A Scientific Basis for Climate Policy

Report of the Scientific Council on Climate Issues

The Environmental Advisory Council
Report 2007:3

The Scientific Council on Climate Issues/Vetenskapliga rådet för klimatfrågor
The Environmental Advisory Council/Miljövårdsberedningen
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STATENS OFFENTLIGA UTREDNINGAR

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To the Minister for the Environment, Andreas Carlgren, and the Parliamentary Committee for the Review of Climate Policy (M2007:03)

The Scientific Council on Climate Issues was established as an organisational entity within the Environmental Advisory Council (Jo 1968:A) by the Minister for the Environment, Andreas Carlgren, in accordance with a government decision taken on 21 December 2006. The Council has been commissioned to provide a scientific assessment as a basis for the work of the Parliamentary Committee for the Review of Climate Policy (M 2007:03). An important part of this task is to provide basic documentation and recommendations for Swedish climate policy targets at national, EU and international level. The Council's remit is to apply from 1 January 2007 to 1 September 2007.

The Scientific Council on Climate Issues herewith presents its report, A Scientific Basis for Climate Policy: Report of the Scientific Council on Climate Issues (Report from the Swedish Environmental Advisory Council 2007:03).

The Council members were Professor Lisa Sennerby Forsse (chair) and professors Christian Azar, Sten Bergström, Anders Biel, Runar Brännlund, Katarina Eckerberg, Thomas B Johansson, Erland Källén, Caroline Leck and Markku Rummukainen, and Dr Elisabet Lindgren.

The Environment Advisory Council staff taking part were Administrative Director Pernilla Knutsson, Desk Officer Åsa Guilamo, Director Lars Lundberg and Associate Professor Fredrik von Malmborg. The Ministry of the Environment was represented by Desk Officer Anna Forsgren.

Stockholm, 31.08.07

Lisa Sennerby Forsse
Chair
Swedish Scientific Council on Climate Issues.
Environmental Advisory Council (Jo 1968:A)

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1 Executive summary

The Scientific Council on Climate Issues has been commissioned by the Government to provide a scientific assessment as a basis for the work of the Climate Committee, the all-party parliamentary committee set up to review Swedish climate policy. An important part of this task is to provide basic documentation and recommendations for Swedish climate policy targets at national, EU and international level.

Scientific understanding of climate change and its implications is constantly increasing. The fourth assessment report of the UN's Intergovernmental Panel on Climate Change, IPCC, corroborates previous data in many respects. To a great extent, the Scientific Council on Climate Issues bases its conclusions on the knowledge compiled by the IPCC, but it has also taken into account research published at such a recent date that it could not be considered in the latest IPCC assessment report. Other relevant studies, too, have been used. In addition, the Council has chosen to emphasise findings of relevance to Sweden nationally and to Sweden as an actor both in the EU and at global level.

In the opening chapters, the Council looks at climate change, its reasons and its consequences for ecosystems and society. The Council then makes recommendations concerning Swedish climate policy targets at global, EU and national levels, aimed at averting dangerous impact on the climate. In the concluding chapters, the Council presents a number of possible measures and policy instruments, and outlines the likely costs involved if the goals are to be achieved. Taken as a whole, the document represents a comprehensive basis for policy decisions that consider what needs to be achieved to reduce the risks of climate impact and what is actually achievable, i.e. decisions involving trade-offs between economic benefits and costs.

Climate policy involves risk assessment under uncertainty. We now have enough knowledge about the climate system and how climate change affects ecosystems and society to take action. A considerable degree of uncertainty remains, however, as regards the climate system and the impact of climate change on ecosystems and society. In other words, there is a danger that the consequences will turn out to be more serious than we are in a position to assess on the basis of present knowledge. This is further reason for taking action.

The Council believes that Sweden must take an active part in research and development focusing on the earth's climate system, climate impacts, vulnerability, adaptation, measures and policy instruments. An important aim in this should be to support such research in developing countries.

Below is a presentation of the Council's most important conclusions.

Climate change and its consequences for ecosystems and society (Chapters 2 and 3)

The earth's climate has become warmer and this has very likely been caused by human activity. The Council has examined the data from the IPCC and concurs with the Panel's overall assessment both of climate change and of its implications for ecosystems and society.

Climate change

The Council notes

- that the global mean temperature has risen by just over 0.7°C over the past 150 years and is currently rising by almost 0.2°C per decade
- that most of the global warming that took place during the latter half of the 20th century was very likely due to an amplified greenhouse effect caused by human emissions of greenhouse gases (GHGs)
- that unless vigorous measures are introduced, the global mean temperature is expected to rise by 1.6–6.9°C by the year 2100,

compared with the pre-industrial era, and then to continue rising in the next century

- that the extent of future climate change depends on factors such as population trends and socioeconomic and technological development
- that most changes in the physical climate occur gradually but that rapid and abrupt changes cannot be ruled out. The risk of abrupt change increases as the temperature rises.
- that further changes in temperature, sea-levels and precipitation, along with those already observed, will display very significant regional variations.

Consequences for ecosystems and society

The Council notes

- that the consequences for ecosystems and society will become more numerous and extensive the faster and higher temperatures rise. In global terms, the negative consequences will outweigh the positive ones.
- that the consequences will differ very significantly between regions, depending on the extent of regional climate change and on variations both in natural systems and in societies' levels of vulnerability and capacity to adapt. Particularly at risk are the Arctic, parts of Africa and Asia.
- that consequences for ecosystems and societies arise both gradually and abruptly. Climate change has already had observable impacts.
- that the consequences that give particular cause for alarm today are the risk of diminished food production and changes in water supply in certain areas, and biodiversity loss and coastal flooding
- that the consequences of climate change may be reinforced by other global changes taking place simultaneously (such as population density, resource use and environmental degradation). Climate change also makes it more difficult to confront other global challenges, including poverty eradication.

- that adaptation measures are essential and should be integrated into international and national efforts to promote social development. The prime focus, however, should be on emission reduction.

Climate policy targets (Chapters 4 and 5)

Very considerable restrictions on GHG emissions will be needed if the risk of harmful climate impact is to be reduced. The Council takes the view that targets must be established for global temperature rise, for the global stabilisation of GHG concentrations in the atmosphere, and for the reduction of emissions. The various targets at global level can largely be derived from one another on the basis of the temperature target. The Council bases its recommendations concerning targets on the current state of scientific knowledge. These targets may need to be revised as our understanding of the climate system and society improves.

The Council's conclusions regarding climate policy targets are presented below and are summarised in the table that follows.

Globally: Temperature target, concentration targets and emission targets

The Council considers

- that the EU's two-degree target is a reasonable basis for emission-reducing measures, but that the possibility of lower temperature rises having severe impacts cannot be ruled out
- that the two-degree target can probably be achieved if GHG concentration in the atmosphere is stabilised in the long term at 400 ppmv carbon dioxide equivalents (CO_2e). If it is stabilised at 450 ppmv CO_2e there is a significant risk that the two-degree target will not be achieved.[1]

[1] The concentration of greenhouse gases (GHG concentration) currently stands at approximately 450 ppmv CO_2e and is increasing by just over 2 ppmv per year. The fact that this has not yet led to a temperature rise of more than 0.7 degrees since pre-industrial times is due to the simultaneous release of particles that have a masking effect, and to inertia in the climate system. That concentration levels below the present one are achievable is due to the fact that greenhouse gases can be absorbed or broken down by natural systems.

- that global GHG emissions in 2020 will need to be about 10 per cent lower than the 2004 level if GHG concentration is to be stabilised at 400 ppmv CO_2e in 2150[2]
- that by 2050 global emissions need to be at least halved compared with the 1990 level (if the target of 400 ppmv CO_2e is to be achieved)
- that by the end of the century global emissions need to have been reduced virtually to zero (if the target of 400 ppmv CO_2e is to be achieved).

The EU and Sweden: Emission targets

The reduction requirements for Sweden and the EU have been calculated using a number of frequently discussed models for how emission reductions are to be differentiated globally, known as differentiation models. The choice among models dealt with in the report does not significantly affect the size of the emission reductions required of Sweden. Other models may yield other outcomes.

The Council considers

- that the EU's GHG emissions compared to the 1990 level should be reduced by 30–40 % by 2020 and by 75–90 % by 2050 if the Union is to take its share of the global responsibility for achievement of the two-degree target
- that Sweden's GHG emissions compared to the 1990 level should be reduced by 20–25 % by 2020 and by 70–85 % by 2050 if Sweden is to take its share of the global responsibility for achievement of the two-degree target
- that a national emission target for Sweden should be formulated as a target with deductible emissions allowances, i.e. that assessment of target achievement is based on the amount of emission allowances allocated or auctioned by Sweden to activities covered by the EU emission trading scheme rather than the actual volume of emissions from these activities.

[2] Compared with the 1990 level, this corresponds to an increase in emissions of about 10 per cent.

Table Recommendations on targets for climate policy

TYPE OF TARGET	LEVEL		
Temperature target	***Global***		
Maximum increase in temperature compared with pre-industrial level	**Max 2˚C**		
Concentration target	***Global***		
Long-term stabilisation level, GHG concentration in the atmosphere			
Probability of achieving the 2˚C target:			
>66 %	**400 ppmv CO_2e**		
approx 50 %	**450 ppmv CO_2e**		
Emission targets	***Global***	***EU***	***Sweden***
Reduction in CO_2e emissions in relation to1990 levels, consistent with a concentration target of 400 ppmv CO_2e			
2020	**0–incr. 10 %**	**30-40 %**	**20- 25 %**
2050	**min. 50 %**	**75–90 %**	**70–85 %**
2100	**almost 100**	**approx. 100**	**approx. 100**

Source: Swedish Scientific Council on Climate Issues.

Note 1: The reduction requirement given for Sweden is based on estimates of what Sweden needs to do to take its share of global responsibility to achieve the two-degree target. The targets that Sweden should set up depend on political assessments that include temperature target, the application of the precautionary principle and whether Sweden should be a frontrunner.
Note 2: Emissions of GHG in Sweden in 2005 were some 7 per cent lower than the 1990 level.
Note 3: CO_2e means carbon dioxide equivalents and ppmv means parts per million by volume.

Measures for reducing emissions (Chapter 6)

The Council has provided an overview of possible measures for reducing emissions. Emissions can be reduced in all sectors of society. Action needs to be taken to avert future increases in emissions as a result of population rise, increased industrialisation, infrastructural development and economic growth.

The Council considers

- that the global emission reductions deemed necessary if the two-degree target is to be met may be achieved by applying both technologies currently available in the market and technologies that may be expected to arrive in the market over the next few decades
- that changes in consumption patterns are of crucial importance when seeking to reduce GHG emissions
- that a combination of increased energy efficiency, energy saving and measures in respect of energy supply are required if the climate targets are to be achieved
- that increased energy efficiency and energy saving have high potential for reducing GHG emissions at low costs
- that renewable energy (bioenergy, sun, wind, water), nuclear power and the capture and storage of CO_2 can help reduce emissions. In the case of nuclear power, generally acceptable solutions must be found to the problems of safety and security, waste, the risk of nuclear weapons proliferation and terrorist acts.
- that the efforts made to reduce GHG emissions over the next few decades will largely determine the extent to which achievement of the two-degree target will be possible
- that achievement of a Swedish emission target for the year 2020 should to an overwhelming extent be sought via a combination of domestic measures, especially in the transport sector, and a reduced allocation of emission allowances to sectors covered by the EU emission trading scheme. Government investment in emission-reducing projects in developing countries, via the Clean Development Mechanism (CDM), may be required as a supplement.

Climate policy costs and benefits (Chapter 7)

Assessments of costs and benefits to society are a crucial part of the climate policy discussion. This refers to costs associated with reducing GHG emissions in sectors such as energy supply, transport, construction, and agriculture and forestry. It also refers to benefits in the form of reduced damage and other benefits that such measures may yield over and above reduced emissions. The delimitation lines drawn when estimating costs and benefits have a decisive impact on the calculations.

The Council considers

- that assessments of the costs of damage caused by climate change are uncertain, to some extent ethically controversial, and strongly dependent on what kind of damage is included, what value is attached to it, and how the future is viewed in terms of value (discounting)
- that there are significant uncertainties in estimates of costs associated with GHG emission reduction
- that the global and national costs of reducing emissions to levels compatible with the two-degree target are significant but compatible with sound macroeconomic development
- that the cost of reducing emissions decreases if cost-effective policy instruments are chosen
- that the cost of reducing emissions decreases if other benefits deriving from greater energy efficiency and renewable energy use are taken into account, such as cleaner air and higher security of energy supply.

Climate policy instruments (Chapter 8)

If the desired measures are to be taken at reasonable cost, both the choice of instruments and the direction of climate policy are crucially important. On the basis of research in environmental economics and other disciplines, the Council has discussed a selection of main issues.

The Council considers

- that the climate issue must be solved through international cooperation
- that policy instruments for reducing GHG emissions should preferably be broad, internationally coordinated, uniform and technologically neutral, but that departures from this principle may sometimes be warranted
- that setting a price on GHG emissions with a view to achieving the climate targets is of fundamental importance
- that the economic instruments of CO_2 tax and emission trading are important and powerful policy instruments if properly designed
- that economic instruments need to be supplemented by other policy instruments such as education, information and legislation
- that Sweden must be proactive in the EU in seeking to improve the EU emission trading scheme. It is important that the emission cap is lowered and auctioning of allowances is applied.
- that new technology is crucial to the task of solving the climate problem. The imperatives in this respect are research and development and policies that create markets for the commercialisation of these technologies.
- that Sweden should work actively at international level to abolish subsidies for extraction and use of fossil fuels.

1 The remit, the role of science and the structure of the report

1.1 The remit

The Scientific Council on Climate Issues was established as an organisational entity within the Environmental Advisory Council by the Minister for the Environment, Andreas Carlgren, in accordance with a government decision taken on 21 December 2006 (Jo 1968:A). The Council has been instructed to provide a scientific assessment as a basis for the work of the Parliamentary Committee for the Review of Climate Policy (ToR 2007:59). An important part of this task is to provide a basis and recommendations for Swedish climate policy targets at national, EU and international level. The remit is described in closer detail in a memorandum presented by Prime Minister Fredrik Reinfeldt and Minister for the Environment Andreas Carlgren at a press conference on 21 December 2006 (See Appendix 1.1). The Council's remit is to apply from 1 January 2007 to 1 September 2007.

1.2 The role of science

The overarching goal of international climate policy is set out in the UN's Framework Convention on Climate Change, which states that atmospheric GHG concentration must be stabilised at a level that would prevent dangerous anthropogenic interference with the climate system. This is also the policy approach in the Swedish environmental quality objective 'Reducing Climate Impact'.

The question of what represents harmful human impact on the climate system is crucial to climate policy, as the answer determines both the extent to which action needs to be taken and the speed required. The role of science is to describe, explain and assess the risks associated with climate change and its effects. However, deciding what type of impact and what level of damage are dangerous, and which risks are acceptable, involves value judgements and therefore must be dealt with in broad-based public processes involving politicians and other relevant actors.

Science can also give policymakers an idea of what present technologies can contribute in this respect, and what the prospects are for innovation and technological advancement. It can also assess the effectiveness of various measures and policy instruments. Subsequently adopting a position on what balance is to be struck between public benefits and costs involves making value judgements.

The assessment reports of the UN Intergovernmental Panel on Climate Change have been an important aid in the Council's work. Since 1990, the IPCC has published four wide-ranging evaluations of the current international state of knowledge in climate-related research. In these assessments, the IPCC also includes scientific material where the conclusions deviate from one another. The IPCC's working methods are described in Appendix 1.2.

The latest IPCC report, the fourth in the series, known as AR4, will be appearing successively during 2007 in the form of four interim reports entitled

- The Physical Science Basis[3]
- Impacts, Adaptation and Vulnerability[4]
- Mitigation of Climate Change[5]
- The AR4 Synthesis Report[6].

The Council has also based its work on scientific data published so recently that it could not be included in the latest IPCC assessment report. Other relevant studies besides those of the IPCC have also been used.

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[3]IPCC (2007a).
[4]IPCC (2007b).
[5]IPCC (2007c).
[6]This final interim report will not be published until after the Council has delivered its own report.

The Council considers that the IPCC is engaged in a powerful and credible process that leads to carefully considered and broad-based reports encompassing both present knowledge and important uncertainties and knowledge gaps. The Council concurs with the IPCC's conclusions, and recommends that these continue to be used as an important basis and means of support for Sweden's national climate effort, including Swedish participation at European and international level. In the Council's view, Sweden must continue to take part in research and knowledge development focusing on the earth's climate system, climate impacts, vulnerability, adaptation, measures and policy instruments. An important element in this should be supporting such research in developing countries.

1.3 The structure of the report

The key conclusions of the Council are presented in the summary at the beginning of this report.

The Council has chosen to start by describing climate change and its underlying causes, and its various impacts on ecosystems and society (Chapters 2 and 3). The question of what adjustments need to be made is discussed only summarily, as this matter has been dealt with by the National Commission on Climate and Vulnerability (M 2005:03). This is followed by an assessment of what kinds of reductions in global GHG emissions are required in order to diminish the risk of harmful climate impact (Chapter 4). Chapter 5 proceeds from the need for a reduction of global GHG emissions to a discussion of the need for reductions in EU and Swedish emissions.

The Council then deals with the prospects for action. Chapter 6 discusses measures and Chapter 7 costs and benefits. Finally, Chapter 8 discusses a selection of key issues relating to policy instruments.

2 Climate change

The earth's surface has unquestionably become warmer. The global mean temperature has risen by just over 0.7 degrees Celsius (°C) over the past 150 years. At present it is rising by almost 0.2°C per decade. The past few years have been the warmest since regular, geographically comprehensive recordings of temperatures began in the mid-19th century.[7] Analyses of tree-rings, drill cores from land ice and other data further suggest that the current mean temperature is probably exceptionally high, even in a millennial perspective.

Most of the global warming seen so far has taken place over the latter half of the 20th century, and this is *very likely*[8] due to an increase in the greenhouse effect caused by human emissions of greenhouse gases. The emissions have increased as populations and welfare have grown, through the burning of coal and oil, and through changes in land use that have involved deforestation, more intensive farming, higher levels of fertilisation, rice-growing and cattle herding etc.

Future GHG emissions will *very likely* cause further warming over the coming century well in excess of what has already occurred. Unless vigorous measures are introduced, the global mean temperature is expected to have risen by the year 2100 by 1.6–6.9°C compared with the pre-industrial era. This corresponds to an increase in warming that is twice to ten times that recorded in the 20th century.

As a basis for its deliberations in this chapter, the Council has primarily used the first IPCC interim report from 2007 on the earth's changing climate system and future projections.[9] This builds on the previous IPCC synthesis report published in 2001

[7]See for instance www.cru.uea.ac.uk
[8]See Appendix 2.1 for a description of the probability concept.
[9]IPCC (2007a).

and also encompasses further advances in knowledge up until the autumn of 2006. From the extensive range of source material available to it, the Council has chosen to highlight those findings that are of particular relevance both to Sweden itself and to Sweden as an actor in the EU and in the global arena.

2.1 What is happening to the climate today?

2.1.1 Global warming and globally rising sea-levels, increased precipitation and more intense dry periods

In its most recent synthesis report, the IPCC concludes that warming is not only evident on a global scale but is also being observed today in all continents except the Antarctic. Among the noticeable effects are rising sea-levels, declining snow cover over wide areas, a reduced spread of marine ice, and shrinking glaciers in mountain areas. These observed physical effects correspond closely to a warming process. In addition, changes are taking place in biological systems around the world; these are dealt with in Chapter 3 together with their implications for society.

The average sea-level in the world rose by almost eight centimetres during the period 1961–2003. This may be explained partly by expanding marine waters due to warming and partly by melting glaciers. The rate of increase in sea-levels has accelerated since the beginning of the 1990s, but at present it is not clear whether this acceleration is of a permanent nature or is due to natural variations.

Land precipitation has generally increased at medium and high latitudes between 1900 and 2005. In subtropical areas and some tropical areas, however, precipitation has tended to decline since the 1970s. Participation trends may reasonably be linked to human influence.[10] Longer and more intense dry periods have been observed, particularly in parts of the tropics and subtropics. Extreme weather conditions have become both more common and more uncommon. The number of severe tropical cyclones over the Atlantic has increased, for instance, while the number of cold winter nights has declined. These effects correspond closely to what might be expected from global warming.

[10] Zhang et al (2007).

2.1.2 Europe has grown warmer and precipitation has both increased and decreased

The warming rate has hitherto been slightly higher in Europe – approximately 0.9°C – than the global mean. In general, the rate of warming has been higher in the winter than in the summer. Precipitation has increased over maritime areas and over the land areas of Northern Europe, while at the same declining in eastern areas of the Mediterranean.

Also, Europe in recent years has experienced a number of extreme weather events, including the summer floods of 2002 that primarily affected Elbe and Dresden, the heat wave in Southern and Central Europe in the summer of 2003, and the mild autumn of 2006. While such extremes sometimes reflect natural weather variations, these were events that are seldom found in unchanging climate conditions.

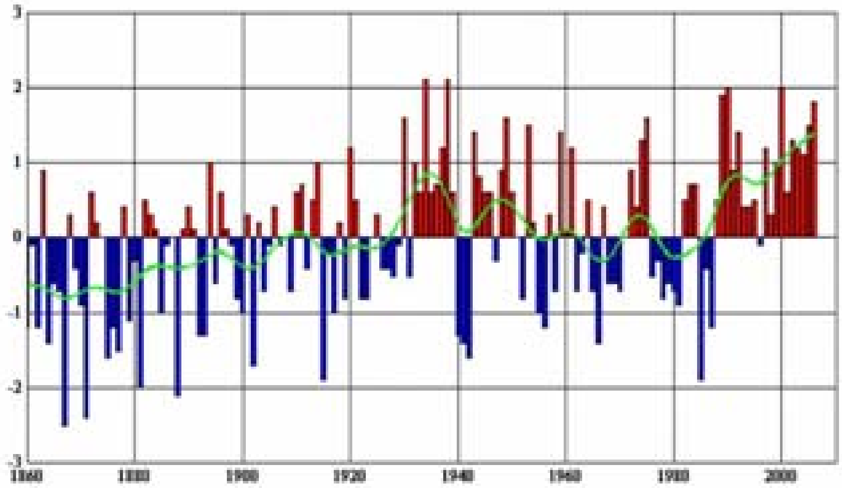
2.1.3 Sweden has grown warmer and wetter[11]

Over the past 15–20 years, Sweden has experienced warmer conditions, especially in spring and winter. Also, precipitation has been heavier in the winter, spring and summer compared with previous corresponding periods in the 20th century.

In Sweden, the 1991–2005 period was almost 1°C warmer and precipitation approximately 7% heavier than during the 1961–1990 period (see Figures 2.1 and 2.2). On an annual basis, the temperatures of recent years are comparable to the regionally warm years of the 1930s. The heavy precipitation that Sweden has experienced over the past 10–15 years has no precedent in the 20th century.

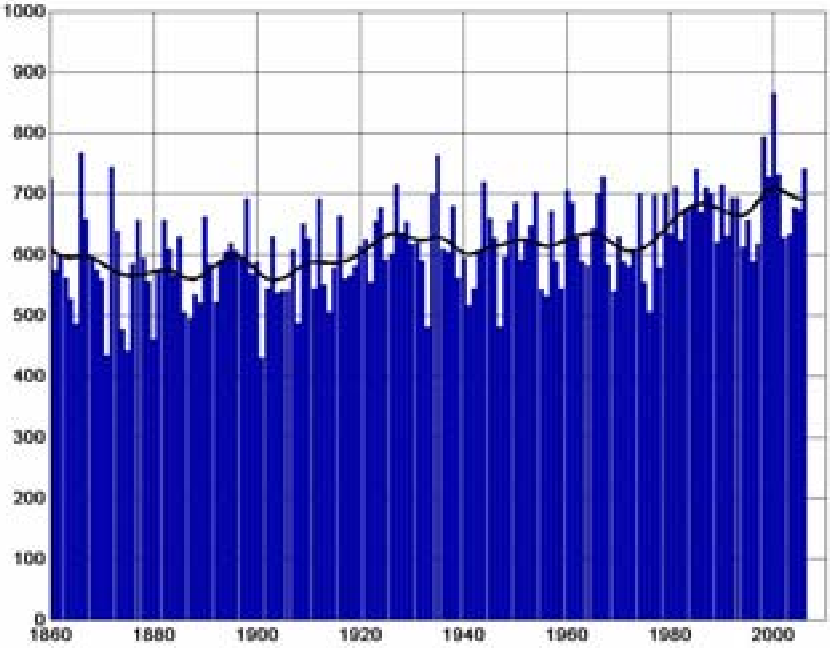
[11] A detailed description of observed changes in Sweden is provided by the Commission on Climate and Vulnerability. The Swedish Meteorological and Hydrological Institute has also published a fact sheet on climate change (SMHI, October 2006).

Figure 2.1 ***Annual mean temperature in Sweden in 1860–2006 in terms of deviation in degrees from the average for the period 1961–1996***



Source: *Based on data from the Swedish Meteorological and Hydrological Institute, SMHI*

Figure 2.2 Annual mean precipitation (mm) in Sweden in 1860–2006
Source: *Based on data from the Swedish Meteorological and Hydrological Institute, SMHI*



2.2 Warming is a result of human activity

Most of the warming experienced since the mid-20th century has *very likely* been caused by increased concentrations of anthropogenic GHGs in the atmosphere (i.e. greenhouse gases generated by human activity). The amounts already released will remain in the atmosphere over a very long period and result in further global warming due to the inherent inertia of the climate system.[12] It is estimated, for instance, that the global mean temperature will probably rise by around a further 0.5°C during the present century[13], even if GHG concentration were to be frozen at the level pertaining in the year 2000. An important cause of intertia in the climate system is the considerable heat-storing capacity of the oceans. Also, the long lifetime of GHGs in the atmosphere has to do with the slowness of the processes that govern their natural uptake, including the carbon cycle.

Present CO_2 levels, therefore, will persist for a considerable period of time even after emissions have been drastically reduced. Approximately 20% of the increased CO_2 levels caused by present-day emissions will still be in the atmosphere after a thousand years.

2.2.1 Higher emissions and increased concentrations of GHG and airborne particles

Emissions

Global GHG emissions have increased dramatically since the advent of industrialism in the mid-18th century. Carbon dioxide accounts for the bulk of human GHG emissions. Other important anthropogenic GHGs are methane, dinitrous oxide ('laughing gas'), ground-level ozone and halocarbons[14]. If current GHG emissions are converted into CO_2 equivalents (i.e. the amount of a greenhouse gas expressed as the amount of carbon dioxide that has the same impact on the climate, corresponding here to a 100-year perspective), CO_2 represents 70% of total climate impact. Of the

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[12] See Appendix 2.2.

