus certainties

Models, such as those used to compile the *Option Document*, include inherent uncertainties. However, the results from this analysis can still be considered ‘robust’, in the sense that they are not changed by deviating assumptions for oil prices or societal developments, and for the development of further potential, and the costs of certain options.

The most important conclusion from the *Option Document* is that significant emissions reductions in 2020 are technically feasible for the Netherlands. The composition of portfolios of measures for minimising the costs is thus also fairly certain. Individual options may incorporate more uncertainties, but in many cases this does not greatly influence the final conclusions, because in this same category of options there are generally alternatives available if the potential for one particular option fails.

Additional uncertainty is created if the desired domestic emission reductions after 2020 are also taken into consideration. The current portfolio of options in the *Option Document* does not discuss this. If stringent targets are to be met after 2020, other long term options will become “cost-effective” in the time period up to 2020.

Closing remarks

This report provides an overview of the most recent insights into the opportunities for national and international climate policy – based on the European 2°C objective. The results clearly show that, both internationally and within the Netherlands, it is technically possible to compile portfolios of measures that could lead to far-reaching reductions of greenhouse gas emissions, to meet the 2°C temperature objective with a reasonable certainty. The costs of such measures are becoming clearer. Contributions are also made towards achieving other national and international environmental and development objectives. However, there are a few important conditions for achieving these goals:

- Broad sets of measures should be used; when certain options are not acceptable or cannot be implemented then costs will rise.
- The timely use of measures; lengthy postponement makes it more difficult and probably more expensive to achieve low stabilisation levels.
- It is preferable to use both instruments that allow a cost-effective approach to emission reduction (e.g. emissions trading and CDM), and instruments that encourage technological innovation.
- A broader participation by both industry and developing countries in new international climate agreements for the period after 2012.

This last point in particular is currently difficult to achieve, considering the varying visions and interests of countries. Placing climate policy into a broader context of sustainable development could help to create new coalitions and the implementation of measures that lead to synergy for climate, security of energy supply and air pollution.

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Glossary

2°C objective: Climate objective of the European Union: the average temperature on earth, compared to pre-industrial levels, may not increase by more than 2°C.

Biodiversity: the total extent and variety of plants and animals. Biodiversity is reduced as a result of climate change, but can also be damaged through construction, or expansion of agricultural land.

Bio-energy: energy from plant and animal residues. Also known as biomass.

Carbon sinks: Reforestation aimed at absorbing carbon dioxide from the atmosphere.

CCS (Carbon Capture and Storage): The capture of the greenhouse gas CO_2 from flue gases, in order to store it (underground) to prevent it reaching the atmosphere.

CDM (Clean Development Mechanism): The so-called 'Kyoto mechanism' through which nations can realise emission-reduction projects in other countries, in exchange for extra emission flexibility in their own countries. CDM projects take place in developing countries (see also JI).

Climate Convention: The basis for international climate policy, signed under the auspices of the UN in 1992, in Rio de Janeiro. Its most important goal: to prevent dangerous anthropogenic climate change.

Clusters: Sets of emission-reduction pathways that could lead to a stable greenhouse gas concentration level. A range indicates the bandwidth within which a certain level could be achieved.

CO_2-equivalent ppm (parts per million): unit used to express the concentration of greenhouse gases in the atmosphere. The effect of other greenhouse gases, other than CO_2, are 'converted' into the equivalent of a certain amount of CO_2 molecules.

Concentration levels: concentrations (of greenhouse gases) in the atmosphere, expressed as ppm CO_2-eq. A stable concentration level is required in order to eventually stop the temperature rise.

Emissions trading: the trade in emission rights. The buyer – a country or a company – purchases surplus emission rights from another country/company.

GDP (Gross Domestic Product): the total income of people living in a country.

Greenhouse gases: gases that disturb the heat balance in the earth's atmosphere because they allow UV rays in the atmosphere to penetrate easily, but do not easily allow the heat generated on earth to exit. CO_2 (carbon dioxide), produced by burning carbon, is the most important gas contributing to a enhanced greenhouse effect. Other gases include methane and laughing gas.

IPCC: Intergovernmental Panel on Climate Change, the international scientific body that periodically publishes detailed overviews showing the current status of scientific research with respect to climate change, measures to prevent climate change, and measures to adapt to the consequences of climate change.

JI (Joint Implementation): A so-called 'Kyoto mechanism' through which the richer nations are allowed to realise emissions-reduction projects in other countries, in exchange for extra emissions flexibility in their own country. JI projects generally take place in former Eastern Block countries (see also: CDM).

Non-CO_2 greenhouse gases: These include other greenhouse gases that are also included in the Kyoto Protocol: methane (CH_4), dinitrogen oxide or laughing gas (N_2O), fluorinated hydrocarbons (HFCs and PFCs), and sulphur hexafluoride (SF_6). Important greenhouse gases that do not fall into this category include: water vapour (H_2O), ozone (O_3) and CFCs (part of the Ozone Treaty).

Reduction pathways: An indication of the possible developments for reducing greenhouse gas emissions in the 21st century. These pathways may vary according to the viewpoints taken and the options used (sectors, regions and types of greenhouse gas).

Reference scenario: Description of future development of aspects such as the economy, world population, deforestation, energy consumption and emissions without extra climate policy.

Scenarios: Possible future developments, for example, in the economy or energy consumption. Scenarios are not predictions for the future, but provide an indication of what could happen, under certan assumptions.

UNFCCC (United Nations Framework Convention on Climate Change): see Climate Convention.