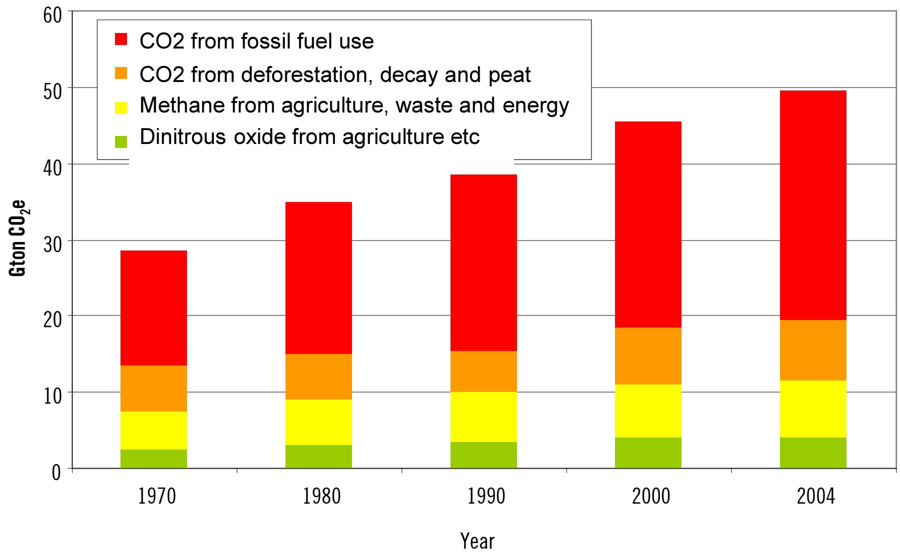
[13] Compared with the period 1980–99, the measure of committed further warming amounts to 0.6 degrees. It should be remembered that the rise in temperature that has already occurred (about 0.7 degrees), noted at the beginning of this chapter, refers to global warming up to the year 2005. (By way of comparison, global warming up to 1990 was 0.5 degrees and in 2000 approx 0.6 degrees).

[14] These comprise freons or CFCs (chlorofluorocarbons), HCFCs (hydrochlorofluorocarbons), HFCs (hydrofluorocarbons), halons and perhalocarbons.

overall impact of current GHG emissions on the climate, emissions of methane and dinitrous oxide combined contribute some 25% and halocarbons adding to the greenhouse effect approximately 5%.

Figure 2.3 shows how global emissions of CO_2, methane and dinitrous oxide have increased since the 1970s, expressed as billions of tons (Gtons) of carbon dioxide equivalents (CO_2e) for each year.

Figur 2.3 Global emission trends for anthropogenic GHGs.



Source: Based on data from the IPCC (2007a).

Concentration levels

Global concentration levels in the atmosphere of CO_2, methane and dinitrous oxide have increased significantly as a result of human emissions.

The increase in the CO_2 concentration level (approximately 35% since the advent of industrialism in the mid-18th century) is due to greater use of fossil fuels and changes in land use, primarily deforestation (especially in the tropics).

Concentration levels for methane and dinitrous oxide have risen as populations and welfare have grown, which has led to changes in land use, including deforestation, farming with increased fertilisation, rice-growing and cattle herding. Today's methane levels are 150% higher than those of 250 years ago, and dinitrous oxide has increased by 16% during the corresponding period.

Ground-level ozone is *inter alia* generated when sunlight reacts with car exhaust emissions, and concentration levels have risen, especially in heavily polluted urban areas.

Emissions of halocarbons, which cause depletion of stratospheric ozone (the earth's protective ozone layer) and also contribute to the greenhouse effect, have been significantly reduced in recent years as a result of international regulation via the Montreal Protocol.[15] The substances that have replaced them, however, are often potent GHGs, and are now found in accelerating concentrations in the atmosphere.[16]

At the same time as the concentration levels of the various GHGs have risen, there has been a significant increase in the amount of airborne particles, including emissions of sulphur and soot. The growing concentration of particles, which works in the opposite way to GHGs, is primarily having a cooling effect on the temperature at the earth's surface since it prevents the rays of the sun from warming the ground.[17]

2.2.2 Anthropogenic change compared with natural change

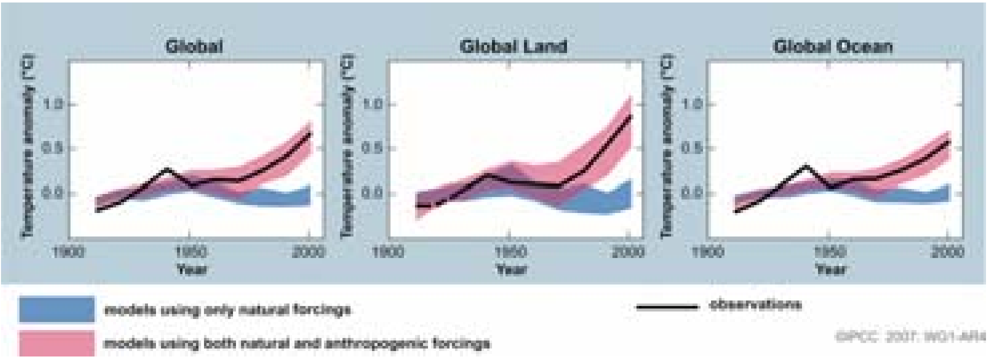
Via model simulations, naturally generated climate variations in terms of temperature or radiative forcing[18] may be quantitatively compared with those attributable to the increases in GHG and particle emissions. Figure 2.4 shows the globally observed temperature trends (black curve) recorded since the beginning of the 20th century, and the trends divided into sea and land. Temperature rise is slower above sea than above land, due to the greater heat storage capacity and slow circulation of the oceans.

In comparisons between observed temperature trends and the trends simulated in climate models, there is close correspondence when both anthropogenic and natural climate-changing factors are included in the simulations (pink fields). However, the model

[15]The Montreal Protocol is an international agreement designed to protect the ozone layer by phasing out the production of a number of harmful substances. The agreement was signed on 16 September 1987 and entered into force on 1 January 1989, since when it has been revised a number of times.
[16]See Appendix 2.3.
[17]See Appendices 2.2 and 2.3.
[18]See list of terms

simulations (light blue fields) that only take into account natural change factors (changes in incoming solar radiation, volcano eruptions and other natural variations in the climate system) deviate considerably from the observed trends after the mid-20th century. If the climate had been driven by natural variations alone, we should have seen a cooling over the past 50 years. This has clearly not been the case.

Figure 2.4 Comparison between observed and simulated changes in temperature on a global scale, including their distribution over land and sea areas (The black curve shows the ten-year average of observed temperature changes relative to 1901–1905.



Source: IPCC (2007a).

Anthropogenic net impact can also be expressed as increased radiative forcing, which now totals 1.6 watts per square metre. Together, CO_2, methane and dinitrous oxide account for radiative forcing corresponding to 2.30 watts per square metre. Growth in ground-level ozone contributes +0.35 watts per square metre. The impact of changes in halocarbon emissions[19] is similar in magnitude to that of ground-level ozone. The cooling effect resulting from anthropogenic emissions of particles amounts to approximately -1.2 watts per square metre.

The natural increase in solar radiative forcing is estimated at no more than 0.12 watts per square metre. This means that radiative forcing caused by incoming solar radiation has at most been less

[19]In terms of their relative contribution to present-day GHG emissions, halocarbons account for a slightly larger proportion of total anthropogenic impact to date. This is due to a decline in emissions of persistent halocarbons in recent decades.

than a tenth of anthropogenic forcing since the advent of industrialism.[20]

Variations in incoming solar radiation are sometimes put forward as an explanation for the climate changes of the 20th century. The Council does not find this explanation feasible. Changes in incoming solar radiation alone are clearly insufficient to explain the variations in temperature at the earth's surface.[21] The conclusion in respect of decisive anthropogenic climate impact over the past few decades takes into consideration the fact that a limited amount of natural impact has also occurred, in the form of powerful volcano eruptions and changes in incoming solar radiation.

In addition, some researchers have put forward the hypothesis that changes in the sun's magnetic field may affect cosmic radiation, which in turn could affect cloud formation on earth and thus the climate. This causal link is physically possible but does not correspond to observations. Based on the studies published in recent years, the Council takes the view that this hypothesis has serious failings and cannot therefore satisfactorily explain the warming that has been observed.

As regards the extent to which particles impact on the climate, this is calculated with greater precision today than in previous IPCC reports, but there is still considerable uncertainty resulting from insufficient understanding of the processes involved. This applies in particular to the impact of particles on the reflective capacity of clouds. In general, cloud description is the prime source of uncertainty in present-day climate projections.[22] Despite these uncertainties, then, it is generally considered that the cooling effect of particles is less than half the level of total warming caused by the increased concentration of greenhouse gases.

2.3 Climate scenarios

Climate scenarios are projections of future climate conditions based on various assumptions concerning factors such as population growth, economic development and technological advance that govern emissions of anthropogenic GHGs. With the

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[20] See Appendix 2.3 for a closer description.

[21] Besides the conclusions drawn in the IPCC's fourth assessment report, this was also discussed recently *inter alia* by Lockwood and Frölich (2007).

[22] See Appendix 2.2.

aid of climate models, emission scenarios can be translated into climate scenarios for the purpose of studying impacts on ecosystems and society.

A number of factors create uncertainty in these climate scenarios. One concerns how the emissions will develop in the future and another how sensitive the climate system is.[23] Possible threshold effects and issues relating to the natural carbon cycle are other areas that are difficult to assess, especially as regards the capacity of sea, forest and land surfaces to absorb CO_2 in a changed climate. In the case of the seas, the solubility of CO_2 diminishes when temperatures rise and when increased concentrations of CO_2 cause acidification of sea water. Over land surfaces, increased temperatures and reduced precipitation may lead to greater respiration and declining vegetation growth and thus to a reduced net uptake of carbon. Climate scenarios only consider these effects to a limited extent. This means that interpreting the scenario findings and drawing conclusions from them involves making risk assessments with a certain element of uncertainty.

The IPCC emission scenarios[24] include assumptions concerning both dramatic and more limited emission increases, as well as intermediate scenarios. Possible development paths up until the year 2100 are discussed. They concern atmospheric concentrations, calculated as CO_2 equivalents, and besides GHG changes include changes in particle levels. Concentration levels of between 600 and 1 550 ppmv[25] by the year 2100 would represent a significant increase compared with the present-day concentration level (which stands at approximately 450 ppmv CO_2e counting all anthropogenic GHGs, with a net level of approximately 380 ppmv when the masking effect of particles is also brought into the equation).

When emissions from coal and oil burning are reduced, however, particle levels in the atmosphere decline faster than GHGs, which means that the latter will probably dominate to an even greater extent in the future. In the latest IPCC report, the total uncertainty interval for global temperature rise up to the year 2100 is between 1.6 and 6.9°C compared with the pre-industrial era.

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[23]A description of climate sensitivity is found in Appendix 2.4.
[24]See Appendix 2.5.
[25]Ppmv = parts per million by volume.

It should be noted that these scenarios do not include any climate policy measures for reducing emissions. Nor does the IPCC identify any particular scenario as being more likely than any other.

2.3.1 Anticipated global climate change over the next 100 years

Even in the climate scenario involving the lowest increase in temperature, extensive and rapid changes are anticipated. Temperature rise over the present century would then be more than double the increase of the past 100 years. The higher emission scenarios involve increases in temperature roughly equivalent to those that occurred between the latest ice age and the present day. Also, the increase in temperature we are now facing would occur over the next 100 years, whereas the transformation of the latest ice age into a warmer climate took 10 000–20 000 years.

Besides increases in temperature, the climate simulations show that global sea-levels will continue to rise by 20–60 centimetres.[26] It is also *very likely* that heat waves, heavy rainfall and winters with very little snow will become increasingly common in a warmer climate. The predicted changes in precipitation will reinforce the current contrasts between naturally moist and dry regions. A *likely* development is an increase in intense tropical cyclone activity, and that such storms will be accompanied by more wind and rain.

As in the case of observed climate change, further changes will vary considerably from region to region. Across the continents, regional warming will develop more rapidly than the global mean. Regional rises in sea-level may deviate from the global mean by as much as several decimetres. In the Arctic area, sea ice cover may disappear altogether during the summer months up until the end of the 21st century. In ocean areas of the southern hemisphere and in the North Atlantic, warming will be below the global mean. The latter is associated with a slight reduction in the strength of the Gulf Stream. At the same time, it is *very unlikely* that warming will cause the Gulf Stream to collapse within the next 100 years.

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[26]In its 2001 assessment, the IPCC put the projected rise in the global sea-level at 9–88 cm for the period 1990–2100. The difference compared to the interval now specified is due to changes in methodology. The impact of factors of a more uncertain nature, for instance, are discussed separately.

2.3.2 Anticipated climate change in Europe

In Europe, the average rate of warming is expected to be slightly higher than the global mean. The differences in warming between Northern and Southern Europe may be fairly limited in annual terms but extensive in winter and summer. Warming may be more pronounced in Northern Europe in winter, while the reverse applies in summer. Locations and seasons showing the greatest temperature changes will also experience the greatest changes in extreme temperature. This means the cold extremes in northern areas in winter will become considerably milder, and heat waves will increase in Central and Southern Europe.

The greatest regional changes in precipitation are expected to take the form of increases in winter in the north and drop-off in summer in Central and Southern Europe, accompanied by an increased risk of drought. As for rises in sea-levels, these will vary across Europe. There are model tendencies showing a 1–2 decimetre higher rise in sea-level along the Norwegian Atlantic coast and the North Sea compared with the global rate, up until the end of the 21st century.

2.3.3 Anticipated climate change in Sweden[27]

Global climate change will have a profound effect on the Swedish climate. As in the case of other parts of Europe, average temperatures in Sweden will be slightly higher than the global mean, and the increase is expected to be most pronounced in winter. In Skåne and along the coast of Götaland, where the snow season is already short, snow will in principle vanish altogether. In mountain areas, the glaciers are expected to shrink gradually or disappear altogether, while snow supply declines. In summer, the greatest increases in temperature are expected to occur in southern Sweden.

Precipitation is expected to increase in the 21st century by 10–20%. This increase will, however, be greater during the colder half of the year. During the summer, southern Sweden can expect reduced precipitation. In the far north, no major changes are expected in summer. Climate models also suggest that westerly winds will increase in winter and that local winds may increase to

[27]A detailed description of anticipated climate change in Sweden is being prepared by the Commission on Climate and Vulnerability.

some extent when the ice withdraws from the Baltic Sea and Sweden's major lakes.

The Baltic Sea level will largely reflect the rise in sea-level predicted for the North Sea, but will also be affected by regional changes in the wind climate. Land uplift will offset a moderate rise in sea-levels around northern and southern parts of the Gulf of Bothnia in particular, although not south of the Stockholm region. A higher sea-level than at present will be evident, especially in winter, along the west coast of Sweden and around the Baltic Proper[28], including the south Swedish coast, Öland and Gotland. The fact that the rise in sea-level will be particularly noticeable in these areas is due to limited uplift and a relatively flat coastline with shores that are prone to erosion. In addition, there is considerable pressure from exploitation in these parts.

Cold extreme temperatures will decline dramatically during the winter half-year, to a greater extent than for average winter warming. Warm extreme temperatures in summer will increase at a more moderate pace, roughly corresponding to average warming in summer. Skyfalls are expected to become more intense throughout the country, including southern Sweden, which is otherwise expected to become slightly drier in the future.

2.3.4 Global climate change after 2100

Even if GHG concentrations in the atmosphere are stabilised in the 21st century, further warming and further rises in sea-levels are expected after 2100 as well. Most of the temperature rises would level out eventually and in practice cease altogether within a century of GHG concentrations becoming stable. Further rises in sea-level are expected, however, due to ocean inertia. Further expansion of sea waters due to warming may result in a rise of a metre or so in the long term. In addition to warming, any melting of land-ice would cause sea-levels to rise in the future.

If global warming were to continue at a rate of more than 2°C compared with the pre-industrial temperature level, this could cause the Greenland icecaps to melt, which would gradually raise sea-levels by as much as 7 metres over a period of a few thousand

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[28]Encompassing the part of the Baltic Sea that is bounded by the Great Belt, Öresund, the Åland Sea, the Gulf of Finland and the Gulf of Riga. In oceanography, the Gulf of Riga and the Gulf of Finland are usually included as well, since the latter has no natural boundary (threshold) to distinguish it from the Baltic Proper. (www.ne.se).

years. In a warmer climate, however, atmospheric steam would increase, which could cause the Antarctic glaciers to grow.[29] It is conceivable, however, that large masses of ice may break loose, which would cause sea-levels to rise further and reduce the Antarctic snow cover. Which of these processes will dominate in the future is very difficult to judge. In qualitative terms, the risk of abrupt changes of this kind may be expected to increase as a result of warming. As regards the risk of more dramatic changes, no satisfactory methods are currently available that would allow us to predict what will happen after the year 2100.

2.4 Reliability of predictions

This chapter shows that a full scientific assessment of climate-related risk is hampered by uncertainties concerning factors such as future emissions, natural system feedback (including the carbon cycle), the optical properties of cloud, and regional climate change. Overall assessments contain areas of uncertainty due to feedback in the climate system and linkage between different effects.

The Council notes that despite such uncertainties the research community is sufficiently well-informed to determine the most likely causes of present-day climate change and to predict future climate change. The uncertainties can be quantified and the conclusions drawn can be graded in terms of likelihood.

2.5 Council conclusions

The Council has made a thorough examination of the IPCC data, and concurs with overall IPCC assessments of climate change.

The Council observes

- that most of the global warming that has taken place over the latter half of the 20th century is attributable with high probability to an increased greenhouse effect caused by human emissions of GHGs.

[29]Much of the Antarctic ice cover is still colder than zero degrees and greater amounts of steam would mean snowfall over the area could increase, which would cause the ice mass to grow.

- that the global warming that has already occurred, at a rate of just over 0.5°C since the pre-industrial era, has led to a range of observed physical effects that correspond closely to GHG-driven warming. These include rises in sea-levels and changes in precipitation.

- that the global mean temperature is likely to increase further even with a hypothetically unchanged GHG concentration in the atmosphere. Whatever development path ensues, therefore, the world is facing further warming of at least 0.5°C over the next 100 years, which corresponds to a total increase in global warming of just over 1°C compared with the pre-industrial era.

- that unless vigorous measures are taken, the global mean temperature is expected to rise by 1.6–6.9°C by the year 2100, compared with the pre-industrial era, and then to continue rising in the next century

- that the extent of future climate change depends on factors such as population trends and socioeconomic and technological development

- that most changes in the physical climate occur gradually but that rapid and abrupt changes cannot be ruled out. The risk of abrupt change increases as the temperature rises.

- that further changes in temperature, sea-levels and precipitation, along with those already observed, will display very significant regional variations. While the global sea-level may rise by an average of approximately 20–60 centimetres over the next 100 years, regional changes may be one or two decimetres above or below the global average. Sea levels will continue to rise for a long time after this period. In addition, anticipated changes in precipitation will reinforce current contrasts between naturally moist and dry regions. In a warmer climate, heat waves, heavy rainfall and winters with little snow will become increasingly common.

3 Consequences for ecosystems and society

Global warming leads to climate effects on ecosystems and society as a result of changes in temperature, higher sea-levels, and changes in precipitation conditions etc. The long-term consequences for ecosystems and society develop gradually or arrive more abruptly in the form of threshold effects. How extensive the consequences of climate change will be depends on vulnerability, which in turn is determined by

1. The nature, magnitude and speed of climate change
2. The sensitivity and buffering capacity of ecosystems
3. The susceptibility of societies, their capacity to adapt and their socioeconomic development level.

This chapter contains an overview of the potential consequences of climate change for various systems and sectors, primarily at global and regional level. In the case of Sweden, the Council refers the reader to the government-appointed Commission on Climate and Vulnerability. Its task is to examine the effects of climate change in Sweden and how the susceptibility of Swedish society to such change may be reduced. The commission is concerned with the following sectors: technological infrastructure, building and spatial planning (including transport and energy), agriculture and forestry, tourism, nature conservancy (including the marine and mountain environments), health issues and water supply.

The presentation is of a general nature and is based both on the most recent IPCC assessment, providing scientific data on climate impacts, adaptation and vulnerability,[30] and on material primarily from the European Environment Agency[31] (EEA), the European

[30]IPCC (2007b).
[31] EEA (2005).

Commission[32] and on newly published research findings that became available after the latest IPCC assessment report.

3.1 Consequences already observed

Climate changes observed over the past few decades have already had an impact in various parts of the world. Most observations of climate impact have been made in Europe. From other areas, the supply of data is extremely limited. Statistically, significant impacts on natural systems[33] have been observed, however, in all continents and in many of the world's maritime areas. Several episodes of massive coral bleaching have occurred at particularly high sea-water temperatures since the mid-1980s. The distribution of a number of species has been affected worldwide. Over the past 25 years, for instance, two thirds of the cold-water fish in the North Sea have had to move northwards as the water has grown too warm. On land, many plant and animal species, including insects, have altered their distribution patterns both in a northerly-southerly direction and vertically. Malaria mosquitoes, for instance, are now able to survive higher up in mountain areas of Africa and South America. In Europe, several species of butterfly have spread northwards, and disease-carrying ticks are now found further north in Scandinavia and higher up in the mountains of Central Europe. Birds' migration patterns have changed, and bushes and trees have begun to take root on bare mountain terrain. Changes in the seasonal rhythms of insect hatching and pollen production etc have also been noted.

The effects of climate change often interact with the effects of other factors, including adaptation measures. This is particularly evident as regards the effects of human activity, which makes it more difficult to quantify the impact of climate on human systems. Climate-related consequences have hitherto been observed in agriculture and forestry, in coastal areas exposed to rising sea-levels, in human activities in the Arctic and in alpine areas, and in relation to health.[34]

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[32] European Commission (2007a).

[33] Natural systems are defined here as ecosystems, water systems and systems characterised by snow, ice and permafrost.

[34] Higher mortality in connection with heat waves, changes in the geographical distribution of disease-carrying species, and changes in pollen allergy seasons.

As noted in section 2.1.2, occasional weather events of an extreme nature cannot be directly linked to the ongoing warming process. In general, however, weather events tally with what can be expected, and there have been significant consequences even in countries with a relatively high level of emergency preparedness. In Europe, a particularly intense heat wave in August 2003 caused the death of more than 33 000 people (half of them in France). In Southern Europe, agriculture, power production and the carbon balance in various ecosystems were also affected. In addition, the heat caused or exacerbated widespread forest fires.

The climate-related effects up to now have probably been both greater and more wide-ranging than it was possible to observe directly. Assembling a proper picture of the situation at the present time is complicated both by inadequate access to data and by the above-mentioned difficulty of quantifying the climate's contribution to an observed effect on human systems in particular, but also on natural systems.

3.2 Anticipated future consequences

3.2.1 Globally and sectorally

Future consequences will vary depending on the range and magnitude of further climate change in terms of temperature rise, higher sea-levels and new precipitation conditions, and will also depend on how vulnerable different areas are. Levels of vulnerability will in turn depend on such factors as local ecosystems, socioeconomic development and resource availability. In general, the consequences of climate change will make it difficult to meet other global challenges, such as the UN's Millennium Development Goals. Also, the consequences need to be related to the wider context of global changes under way at the same time.[35]

The consequences of climate change are expected to be most severe in areas that are already vulnerable as a result of other stress factors, such as unequal access to resources, other forms of environmental impact, food supply problems and societies' inability to adapt.

[35]See for instance IGBP (2004) and WRI (2005)

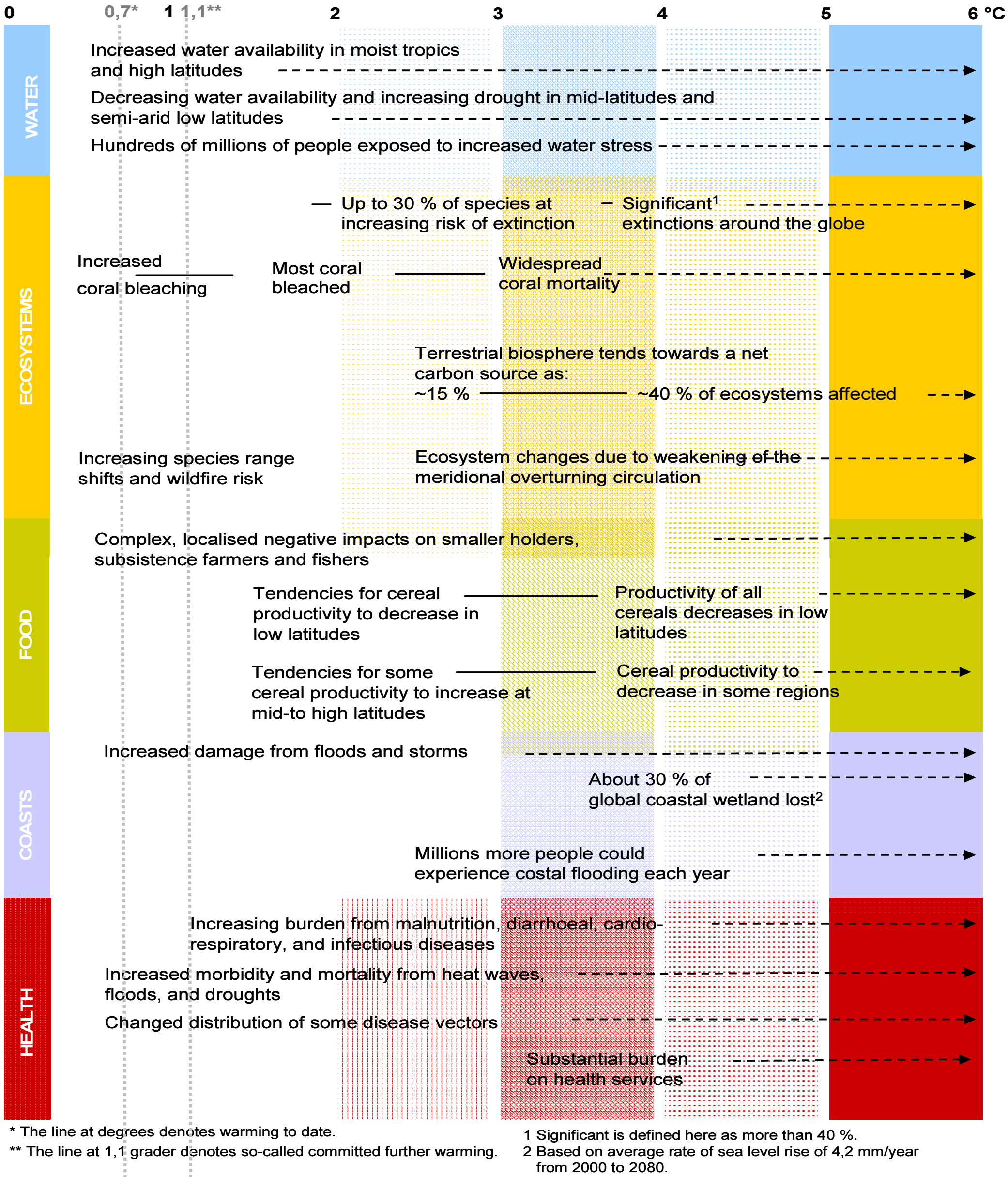
The following regions have been identified by the IPCC as being particularly susceptible to climate change:

- The Arctic region – due to rapid increases in temperature and the region's specialised ecosystems.
- Africa, particularly the sub-Saharan parts – due to a low adaptation capacity.
- Small island nations such as Tonga and the Maldives – as they are particularly at risk from rising sea-levels.
- Densely populated delta areas of Asia and Africa – due to combination effects caused by rising sea-levels, flooding and storms.

In global terms, particularly sensitive systems and sectors (see also Figure 3.1) are water resources in already dry regions, agricultural production close to the equator, coastal areas, marine and terrestrial ecosystems,[36] coastal lowlands, and human health in areas with a low adaptation capacity.

[36]The term terrestrial systems refers to systems on land as opposed to marine (ocean) ecosystems.

Figure 3.1 Basic consequences in relation to average global risesin temperature compared with 1861-1890



Source: IPCC (2007b). Based on the Swedish Environmental Protection Agency's Swedish translation of the IPCC report for 2007 on climate impacts, adaptation and vulnerability.

NB: The sample presented in Figure 3.1 is based on studies that have established quantified impacts on the basis of varying changes in temperature with a high level of confidence (i.e. with an 8 in 10 chance of proving correct).

It should be noted that the current level is represented in the figure by a vertical line at 0.7 degrees, while what is known as committed further warming – caused by past emissions (see Chapter 2) – is represented by a line at 1.1 degrees. A number of effects are already occurring, while others will not now be possible to prevent, even were the world to immediately take strong global action to limit emissions. Adaptation measures are therefore essential. In general, climate effects at the global level increase in both number and magnitude as temperatures rise. This means that as a matter of priority, action must be taken to reduce emissions.

Climate impacts create problems in the following sectors in particular:

Water resources: Changes in water supply at the global level are among the effects that may have the most serious ramifications. Such changes may cause water shortages in areas already at risk and more severe flooding in others. The Himalayas are a case in point. There, melting glaciers initially create greater flows with the attendant risk of flooding, and then lead to reduced water supply in catchment areas, which comprise some of the most densely populated regions on earth.

Agriculture and forestry: Water supply also affects agricultural production. Increased drought in sub-Saharan Africa, for instance, will severely jeopardise local food supply. Local rises in temperature of up to 1–3 °C[37] have both beneficial and adverse effects on agriculture, depending on the region, but in global terms food production could increase. Further rises in temperature are adversely affecting a growing number of regions, and in global terms there is a risk of production decline, especially if adaptation is ineffective. In the case of forestry production, it is estimated that global productivity will initially improve, although with substantial regional variations.

Ecosystems: The structure or function of an ecosystem may alter abruptly when changes for instance in the climate and length of season affect different species in a given area to different extents. This may work to the advantage of certain species at the expense of others. One phenomenon that has already been observed in Europe is that the early arrival of spring causes butterflies to adapt rapidly and hatch earlier. Small birds, however, whose young live on

[37]Since terrestrial areas warm up faster than marine areas, local warming is exceeding average global warming in the 21st century, and local warming of a certain magnitude thus occurs earlier in agricultural areas than on a global scale.

insects, continue to hatch at normal times, and are increasingly starving to death since they miss the period during which food is plentiful.

Climate change in combination with human activity such as large-scale changes in land use and the over-exploitation of natural resources may have an increasingly negative effect on biodiversity, life-sustaining ecosystem functions and important ecosystem services.[38] In the event of global warming of more than a couple of degrees compared with the pre-industrial era, it is estimated that around 20–30 per cent[39] of the world's plant and animal species are probably under increased risk of extinction.

Rising sea-levels and coastal zones: The effects of rising sea-levels are expected to affect millions of people in the form of increased vulnerability to flooding. The most vulnerable parts are the large delta areas of Asia and Africa, and the world's small island nations. There is a growing risk of salination of coastal farmland and drinking water, of erosion and of the advent of new insect hatching sites.

Health: Climate-related health consequences will be most pronounced in impoverished parts of the world. Reduced food supply leads to malnutrition and increased susceptibility to many severe infectious diseases. Changes in temperate seasons or in dry periods/rainy seasons lead to a general increase in diseases spread by insects, rodents and ticks. Also, many parasites react favourably to warmer climates. As temperatures rise and water flows change, there will be an increased risk of outbreaks of cholera, salmonella and other diarrhoea-inducing diseases spread via water and food. Extreme weather-related events cause all kinds of damage ranging from deaths and accidents in emergency situations to outbreaks of infectious diseases in their wake. Health effects due to air pollutants such as ground-level ozone and particles are also expected to increase.[40]

Locally, a changed climate may also have some positive effects. The climate in a given area may for instance be unsuitable for certain types of parasite or for the survival of infection-carrying species. At higher latitudes, cold-related health effects such as

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[38] I.e. services with which nature supplies us 'free of charge', such as pollinating insects, water purification, natural pesticides, carbon storage and the development of fertile soil.
[39] Based on studies of a representative selection of the world's plant and animal species.
[40] Higher temperatures mean more ground-level ozone is produced, while reduced precipitation results in less particle washout in the atmosphere.

frostbite/death from exposure, cold-generated muscular spasms and rheumatic disorders may become fewer.

Socioeconomic consequences: Climate impacts on socioeconomic systems generally show considerable regional variation. The most vulnerable areas are densely populated coastal zones and societies and activities that are susceptible to extremes or which are dependent on climate-sensitive local resources. Some climate effects (e.g. coastal consequences, reduced water supply and agricultural production) are expected to generate migration flows and population resettlements, which in turn affects neighbouring areas in particular.

Security policy aspects: The climate issue came before the UN Security Council for the first time in April 2007. Considerable uncertainty remains as to how climate change will affect the security situation. Political conflicts could arise as a result of adaptation measures or measures to reduce emissions. Some of the consequences of climate change, such as reduced water supply and major displacements of populations, could cause existing or latent conflicts to intensify.

3.2.2 In Europe

Most of Europe will probably not be as severely affected by climate change as parts of Asia and Africa. In the EU, cooperation and integration processes may come under pressure since climate change is expected to affect different regions to different extents in the Union. This could create tensions, for instance if the need arose to redraft the EU Common Agricultural Policy.[41]

Southern Europe: During the present century, Europe is expected to witness a partial shift in favourable agricultural conditions from south to north. Southern Europe may experience problems with high summer temperatures, summer droughts and reduced water supply. This may result in smaller crops, lessen the potential for hydroelectric power and adversely affect summer tourism. More numerous and intense heat waves are expected to impact on health, as is the predicted deterioration in air quality due to higher concentrations of ground-level ozone and particles. More forest fires in the region may also add to bronchial disorders.

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[41] Haldén (2007).

Central and Eastern Europe: Summer precipitation is expected to decline, which would cause water shortages. Forest productivity is also expected to decline, while at the same time more frequent fires are expected on moorland. There will be a growing risk of health effects in connection with heat waves and flooding etc.

Northern Europe: Initially, climate change is expected to have both negative and some positive effects. Examples of positive effects are reduced heating requirements, reduced cold-related health effects, larger crops, increased forest growth and better conditions for hydroelectric power production. As climate change continues, however, negative effects will arise – e.g. flooding, threats to ecosystems and greater soil instability – and will probably offset the benefits. Scandinavian societies may may need to adapt from colder conditions to mild winters and hotter summers. The spread of many ecosystem-related diseases (such as borrelia infections) will increase.

Sweden: For a detailed description of the consequences of climate change for human and biological systems, and for economic analyses of Sweden's situation, the Council refers the reader to the final report of the Commission on Climate and Vulnerability, due in October 2007, and to its interim report on the risks associated with flooding.[42]

3.3 Council conclusions

The Council has made a thorough examination of the IPCC data, and concurs with overall IPCC assessments of climate change and its implications for ecosystems and society.

The Council observes

- that the consequences for ecosystems and society will be more numerous and extensive as temperatures rise. Globally, the consequences will be more negative than positive.
- that the consequences will differ very significantly between regions, depending on the extent of regional climate change and on variations in both the levels of vulnerability and adaptability

[42]Swedish Government Official Report 2006:94 Översvämningshot. Risker och åtgärder för Mälaren, Hjälmaren och Vänern.

of natural systems and societies alike. Particularly at risk are the Arctic, parts of Africa, and Asia.

- that the consequences for ecosystems and society will develop both successively and abruptly. Climate change has already had observable effects.
- that the consequences giving particular cause for alarm are the risk of reduced food supply, changes in water supply in certain areas, loss of biodiversity, and greater exposure to coastal flooding.
- that the consequences of climate change may be intensified by other global changes taking place simultaneously (such as changes in population density, resource use and environmental degradation). Climate change also makes it more difficult to confront other global challenges, such as poverty eradication.
- that from a national perspective, the climate impacts should be taken into consideration when seeking to achieve Sweden's environmental objectives.
- that adaptation measures are essential and should be integrated into other international and national socioeconomic development efforts. The prime focus, however, should be on reducing emissions.

4 The need to reduce global emissions

4.1 Target structure for climate policy

The overarching goal of international climate policy is set out in the UN Framework Convention on Climate Change from 1992, which states that atmospheric GHG concentration must be stabilised at a level that would prevent dangerous anthropogenic interference with the climate system. The convention also states that such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

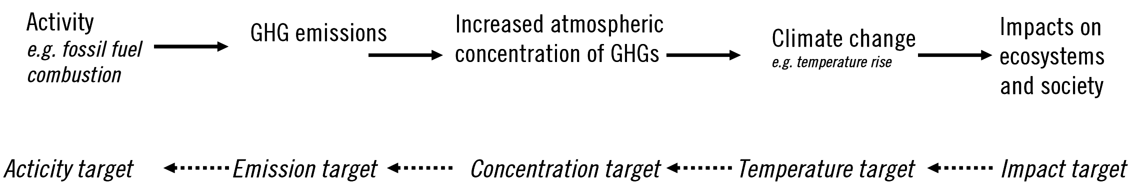
4.1.1 Different types of goals for limiting climate impacts

The overarching climate objective should in reality be a target for limiting climate impacts (see Figure 4.1). Such a target is difficult to formulate, however, as there are a wide variety of impacts, as well as knowledge gaps. Instead, temperature, concentration, emission and activity targets are used, defined as follows:

- *Temperature targets:* Targets for the highest acceptable increase of global mean temperature. A highest acceptable rate of warming may be included.
- *Concentration targets:* Targets for the highest acceptable GHG concentration in the atmosphere (known as the stabilisation level).
- *Emission targets:* Targets for the highest acceptable level of emissions. These may also be expressed as reduction requirements over a given period of time.

- *Activity targets:* Targets specifying special measures or activities that may be expected to help reduce emissions (e.g. targets concerning greater energy efficiency or investment in R&D, or targets specifying that renewable energy sources are to comprise a certain share of primary energy supply).

Figure 4.1 The link between human activity, GHG emissions, climate changes and their impact on ecosystems and society, and various types of climate targets



Temperature targets are specified on the basis of what impacts major climate changes – expressed in terms of global mean temperature rises – may be expected to have on ecosystems and society. The question of what is acceptable is value-related and cannot be determined on scientific grounds (see Chapter 1).

Concentration targets are based on scientifically established links between rises in GHG concentrations and rises in temperature. Both temperature targets and concentration targets are global in nature as they are affected by overall global emissions of GHGs.

A global emission target can then be derived from the concentration target by means of scientifically calculated links showing which global emission levels are compatible with different atmospheric concentrations of GHGs. Emission targets can be expressed as a certain volume of emissions, either overall or per capita, that may not be exceeded in a given year. They can also be recalculated so as to specify reduction requirements over a given period of time. Emission targets are the types of targets that are easiest to convert into strategies and measures.

Regional and national emission targets cannot be determined scientifically, but they can be calculated on the basis of global emission targets and of a politically established distribution between regions and countries. Alternatively, they may be largely based on assessments of what is politically necessary or feasible.

Emission targets can also be set for different sectors of society, both at national and regional level. Such sectoral targets are generally established by striking a balance between necessity and feasibility.

Activity targets can be formulated in support of desired emission targets, but have no quantifiable link with them.

4.1.2 Weighing up the socioeconomic consequences

Besides the evaluations and political assessments that need to be made when deciding what is dangerous, the socioeconomic consequences must also be considered at the political level. The costs and benefits of climate policy imperatives can then be placed in relation to the costs and benefits of action in other more or less closely related policy areas. Trade-offs may also involve considering whether the measures are only to be introduced in a specific region or nationwide, or whether domestic measures can be supplemented by measures in other countries, given that this is permissible under international agreements.

Support data for the political consideration of harmful climate impact as against socioeconomic consequences are dealt with in Chapters 6, 7 and 8.

4.2 Assessment of dangerous human interference with the climate system

4.2.1 Assessments in the scientific literature

In the scientific literature it has occasionally been argued that the risk of unacceptable interference with the climate system increases dramatically if the global mean temperature rises by more than 2 degrees Celsius (°C) compared with the pre-industrial level.

Prior to the UN climate convention's first Conference of the Parties in Berlin in 1995, the German Advisory Council on Global Change (WBGU) adopted the position that such a rise in temperature was absolutely unacceptable. It argued that the temperature should not be allowed to rise by more than 0.2°C per decade if various systems were to be capable of adapting.

The UN-appointed Scientific Expert Group (SEG) presented a report on climate change and sustainable development to a UN meeting on sustainable development in the spring of 2007.[43] The report recommended that the aim of public efforts to reduce GHG emissions should be to limit the rise in global mean temperature to 2°C (if possible), and in any case to ensure that it does not rise to 2.5°C above the pre-industrial level. The SEG took the view that a rise in temperature in excess of 2–2.5°C above the pre-industrial level would dramatically increase the risk of exceeding climate-related thresholds beyond which unacceptable impacts on human welfare might develop, whatever efforts are made to adapt.

It is worth noting that the IPCC has not taken a position on the level at which temperature rise is or may be deemed to be harmful.

4.2.2 Political assessments

At present there is no global political consensus on where to draw the line when defining what represents harmful or dangerous climate impact. Both the EU and Sweden, however, have adopted political objectives that specifically set limits for what might be regarded as a dangerous level of interference.

The EU two-degree target

Based on the information provided in the second IPCC assessment report, the European Council adopted a target as early as 1996 specifying that global mean temperature should not be allowed to rise by more than 2°C compared with pre-industrial levels. This target has since been reaffirmed on a number of occasions both by the Environment Council and the European Council, most recently on 8–9 March 2007, as the basis of the EU's long-term climate strategy. Originally, the two-degree target was linked to stabilisation of the carbon dioxide concentration in the atmosphere at 550 ppmv CO_2[44], which is equivalent to a GHG concentration of approximately 650 ppmv CO_2e. Given current scientific knowledge of the climate system, the stabilisation level that is compatible with the two-degree target is now thought to be considerably lower. The European Commission's communication from January 2007 on a strategy for achieving the two-degree target is based on a

[43] Bierbaum et al (2007).
[44] For comparative purposes, it is worth noting that the pre-industrial concentration of CO2 was approximately 280 ppmv.

stabilisation of GHG concentration at a maximum 450 ppmv carbon dioxide equivalents (CO_2e).

The Swedish environmental quality objective 'Reduced Climate Impact'

In 2002, the Swedish Riksdag (parliament) decided that GHG concentration in the atmosphere (according to the Kyoto Protocol and IPCC definitions) should be stabilised at a level below 550 ppmv CO_2e).[45] As shown below (section 4.3), this level is *very likely* incompatible with the EU two-degree target, which Sweden has supported through decisions in both the European Council and the Environment Council.

In connection with its 2005 decision on national environmental objectives,[46] the Swedish Riksdag declared that the target for reduced climate impact should be reformulated as a temperature target to correspond with the EU's long-term goal of no more than 2°C global warming compared with pre-industrial levels. When Sweden's 2006 climate policy was adopted,[47] however, the question of how the long-term climate objective should be expressed was referred to the 2008 climate policy review.[48]

In the data they have jointly supplied to the 2008 policy review, the Swedish Environmental Protection Agency and the Swedish Energy Agency have proposed that the present concentration target be replaced by a temperature target. The target level they propose is a maximum increase in the global mean temperature of 2°C compared with the pre-industrial level.

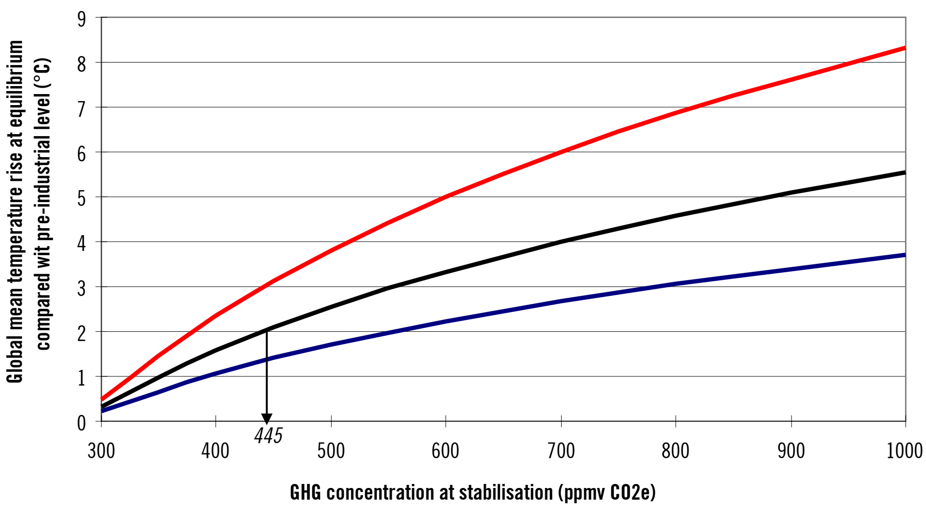
4.3 GHG concentrations must be stabilised at low levels

The relationship between atmospheric GHG concentration and global mean temperature rise is expressed in a fairly simplified form by the term climate sensitivity (see Appendix 2.4). Climate

[45]Government Bill 2001/02:55:00, Report Govt Bill 2001/02:55, Report 2001/02:MJU10, Riksdag Communication 2001/02:163. 2001/02:163.
[46] Govt Bill 2004/05:150, Report 2005/06:MJU3, Riksdag Communication 2005/06:48.
[47]Government Bill 2005/05:172, Committee Report Govt Bill 2005/02:55, Report 2001/02:MJU10, Riksdag Communication 2001/02:163. 2005/06:389.
[48]Under the 2002 climate policy decision, Sweden's climate strategy is to be reviewed and where necessary revised at specified intervals.

sensitivity is a measure of the extent to which the global mean temperature can be expected to rise if the increase in GHG concentration corresponds to a doubling of the CO_2 concentration in pre-industrial times. According to the IPCC, climate sensitivity is most probably 3°C. Figure 4.2 shows that GHG concentration thus needs to be stabilised at a level just below 450 ppmv CO_2e if the global mean temperature rise is not to exceed 2°C compared with the pre-industrial level. Detailed studies of the probability distribution of climate sensitivity suggest, however, that temperature rise is as likely to remain at 2°C as it is to increase if GHG concentration is stabilised at such a level.[49] Also, stabilisation at this level is associated with a non-negligible chance that the global temperature rise may exceed 3°C. If the *likely* rise in temperature[50] is to be restricted to 2°C, GHG concentration must in the long run be stabilised at a level corresponding to 400 ppmv CO_2e or lower. The lower the stabilisation level of GHG concentration, the less risk there is of serious climate impact.

Figure 4.2 Stabilisation scenarios and how they relate to global mean temperature rise at equilibrium



Source: IPCC (2007c).

NB: The upper curve (red) represents temperature rise at a climate sensitivity level of 4.5°C. The middle curve (black) represents temperature rise at a climate sensitivity level of 3°C. The bottom curve (blue) represents temperature rise at a climate sensitivity level of 2°C.

[49]Meinshausen (2006).
[50] The probability concept as defined by the IPCC is explained in Appendix 2.1.

The present concentration of carbon dioxide is approximately 380 ppmv CO_2e, while the concentration of greenhouse gases is 450 ppmv CO_2e. GHG concentration is now rising at a rate of about 2–2.5 ppmv CO_2e per year. As noted above, the impact of greenhouse gases on global warming is countered by the anthropogenic emission of particles (see Appendix 2.3). The cooling effect of particles happens to be of roughly the same magnitude as the warming effect of non-CO_2 greenhouse gases, which means the net impact of GHGs and particles on global warming corresponds to the contribution from CO_2 alone. In the medium and long terms, however, this dampening effect is expected to diminish,[51] since particle emissions are expected to decline as a result of health promotion measures etc (see Section 2.3). Thus we are already very close to a stabilisation level compatible with the two-degree target. Emission levels, however, continue to rise.

4.4 Global emission levels for stabilising GHG concentration

4.4.1 Growth in global emissions must be stopped now

Due to the dynamic nature of the climate system, and not least to the long atmospheric lifetimes of certain GHGs (10–1 000 years), it is the accumulative emissions of GHGs over long periods of time rather than the momentary emissions that decide at what level GHG conclusions may be stabilised (see Appendix 2.2). This means that over time there are a number of different ways – emission pathways – of achieving a given level of stabilisation.

An important finding in studies of emission pathways at various levels of stabilisation is that global emissions ought to peak within 10–15 years and then decline if GHG concentration is to be stabilised in the long term (around the year 2150 and beyond) at levels of approximately 400–450 ppmv CO_2e. If climate policy measures are based on higher stabilisation levels, emissions may begin declining slightly later in time, in which case however the likelihood of temperature rise being limited to 2°C compared with the pre-industrial level would be reduced.

[51]This is reflected in various climate model scenarios describing emission trends for different radiative forcing pollutants.

If the starting point for a global reduction in emissions is delayed, there will be an increased need of essential reductions in the medium term. A delay of 5–10 years could mean that the reduction rate would have to be doubled within a few decades if the chances of achieving a certain level of stabilisation are not to be jeopardised. Waiting to take steps to reduce global GHG emissions is a highly risky enterprise.

4.4.2 Global emissions must be significantly reduced

The IPCC's assessment of research concerning the extent to which emissions will have to be reduced in order to stabilise GHG concentration focuses on emissions of CO_2. Of those studies that have analysed emission pathways for the stabilisation of greenhouse gases other than carbon dioxide – known as multigas studies – very few have analysed aggregate stabilisation levels closer to 400 ppmv CO_2e.

In 1990, global emissions of GHGs, as defined by the Kyoto Protocol and including emissions both from land use and forestry and from external transport amounted to 39 Gtons of CO_2e. In 2004, global emissions of greenhouse gases rose to 49 Gtons of CO_2e (IPCC, 2007c).[52]

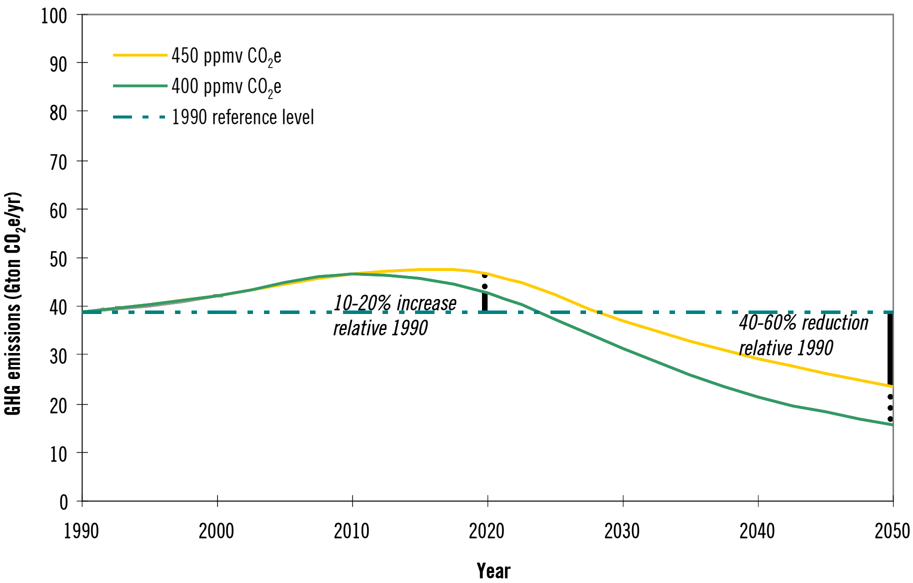
Figure 4.3 shows what the GHG emission trend (incl. emissions from land use and forestry activities) may need to be up to the year 2050 if concentration is to be stabilised at 400 ppmv CO_2e (green curve) and 450 ppmv CO_2e (yellow curve) respectively.

If climate policy assumes that in the long term (around 2150 and beyond) GHG concentration needs to be stabilised at 400 ppmv CO_2e, there can be an increase in global emissions of approximately 10% up to the year 2020 in relation to the 1990 level (see Figure 4.3). This, however, represents a 10 per cent reduction on the current emission level. In 2050 global emissions need to have declined by approximately 55–60% compared with the 1990 level, or by 70% compared with the present level.

[52]IPCC (2007c).

Figure 4.3 **GHG emission pathways 1990–2050 (incl. emissions from land use and forestry activities) for different levels of stabilisation in atmospheric concentrations**

Source: Based on data from den Elzen & Meinshausen (2006).



If instead the starting point for emission-reducing measures is a stabilisation level of 450 ppmv CO_2e, slightly higher global emission levels are permissible. In 2020 these could be about 20% higher and in 2050 will need to be about 40% lower than the 1990 level.

By the end of this century, global emissions of greenhouse gases will, according to some studies, have to decline to a level of around 5–10 Gtons of CO_2 per year. There are also studies indicating that global net emission rates at the end of the century may have to be negative for a certain period if GHG concentration – following a temporary increase from the present level – is to be stabilised in the long term at levels below 400–450 ppmv CO_2e. In sum, this means that emissions in the year 2100 will have to be close to zero.

If GHG concentration is to be kept stable, global GHG emissions in the long term must not exceed nature's capacity for absorbing or breaking down such gases. In the long term, it is estimated that emissions will need to be in the region of 3–9 Gtons of CO_2e per year around 2150–2300.[53] Research findings of recent

[53]IPCC TAR (Prentice et al, 2001).

years suggest, however, that the scope for anthropogenic emissions at equilibrium may be reduced as a result of carbon cycle feedback mechanisms. Natural emissions of methane and carbon dioxide may increase, for instance, while the capacity of the seas and the biosphere to absorb anthropogenic emissions may diminish (see Chapter 2).

4.5 Council conclusions

The Council considers[54]

- that drawing a universally acceptable line between harmless and harmful (dangerous) climate impact may be both impossible and unsustainable.
- that the EU two-degree target is a reasonable starting point for emission-reducing measures, but that the possibility of lower temperature rise generating undesired effects cannot be ruled out.
- that in the long term the atmospheric concentration of greenhouse gases needs to be stabilised at a level below 400–450 ppmv CO_2e if the global mean temperature is not to exceed 2°C compared with the pre-industrial level.
- that if the two-degree target is to likely to be achieved, greenhouse gas concentration needs to be stabilised at a level not exceeding 400 ppmv CO_2e.
- If it is stabilised at 450 ppmv CO_2e there is a significant risk that the two-degree target will not be achieved.
- that by 2020 global emissions of greenhouse gases must be 10 per cent lower than the 2004 level if GHG concentration is to be stabilised at 400 ppmv CO_2e in 2150. Compared with the 1990 level this corresponds to an increase in emissions of approximately 10 per cent.
- that by 2050 global emissions need to be at least halved compared with the 1990 level (if the target of 400 ppmv CO_2e is to be achieved)

[54]The target levels specified by the Council are based on the scientific knowledge currently available. The levels (for temperature rise, concentration and emission reductions) may therefore need revising as knowledge concerning the climate system and socioeconomic factors etc improves.

- that by the end of the century global emissions need to have been reduced virtually to zero (if the target of 400 ppmv CO_2e is to be achieved).

5 Emission reduction needs in the EU and Sweden

The aim of the present chapter is to break down global emission reduction needs into specific emission reduction needs for the EU and Sweden. The chapter starts by examining the distribution of global GHG emissions among countries and groups of countries. It continues with a discussion of theoretical models for sharing the responsibility for reducing global emissions among (groups of) countries. A special analysis is devoted to the outcomes for Sweden and the EU[55] for 2020 and 2050. The chapter is based largely on a comparative analysis of various sharing models conducted by Ecofys on behalf of the UK Department of the Environment, Transport and the Regions.[56]

The present chapter is based on the premise that the sharing specifies the quantity of emission rights each country will initially receive under an international climate regime. One (1) emission right means the right to discharge one metric ton of carbon dioxide equivalents (CO_2e). Initially allocated emission rights can then be traded away to other countries.

5.1 Regional distribution of current greenhouse gas emissions

In 2004, global emissions of greenhouse gases (GHG) as defined in the Kyoto Climate Protocol[57] totalled approximately 49 Gtons of

[55] Note that the present chapter does not explicitly deal with internal burden-sharing with respect to EU emission targets for 2020. Nor does it address Sweden's commitments for the next commitment period in the context of an international climate regime. However, the prevailing approach to distribution issues is applicable in these cases.
[56] Höhne et al (2007).
[57] Carbon dioxide (CO_2), methane (CH_4), dinitrous oxide (N_2O), hydrofluorocarbons (HFCs), perhalogenated fluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

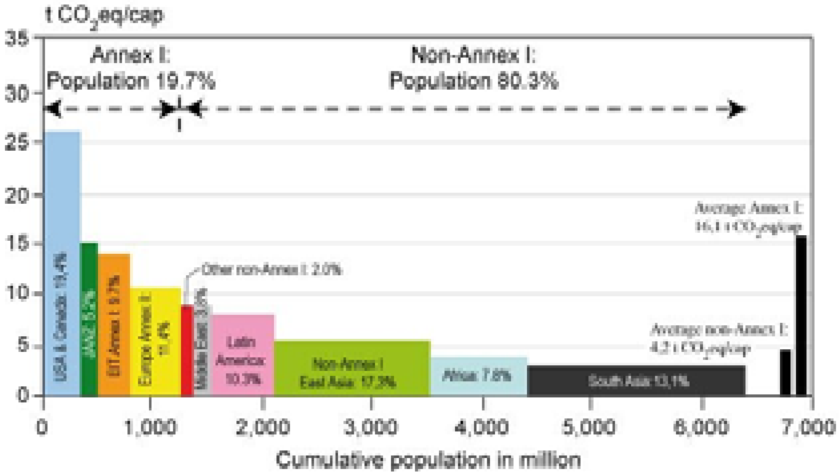
CO_2e. Emissions are unevenly distributed among the world's nations and regions. The world's industrialised nations (Annex I countries in the United Nations Framework Convention on Climate Change) accounted for almost 60 per cent of aggregate GHG emissions up to the year 2000, while developing countries (non-Annex I countries) contributed approximately 40 per cent.[58] However, the latter's contribution to global warming is steadily growing. In 2004, developing countries accounted for 54 per cent of global GHG emissions. It must be added here that the industrialised nations contain a considerably smaller proportion of the world's total population and enjoy a larger share of total world GDP than the rest of the world. Emissions per capita are higher in industrialised nations than in developing countries. In terms of emissions per GDP, however, the reverse is the case (see Figures 5.1 and 5.2). Although emissions in developing countries are expected to grow more rapidly, uneven emission distribution per capita and GHG emissions per GDP are both likely to persist.

Average global per capita GHG emissions totalled approximately 7.5 tons of CO_2e in 2004. Swedish per capita emissions, amounting to 8.1 tons of CO_2e in the same year, are somewhat above the global average.[59] Average GHG emissions in the industrialised world in 2004 totalled 16.1 tons of CO_2e per capita, while the average person in the developing world emitted 4.2 tons of CO_2e. However, within each group of countries, including developing countries, the difference is substantial. For example, per capita GHG emissions in some 50 developing countries, among them Brazil, Indonesia, South Africa and Argentina, are above the global average. In 2004, China emitted approximately 5 tons of CO_2e per capita per year, while India accounted for some 3 tons of CO_2e per capita per year.

[58] Höhne & Blok (2005).

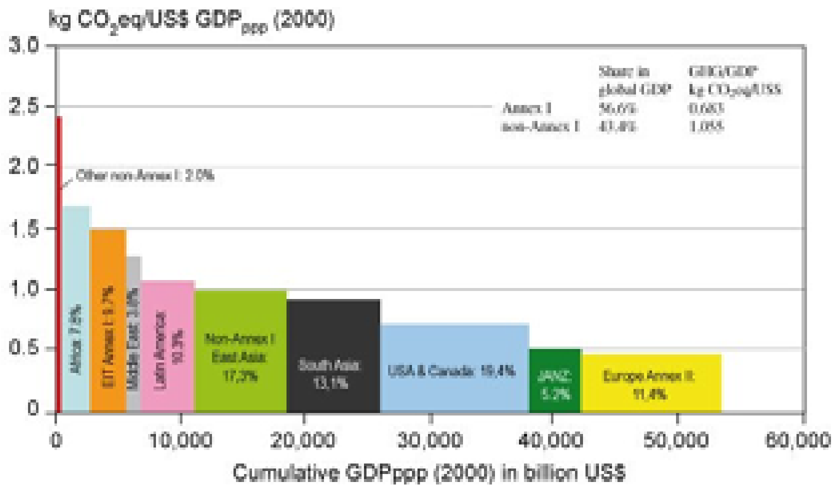
[59] Includes emissions from external aviation and shipping and net emissions from land use and forestry.

Figure 5.1 **Distribution of regional per capita GHG emissions among populations in different groups of countries, 2004. (Percentages indicate regional share of global GHG emissions).**



Source: IPCC (2007c).

Figure 5.2 **Distribution of global GHG emissions per unit of GDP (USD) adjusted for purchasing power, and total GDP for different groups of countries, 2004. (Percentages indicate regional share of global GHG emissions).**



Source: IPCC (2007c).Assuming the *likelihood* that the global mean temperature will not rise more than 2°C above pre-industrial levels, it will be necessary to reduce global GHG emissions to approximately 16–18 Gtons of CO_2e per year by the middle of this century.[60] This is equivalent to just under 2 tons of CO_2e per capita per year, assuming an expected world population of 9 billion in 2050. Towards the end of this century, per capita emissions should be limited to under 1 ton of CO_2e per year. Clearly, action to reduce emissions will be needed not only in the industrialised world, but also in many developing countries. One example is India, which is poised for vigorous economic growth with increased emissions as a likely consequence. Per capita emissions are already above the level regarded as sustainable in the long term.

5.2 Sharing models in the climate policy discussion

5.2.1 Sharing models and international emission reduction commitments

The binding emission reductions set out in the Kyoto Climate Protocol were not derived from a particular principle or sharing model, but were the outcome of negotiations that took the interests of the parties involved and national conditions into consideration. The only precepts to be applied were theClimate Convention's basic principle of "common but differentiated responsibility" and the common assumption that industrialised nations would take the lead in efforts to reduce GHG emissions in view of their preponderant contribution to accumulative emissions. This was reflected in the fact that only parties in one of the categories (Annex I countries) were subject to binding commitments to reduce their GHG emissions by 2012. However, this principle does not preclude developing countries, which now account for more than half of total annual emissions, from committing themselves to emission reductions under future international climate agreements. This is also a core issue in ongoing negotiations on an international climate regime after 2012.

[60] Equivalent to a concentration of 400 ppmv CO_2e (see Figure 4.3).

It is likely that sharing of emission allowances and decisions on reduction commitments under the Climate Convention (UNFCCC) or an ensuing protocol will continue to be settled by negotiation, rather than through the application of a specific sharing model. However, one or more models, separately or in combination, may be applied to guide individual negotiating parties. Sharing models can also serve as a basis for formulating national emission reduction targets.

Discussions on international climate policy after 2012 have given rise to a number of proposals for models for sharing emission reduction commitments in the climate field. The principle of equal per capita emissions by 2050 is one example. Some of the more frequently discussed sharing models are examined in Appendix 3.1.

5.2.2 A comparison of sharing models

A number of sharing models have been assessed and compared, both qualitatively and quantitatively in various studies. The most important result to emerge from these comparative analyses – which has also been underlined by the IPCC – is that the level of global stabilisation chosen has a stronger impact on the emissions reduction requirement for most industrialised nations and regions (but not the US) than the chosen sharing model. The various models applied by the Scientific Council on Climate Issues (see Appendix 3) yield relatively small variations in the reduction requirement for a given country and stabilisation level. Reduction requirements may however vary from country to country. Other models not yet analysed could yield more varied results. For example, burden allocation based on the principle of equal per capita emissions *now* would intensify the demand for early reductions in the industrialised world.

However, the various models appear to be having a significant impact on reduction requirements in certain Annex I countries – the US in particular – which have not ratified the Kyoto Protocol. They also predict varied outcomes for many developing countries which currently have no binding commitments on emission reductions. Requirements generated by the various models differ on when and how developing countries should be covered by commitments on emissions limitation. Models that favour poorer developing countries, such as India, tend to be disadvantageous not only for the richer developing countries like China, but also for the

US. This could complicate negotiations on a future international climate regime after 2012.

5.3 Estimated emission reduction requirements for the EU and Sweden

Ecofys was commissioned by the UK Government to evaluate the outcomes of various sharing models for a large number of industrialised and developing countries. Estimates were made for a range of stabilisation levels with respect to GHG concentrations and commitments on population development, GDP development, etc. Data on Sweden were supplied by Ecofys at the special request of the Council.[61] [62] Table 5.1 shows estimated emission reductions (averaged over different models) for industrialised (Annex I) countries as a whole, the EU, Sweden, the UK and Germany. As the last two EU member states have played a significant part in the development of a European policy on climate change and, like Sweden, drew up emission reduction targets in addition to their international commitments early on, a comparison would be of interest. The reduction requirements for the stabilisation of GHG concentrations at levels corresponding to 400 and 450 ppmv CO_2e by 2020 and 2050 respectively are set out in the table below.

If global emission reduction targets for each point in time are to be met, all countries must comply with the reduction requirements indicated in the estimates. Should one or more countries fail to contribute to sharing in accordance with the estimates below, other nations will be obliged to reduce their emissions by a larger amount than specified if global emissions are not to exceed the maximum limit regarded as necessary.

[61] Höhne & Moltmann (2007).
[62] Ecofys reports, containing descriptions of the various models, bases for calculation and results obtained are available on the Environmental Advisory Council website: www.sou.gov.se/mvb.

Table 5.1 Relative changes in emission allowances (before emission trading) for various (groups of) countries in 2020 and 2050, compared with 1990 levels, at various levels of stabilisation of atmospheric GHG concentrations.

Stabilisation level [ppmv CO2e]	**Region**	**2020**	**2050**
400	The world	+10%	-40%
	Annex I	-25% to -45%	-70% to -95%
	EU 25	-30% to -40%	-75% to -90%
	Sweden	-20% to -25%	-70% to -85%
	United Kingdom	-35% to -40%	-80% to -90%
	Germany	-40% to -45%	-80% to -95%
450	The world	+30%	-10%
	Annex I	-15% to -30%	-55% to -90%
	EU 25	-20% to -30%	-65% to -90%
	Sweden	-5% to -15%	-60% to -80%
	United Kingdom	-25% to -30%	-70% to -90%
		approx. -35%	-75% to -90%
	Germany		

(*Source*: Höhne et al (2007), Höhne & Moltman (2007).

NB: Intervals indicate the spread of results between sharing models. Note that the reduction requirements do not cover net emissions from land use and forestry or from external aviation and shipping. Global reduction requirements at different time points may therefore deviate from those set out in Chapter 4. Note also that the Ecofys distribution estimates were based on global emission paths which differ somewhat from those delineated in Chapter 4.. The latter is based on the assumption that GHG concentrations over a transitional period may exceed the stabilisation level and fall thereafter, while the former assumes that the stabilisation level will be attained without overshoot. Thus the emission path used by Ecofys for stabilisation at 450 ppmv CO_2e is broadly the same as that defined in Chapter 4 (Figure 4.3) for stabilisation at 400 ppmv CO_2e. Similarly, the Ecofys emission path for stabilisation at 550 ppmv CO_2e broadly corresponds to the path for stabilisation at 450 ppmv CO_2e shown in Figure 4.3. See also Appendix 3.2.

5.3.1 Emission reductions for the EU by 2020 and 2050

Outcomes of sharing models

The outcomes of the various sharing models show that the EU[63] needs to reduce emissions from their 1990 levels by approximately 30–40 per cent by 2020 and by 75–90 per cent by 2050 to ensure a *likelihood* of meeting the two-degree target (equivalent to 400 ppmv

[63] EU excluding Malta and Cyprus, which as non-Annex I countries have no binding commitments on emission reduction.

CO_2e, see Table 5.1). Reduction requirements for member states vary and may be higher or lower than for the EU as a whole.

Although no sharing analysis for 2100 has been conducted, it is reasonable to assume, in view of the low global emission levels required, that emissions by the EU and other industrialised regions will have fallen to virtually zero towards the end of the century.

EU greenhouse gas emission reduction targets

The EU position, based on the European Commission's analysis and other assessments of global climate change[64] and adopted following decisions by the European Council and the Environment Council, is that the world's industrialised nations must together reduce their GHG emissions by approximately 30 per cent by 2020 and by 60–80 per cent by 2050 relative to 1990 levels.

In March 2007, the European Council decided on an EU emission reduction of 30 per cent on 1990 levels by 2020, provided that other industrialised nations undertook comparable emission reductions and that the economically more advanced developing nations contributed to global emission reductions in accordance with their respective obligations and circumstances. The EU also decided to reduce its emissions of GHGs by *at least* 20 per cent during the same period, regardless of what other countries did. This target will be achieved through a combination of domestic measures and measures adopted in countries outside the EU.

In light of the results presented in the previous section, EU targets and emission reductions, both for Annex I countries as a group and for the EU as a whole, appear to be on the conservative side. A possible explanation for this is that the EU target is based on a stabilisation of GHG concentration at 450 ppmv CO_2e (cf Chapter 4.2.2) and is adjusted for the economic impact of emission reductions.[65]

[64] European Commission (2006, 2007b).

[65] The European Commission (2007c) has estimated that a 21 per cent reduction in internal EU GHG emissions by 2020 will result in an 0.09 per cent reduction in GDP growth.

5.3.2 Emission reductions for Sweden until 2020 and 2050

As regards Sweden, estimates yielded by the various sharing models indicate that to assume its share of global responsibility for long-term stabilisation of atmospheric GHG concentration at 400 ppmv CO_2e, it will need to cut its own emissions by approximately 20–25 per cent on 1990 levels by 2020 (see Table 5.1). By 2050, a 70–80 per cent reduction on 1990 emission levels will be necessary. If stabilisation at 450 ppmv CO_2e is adopted as a basis, the emission reduction requirements will be lower: 5–15 per cent by 2020 and 60–80 per cent by 2050.

The models yield lower emission reduction requirements for Sweden compared with the EU as a whole, individual EU member states and other Annex I countries (see Table 5.1). This applies particularly to 2020, but also to 2050. This is because Sweden's GHG emission levels are already comparatively low relative to its population and GDP.

As in the case of most industrialised countries, choice of model plays a relatively minor role in the outcome for Sweden. The estimates show that the disparities between different models in terms of reduction requirements are generally smaller for a given stabilisation level than between stabilisation levels. However, one model (the Multistage Model – see Appendix 3.1) yields a significantly higher reduction requirement than other models for Sweden for 2050: 85 per cent instead of 70–75 (stabilisation at 400 ppmv CO_2e). This is because developing countries, according to this model, are subject to lower or no reduction requirements, while industrialised countries normally assume a greater share of the global responsibility.

The outcomes for Sweden for 2020 are materially affected by the input values applied for GHG emissions in 2010.[66] Estimates are based on the assumption that Swedish emission levels for 2010 are in line with our Kyoto commitment following the internal, EU 15 sharing agreement, i.e. +4 per cent on 1990 levels. However, Sweden's own target for domestic emissions for the period 2008–2012 is 8 percentage points lower, i.e. -4 per cent on 1990 levels. Forecasts indicate that Sweden will meet this target. If this lower emission level is used as a basis for calculating Sweden's share, the

[66] When estimating national reduction requirements using different burden-sharing models, future emission levels up to 2050 based on estimated reduction levels in 2010 are calculated first. Emission levels for 2020 and 2050 are then related to 1990 levels (see Höhne et al., 2007; Höhne & Moltmann, 2007).

reduction requirement on 1990 levels for 2020 will be 5 percentage points higher, i.e. 25–30 per cent. If current emission levels are taken into account in coming sharing arrangements within the EU and in negotiations on future commitments, Sweden – precisely because we are expected to achieve our own, more ambitious, emission reduction target – may have to assume a larger share of the responsibility for reducing global emissions by 2020 than would have been the case if our Kyoto commitment constituted our only national emission reduction target for 2008–2012. The same could apply to other EU countries such as the UK and Germany, which are expected to meet their Kyoto commitments in accordance with EU sharing decisions in full.

The reverse applies to countries, such as the US and Spain, whose domestic emission levels will be significantly higher than specified in their Kyoto commitments. The choice of a reference value as a basis for future commitments is thus likely to be crucial not only in the context of upcoming negotiations on commitments towards an international climate regime but also with regard to the sharing of EU emission reduction targets for 2020. The Scientific Council on Climate Issues therefore considers that Sweden's position in the EU and the UN should be one of active support for the view that sharing should not be based on the various countries' current global GHG emission levels or on estimated levels for 2010. If sharing were to be determined on this basis it could encourage the emergence of an incentive structure under which a country would benefit from having high emission levels and suffer if its emissions were low. This would not be conducive to good climate policy.

The reduction requirements for Sweden as specified above are based on estimates of what Sweden needs to do in order to assume its share of global responsibility for achieving the two-degree target. The emission targets adopted by Sweden will depend on political assessments of considerations such as temperature targets, the precautionary principle, the socioeconomic impact and whether Sweden should play a forward role in international climate policy (see also Chapter 8).

5.4 Devising national emission reduction targets

Basically, an emission reduction target for a country or group of countries can mainly be framed in one of two ways: on the basis of emission reductions *in* the country or on the basis of reductions *for* the country. In the latter case, a country may supplement domestic emission reductions with reductions effected in other countries by buying transferable emission rights from other countries under the Kyoto Mechanisms.[67].

5.4.1 EU Emission Trading Scheme and the national emission reduction target

The picture is complicated by the EU scheme for GHG emission trading between companies (EU ETS). Companies operating in an EU member country and covered by the scheme can buy emission rights from companies covered by the scheme in any EU member country rather than implement emission reductions of their own. Companies covered by the EU ETS can in certain circumstances also buy emission rights through two project-based mechanisms, Joint Implementation (JI) and the Clean Development Mechanism (CDM), to supplement either their own emission reductions or European emission rights.

The Council accordingly takes the view that activities and emission sources covered by the EU ETS, i.e. the trading sector, should be distinguished from other activities and emission sources (the non-trading sector) in the context of a national emission reduction target. With regard to the trading sector, the amount of emission rights initially allocated to Swedish industrial facilities and activities under the EU ETS and not the actual emissions from those facilities should be the key determinant of a national emission target. These are normally referred to as deductible emission allowances. This is the approach adopted by EU institutions such as the European Commission and the European Environmental Agency to activities in the EU ETS when assessing progress by member states in meeting their Kyoto commitments.

[67] Flexible mechanisms refer to mechanisms so defined in the Kyoto Protocol, namely international trading of emission rights between states and the two project-based mechanisms: joint implementation (JI) and the clean development mechanism (CDM).

5.4.2 State use of the Kyoto Mechanisms as a complement to national measures in sectors outside the EU ETS

Regarding activities not covered by the EU ETS – the non-trading sector, i.e. transport, certain industries, housing and services, agriculture, waste management and land use and forestry – a national emission reduction target can embrace emissions both *in* and *for* the sector. A national target can focus strictly on domestic emission reductions or permit utilisation of the Kyoto Mechanisms. Regardless of how the target is framed, it is in these non-trading sectors that the government, by applying different policy instruments, can have an impact on emissions at national level.

Where a national target provides for use of the Kyoto Mechanisms it is the government that buys emission rights, either via intergovernmental trade or under the project-based mechanisms, JI or CDM, as a complement to national measures. A government can thus choose to buy emission rights on a limited scale instead of implementing reduction measures in full, for example in the transport sector. However, the Kyoto Mechanisms may only be used to supplement domestic measures; a significant proportion of emission reduction efforts must take place in Sweden. Although individual actors in non-trading sectors may trade emission rights, these may only be used to meet company targets.

Whether the state should use the Kyoto Mechanisms to supplement domestic measures aimed at achieving a national emission reduction target – either voluntarily or in conformity with an international agreement – is a complex question. Among other observations, the Council notes the following:

1. Extensive use of the CDM in particular would call for the development of rules designed to ensure that reduced emissions achieved through projects in developing countries that do not themselves have internationally binding reduction commitments extend beyond the emission limitations that need to be achieved in these countries, according to the various sharing models, if the concentration of GHGs is to be stabilised at 400–450 ppmv CO_2e.

2. Extensive use of the Kyoto Mechanisms could also distract from efforts to introduce measures needed for more long-term structural changes that would help to reduce emissions

in Sweden (and globally) to almost zero by the end of the century.

3. Extensive use of the Kyoto Mechanisms, particularly CDM, *instead of* reducing emissions at home could send a signal to developing countries that not even Sweden – a country that preaches the importance of measures to limit climate change – believes that it is possible to combine high welfare standards with low carbon dioxide emissions.

4. Use of the Kyoto Mechanisms would enable Sweden to neutralise (100 per cent reduction) its emissions in the short and medium term (cf Norwegian Government proposal to the Stortinget No. 34, Norwegian Climate Policy (2007).

5. Use of the Kyoto Mechanisms would give Sweden the opportunity to take an active part in their development as an international climate policy instrument of potential benefit to other nations and international climate cooperation.

6. In view of the low prices of emission rights, e.g. from CDM, compared to the cost of domestic emission reduction measures in the sectors not covered by EU ETS, it should be more cost-effective to use the Kyoto Mechanisms, at least in the short term. If emission reduction commitments were to be met solely through domestic measures, the national and global costs of achieving a given global emission reduction would be higher.

5.4.3 A national target should include emission sources regulated by international climate agreements

Another important question in relation to a national emission target is what sectors and (types of) emission sources should be included in the target. The national emission reduction target for 2008–2012 does not include emissions from external aviation and shipping or net emissions from land use and forestry. On the other hand, Sweden's commitment under the Kyoto Protocol includes the possibility of using forest carbon sinks as a means of fulfilling that commitment, though only to a limited and predetermined extent. These types of emission sources are significant from an international perspective (see Chapter 6), either because they account for a major proportion of global emissions (forestry) or because they are responsible for rapidly growing emissions (external transport). In the view of many observers, e.g. Stern (2007), such sources should be more explicitly incorporated in any future climate regime. If this transpires, they should also form part of the Swedish emissions reduction target. The Council recommends that Sweden's national reduction target be periodically reviewed in response to changes in the regulatory framework governing international climate policy.

5.5 Council conclusions

The Council considers[68] that EU GHG emission levels should be reduced by 30–40 per cent on 1990 levels by 2020 and by 75–90 per cent by 2050 if the EU is to assume its share of global responsibility for achieving the two-degree target

- that Swedish GHG emission levels should be reduced by 20–25 per cent on 1990 levels by 2020 and by 70–85 per cent by 2050 if Sweden is to assume its share of global responsibility for achieving the two-degree target

- that a national emission target for Sweden should provide for deductible emission allowances. This means that the target should be designed so that the quantity of emission rights allocated for activities covered by the EU emission rights trading scheme should be used as a basis for assessing target achievement, rather than actual emissions from these activities.

- that the choice between sharing models dealt with in the report does not significantly affect the size of emission reductions required of Sweden or of most other industrialised nations and regions. The national emission reduction requirement is more affected by the choice of concentration target as a basis for emission reduction measures.

[68] The target levels specified by the Council are based on current scientific knowledge and may need to be revised as our understanding of the climate system, society, etc. increases.

- that the choice of sharing model is, however, significant for many developing countries as well as some industrialised countries, particularly the US

- that the choice of input emission values as a reference point for future commitments may prove very important in future negotiations on commitments within an international climate regime and in the context of sharing EU emission targets for 2020

- that Sweden should actively seek support in the EU and UN for the view that sharing in the EU and determinations regarding future commitments should not be based on the current GHG emission levels from different countires or on estimated levels for 2010.

6 Action to reduce emissions

The present chapter addresses a number of issues in connection with measures to reduce GHG emissions at both global and national level. It opens with an account of the distribution of GHG emissions among various sectors. This is followed by a comparison of emission levels for different concentration targets. The levels are set in accordance with reference paths for emission trends assuming no new measures or policy instruments are introduced. The chapter concludes with a discussion of proposed emission reduction measures and the potential for reducing emissions in different sectors.

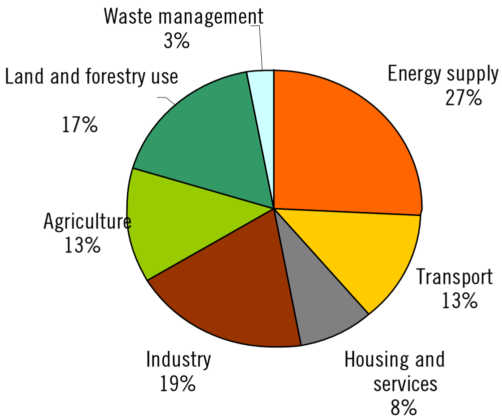
6.1 Emissions and trends at sectoral level

6.1.1 Global trends

Global GHG emissions as defined in the Kyoto Climate Protocol[69] amounted to approximately 45 billion tons (Gtons) of CO_2e in 2000 and approximately 49 billion tons (Gtons) of CO_2e in 2004. The latter figure represents an increase of 70 per cent on 1970 levels. Almost 60 per cent of all emissions were linked to the burning of fossil fuels.

[69] Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrogenated fluorocarbons (HFCs), perhalogenated fluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

Figure 6.1 Breakdown by sector of global GHG emissions, 2004.



Source: Based on data from IPCC (2007c).

NB: Emissions from external shipping and aviation and net emissions from land use and forestry (deforestation) included. Total emissions: 49 billion tons (Gtons) of CO_2e.

As we see from the figure, the energy supply sector accounts for the largest share of global emissions. This sector also recorded the biggest increase in emissions since 1970 – over 145 per cent. Carbon dioxide accounts for approximately 80 per cent of all emissions from this source. The remainder is mainly methane. Emissions from the transport sector have risen steeply – by 120 per cent – since 1970, and now make up approximately one eighth of all global emissions. Agriculture, with emissions of mainly methane and nitrous oxide, accounts for a similar proportion. Here, however, emissions have risen far less – 27 per cent – than in other sectors. The rate of increase in the housing and services sector has also been relatively low – 26 per cent. The business/industry sector accounts for one fifth of all global emissions, which have risen by 65 per cent since 1970. Land use and forestry, including deforestation (mainly in the tropics) is the third largest emission source in global terms. This sector accounts for almost one seventh of all global GHG emissions (mainly carbon dioxide), exceeding the transport sector's contribution. Following a modest decline between 1970 and 1995, emissions from this sector have increased by almost 50 per cent.

Development in the energy sector between 1970 and 2000 resulted in lower energy intensity (expressed as the total supply of primary energy per GDP unit) and reduced carbon dioxide intensity (expressed as carbon dioxide emissions per unit of total primary energy supply, or TPES, and per GDP unit). However, the emission reduction effects of this trend were countered by high GDP and population growth. Although emissions were not growing at the same rate as the global economy, 2000 marked a break in the trend as relative emissions of carbon dioxide from the energy supply sector began to rise.[70] The depletion of conventional petroleum resources could lead to a changeover to production of coal-based liquid propellants. This is a worrying development from a climate standpoint as carbon dioxide emissions from such energy sources are twice as high as from petrol and diesel.

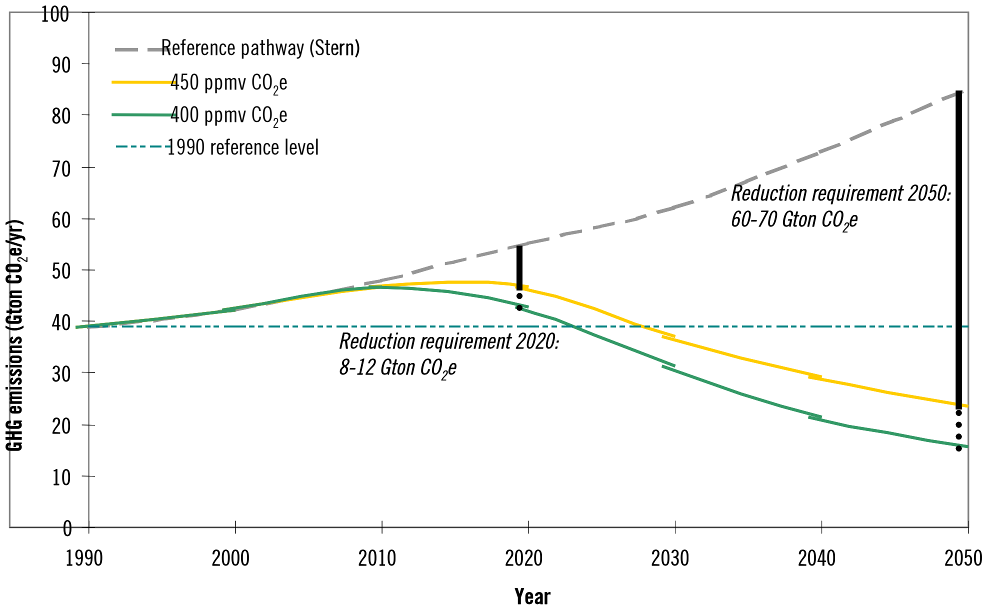
According to IPCC reference path scenarios (SRES, see Appendix 2.5) global GHG emissions could rise by 25–90 per cent during the period 2000–2030 if no additional measures/policy instruments are introduced to counter current trends. The scenarios also suggest that fossil fuels will continue to play a dominant role in the global energy mix. Carbon dioxide emissions from the energy system are expected to rise by 45–110 per cent in the same period. It is estimated that at least two thirds of this increase will take place in developing countries.

The emission trends predicted in the Stern Review[71] for the period up to 2050 are based on the assumption that no action is taken to counter current trends. According to these prognoses – based *inter alia* on International Energy Agency (IEA) data on the development of the global energy system – global GHG emissions could total approximately 55 billion tons (Gtons) of CO_2e per year by 2020 and 85 Gtons of CO_2e per year by 2050. This is considerably higher than the global emission levels regarded as necessary to ensure a *probability* of preventing the global mean temperature from rising by more than 2°C above pre-industrial levels (see Chapter 4). Stern's estimates lie in the topmost interval of the IPCC reference path scenarios. However, as they are based on more detailed assessments of (for example) energy system trends, and given that global emission trends have so far exceeded

[70] IPCC (2007c).
[71] Stern (2007).

the highest IPCC emission scenarios, the estimates furnish a reasonable basis for delineating a set of requirements for measures that need to be taken in order to reduce emissions. The actual global reduction requirement for 2020 and 2050 respectively is greater than a comparison with the base year 1990 would suggest.

Figure 6.2 Emission pathways in 1990–2050 for global GHG emissions for various stabilisation scenarios and reference pathway scenario.



Source: Based on data from den Elzen & Meinshausen (2006) and Stern (2006).

NB: Emission pathways include emissions from land use and forestry.

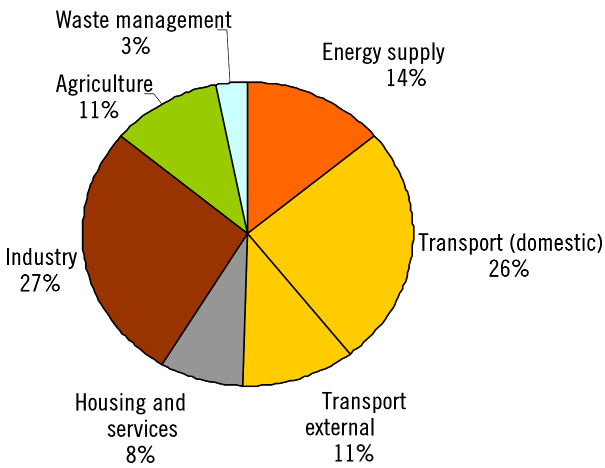
As Figure 6.2 shows, there is a need for measures capable of achieving annual emission reductions, relative to the reference path, of approximately 10 billion tons (Gtons) of CO_2e by 2020 and as much as 60–70 Gtons of CO_2e by 2050. This must be achieved in a period of global economic expansion, with a growing world population and a steadily rising total supply of primary energy. Thus the challenge is twofold: to avoid future emission increases due to population growth, increased industrialisation, an expanded energy infrastructure and economic growth while actually bringing about emission reductions in the existing economy.

6.1.2 Trends in Sweden

Total GHG emissions in Sweden in 2004 came to just under 72 million tons (Mtons) of CO_2e.[72] The figure includes just under 9 Mtons of CO_2e from external shipping and aviation and a carbon sink of just over 5 Mtons of CO_2e from land use and forestry.[73] Swedish emissions in 2005, as reported to the UN Climate Secretariat, amounted to almost 67 Mtons CO_2e, a reduction of 7 per cent on 1990 levels.

Figure 6.3 shows that the transport sector (domestic plus external transport) accounts for more than one third of Sweden's GHG emissions. Emissions in this sector have risen steadily since 1990. External shipping accounted for the most rapid increase. Emissions from external aviation and heavy road vehicles have also contributed substantially.

Figure 6.3 Breakdown by sector of GHG emissions in Sweden, 2005.



Source: Based on data from the Swedish Environmental Protection Agency (2006).

NB: Emissions from external shipping and aviation are shown in the diagram but are not included in reports relating to Sweden's international commitments on emission limitation under the Kyoto Protocol. Net emissions from land use and forestry are not shown as these were negative in 2005. Total emissions amounted to 73 Mtons of CO_2e.

[72] Swedish Environmental Protection Agency.

[73] Net emissions from land use and forestry, i.e. the difference between emission and uptake of carbon dioxide by land and vegetation, have been negative in Sweden for a number of years, making this sector a coal sink.

Along with the transport sector, industry accounts for the biggest share of Sweden's GHG emissions. Emission levels in this sector have remained largely unchanged since 1990. Energy supply, which makes up the largest share of global GHG emissions, accounts for just one eighth of all emissions in Sweden. Emission levels vary widely from year to year according to ambient temperatures and precipitation levels. Emissions in this sector have decreased since 1990, partly as a result of a significant shift to biofuel use.[74] Emissions from the energy sector have fallen sharply on 1970 levels Future trends will depend on the development of Sweden's energy policy. Emissions from other sectors have fallen steadily since 1990. The housing and service sector has seen the biggest reduction following major expansion of the distance heating network.

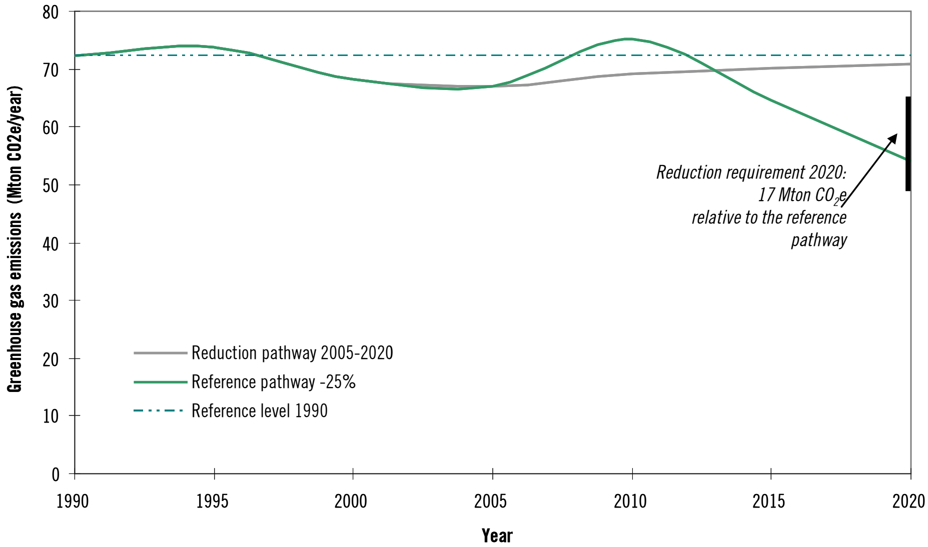
As mentioned earlier, net discharges from land use and forestry were negative in 2005, making this sector a carbon sink. This has been the case each year since 1990, despite large annual fluctuations. At their lowest, net discharges (maximum carbon sink effect) totalled approximately 33 million (Mtons) of CO_2e in 1996 and again in 2000; the highest figure was 4 Mtons of CO_2e, reported in 1990 and 2005.

In their latest prognosis on emission trends in Sweden up to 2020, the Swedish Energy Agency and the Swedish Environmental Protection Agency estimate that GHG emissions as defined in the Kyoto Protocol (excluding emissions from external shipping and aviation and land use and forestry respectively) will be approximately 4 per cent below 1990 levels in 2010 and 2 per cent below in 2020,[75] assuming unchanged policy instruments. It is mainly emissions in the transport and industry sectors that will continue to rise and thus outweigh reductions in other sectors.

[74] Just over 20 million tons (Mtons) of CO_2 were emitted from biomass combustion (Swedish Environmental Protection Agency). Under international reporting rules, these emissions are not included in the statistics as the growth in biomass fuel production has exceeded felling in Sweden. Net CO_2 emissions from living biomass, i.e. the difference between emissions from harvested biomass and biomass absorption, were -16 Mtons of CO_2 in 2005. If felling were to exceed production growth, this would be treated as a change in net emissions from land use and forestry.

[75] Swedish Energy Agency & Swedish Environmental Protection Agency (2007a).

Figure 6.4 GHG emission paths for Sweden in 1990–2020 (excl. emissions from land use and forestry and external shipping and aviation).



Source: Based on data from the Swedish Energy Agency & the Swedish Environmental Protection Agency (2007a) and Höhne & Moltmann (2007).

Actual emissions in Sweden are shown for the period 1990–2005. The reference pathway (grey curve) and the emission pathway for a 25 per cent reduction (green curve) are shown for the period 2005–2020.

As stated in the previous chapter, the outcome for Sweden in 2020 in terms of its share of the global effort to achieve the two-degree target could entail an emission reduction requirement of approximately 20–25 per cent on 1990 levels. In view of the emission trends indicated by the reference pathway, this means action must be taken to ensure an annual emission reduction of just under 17 Mtons of CO_2e in 2020 (see Figure 6.4). Although no full prognosis on emission trends for Sweden up to 2050 has been made, the actual annual reduction requirement relative to 1990 levels will be approximately 50–60 Mtons of CO_2e in 2050. By comparison, Sweden's GHG emissions in 2005 totalled 67 Mtons of CO_2e. All in all, these are very extensive reductions and vigorous action will be needed.

6.2 Emission reduction measures in the short and medium term

Since its first Assessment Report, the IPCC has consistently referred to a number of more or less accessible measures to reduce global GHG emissions. In its latest Assessment Report, the IPCC points to the need for and the potential of technology-based measures and lifestyle changes, to achieve the emission reductions required in the short and medium term in order to stabilise the concentration of atmospheric GHGs.

6.2.1 The global potential for emission reduction by 2030

There are a number of ways of viewing the potential for reducing GHG emissions. The *economic potential* is the potential for emission reduction based on economic profitability and assuming perfectly functioning markets. The *market potential* is based on private costs, having regard to prevailing policy instruments and measures and to constraints that limit the ability to adopt and implement relevant measures. The economic potential is generally greater than the market potential.

According to IPCC estimates, the global economic potential will reduce annual GHG emissions to approximately 5–31 billion tons (Gtons) of CO_2e by 2030, depending on the price 'set' on GHG emissions, or, more accurately, on the cost levels contemplated for emission reduction measures. At a price equivalent to SEK 140/ton of CO_2e, the estimated reduction potential is 9–18 Gtons of CO_2e per year.[76] At a price equivalent to SEK 350/ton of CO_2e, the potential rises to 13–26 Gtons of CO_2e per year, and at a price equivalent to SEK 700/ton of CO_2e, the estimated potential is 16–31 Gtons of CO_2e per year. It should be noted that the IPCC points to a reduction potential of approximately 5–7 Gtons of CO_2e per year in 2030 achievable at negative cost, i.e. measures would be immediately profitable. If measures are to implemented, however, existing constraints will need to be removed.

[76] Based on an exchange rate of SEK 7/USD.

These estimates may be compared to the reference pathways presented above (Section 6.1). These will provide some indication of whether and to what extent the estimated reduction potential, relative to the estimated reduction requirement, will be sufficient to achieve the two-degree target. The annual reduction requirement in 2020 will be approximately 8–12 billion tons (Gtons) of CO_2e compared to the reference pathway. Figure 6.2 shows that the corresponding annual reduction requirement in 2030 will be approximately 25–30 Gtons of CO_2e. Thus it appears that the short- and medium-term global emission reduction requirement (by 2030) can be met on the basis of already existing technology or technology likely to be commercially available within a few decades. However, this will require a range of policy instruments, in particular a price label on GHG emissions.

6.2.2 Measures and reduction potential in different sectors

The global emission reduction potential is unevenly distributed among different sectors and regions. According to IPCC estimates, the economic potential in 2030 will be greatest in the 'buildings' sector (cf 'Housing and services' in Figure 6.1). Indirect emission reductions have also been included in the potential for this sector due to reduced electricity demand in housing and services.

The IPCC also estimates that most of the economic reduction potential is to be found in countries outside the OECD, i.e. in developing countries. This is because of generally higher energy and emission intensity in these countries and the fact that with the right incentives anticipated large-scale investment in new energy infrastructure in these countries between now and 2030 can be predicated on low-carbon technologies from the outset.[77] Another reason is the fact that the bulk of global emissions from land use and forestry originates in developing countries.

[77] The International Energy Agency (IEA) has estimated that decisions to invest as much as USD 20 000 billion in energy infrastructure projects around the world will be made between now and 2030. A substantial portion of this investment will take place in developing countries. Owing to the long life of energy generation facilities and other infrastructural capital stock, the decisions are expected to have a long-term effect on GHG emissions. An estimated net additional investment of 0–10 per cent will be needed to bring energy-related global CO_2 emissions back down to 2005 levels by 2030, even allowing for major infrastructural expansion and increased primary energy use.

Numerous strategies exist for reducing emissions in each sector. Table 6.1 presents an overview of the mitigation technologies and practices regarded as important by the IPCC.

Table 6.1 **Table 6.1 Important mitigation technologies and practices, by sector**

Sector	Key mitigation technologies and practices currently commercially available	Key mitigation technologies and practices projected to be commercialised before 2030
Energy supply	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of Carbon Capture and Storage (CCS, e.g. storage of removed CO2 from natural gas).	CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and waves energy, concentrating solar, and solar PV.
Transport	More fuel efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning.	Second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries.
Buildings	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation ; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycle of fluorinated gases.	Integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar PV integrated in buildings.
Industry	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO2 gas emissions; and a wide array of process-specific technologies.	Advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture.
Agriculture	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH4 emissions; improved nitrogen fertilizer application	Improvements of crops yields.

	techniques to reduce N2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency.	
Land use and forestry	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use.	Tree species improvement to increase biomass productivity and carbon sequestration. Improved remote sensing technologies for analysis of vegetation/ soil carbon sequestration potential and mapping land use change.
Sector:	Key mitigation technologies and practices currently commercially available	Key mitigation technologies and practices projected to be commercialised before 2030
Waste management	Landfill methane recovery; waste incineration with energy recovery; composting of organic waste; controlled waste water treatment; recycling and waste minimization.	Biocovers and biofilters to optimize CH_4 oxidation.

Source: IPCC (2007c).

NB: Sectors and technologies are not listed in any particular order.

As Table 6.1 shows, there are numerous opportunities for emission reduction in many sectors. It is also clear that no single practice, technology or sector can effect the emission reductions needed to substantially reduce the risk of dangerous human impacts on the climate system. The IPCC's assessment of the emission reduction potential in different sectors in the medium and short term may be summarised as follows:

- New investment in energy infrastructure in industrialised and developing countries, energy infrastructure upgrades in industrialised countries and strategies designed to promote energy security can often create conditions conducive to GHG emission reductions relative to emission trend reference paths. Other co-benefits are often country-specific but include reduced air pollution, improved trade balance, provision of modern energy services in rural areas, and job opportunities.

- Electricity from renewable energy sources accounted for 18 per cent of electricity production in 2005 and could account for 30–35 per cent of production in 2030

- Nuclear power accounted for 16 per cent of electricity production in 2005 and could account for 18 per cent of production in 2030. However, development in this area is still limited by issues of security, nuclear weapons proliferation and nuclear waste.

- Although there are many opportunities for emission mitigation in the transport sector, their effect may be offset by sectoral growth. There are also numerous constraints on the various emission mitigation practices/technologies, such as consumer preference for larger, higher-performance cars, increased air travel, etc.

- Measures to enhance energy efficiency in new and existing buildings can significantly reduce CO_2 emissions and generate net economic gains. While there are many obstacles to the realisation of this potential, there are also significant co-benefits, e.g. improved air quality.

- The economic potential in the industry sector is mainly in energy-intensive industries. Neither industrialised nor developing countries make full use of the emission mitigation options available.

- Measures in the agricultural sector can together, and at little cost, play a major role in enhancing carbon sinks in agricultural land, reducing GHG emissions and providing biomass for energy purposes

- Forestry-related mitigation measures can together, and at a modest cost, significantly reduce emissions and increase CO_2 binding through carbon sinks in land and vegetation. They can also be designed to generate synergies with adaptation measures and work on sustainable development.

- While consumer waste is only responsible for a small proportion of global GHG emissions, the waste sector can still make a positive contribution to emission reduction at a low cost, as well as promote sustainable development

The Council also takes the view that geo-engineering options, such as ocean fertilisation to increase CO_2 sequestration, or attempts to attenuate solar radiation by releasing aerosols or reflective particles into the upper atmosphere are speculative at best and could have unforeseen repercussions. In view of the complexity of the climate system, the Council considers that projects of this kind would be ill-advised.

In addition to the technologies and practices listed in Table 6.1, the IPCC refers in its latest report to the need for more overarching, non-technological initiatives to reduce GHG emissions and supplement the more technology-based measures. In certain cases, it may also be necessary to remove constraints on implementation of technological measures and thereby unleash the economic potential.

Examples of measures include regulation of transport demand *inter alia* through town planning – which can help reduce the need for transport – and provision of public information and education – which can reduce car use and encourage more energy-efficient driving habits.

In the industry sector, management tools such as personnel training, bonus incentive schemes, consistent feedback and documentation of existing practices can help remove organisational constraints, cut down energy consumption and reduce GHG emissions.

In general, the Council considers that technology-based measures, supported by non-technological measures such as information, education, etc. can help effect the necessary emission reductions in most areas, e.g. road transport, heating, electricity and consumption. However, the Council acknowledges two problem areas where technological solutions will not suffice; changes in consumption patterns will also be required. These are aviation and large-scale production and consumption of meat (principally beef).[78] Moreover, these are both areas in which emissions are increasing at global level.

6.2.3 Measures and reduction potential in Sweden

As distinct from assessments at global level, an assessment of the need for measures and the potential to meet national (or regional, e.g. EU) emission reduction targets must take account of the way

[78] According to Steinfeld el al (2006), meat production accounts for 18 per cent of global GHG emissions.

in which the target is framed. As discussed in Chapter 5, national or regional emission targets can relate to domestic emissions only or provide for the application of the Kyoto Mechanisms to a greater or lesser extent. In the latter case, emission reductions implemented in other countries can be counted towards the national target through the purchase of transferable emission rights.

The Council notes that draft proposals for Climate Strategy CheckPoint 2008 (*Kontrollstation 2008*) drawn up by the Swedish Energy Agency and the Swedish Environmental Protection Agency contain a sector-based survey of possible measures for implementation in Sweden.[79] The agencies conclude that GHG emissions in Sweden can be reduced in the medium term, i.e. up to 2020, and that scope for implementing mitigation measures exists in all sectors.[80] Energy efficiency enhancement was identified as the least expensive measure in almost all sectors. The Council notes that although their relative potential may differ, the measures singled out by the IPCC as important (see Table 6.1) are also identified as significant in the Swedish context. For example, the emission reduction potential in the Swedish energy and agricultural sectors relative to other sectors is considerably lower than at global level. Certain technologies, such as the capture and storage of carbon dioxide (CCS) and the development of second-generation biofuels, are not expected to have made enough commercial impact to affect GHG emissions in Sweden by 2020. In some areas, there is considerable technological potential for reducing emissions through energy efficiency enhancements, which would also yield substantial economic savings. However, the agencies point out that the commercial potential for measures of this type may be considerably smaller.

The agencies have also assessed the feasibility and consequences of reducing emissions in Sweden by 25 per cent on 1990 levels by 2020.[81] They begin by proposing – as does the Council (see Chapter 5.4) – that a national emission target should focus on the total quantity of emission rights allocated for activities covered by the EU ETS, and not on actual emissions. This is an important point of departure for their impact analysis.

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[79] Swedish Energy Agency & Swedish Environmental Protection Agency (2007b).
[80] The analyses cover the emission sources currently included in the report, in accordance with the Kyoto Climate Protocol. Emissions from international aviation and shipping, which are increasing rapidly, and net emissions from land use and forestry are thus excluded.
[81] Swedish Energy Agency & Swedish Environmental Protection Agency (2007c).

According to the agencies, measures and policy instruments in the sectors not covered by the EU ETS, particularly the transport sector, could alone reduce emissions by 4–6 million tons (Mtons) of CO_2e per year by 2020 without adversely affecting the economy. This is only a small proportion of the approximately 17 Mtons of CO_2e per year that emissions would need to be reduced by to meet an emission target of -25 per cent by 2020 (cf Figure 6.4). The Swedish Energy Agency and the Swedish Environmental Protection Agency therefore consider that a substantial cut in emission right allocations to sectors in the EU ETS will be needed to meet the -25 per cent target. In their view, a reasonable reduction rate in sectors covered by the EU ETS would be in the order of 6–10 Mtons of CO_2e per year.

In the agency's view it may be necessary for the state to invest in climate projects outside Sweden (CDM and JI) in the period 2008–2017 to ensure that the 25 per cent target is met without significant adverse impact on the economy. The need for emission rights accruing from emission-reducing projects in other countries could be equivalent to 2–4 Mtons of CO_2e per year in the period 2013–2022. This would presuppose an annual project investment allocation of SEK 200–600 million in the period 2008–2013. If the Kyoto Mechanisms were not used for target fulfilment, the agencies consider that further measures and policy instruments, as well as more rigorous policy parameters (e.g. a tax on fuel), would be needed to achieve a 25 per cent emission reduction.

As mentioned earlier (see Chapter 5.4.2), the question of whether the government should use the Kyoto Mechanisms to supplement domestic measures is, in the Council's view, a many-sided issue.

6.3 Emission reduction measures in the long term

Compared with trend assessments for the period up to 2030, assessments of the global reduction potential in the longer term are less confident. The IPCC considers that stabilisation levels as low as 490 ppmv CO_2e can be achieved using available technologies and technologies that may be expected to become commercially available in the next few decades. The Council notes that the IPCC has not estimated the reduction potential for stabilisation of atmospheric GHG concentrations down to 400 ppmv CO_2e. The Council therefore considers it highly probable that technologies which are still in the early stages of development will be needed to attain very low stabilisation levels (400 ppmv CO_2e and lower).

The Council shares the IPCC's view that the contribution of different technologies to required emission reduction rates will vary over time, between regions and according to the stipulated stabilisation level. There can be no doubt, however, that whatever the time scale or stabilisation level, energy efficiency enhancement and energy saving measures will play a key role. The same applies to measures for reducing non-CO_2 emissions and to measures for reducing CO_2 emissions from land use and forestry. To achieve lower stabilisation levels, greater emphasis should be placed on utilisation of low-carbon energy sources such as renewable energy and nuclear power, and on CCS from both fossil and renewable fuels. Atmospheric CO_2 can be removed by combining biomass-generated electricity with CCS technologies. As mentioned in Chapter 4.4.2, there may be a negative global CO_2 emission requirement towards the end of the century. Moreover, modern bioenergy technology is considered capable of contributing substantially to the renewable energy part of the portfolio of reduction measures. In these scenarios, the carbon intensity of the energy supply and the economy as a whole will need to decrease far more rapidly than hitherto.

Achieving different stabilisation levels and reducing the cost of developing technological solutions will call for investment in low-GHG emission technology, wide dissemination of the same, and technological advances through public- and private-sector research, development and demonstration. The lower the stabilisation levels, particularly at 450 ppmv CO_2e and below, the greater the need for more effective research, development and demonstration, and investment in new technology in the coming decades. This presupposes effective action to remove constraints on the development, acquisition, use and dissemination of technology.

6.4 Council conclusions

The Council considers

- that the global emission reductions deemed necessary to the achievement of the two-degree target may be achieved by applying both technologies currently available in the market and technologies that may be expected to arrive in the market over the next few decades

- that changes in consumption patterns are of crucial importance when seeking to reduce GHG emissions
- that a combination of increased energy efficiency, energy saving and measures in respect of energy supply are required if the climate targets are to be achieved
- that increased energy efficiency and energy saving have high potential for reducing GHG emissions at low costs
- that renewable energy (bioenergy, sun, wind, water), nuclear power and the capture and storage of CO_2 can help reduce emissions. In the case of nuclear power, generally acceptable solutions must be found to the problems of safety and security, waste, the risk of nuclear weapons proliferation and terrorist acts.
- that the efforts made to reduce GHG emissions over the next few decades will largely determine the extent to which achievement of the two-degree target will be possible
- that achievement of a Swedish emission target for the year 2020 should to an overwhelming extent be sought via a combination of domestic measures, especially in the transport sector, and a reduced allocation of emission allowances to sectors covered by the EU emission trading scheme. Government investment in emission-reducing projects in developing countries, via the Clean Development Mechanism (CDM), may be required as a supplement.

7 The costs and benefits of climate policy

7.1 General considerations regarding the costs and benefits of climate policy

The issue of the costs and benefits of climate policy is both complex and problematic. However, it is central to any discussion of policy aims and ambition levels.

The conventional tool for evaluating measures to improve the environment is a cost-benefit analysis. In this approach, costs are weighed against benefits. The principle is simple. In practice, however, it can be difficult to calculate costs and benefits fairly. For one thing, climate change has large-scale effects. At issue are profound, long-term changes in the earth's capacity to sustain conditions for life, to which no monetary value can be assigned without entering into ethical controversy. Secondly, many of the changes are irreversible. If they are allowed to continue, it will be impossible to restore the climate to its former state. A third consideration is the large element of uncertainty involved. We lack precise, certain knowledge of the effects – particularly the long-term effects – of climate change. All these circumstances add up to a compelling argument for a climate policy based on the so-called precautionary principle, i.e. preventive measures to protect the environment and human health should be taken even if there is scientific uncertainty about the risks involved.

The choice of system boundaries is of crucial importance when assessing the cost of a measure or set of measures. Should one take a narrow view of climate measures, or set them in a wider context? To use the energy sector as an illustration, one could proceed on the assumption that all energy system changes were aimed exclusively at reducing climate gas emissions, in which case all such changes would be accounted as a climate policy cost. If instead one takes the view that the energy system changes are prompted by considerations other than climate, and that the measures lead to reduced greenhouse gas (GHG) emissions into the bargain, the effect on the climate is seen as a 'bonus', just one of several end results.

Today's energy systems face demands and challenges of many kinds. Besides reducing GHG emissions, these include securing access to energy (as conventional oil and gas resources grow increasingly scarce), limiting air pollution, tackling political risks, e.g. nuclear weapons proliferation and terrorism, and supplying energy to the two billion people in the world who currently lack access to modern energy carriers. If solutions could be found that simultaneously met all relevant energy system requirements, the cost of climate policy measures would be considerably lower – perhaps even zero. According to a number of assessments, there are solutions capable of concurrently meeting all the various energy system requirements more effectively than would be possible if present trends were to continue.[82] One conclusion is that it is vital to indicate clearly what climate policy cost estimates include.

With regard to the cost of damage to lives, property, etc., the Council would emphasise that costs at regional and local level could be very high for those affected. An example is population displacement caused by flooding in coastal areas.

7.2 The cost of reducing emissions

7.2.1 At international level

Reduction of GHG emissions entails societal costs: resources must be allocated for equipment, new technology and the work of changing processes and behaviour.

The IPCC Fourth Assessment Report provides estimates of the global economic cost of emission reduction (see Table 7.1). Of particular interest here is the lowest stabilisation level given for the concentration of atmospheric GHGs (445–535 ppmv CO_2e) as this is in closest agreement with the Council's recommendation. In its report, the IPCC predicts a GDP loss of up to 3 per cent for 2030 and a loss of up to 5.5 per cent for 2050. The figures are global averages, and regional variations may be considerable. In terms of

[82] IEA (2006), UNDP (2004).

annual GDP growth, this is equivalent to a fall-off of up to 0.12 percentage points. At higher concentration levels, the growth rate would be 0.5 to 0.1 percentage points lower than it would otherwise be.

Table 7.1 Estimated economic cost of achieving different long-term stabilisation levels of atmospheric GHG concentrations by 2030 and 2050 respectively.

Stabilisation levels (ppmv CO2e)	Median GDP loss %		Range of GDP reduction %		Reduction of average annual GDP growth rates, percentage points	
	2030	2050	2030	2050	2030	2050
590—710	0.2	0.5	-0.6—1.2	-1—2	<0.06	<0.05
535—590	0.6	1.3	0.6—2.5	little increase: -4	<0.1	<0.1
445—535	n.a		<3	<5.5	<0.12	<0.12

Source: IPCC (2007c).

NB: GDP at market prices. Negative figures indicate increased GDP. Estimates assume functioning markets and cost-effective policies. Benefits from reduction measures and disparities between rich and poor countries are not included.

Stern (2007) estimates that the economic cost will be 1 per cent of GDP. This is an average figure with an uncertainty range of +/-3 per cent. A stabilisation level of 500–550 ppmv CO_2e is achievable for this cost. If the level were to be set at 450–500 ppmv CO_2e, which increases the likelihood of meeting the two-degree target (though not sufficiently in the Council's view, see Chapter 4), the cost would be three times as high (Stern, 2007, p. 276). The Stern Review considers that the cost of reduction is significant but manageable.

It should be emphasised that cost estimates in the Stern Review and IPCC reports assume cost-effective policies and functioning markets. In a real world, total costs may be considerably higher. On the other hand, the estimates are in most cases based on a relatively static view of reduction costs. The possibility of lower costs stemming from new technologies cannot be excluded, at least in the long term (see Chapter 8.3).

The European Commission (2007c) provides an estimate of the economic costs in the impact assessment accompanying its climate policy communication of January 2007. The estimates are based on the two-degree target, with a gradual stabilisation of atmospheric GHG concentrations at 450 ppmv CO_2e. The global GDP for 2030 would be 4.6 per cent lower than the base alternative, equivalent to a drop of 0.19 percentage points in annual GDP growth for the period 2005–2030. The corresponding figures for EU27 would be 5.8 per cent and 0.24 percentage points respectively. The overriding conclusion drawn by the Commission is that GHG emission reduction is fully compatible with sound economic growth. GDP losses resulting from the cost of emission reduction would be marginal. This applies to industrialised as well as developing countries. Annual growth in China and India would fall by 0.06 and 0.1 percentage points respectively.

A study commissioned by the Nordic Council of Ministers (2007) has assessed the feasibility and cost for the Nordic region as a whole of reducing GHG emissions to 60–80 per cent of 1990 levels by 2050. It concluded that a reduction to just under 60 per cent at a cost of 0.5–1 percent of GDP was feasible. The findings were based on analyses of part of the emissions, mainly in the energy and transport sectors.

These studies indicate that the cost of reducing emissions to long-term sustainable levels is manageable and would not be a shock to the global economy. What is important, however, is the level of ambition chosen, the fact that cost-effective solutions *are* chosen and that emission reductions are implemented gradually. It should also be noted that costs are unevenly distributed among industries and regions.

7.2.2 At national level (Sweden)

A number of studies have been made of the economic cost of Swedish climate policy. The National Institute of Economic Research has carried out studies for the FlexMex commission (SOU 2005:10) and Climate Strategy CheckPoints for 2004 and 2008, based on its environmental medium-term economic model for the Swedish economy (EMEC). Such a model has the advantage of being able to give an overall picture of the Swedish economy and identify repercussions on different sectors and economic variables. Other studies of note are Carlén (2004), Bohm

(2004) and Hill & Kriström (2005). These have mainly focused on comparing the socio-economic consequences of alternative types of objectives and policy instruments for Swedish climate policy. However, they are not directly comparable with the type, compiled by the IPCC, referred to above. One reason for this could be difficulty in establishing a reference alternative to compare with, particularly with regard to establishing what tax systems and policy instruments would be like in the absence of a climate policy.

In 2003, the National Institute of Economic Research compared three climate policy alternatives designed to achieve a 4 per cent mean emission reduction on 1990 levels for the period 2008–2012. The first alternative posited a target for emissions in Sweden which did not take international trade into account. The second involved participation in the EU ETS and the deduction of net imports of emission rights in the ETS sector from the emission reduction target (an emission target with deductible emission allowances). The third entailed participation in the EU ETS *along with* the requirement to meet the national target irrespective of emission rights purchased. The second and third alternatives differ from the first with regard to participation in the ETS sector. In all three cases, the existing emission tax scheme would be replaced by a national trading scheme for emission sources not covered by the EU ETS.

According to the study, the most cost-effective alternative (emission target with deductible emission allowances + international emission trading) would entail an annual GDP loss of 0.1 per cent. The corresponding figure for the least cost-effective option (emissions in Sweden only, no international emission trading) would be 0.3 per cent. In the second case, according to the study, it is how the target is formulated (with or without deductible emission allowances) that has the largest bearing on costs; unless emissions are deductible, profits from emission trading will be low. In the third case, profits from emission trading are determined by the market price of emission rights. Modelling outcomes in a study for the FlexMex commission (National Institute of Economic Research, 2005) show that there are socio-economic gains to be made from an emission target with deductible emission allowances and wider participation in the EU ETS.

The National Institute of Economic Research (2007) was commissioned by the Swedish Environmental Protection Agency and the Swedish Energy Agency to undertake modelling as a basis for Climate Strategy CheckPoints for 2008. Several alternative climate policy scenarios were compared with three target levels for the period up to 2020: an emission reduction on 1990 levels of 10 per cent, 25 per cent and 40 per cent respectively. An emission target with deductible emission allowances is assumed (the trading sector's allocated emissions are deducted from the emission target). The results showed that the way policies are framed is important. The size of the allocation to the trading sector (EU ETS) is of particular significance. If the allocation is large, the sector not covered by EU ETS will have to bear a large share of the reduction burden and many costly measures will need to be taken there. Another cost-escalation factor according to the study is continued liability by the trading sector for carbon dioxide tax. The most cost-effective alternative is restrictive allocation to the trading sector and no carbon dioxide tax liability for that sector.

Table 7.2 provides a comparison of the effect on GDP of the cheapest and costliest policy alternatives, according to the study. GDP is compared with a reference alternative (unchanged policy instrument). The table shows that the effect on GDP may be small, even at the minus 40 per cent target level, but if cost effective policy alternatives are not chosen GDP will decrease significantly.

Table 7.2 Effect of reduction targets in the period up to 2020 on annual GDP in Sweden

Reduction target 2020	GDP, % per year with:	
	Cheapest policy	Costliest policy
Minus 10 %	+0.01	0.00
Minus 25 %	-0.01	-0.31
Minus 40 %	-0.07	-0.71

Source: National Institute of Economic Research (2007).

NB: Reductions for 2020 on 1990 levels.

In his study, building on a report by the National Institute of Economic Research (2003), Carlén (2004) attempted to estimate the cost to Sweden of choosing a more ambitious target than the international commitment (-4 per cent instead of a +4 per cent change in mean GHG emissions averaged over the period 2008–2012 compared with 1990 levels). His conclusion was that the total cost of achieving the current target (-4) will be SEK 5–9 billion per year for the period 2008–2012 (SEK 25–45 billion for the whole period) compared with a reference alternative with no climate policy. If Sweden were to content itself with meeting the +4 per cent Kyoto commitment, the cost would be SEK 1.2–2.3 billion per year (0.05–0.1 per cent in GDP terms), or SEK 6–11.5 billion for the whole period, i.e. 25 per cent of the cost of meeting the present target (-4 per cent).

Hill & Kriström (2005) analysed the socio-economic cost of various climate policy target alternatives (domestic target or climate target) and of the EU ETS. They concluded that because of the price of emission rights it would be economically advantageous to change over to an emission target with deductible emission allowances. They also noted that a target with deductible emission allowances would not necessarily result in higher emissions in Sweden; emissions could actually be lower, depending on the price of emission rights. Further analyses of the effect on different industries showed that emission trading benefits electricity producers, but not iron, steel and metal product industries or petroleum refineries.

7.2.3 Cost factors

While it is of course difficult if not impossible to estimate the cost of emission reduction exactly, the estimates available hopefully provide a rough guide. Estimates of costs and of changes in growth rates clearly show that an ambitious climate policy is compatible with sound global economic growth. It is also compatible with the continued development of the world's poor countries and rapidly growing developing economies. However, it should be noted that with the more ambitious concentration targets recommended by the Council (long-term stabilisation of the concentration of atmospheric GHGs at levels approaching 400-450 ppmv CO_2e) the higher end of the range of reduction costs should be applied.

The global costs of climate policy presented assume

- that cost-effective policy instruments are chosen
- that the emission reduction path is not too steep at the initial stage
- that new, cost-effective technology is/will become available.

If these conditions are not met, the cost will presumably be higher than estimated.

In addition, the following factors are important in the context of Sweden's national climate policy:

- level of ambition of the national target
- what is included in the target, e.g. does it make provision for international emission trading?

An effective climate policy will have a number of positive spin-offs, which are not included in most calculations. Perhaps the most important of these are beneficial impacts in other environmental areas. For example, it will have a favourable effect on air quality at local and regional level. Other benefits include a more secure energy supply, greater energy efficiency and the emergence of new environmental or energy technology enterprises and industries. If such effects are taken into account, this will of course have a favourable impact on the cost scenario.

A further potentially important aspect is that emission reduction measures can be profitable in individual cases or activities. This applies particularly to energy efficiency enhancement, an area offering major potential, which for various reasons – including lack of information – has not been realised. However, it should be pointed out that while reduction measures are profitable in certain individual instances, this is hardly the case here.

7.3 The cost if global warming is allowed to continue

7.3.1 Intergovernmental Panel on Climate Change (IPCC)

The IPCC[83] has provided estimates of the cost of damage resulting from increases in global mean temperature. Their findings are based on a large number of studies. Cost elements include fall-offs in agricultural production and other climate-dependent industries, damage from flooding and storms, and impacts on infrastructure, biodiversity, health and water supply (see Chapter 3). These costs can be regarded as climate policy benefits; they represent the value of damage avoided due to successful policies.

It should first be emphasised that estimates of this kind are also subject to significant uncertainties. Although we now have a better understanding of the effects of global warming, question marks about when, where and how these effects arise still remain.

[83] IPCC (2007b). A calculation of the cost to Sweden of damage and harmful impacts is included in the Climate and Vulnerability Inquiry report.

Moreover, is it difficult or impossible in some cases to place a monetary value on the impacts on ecosystems and societies.

In its latest report, the IPCC estimates that mean global losses may amount to 1–5 per cent of GDP given a warming of 4°C on 1990 levels. Developing countries are expected to suffer even greater losses. This figure, taken from the IPCC's Third Assessment Report of 2001, is based on three studies, including one by Nordhaus & Boyer (2000). The figures are discounted values of harmful impacts along certain development paths. The discounted damage-related costs are GDP-related. According to Nordhaus & Boyer (2000), costs will increase significantly with higher temperature rises. Disaster-related costs carry significantly greater weight in their study than other types of cost. The IPCC points out that aggregate estimates of damage costs very probably underestimate damage, as non-quantifiable effects are not included in the calculations.

The report assesses the economic costs of climate change using a method that has attracted increasing interest in recent years, namely the social cost of carbon (SCC), i.e. the economic costs to society of carbon.[84]This is an estimate of the economic value of the harmful impacts caused by every additional ton of carbon in the atmosphere (which can also be interpreted as the revenues or benefits to be accrued from an emission reduction equal to one ton of carbon). The SCC-based calculations (like the estimates above) are beset by methodological problems. In theory, SCC is a useful instrument. Provided estimates include all relevant cost items, and assuming properly functioning markets, emission reductions should continue until the cost of the last eliminated unit of emission is equal to the SCC. According to the theory, a tax should be set at a value equal to the SCC. In practice, however, this would only be possible if the above conditions and assumptions were met.

The IPCC refers to a large number of SCC estimates with a wide range of outcomes. Peer-reviewed estimates have a mean value of SEK 84 per ton of CO_2 with a broad spread around the mean. Stern puts the SCC at SEK 600 per ton of CO_2. These figures can be related to the Swedish carbon dioxide tax, whose normal rate is SEK 930 per ton of CO_2, i.e. considerably higher than the estimated mean global SCC.

[84] ibid.

7.3.2 The Stern Review

The Stern Review[85] presents estimates of the socio-economic cost of climate change. According to these estimates, which have attracted considerable attention, a temperature rise of 5–6 degrees Celsius above pre-industrial levels would in 2200 result in an annual consumption loss of the order of 5–20 per cent of GDP in a business as usual (BAU) scenario. Stern compares the impact on the economy with the 1930s depression and the two world wars. (It may be added, as a comment on this comparison, that the impact of climate changes, though similar in magnitude, would be far longer lasting). Stern's findings point to considerably higher costs than predicted in previous analyses, such as those included in the 3rd IPCC report of 2001 and in Nordhaus & Boyer (2000).

There are two main reasons why Stern's figures are so high. One is that more effects are included in the calculation, i.e. Stern uses a wider system boundary than many other observers. The other is that he applies a low discount rate (1.4 per cent).

With regard to types of effects, previous studies have often been limited to gradual changes and market effects, i.e. effects to which a market price can be attached, e.g. production losses in agriculture, the industry expected to suffer most in this respect. Stern goes further, taking into account non-market price effects on the environment and health, as well as the effects of shocks and disasters. Stern maintains there is genuine uncertainty about the consequences of climate change; we cannot rule out catastrophic events which could lead to the breakdown of social and economic systems. He also takes the view that the possibility of dramatic threshold effects, such as strong methane effluxes, reduced ability of oceans to sequester CO_2, etc. should be taken into account.

The estimates in his report indicate a drop in consumption of 5–7 per cent (the higher figure corresponds to a scenario with higher climate sensitivity) if market-price effects and disaster risks are included, and 11–14 per cent if non-market price effects are added. When more weighting is given to the impacts on developing countries,[86] and a number of possible self-reinforcing negative effects in the climate system are taken into account, a maximum figure of 20 per cent is obtained for per capita consumption loss in 2200. Stern nevertheless considers these estimates to be on the

[85] Stern (2007, esp. Chaps 2 and 6).

[86] A correction of the socio-economic costs which takes into account the fact that developing countries have smaller economies and damage costs are therefore undervalued.

conservative side and that even worse outcomes are possible. An important aspect of Stern's analysis is the fact that allowance is made for uncertainty and risk, i.e. the possibility of being overtaken by unexpected events.

The Council agrees with Stern's contention that low-probability catastrophic events should be counted among the potential effects of climate change. One example is methane emission from melting permafrost tundra. Low-probability, large impact risks of this kind feature prominently in the nuclear energy debate. They are the type of risk which, on a smaller scale closer to everyday life, we insure ourselves against. Fire is one example.

As previously mentioned, one of the foremost causes of the major disparities in the findings is related to *discounting*. In economics, discounting is a widely accepted procedure for comparing present and future economic quantities. A discount rate is used to adjust the value of future flows. As climate changes take place over long periods of time – hundreds, or even thousands, of years – discounting principles are of considerable importance. For example, SEK 1 million discounted at a rate of 3 per cent will be worth SEK 52,000 in a hundred years, but only SEK 3,000 at a discount rate of 6 per cent. Stern's discounting method has been the subject of some debate.

The choice of discount rate is not a given. In principle, it is determined by three factors: (1) a time reference – the fact that one would rather have a sum of money now than later, (2) a factor expressing that further increases in income will be worth increasingly less, and (3) a factor expressing growth in the economy.[87]

Stern considers that traditional discounting methods are relevant for comparisons between marginally different alternatives. In his view, however, such alternatives cannot be considered in the context of climate changes, which involve fundamental transformations. As regards cost sharing between present and coming generations, Stern maintains that ethical considerations must come into play. He contends that if future generations were represented in the climate policy debate they would demand the same rights claimed by this generation. Accordingly, he assigns a low value (0.1 per cent) to the purely time preference.

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[87] This is expressed mathematically by Ramsey's equation: $r = \delta + \gamma g$, where r denotes the interest rate, δ the purely time preference, γ the elasticity of the marginal benefit of changes in consumption, and g the rise (in percentage terms) in GDP (income).

The Council considers that discounting can to some extent be seen as an ethical issue where long time perspectives are involved. A high value for the time preference gives future generations little weight. Other discount rate-related elements – income and the depreciation value of increases in income – do not have an ethical dimension. Climate change affects the lives and health of many people, especially if the far from negligible likelihood of catastrophic events and impact is taken into account. These are aspects which, in the Council's view, are not always fairly reflected through discounting.

7.4 Council conclusions

The Council considers

- that assessments of the costs of damage caused by climate change are uncertain, to some extent ethically controversial, and strongly dependent on what kind of damage is included, what value is attached to it, and how the future is viewed in terms of value (discounting)
- that there are significant uncertainties in estimates of costs associated with GHG emission reduction
- that cost-benefit estimates and similar climate policy assessments should therefore be interpreted with caution, but that they can still provide valuable information about approximate quantities and economic implications
- that the global and national costs of reducing emissions to levels compatible with the two-degree target are significant but compatible with sound macroeconomic development
- that the cost of reducing emissions decreases if cost-effective policy instruments are chosen
- that the cost of reducing emissions decreases if other benefits deriving from greater energy efficiency and renewable energy use are taken into account, such as cleaner air and higher security of energy supply.

8 Climate policy instruments

8.1 Introduction

Chapter 6 discussed various ways of reducing GHG emissions. The question is what society can do to ensure that the desired measures are introduced. Various policy instruments are available and these may be divided into three main groups: *Regulatory measures* via laws and other regulations, *economic incentives* in the form of taxes and subsidies, and *informative instruments* in the form of knowledge transfers etc. Policy instruments can also be divided into general ones and sector-specific ones. Climate policy is further influenced by policy instruments in other policy areas. Overall, a crucial factor is to the extent to which central government and other public actors, the market and civil society become actively involved in climate policy. Their roles may vary in size and scope.

The climate issue is a long-term one, with complex processes that are characterised by a considerable degree of uncertainty. It is also a broad issue affecting a range of different sectors and must be tackled at different levels, from the global to the local. Today, there is a high level of commitment to the climate issue among citizens, enterprises and NGOs. Many municipalities are working actively with the issue. Voluntary efforts play an important role. These should not be viewed simply as a supplement to government policy but as a driving force in themselves. They make such policies possible both by developing new solutions and by helping to raise awareness among citizens and in the business community. In addition, climate work involves cross-sectoral efforts and cooperation between private and public actors. The importance of a cross-sectoral approach is emphasised in the latest IPCC assessment report. This stresses that there is much to be gained from seeking synergies and common initiatives across sectoral boundaries. Information and knowledge transfer may have a favourable effect in themselves, but their chief function is to provide support for other climate measures. They are a means of creating a more climate-friendly society.

We noted at the beginning of Chapter 7 that climate policy needs to be viewed in a wider perspective. Defining the system boundaries is an important aspect. One example in point is that China's ambitious goals for improving energy efficiency could have a highly favourable effect on the climate.

Climate policy thus embraces a wide range of issues. The Council is not in a position to deal with them compehensively and in detail and has chosen to focus primarily on two main elements in pursuit of an effective policy for reducing GHG emissions:

1. Setting a *price* on GHG emissions.
2. Promoting *technological advance* (over and above the effects deriving from price-setting).

Some further comments may initially be required here.

Firstly, the climate problem is *global* in nature. In principle, it makes no difference where the emissions take place – they spread uniformly through the atmosphere whatever the location of the source. A single country cannot control climate impact on its own. This fact suggests that as many countries as possible must take action. At the same time, it raises the question of what contribution a small country should be making to other countries which have begun reducing their emissions.

Secondly, measures and instruments must be *powerful.* As the previous chapters have shown, the task is a very challenging one. In the long term, the emission of greenhouse gases will have to be virtually eliminated. This will necessitate a major adjustment of the global economy. The challenge is to be met at a time when both production volumes and energy needs are growing.

Thirdly, *cost efficiency* – the greatest possible improvement in the environment at a given price – is also a desirable goal. To gain acceptance for climate policy moves, however, there may be reason to weigh them against other principles in certain situations.

Fourthly, *a long-term perspective and transparency* are required in order to send the right signals to economic actors (consumers and producers). Over the next few decades, climate impact will be determined to a great extent by the investment decisions taken today. When taking such decisions, economic actors must be aware that the long-term imperative is low emission levels.

8.2 Setting a price on emissions: Economic instruments

Economic incentives represent important and powerful instruments in current Swedish climate policy. The CO_2 tax and the EU emission trading scheme are potentially the two most important instruments developed specifically for climate policy, but there are also other economic instruments of vital importance in this respect (energy taxes, including fuel taxes, feed-in tariffs, electricity certificates and the like).

The climate problem represents a market failure in the sense that market prices have not reflected the actual price of using the atmosphere for GHG emissions. Nor can we expect a fair price to develop of its own accord; it needs to be established through political intervention, e.g. via a tax on carbon dioxide. To a great extent, the approach outlined below is also appropriate in the case of emission trading.

The CO_2 tax has a number of valuable features. First, if it is properly designed, it is cost-effective. A well-designed tax leads to a cost-effective distribution of the emission cuts in question. A tax per unit of CO_2emission (in Sweden, the current standard rate is SEK 0.93 per kg CO_2) forces each source of emission to choose between releasing carbon dioxide into the atmosphere and paying the tax, or reducing the emission and thus reducing its tax payment. If it is cheaper to reduce emissions than to pay tax on them, the source reduces them (given that it is adequately informed about this possibility and no other constraints are present). Thus it is profitable to reduce emissions as long as the reduction cost is lower than the tax. Ultimately, all sources of emission will have the same marginal cost (= the tax) for emission reduction, which promotes cost efficiency.

Another good thing about a CO_2tax is that policymakers do not need to be fully informed about technologies, production processes and other aspects that determine the costs of emission reduction. Costs and opportunities tend to vary considerably between consumers and enterprises, and it is difficult or impossible to acquire a detailed understanding of them all; in practice, there are numerous – probably thousands – of potential measures with a variety of costs. A tax leaves it up to the enterprise or household to decide what action to take. This is a considerable advantage when compared with a system involving a quantitative emission limit (which can either be set uniformly for all facilities in the form of a threshold value or individually via a licensing procedure). In such a system, there is no guarantee that reduction measures will be taken where costs are lowest.

A third useful feature is that a tax yields, at least in the short term, revenue that can be used for such things as correcting the undesirable effects a tax can lead to. It is well known, for instance, that the CO_2 tax has a regressive distribution effect, i.e. that households with low incomes tend to be burdened with a relatively large share of the tax. Revenue from the tax could thus be used to compensate for such an effect.

A CO_2 tax allows you to revise the price for GHG emissions upwards so that it better reflects the socioeconomic cost of releasing such gases into the atmosphere. This higher price leads to changes in behaviour and efficiency gains in all sectors (although to varying extents, depending on reduction costs) liable to the tax.

Table 8.1 Global economic potential for emission reductions, 2030

Price USD per CO_2e	Economic potential $GtCO_2e/yr$	Reduction relative to SRES A1 B (68 tCO_2e/yr) (%)	Reduction Relative to SRES B2 (49 tCO_2e/yr) (%)
20	9–18	13–27	18–37
50	14–23	21–34	29–47
100	17–27	25–38	35–53

Source: IPCC, 2007c.

NB: SRES refers to the IPCC climate scenarios. Scenario A1 B implies rapid economic growth up to about 2050, rapid technological advance, and a balance between energy supply sources. Scenario B2 implies less rapid economic growth, moderate growth in population and less rapid technological advance. (See also Appendix 2.5).

According to the IPCC (Table 8.1, see also Section 6.2.1), a global rise in the price of GHG emissions would cause them to decline very significantly. A price rise can be achieved by means of a global tax or a global emission market. A global price of USD 20 (SEK 140, or 1/7 of the normal Swedish CO_2 tax) per ton CO_2e would result in a reduction of 9–18 Gtons of CO_2e. The table shows that with higher prices, still greater reductions can be achieved. In other words, the IPCC report shows that from a Swedish viewpoint, a relatively low price can have a very substantial global effect.

Thus a fundamental problem in the climate policy field is that for the bulk of the world economy, releasing greenhouse gases into the atmosphere costs too little. Only the EU countries and a few other countries have either introduced a specific tax on greenhouse gases or introduced an emission trading scheme.[88] In other words, the incentives for making energy more efficient and changing behaviour in order to reduce emissions are weak in most countries of the world. This is without doubt the most important reason why global GHG emissions are continuing to grow today in accordance with a reference scenario featuring high emission levels.

A global and by Swedish standards relatively low CO_2 tax would thus be a powerful climate policy instrument impacting across the board. Such a tax would, at a stroke, create the incentives for changes in behaviour, resulting in major improvements in energy efficiency and large-scale reductions in emissions. In many countries and regions, this would also have positive side-effects, not least in the form of better air quality. Also, this alternative would require less international coordination and less joint administration than the economically comparable method of emission trading. Nordhaus (2007) has argued in favour of a global tax rather than a global trading scheme. His reasoning is largely in line with the arguments put forward above.

The discussion concerning marginal costs also leads to the conclusion that emission reduction targets should apply as widely as possible – preferably globally and to all sectors of the economy and for all greenhouse gases. Since the costs of emission reduction can vary considerably between enterprises, industries and sectors, requiring the same reduction level of all parties is not cost-effective, whether sectors, regions or nations. If for instance all sectors were to be required to reduce their emissions by 10 per cent – which might be seen as a 'fair' policy approach – this would mean disregarding the fact that costs differ between sectors. A number of unnecessarily expensive measures would be taken. The same reasoning could be applied to nations. It should not be taken for granted that the burden of reducing emissions by a set global amount should be shared equally by all nations, as cleaning costs

[88]Other energy taxes that are not specifically designed to impact on the climate also have a restraining effect on GHG emissions. Most of these are justified primarily on fiscal grounds, i.e. their aim is to bring in tax revenue, not to make an environmental impact.

differ. It is cost-effective if emissions are reduced in countries where costs are low. This has a better impact on the environment at a given cost.

One implication of this is that a CO_2 tax should be uniform for all sectors and should preferably encompass the entire economy. In practice, however, it has proved difficult to maintain a uniform tax rate due to the fact that the tax affects competitive conditions. For sectors exposed to international competition, where production may be located in a number of different countries and where energy costs are an important factor, as is the case for Swedish basic industry, for instance, there is reason to set a lower tax level. Environmental aspects also need to be taken into consideration, as a given activity may be undertaken in countries with less strict environmental requirements, in which case a tax would have a negative environmental impact. Competitive and environmental aspects thus have to be weighed against the distorting effect (welfare loss) and reduced emission impact in the home country resulting from a differentiated tax. This justifies maintaining a degree of differentiation in Sweden's CO_2 tax.

The difficulty of maintaining a uniform tax rate is one of the disadvantages of an environment tax. Another is that goal achievement can be problematic in cases where this presupposes very high tax rates that are deemed unacceptable for political or other reasons.

In a world where CO_2 taxation varies considerably between countries, those with a high tax rate will suffer in international competition. This gives rise to an interesting question that is likely to grow in importance as the demands for emission reductions increase: would an excessively low rate of CO_2 tax be regarded as unlawful government support in the international trading arena? This prompts the question of whether a CO_2 tax on imports of energy-intensive goods (e.g. steel, aluminium, cement) might be introduced. Overall, this is a technically, economically and politically complicated issue that the Council has not been in a position to address.

The Council notes further that fossil fuels are still being extensively subsidised, either directly or indirectly. This is not compatible with sound climate policy. One exception could be the subsidising of LPG for cooking in poor countries, as this could reduce both deforestation and GHG emissions.

8.3 Promoting technological advance

There is broad support in the IPCC for the view that technology is of great importance to the climate issue. Technology is widely discussed in the IPCC's fourth assessment report. Technological advance is described as a complicated process that cannot be summed up in a simple way that is acceptable to all. It is a process with many steps, components and links to various sectors of society. Technological advance encompasses research and development (R&D), where new knowledge evolves through contributions by universities, entrepreneurs, central government and other actors; learning, where new knowledge is discussed and used; and knowledge transfers between individuals, enterprises, industries and countries. All three sources are crucial to technological advance in society.

One methodological advance which has been made since the IPCC's Third Assessment Report, in 2001, is that model analyses have now been carried out dealing with technology as an endogenous variable. This means that instead of viewing technology as something given, you let it vary and be determined by the value of other variables in the model. As investment in the various technologies increases, the cost of using them declines (learning-by-doing). The outcomes of such analyses point to greater benefits from technological input and from the practice of introducing reduction measures at an early stage. They also point to a significant positive impact on costs, and in some cases net earnings.[89] The model estimates show that prices of SEK 140–560 per CO_2e in 2030, and of SEK 210–1100 up to 2050, would be consistent with a stabilisation level of approximately 550 ppmv CO_2e in the atmosphere in 2100. According to model estimates that take into account technological change, it would suffice if prices were slightly lower: SEK 35–450 per ton CO_2e in 2030 and SEK 100–900 kronor per ton CO_2e up to 2050. These figures are based on assumptions such as the pursuit of cost-effective policies.

The IPCC considers that in the long term, and in order to bring about technological shifts, major investments in technological advance will be required. Taxes and trading schemes are highly important instruments for promoting technological advance and technology dissemination. They have a dynamic, long-term impact, and they also encourage enterprises to develop new technology and

[89] IPCC (2007c).

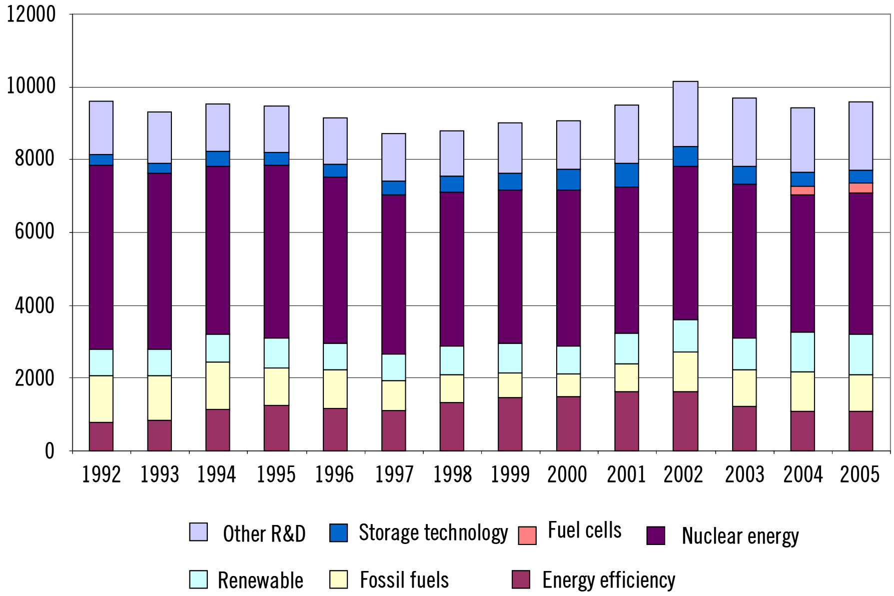
to use it in reducing emissions. Nevertheless, the market cannot be expected to generate a sufficient level of technological change without the presence of other policy instruments besides taxes and trading schemes. There are two well-established reasons for this:

1. *Price signals* do not currently reflect the full cost of environmental damage caused by GHG emissions. As prices at global level are too low, the incentives for developing technology are too low as well. Also, a trading scheme offers uncertain incentives since those who invest in R&D cannot be sure what future prices will be. A CO_2 tax is associated with political uncertainties that have the same effect.

2. It may be difficult for an enterprise developing new technology to *profit sufficiently* to cover costs. This is a classic problem in R&D that has to do with limited opportunities for protecting knowledge by means of patents or other methods.

In light of the above, one might expect publicly financed research in such a key climate policy field as energy research – particularly research into renewable energy – to be on the rise. This, however, is not the case (Figure 8.2).

Figure 8.1 Publicly financed energy research in the IEA countries, 1992-2005



Source: Based on data from the IEA (2006).

The IPCC makes no specific recommendations as to how policies on technology should be pursued. The Council for its part wishes to offer some comments. Besides greater public financing of R&D, public support may be needed to help new technology out into the market. Central government may need to create markets so that technologies can evolve from the laboratory stage to commercialisation. What is needed is a self-reinforcing process driven by dynamic learning and economies of scale, where cost reductions generate market growth, which in turn results in investments and learning that lead to further cost reductions. This can be achieved by means of various policy instruments, including regulated feed-in tariffs, investment subsidies, green certificates, standards and public procurement (e.g. of greens cars or ethanol-fuelled buses). In practice, however, careful consideration is needed to ensure the development of projects and programmes that genuinely offer the right incentives and generate new technology capable of surviving without public subsidy.

Wind power and solar cells are two examples of what such policies can achieve. In the case of the former, a number of countries, including Germany, Denmark and Spain, created incentives that led to a tripling of installed wind power capacity in 1998–2002, i.e. a growth rate of over 30 per cent per year. In the case of solar cells, programmes in Japan and Germany resulted in a 25 per cent annual increase in installed global capacity between 1980 and 2002.

There is much to say about the way measures are designed. One observation concerns funding for more sophisticated new technologies as opposed to more straightforward new technologies. More advanced technologies which have yet to become commercially viable when the funding is distributed may not get a proper chance. If, for instance, biofuel funding were to be provided to the commercially most competitive alternative today in a technologically neutral manner, it would go to ethanol manufactured from maize, wheat or sugar beet. Ethanol made from cellulose or wood gasification, which are generally considered more promising techniques, would suffer in consequence. Choosing the right point in time is important, and there is a risk of becoming locked into a particular line of development if too much investment is directed at a certain type of technology.

8.4 Climate policy at various levels

8.4.1 Global

Climate change is a genuinely global issue. No single country can solve the problem alone. Action on a global scale is required. The Council wishes to stress most strongly that international cooperation is absolutely essential in confronting the climate threat.

Experience to date has shown that it is difficult to put the necessary measures in place, and the current rate of global emissions roughly corresponds to a reference scenario featuring high emission levels.[90]

The much-discussed problem of how individual actors behaving rationally on the basis of self-interest nevertheless contribute to an outcome that is to the public detriment is an apt one in relation to the global climate issue. Ostrom (1990) has identified a number of

[90]Zhang et al (2007).

principles that interact to make the resource dilemma manageable in local communities. One such principle is that those who have access to the resource in question must be clearly defined. Other principles are that rules for utilisation of the resource are modifiable, that the state of the resource can be monitored, and that both escalating sanctions for over-use of the resources and mechanisms for conflict resolution are in place. Given these principles, standards for resource utilisation can be formulated. The question is whether these principles also apply in the case of large-scale resource dilemmas such as the climate. There are clear problems of definition in this respect, and monitoring, sanctions and standards are difficult to establish, which in turn may mean that they do not enjoy the requisite trust.

The Kyoto Protocol under the UN climate convention is one step on the road to a global solution and also represents the most immediate basis for further international cooperation. But the Kyoto Protocol has weaknesses that the Council would like to draw attention to:

- Participation is far too limited. The US and Australia have signed the protocol but have yet to ratify it. Among the twelve largest emission countries in terms of total volume, China, India and Brazil, too, all lack a ceiling for their emissions. Those countries with a ceiling in place account for no more than a third of global emissions. A future agreement must be much broader-based and encompass not only the US but also many developing countries.
- Withdrawal is far too easy. The sanction rules are far too lenient.
- There is uncertainty as to which rules will eventually apply.
- Sufficient incentives for technological advance are lacking.

Mechanisms of the Kyoto Protocol

Article 3.3 of the UN climate convention states that policies and measures for dealing with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. Under the convention and the Kyoto Protocol, opportunities are available for emission trading between nations, and joint projects both between industrialised countries and between industrialised and developing countries can be undertaken via the project-based mechanisms

CDM *(Clean Development Mechanism)* and JI (*Joint Implementation*).

Emission trading means that countries with quota commitments (Annex I countries) can exchange quotas *(Assigned Amount Units, AAU)*, which in turn means that countries not requiring their full quota can sell them to countries wishing to supplement national measures in order to meet their commitments. This form of trading can be expected to generate larger volumes towards the end of the first Kyoto period.

The CDM was established as a way both of encouraging developing countries (without quantitative commitments) to reduce their emissions and of encouraging cooperation between developing and industrialised countries, and also to promote technology transfer. The rules state that a CDM project must lead to a further reduction in emissions. An administrative procedure both verifies that a project meets the requirements and specifies the size of the reduction. The stock of CDM projects has grown rapidly. In August 2007, some 760 projects had been registered and together these were expected to have a reduction potential of over 1 million tons of CO_2e for the period 2008-2012. The administrative procedure is quite substantial and there is a considerable degree of uncertainty associated with it. The CDM may have a valuable role to play, but viewed in relation to the very extensive need for emission reductions and for investments in the energy sector in developing countries, it cannot be expected to have any great impact in quantitative terms. An important point, however, is that the CDM has given the developing countries an interest in the Kyoto Protocol.[91]

Joint Implementation has not been in use very long and experience of it is therefore less widespread. Under JI, Annex I countries can undertake joint projects for reducing emissions in any given Annex I country. The expectation was that primarily emission-reducing projects in transition economies would develop as a result.

The Council considers that once the Kyoto Protocol's project mechanisms become more widely accessible, the prospects for improving cost efficiency in climate policy will improve.

[91]Statistics about the CDM are available at www.cdm.unfccc.int. Experience of the CDM is discussed in Lecocq & Ambrosi (2007) and Stern (2007).

Other issues

There are many issues of a global character in the climate field. One concerns development assistance. This should continue to focus on poverty alleviation but greater weight should be attached to climate issues, in particular to cooking and fuel gathering, which are generating significant emissions in developing countries.

8.4.2 EU

The EU level has a special role to play in both international and Swedish climate policy. This is because

- Swedish climate policy and EU climate policy are partially integrated since policy instruments include legislation adopted at EU level (e.g. provisions concerning the EU ETS, car exhaust emission requirements, energy tax),
- The EU has a mandate to act in the global arena. Besides being a party to the UN climate convention and the Kyoto Protocol, the EU engages in bilateral summit meetings with the US, Russia, China, India and other important countries where the climate issue is discussed.

Hitherto, the EU has played a highly important and positive role in the climate policy arena. It actively helped to save the Kyoto Protocol, and it established the emission trading scheme EU ETS as one of the most wide-ranging international policy instruments seen in the environmental field to date. The EU is also in the process of developing an energy and climate policy that includes both Community legislation and the coordination of national policies. Through decisions taken at the meeting of the European Council in March 2007, the EU has established ambitious targets for its energy and climate policy work. European objectives, laws and regulations concerning efficient energy utilisation, renewable energy and biofuels have an important impact at national level.

The drawbacks as regards decisions at EU level are that ambition, policy focus and speed of operation are sometimes less than optimal, viewed from the individual member state's perspective.

The EU ETS

The EU's emission trading scheme (ETS), launched in 2005, is a means by which the EU can fulfil its obligations under the Kyoto Protocol (minus 8 per cent on average in 2008-2012 compared with 1990). To date, this is the only international GHG emission trading scheme in operation. At present, it covers energy production and energy-intensive industry (approximately 11 000 facilities accounting for some 40 per cent of GHG emissions in the EU). The scheme is an important element in the climate policy work of both Sweden and other EU countries. In the Council's view, the EU ETS has both advantages and disadvantages.

As noted previously, a trading scheme may in principle be equated with a CO_2 tax. In the case of a tax, central government owns all the emission rights and sells them at a fixed price (= the tax rate). In a trading scheme, the rights are owned by an enterprise (which has been given them free of charge or has purchased them in an auction). The sum of all the rights represents the total permitted emission volume. Those who have a surplus can sell it to those with a deficit. The market price that will then be established is determined by the total emission ceiling (supply) in relation to reduction costs (demand). Enterprises with high reduction costs choose to purchase rights from enterprises with low costs, which are more inclined to reduce their emissions. Accordingly, a trading scheme means that the prescribed total reduction is achieved at the lowest cost (cost efficiency).

One advantage of trading schemes is that the final outcome is known in advance (emission levels at the end of the year for each respective period, given an efficient control system). The total sum of emission rights represents the desired emission ceiling. In theory, any level could be chosen as a ceiling. In practice, of course, the more ambitious the target the more the socioeconomic costs rise, since it becomes increasingly difficult to find cheap ways of reducing emissions. Where a tax is concerned, on the other hand, the final outcome in terms of reduced emissions cannot be known. In practice, an important factor in the choice between a tax and a trading scheme is the extent to which it is possible to implement policy and what such policies will cost.

The EU ETS is currently going through a trial period that has revealed a number of shortcomings in the scheme.

- The allocation of quotas was excessively generous, which led to a sharp fall in the price of emission rights (to less than 1 euro per ton CO2 in the summer of 2007, down from a peak level of just over 30 euros). For the coming trading period, however, the price at the time of writing (August 2007) is considerably higher (about 20 euros), which suggests that allocation is expected to correspond more closely to actual needs.
- During the trial period, emission rights were largely distributed free of charge. The rules allow for the auctioning of up to 5 per cent of the rights for the period 2005–2007 and up to 10 per cent for the period 2008-2012. Free allocation is worth pondering for economic and political reasons, but it represents a transfer of wealth to polluting enterprises and conflicts with the principle of 'the polluter pays'. Free allocation may be based on historical emissions or benchmarks. A shift to auctioning – preferably based on a harmonised Community approach – should be sought. An important point worth noting is that the choice of allocation method (free or by auction) does not in theory affect emission reduction incentives, as it is the alternative cost that is the key factor in this respect. The alternative cost is the market price on emission rights, and it is not affected by the choice of allocation method. In practice, free allocation based on historical emissions can mistakenly provide an incentive to *increase* emissions, since the ambitious lose out.
- Long-term rules are important for ensuring that technological advance and investment are governed by the right signals. After the first and second periods, the aim should be to establish long-term expectations both of a lower ceiling and as regards key elements in the design of the scheme (such as allocation).

There are theoretical advantages to be gained from broadening the scheme to embrace additional sectors and countries (the same CO_2 price then applies over a wide area). In practice, however, this is not so simple. The terms and conditions that apply to new countries or regions must be properly set. Should new countries be given too generous an allocation, for instance, this could result in an unjustified transfer of wealth and in the wrong incentives being given to polluting enterprises in the new country. Also, if the supply of emission rights were to increase as a result of over-allocation, this could distort price formation. The accession of countries lacking ambition in the climate policy field could cause the scheme to work less efficiently.

Like CO_2 tax, trading schemes are valuable in that they create incentives for technology spread and development. They help spread technology by giving enterprises the incentive to acquire new techniques for reducing GHG emissions, as long as the cost of such techniques matches the price of emission rights. Enterprises supplying emission-reducing equipment are given a long-term incentive to develop new, cost-effective technology. Trading schemes, however, represent an effective way of *spreading* technology rather than *developing* it.

Sweden should be proactive in seeking a strong role for the EU in the climate policy arena. This means for instance improving the EU ETS (the emission ceiling must be lowered and rights must be auctioned).

It is crucial to EU credibility that the Community targets in respect of emission reductions for 2008–2012 be achieved.

As in the case of national climate policy, market-based instruments should play a leading part in the EU's climate policy work. A CO_2 tax can play an important role outside the trading sector. (Besides Sweden, only Finland, Denmark and the Netherlands among EU member states currently have a CO_2 tax in place.) At present, using taxation as a policy instrument is problematic as it requires unanimity.[92] Dropping the unanimity requirement for climate-related taxes is a move worth considering.

8.4.3 National

One of the issues in national climate policy is whether Sweden should do more and take a lead. Such a course could involve setting national targets that are more ambitious than our share of global responsibility (see Chapter 5). Another interpretation might be that we agree to tougher reduction requirements than most other industrial countries. How the term 'take a lead' is interpreted – what it implies – is of considerable importance when deciding whether or not to actually do so.

[92] A certain degree of tax harmonisation in the energy field has been established by the Council Directive restructuring the Community framework for the taxation of energy products and electricity (2003/96/EC of 27.10.2003), which was adopted after several years of negotiation.

In the following, the Council presents some of the arguments for and against taking a lead in national climate policy.

The arguments in favour of such a course are as follows:

- Sweden can credibly adopt the role of trailblazer in international climate work. With an ambitious and effective climate policy of its own, Sweden is better placed to be proactive in international negotiations.
- Sweden can serve as a good example to others. The fact that Sweden, along with a few other countries, has shown by its actions that an ambitious climate policy is compatible with sound economic growth could inspire other countries to follow suit.
- An ambitious climate policy could reflect what the Swedish people demand. Economic theory holds that environment policy goals should take into consideration both the cleaning costs and the will to pay of those affected. (Optimal emission reduction derives from marginal benefit and marginal cost.) The Swedish people may be willing to pay the extra socioeconomic cost that an extra-ambitious climate goal would generate, in which case Sweden should take a lead. Whether this willingness is present, the Council cannot say.
- Another argument is that by beginning to reduce its emissions, Sweden can build up industrial activities that generate employment and export opportunities in the future when other countries begin taking similar steps. This argument is part of what is known as the Porter hypothesis, which says that a stringent environmental policy, properly formulated, generates competitive advantages.[93]

Three reasons can be put forward for not taking a lead:

- Firstly, there are analyses showing that more stringent emission requirements lead to additional socioeconomic costs (see Chapter 7). 7).
- Secondly, Sweden cannot impact on global emission levels to any great extent as Swedish emissions represent such a small share.

[93]After the US economist Michael Porter (see Porter & van der Linde, 1995). The Porter hypothesis, however, is disputed – see Palmer et al (1995).

Extra reduction would make no difference. Even if Swedish emissions were to cease altogether, there would be no impact.

- Thirdly, there is a risk of 'leakage' of environmentally degrading activities. In other words, production with high emissions will be undertaken by countries with a less stringent climate policy. If this proves to be the case, the environmental effect could be neutralised or rendered negative. Such impacts can, however, be countered by designing policy instruments that take into account the risks associated with the relocation of production.

In sum, there are grounds both for taking a lead and for not doing so. It is only fair that Sweden should accept its share of global responsibility for achieving the two-degree target. The question of whether Sweden should adopt a more ambitious national target is a complex one and ultimately involves political considerations

8.5 Council conclusions

The Council considers

- that the climate issue must be solved through international cooperation
- that the policy instruments for reducing GHG emissions should preferably be broad, internationally coordinated, uniform and technologically neutral, but that departures from this principle may sometimes be warranted
- that setting a price on GHG emissions with a view to achieving the climate targets is of fundamental importance
- that the economic instruments of CO_2 tax and emission trading are important and powerful policy instruments if properly designed
- that economic instruments need to be supplemented by other policy instruments such as education, information and legislation
- that Sweden must be proactive in the EU in seeking to improve the EU emission trading scheme. It is important that the emission cap is lowered and auctioning of allowances is applied.
- that new technology is crucial to the task of the climate problem. The imperatives in this respect are research and development and

policies that create markets for the commercialisation of these technologies.

- that Sweden should work actively at international level to abolish subsidies for extraction and use of fossil fuels.

Appendices to Chapter 1

Appendix 1.1 Memorandum, 21 December 2006, with the remit

The Government seeks to align business, research and policy work in the climate field (Background to press release of 06-12-21)

Climate change affects us all and requires us all to act. The current rapid increase in the concentration of greenhouse gases needs to be moderated and stabilised at a level that will not harm people and the environment.

The Government's climate policy goals are highly ambitious. We want Sweden to take a lead in climate work at both national and international level. Our aim is for Sweden to become an example of an environmentally minded modern society based on renewable resources and pursuing growth policies in harmony with the earth's climate conditions.

Sweden has undergone a major shift from oil to biofuels and other renewable energy sources, and has reduced its GHG emissions by over 40 per cent since the 1970s. Between 1990 and 2005, emissions fell by over seven per cent. While this transition was taking place, growth in Sweden since 1990 has increased by 36 per cent.

Further major reductions in emissions are necessary, but given what has already been achieved in this area, further improvements will pose an increasing challenge. It is also clear that most of the answers to the climate problem are not to be found nationally but will necessitate both purposeful, focused policies extending beyond Sweden's boundaries and closer international cooperation.

For the transition to be maintained, various actors in the political, business and scientific fields will need to become actively involved to a far great extent than at present and to pool their resources in confronting the challenges ahead. The Government, therefore, is inviting the whole of Swedish society, every section of the community, to help us bring about the changes that will be required in the years to come.

- Emission reductions must be combined with vigorous development efforts in the business sector focusing on research, innovation, technological advance, the rapid introduction of new technology, and export investments.
- Climate policy goals must build on responsible data from the scientific community and leading experts, not on political auctioneering.
- Action plans and measures need to be based on a broad understanding of the great challenge facing us. The rules under which business and industry operate must be both clearly defined and enduring. The climate policy challenge needs to be discussed in a spirit of broad political understanding.

The Government presented the basic principles in its climate policy work in connection with the parliamentary debate on the subject. It is now launching three initiatives to broaden and deepen cooperation between business, research and policymaking.

- A Swedish Commission for Sustainable Development
- A Swedish Scientific Council on Climate Issues.
- A Parliamentary Committee for the Review of Climate Policy

The aim is to pave the way for a closer analysis of the climate tasks and opportunities ahead, prior to formulating conclusions, objectives and practical measures.

These initiatives will result in the introduction of a climate policy bill, planned for 2008, and will also enable Sweden to play a leading role in international negotiations on the new climate arrangements that will need to be put in place during Sweden's presidency of the EU in 2009.

The Commission for Sustainable Development

The Government is appointing a Commission for Sustainable Development. Sweden's increased ambitions in the climate policy field necessitate deeper and wider cooperation between business, policymaking and research. The work of the Commission will be a decisive factor in the forthcoming transformation of Swedish society.

Based on the principle of sustainable development, the Commission will promote work across sectoral boundaries, adopt an international perspective and take into account ecological, social and economic aspects alike.

Climate change will be the focal point of the Commission's work. The Commission is to prepare specifically for the Swedish presidency of the EU in 2009. Its task will be to examine how organisational arrangements, regulatory frameworks and policy instruments can be updated and made more effective so as to facilitate work on sustainable development and environment-driven growth.

Prime Minister Fredrik Reinfeldt will chair the Commission, and his deputy will be Minister for the Environment Andreas Carlgren. In other respects, the Commission will be broad-based, bringing together representatives of business and industry, independent organisations, the research community, public authorities and the political arena.

As part of the Commission's work, the Government will also be initiating discussions on business development and technological advance etc, from both an international and a national perspective. Various ministers will take part in the work of the Commission, depending on the issue in hand.

The Government will decide the timeframes, work procedures and organisational arrangements in the spring of 2007.

Climate seminar, 7 March

On 7 March 2007, the Commission will begin its work with a seminar organised by the Government in collaboration with the Commission on Climate and Vulnerability. There, the UN Intergovernmental Panel on Climate Change will present its latest findings on the scientific background to the climate problem.

The Swedish Scientific Council on Climate Issues

The Government has appointed a Scientific Council on Climate Issues. The main purpose of the Council is to provide scientific assessments as a basis for the 2008 climate policy bill.

An important task in this respect will be to provide scientific documentation and make recommendations concerning the future commitments of the EU and Sweden. The recommendations of the

Council should primarily focus on the targets that need to be set for Swedish climate policy, at both national and international level.

The Council's task is to

- gather, process and compile interdisciplinary information in the climate field,
- provide a forum for different views and opinions, and discuss goal conflicts,
- describe international work in the climate field, and
- provide up-to-date and balanced documentation as a basis for Swedish climate policy decisions.

Work can begin without delay, since the present Environmental Advisory Council is to be transformed into the Scientific Council on Climate Issues.

The Scientific Council is to be chaired by Professor Lisa Sennerby Forsse, Vice-Chancellor of the Swedish University of Agricultural Sciences. Other members with specific skills relating to the climate issue have also been appointed (see Appendix).

The aim is for the Council to recommend new climate policy objectives in the summer of 2007.

The Climate Committee for the Review of Climate Policy

All Swedish parliamentary parties have been invited to join a parliamentary committee whose main task will be to prepare the national climate policy bill. The committee's terms of reference and the committee chair will be presented in early 2007. Thereafter, the Government will seek to ensure broad political support for Sweden's climate policy efforts.

The Swedish Environmental Protection Agency and the Swedish Energy Agency have been given a joint government mandate to develop basic data for the evaluation of Swedish climate policy. Part of this documentation will be delivered in the spring of 2007 and will be an important feature of the Committee's initial work.

The Committee will have early access both to the latest assessment report from the UN IPCC and to other international material that can facilitate the task of evaluating Swedish efforts in the climate field.

Another important contribution to the supporting data will be the recommendations of the Scientific Council on Climate Issues, which will be delivered to the Committee.

Appendix 1.2 The UN's Intergovernmental Panel on Climate Change

The results of international climate research are regularly summarised by the UN's climate panel, the IPCC. The IPCC reports describe what we know about climate change and its contributory causes, the consequences of such change, and possible action that can be taken to limit climate change and its consequences. The IPCC was established in the late 1980s as part of the UN system (at the initiative of the World Meteorological Organisation, WMO, and the United Nations Environment Programme, UNEP), and has hitherto produced four wide-ranging assessment reports. The reports aim to give an overall picture of climate research findings and to make this information accessible to politicians and the community at large. They provide an in-depth summary of developments on the international climate research front, based on scientific articles published in the international literature. The reports discuss both what we know about the climate system and where knowledge gaps exist, and in what areas scientific opinion is divided. Scientific knowledge of the issue develops as published articles are disputed and researchers present new interpretations of connections and relationships previously observed. Notwithstanding this process, our knowledge of the climate system is well established in certain specific parts, and science can therefore confidently identify causal relations and possible climate developments in the future.

The latest IPCC report, the fourth, will be published in stages in 2007 by means of four interim reports. Three of these have been produced by working groups, and the fourth is a synthesis of the first three. The first interim report, developed by Working Group I (WGI), discusses the physical basis of the climate system, proceeding from such disciplines as meteorology, oceanography and physical geography. The second working group (WGII) looks at the impacts of climate change on ecosystems and society, and discusses adaptation measures and vulnerability. This group's data comes principally from biologists, hydrologists, medical experts and social scientists. The third working group (WGIII) discusses possible ways of limiting greenhouse gas emissions and what other measures might be taken to mitigate human impact on the climate. Contributors include engineers, economists and other social scientists.

The three groups work in parallel, but the material assembled in WGI is of course highly relevant as supporting data for WGII and WGIII. The IPCC does not engage in any research of its own. Its task is to summarise the research findings that have been published in recent years. Due to the powerful impact that its reports have had and continue to have, the IPCC collates international climate research to some extent so as to make its findings as comparable as possible. The IPCC has, for instance, produced a number of scenarios for the future emission of greenhouse gases, and many of the climate-model experiments undertaken in the research community use these emission scenarios. Consequently, different model outcomes become comparable, and estimated degrees of uncertainty can be shown consistently. Work on the development of climate models, however, has not been coordinated; here, the international scientific community is totally free to focus its efforts on those parts of the climate system that it considers most urgent. As a result, different climate models have been developed based on different premises, and the differing results give us an idea – based on our current knowledge – of the uncertainty that is due to insufficient understanding of the processes which determine how sensitive the climate system is to changes in greenhouse gas concentrations.

When a new report is to be produced, the first step is to decide who is to be given prime responsibility for each respective working group. This decision is taken by the IPCC's governing body (the Panel), which comprises representatives of countries belonging to the above UN organisations, the WMO and/or UNEP. The preparatory work also includes meetings and conferences at which current climate issues are dealt with and where the international research community is given the opportunity to discuss and present its views and opinions.

The heads of the working groups are responsible for producing a report within a given timeframe. To perform this task, a large group of authors is selected following consultations with the various countries' government agencies responsible for IPCC work at national level. The aim is to enlist both experienced, established climate researchers and younger researchers, as well as researchers from countries that do not traditionally have a prominent international research profile in the climate field. This applies in particular to developing countries that lack the resources to undertake climate research on any great scale but where individual researchers are encouraged to take part. At the same time as the author groups are established, special reviewers are selected for each chapter of the report. These reviewers are well established experts and/or internationally respected researchers.

The author groups produce two consecutive draft reports which are circulated among those sections of the research community that are affected by the issue, for an initial scrutiny ('peer review'). Both the specially selected review experts and many of the other researchers take part in the review process. A third draft is then produced which is subject to a further review by a wider circle of researchers and government agencies possessing specialist knowledge. A fundamental requirement is that the review process is fully documented and made available to all. All comments submitted must be replied to in writing by the author of the chapter concerned. The reply describes either how the author has given the comment due consideration in the text or why the author has chosen to ignore the comment.

The lead authors and the convening lead authors (working group leaders) have formal responsibility for the review process in the same way as an editor has responsibility for a scientific journal. After the third review, the main text of the report is finalised. As a rule, each part comprises over a thousand pages. Meanwhile, a summary for policymakers (SPM) is produced. This text, too, undergoes a review process. Summaries for policymakers may not exceed 30 pages and are reviewed in a further round before they are finalised at a conference to which all states belonging to the UN organisations WMO and/or UNEP are invited to send researchers and government experts. Representatives of other UN bodies such as NGOs (e.g. industrial trade organisations and environment organisations) are invited to take part as observers. The participation of government agencies means that politicians and policymakers take the process seriously, while the participation of the research community guarantees scientific quality and credibility. Discussions at these meetings can be both lengthy and detailed. It is a matter of finding the precise expressions and terms that accurately summarise the scientific data on which policies are to be based. After each meeting of the three working groups, the summary content is no longer changed.

The contents of the main report are not disputed at these meetings since they have already been reviewed by the international research community. Credibility derives partly from the fact that the material is based on internationally reviewed research articles and partly from the fact that the IPCC reports themselves undergo an extensive, high-quality review process.

Appendices to Chapter 2

Appendix 2.1 Description of probability/likelihood

Likelihood refers to a probabilistic assessment of a specific outcome having occurred or occurring in the future. Likelihood may be based on quantitative analysis or an elicitation of expert views. The Council uses the following terms when assessing the likelihood of specific outcomes, in accordance with IPCC (2007a).

Term	Likelihood of the occurrence/outcome
Virtually certain	>99% probability
Very likely	90–99 %
Likely	66–90 %
About as likely as not	33–66 %
Unlikely	10–33 %
Very unlikely	1–10 %
Exceptionally unlikely	< 1 %

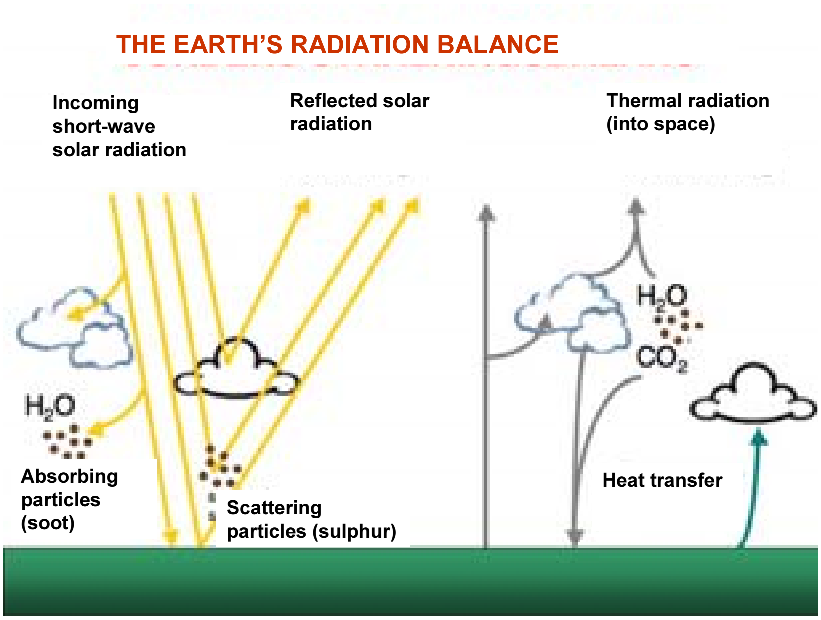
Appendix 2.2 The climate system

The function and natural variability of the climate system

The atmosphere encloses the earth like a thin protective layer of gas. Solar radiation, which pierces the atmosphere after being reflected or absorbed, warms the surface of the earth. The earth's surface in turn sends thermal radiation up into space, most of which is absorbed by radiatively active gases in the atmosphere, known as greenhouse gases, and by cloud (see Figure B2.1). As a result, the atmosphere warms up and sends thermal radiation both down towards the earth's surface and up into outer space. The downward thermal radiation heats the earth's surface further, as a result of which the earth has a much higher temperature than it would have had without its protective atmospheric layer. This warming amounts to about 30°C and is called the greenhouse effect. The natural greenhouse effect is a precondition of life on earth.

The most important naturally-occurring greenhouse gases are steam, carbon dioxide, methane, nitrous oxide (laughing gas) and ozone. By far the largest part of the *natural* greenhouse effect is that which is caused by steam and cloud, followed by carbon dioxide. Both steam and carbon dioxide are only to be found in small amounts in the atmosphere. Steam comprises less than 1 per cent of the atmosphere's total mass, while carbon dioxide comprises only 0.04 per cent. Despite their small amounts, these gases are crucial to the greenhouse effect. Oxygen and nitrogen gas, which together make up 99 per cent of the atmosphere's mass, have no impact on the greenhouse effect.

Figure B2.1 The earth's radiation balance



NB: The figure shows how about half of the incoming short-wave solar radiation is absorbed at the earth's surface and heats it up. The rest is reflected back into space or is absorbed in the atmosphere. Thermal radiation from the surface of the earth is captured by greenhouse gases in the atmosphere. The atmosphere in turn warms up and sends thermal radiation both down towards the earth's surface and up into space. The downward radiation heats the earth's surface further. This is called the greenhouse effect. The greenhouse effect is determined principally by steam (H_20), carbon dioxide (CO_2) and cloud. Cloud and particles affect how incoming solar radiation is reflected. Soot particles absorb solar radiation and heat up the atmosphere. The atmosphere is also warmed up by heat transfer from the surface of the earth. The temperature at the earth's surface is thus affected by changes in the concentration of greenhouse gases and particles in the atmosphere, by changes in the condition of the soil, and by changes in solar radiation.

Cloud affects how much solar radiation is reflected back into space and also contributes to the greenhouse effect. The shape of clouds, their water-drop and ice-crystal content and their vertical distribution all determine whether the combination of solar radiation reflection and greenhouse effect leads to a cooling or a warming of the earth's surface. The presence of airborne particles also has a cooling effect on the earth's surface as they directly scatter incoming solar radiation back into space. Depending on their chemical composition, particles containing absorbent substances, such as soot, also warm up the air.

In addition, the atmosphere is warmed up from the earth's surface by means of direct heat transfer and by the heat released when clouds are formed as a result of steam turning into small water drops and ice crystals. Warming in connection with cloud formation is particularly evident in the tropics, where large amounts of steam are to be found. The tropics, therefore, have a surplus of heat that is a direct result of the high level of solar radiation delivered there. Close to the earth's poles, where solar radiation is much weaker, we find a heat deficit instead. The difference in warming between the tropics and higher latitudes is offset by atmospheric and oceanic heat transfer, which is determined by winds and sea currents (circulation patterns).

The climate at the earth's surface, therefore, is determined by a complex combination of solar radiation, heat emission and heat transfer. Roughly speaking, the climate at a given location on the planet is determined by its latitude: the further north or south of the equator, the colder it becomes. In the Nordic region, however, we have a warmer climate than other places on the same latitude, such as Alaska and Siberia. This is partly due to the Gulf Stream, a warm ocean current that transports heat from tropical parts of the Atlantic northwards, and partly to a general south-westerly current in the atmosphere that also transports warm air northwards from subtropical climes. Circulation in the atmosphere and the oceans, therefore, has a decisive impact on the regional climate, which may differ very considerably from the average climate at a given latitude.

If we alter the concentration of greenhouse gases and particles in the atmosphere, this directly affects the climate at the earth's surface. Increased CO_2 concentration boosts the amount of heat being radiated towards the earth and causes warming. At the same time, the amount of atmospheric steam is affected; with warming, evaporation increases and warmer air contains more steam. This natural feedback therefore causes warming to intensify at the earth's surface. Meanwhile, cloud cover (see Appendix 2.3) and atmospheric and oceanic circulation are also affected. As we know, circulation is primarily a result of differences in warming. If the heat balance changes, circulation is also affected. A changed circulation pattern in certain regions can either strengthen or weaken the warming process. The intensity of this feedback is determined by the intricate interaction between heat balance and circulation.

Climate models and known uncertainty factors

To determine the total climate impact of a given change in the atmospheric composition of radiatively active gases, particles and clouds, fundamental laws of physics are applied to the various parts of the climate system. Physical laws can be formulated as mathematical correlations, which can then be used to determine climate change in quantitative terms. Despite the simplifications that distinguish climate models, the complexity of the climate system necessitates the use of very large-scale calculation models requiring powerful computers.

With the aid of climate models, we can calculate the impact of prescribed changes in the above parameters, in comparison with the natural factors that affect the climate. This approach can be used to help us understand what proportion of previously observed warming may be due for instance to a more pronounced greenhouse effect, and what level of warming we can expect in the future.

Natural changes in the strength of solar rays affect the climate, as do powerful volcano eruptions since the resultant particles prevent the rays from reaching the earth's surface. Natural variations in the atmospheric and oceanic circulation patterns also affect the climate at the surface of the earth, including the extensive variations in temperature known as El Niño found in the Pacific region. During what are known as El Niño years, large amounts of heat are transferred from the sea to the atmosphere, which causes warming. Also, this has an impact on circulation patterns, which means precipitation and drought are also affected over large areas. In the aftermath of an El Niño, circulation returns to its previous state: heat content is restored to the sea and the temperature in the atmosphere falls. There are many other natural variations of a similar kind that profoundly affect the climate in various regions for shorter or longer periods. Some are so powerful and widespread that they have a noticeable effect on the global mean temperature.

Changes in the greenhouse effect can have an impact both on the global mean temperature and on regional climate variations. The clearest signal of the two is the impact on the global mean temperature. Regional impacts are more uncertain since they are so strongly affected by changes in the atmospheric and oceanic circulation patterns.

In today's climate models, cloud is the principal uncertainty factor. The uncertainty is exacerbated both by deficiencies in the modelled geographical distribution of cloud and by the clouds' total contribution to the solar radiation reaching the ground, heat emission and heat transfer This is because the formation and dissolution of cloud is strongly linked to weak vertical movement in the atmosphere, which in turn is linked to minor variations in the extensive, horizontal patterns of movement. Also, minor errors in horizontal winds can cause large-scale relative errors in vertical movements. The other major uncertainty is due to the whiteness or reflection capacity of clouds and their heat radiation properties. A crucial role is played here by the size of water-drops and the structure of ice crystals in clouds.

Various climate models differ first and foremost in the way they describe processes governing cloudiness. How different models describe the properties of clouds directly accounts for much of the uncertainty specified in the IPCC climate scenario findings. Uncertainty in cloud descriptions is, however, fairly well captured by comparing the outcomes of various climate models with one another.

Appendix 2.3 Climate-changing gases and particles in transition a result of human activity

Carbon dioxide

Carbon dioxide, CO_2, is an important greenhouse gas, and is primarily released in the burning of fossil fuels such as coal, oil and natural gas. The remainder comes from deforestation and fires in wooded areas, particularly tropical forests, and from emissions produced in cement manufacturing. Atmospheric CO_2 concentration has increased by over 35 per cent since the advent of industrialism in the mid-18th century (from approximately 280 ppmv in 1850 to 379 ppmv in 2005). The current CO_2 level is unique in an historical perspective. It is probably the highest level for at least 650 000 years, which is the equivalent of six ice ages.

Methane and nitrous oxide

Together, methane and nitrous oxide (laughing gas) are the most important anthropogenic greenhouse gases after CO_2. These gases are closely associated with increases in population and welfare, due to lifestyle patterns that bring about changes in land use. Twenty five years ago, natural emissions of methane from wetlands were for the first time exceeded by anthropogenic emissions from rice-growing, cattle herding, waste management and leaking gas pipes etc. Today, methane levels are 150 per cent higher than 250 years ago. The rate of increase has, however, slowed since the early 1990s. The research community has no clear-cut explanation for this. Nitrous oxide has increased by 16 per cent over the same period. Nitrous oxide emissions from the fertilisation of farmland are as extensive today as the natural emissions from the world's oceans.

Ground-level ozone

Since the advent of industrialism, there has been a substantial increase in ground-level/tropospheric ozone associated with emissions of ozone-forming compounds (nitrogen oxides, carbon monoxide and hydrocarbons). Ozone formation is particularly evident above severely polluted areas. The higher levels of ozone-forming gas emissions have been caused by increased use of fossil fuels, biomass combustion and intensive, high-yield farming.

Estimates of ozone's radiative forcing are based on photochemical model calculations, since the pre-industrial levels cannot be determined with sufficient accuracy.

Halocarbons

This is a generic term for all organic compounds containing halogens, and covers freons or chlorofluorocarbons (such as CFC-11 and CFC-12), hydrochlorofluorocarbons, hydrofluorocarbons, halons and perhalocarbons. For a couple of the most short-lived compounds, such as carbon tetrachloride and CFC-11, levels have been diminishing (in the case of CFC-11, for instance, by approximately 2 per cent per annum) since the mid-1990s. The fact that despite the major reductions in emissions that have occurred atmospheric levels have not declined more is explained by the difficulty of breaking down these compounds in the atmosphere, which means they persist for a long time. CFC-12 is another highly radiative freon that has now achieved equilibrium in the atmosphere (i.e. emissions=sinks). Due to its 100-year lifetime, its atmospheric level will decline by 1 per cent per annum even when emissions have ceased.

Pursuant to the Montreal Protocol, ozone-depleting halocarbons have been replaced by compounds that have no impact whatsoever on the ozone layer. These are now found in ever-increasing concentrations in the atmosphere and are usually potent greenhouse gases.

Stratospheric ozone

In the stratosphere, in an atmospheric layer 10–30 km above the earth's surface, the greenhouse gas ozone is considerably more prevalent than in ground-level strata. At these heights, ozone depletion caused by previous emissions of halocarbons has contributed to a lowering of the air temperature. Fewer ozone molecules are able to absorb outgoing thermal radiation (see Appendix 2.2), which helps reduce the greenhouse effect in stratospheric ozone and results in a weak negative radiative forcing of -0.05 watts per square metre, which has a cooling effect.

On the other hand, the presence of radiatively active halocarbons in the stratosphere means outgoing thermal radiation will be absorbed very efficiently. This intensified greenhouse gas is estimated at 0.34 watts per square metre in the troposphere, and easily offsets the cooling caused by ozone depletion.

Particles

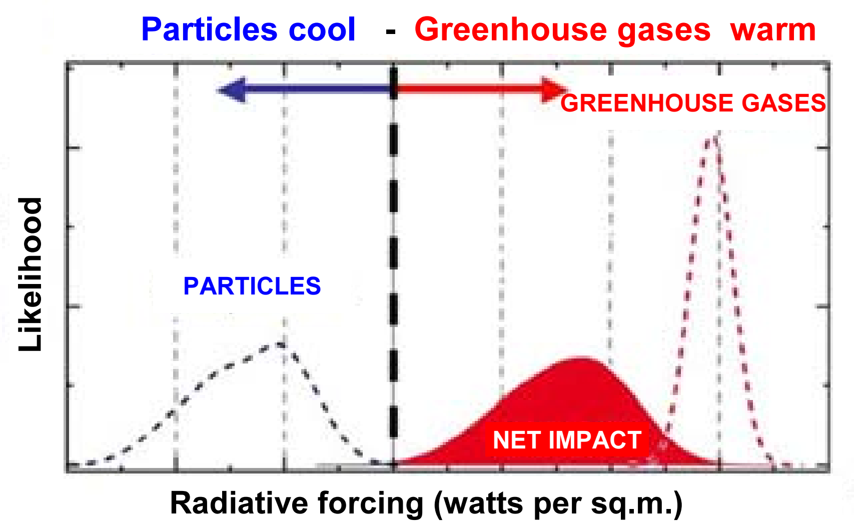
At the same time as coal and oil burning has reinforced the greenhouse effect, the amount of (airborne aerosol) particles has increased. Examples of the latter are particles formed in the atmosphere from emissions of sulphur dioxide. Emissions of soot particles are a further example. The increasing concentration of particles primarily has a cooling effect (both directly and indirectly via cloud formation) on the temperature at the earth's surface since it prevents the sun's rays from heating up the soil.

Clouds consist of billions of drops of water. Each drop contains a tiny particle, a core of condensation known as a cloud condensation nucleus (CCN), that is about one thousandth of a millimetre in diameter. Without CCNs, steam in the air would be unable to condense into drops of water and form clouds. As the number of CCNs (particles) in the atmosphere increases, more particles are forced to share the same amount of water. This means more but smaller drops of cloud (whiter clouds with longer lifetimes) are formed, as a result of which more sunlight is reflected back into space instead of heating up the soil. Thus for the same amount of water, pure cloud is less white.

The number of available particles alone does not determine the optic qualities or 'whiteness' of cloud. The particles' chemical composition is also an important factor. If they only comprise soot, steam has difficulty adhering and no cloud drops are formed. If, on the other hand, the particle population is dominated by water-soluble sulphur-containing compounds such as sulphate, water is efficiently absorbed. A situation in which the particle population consists exclusively of soot – or where particles are too few in number, e.g. in areas with little anthropogenic interference – is unlikely to arise. In general, therefore, the supply of particles is not a limiting factor in cloud formation. The relative number of particles and their chemical composition, however, affect the whiteness of clouds and their ability to reflect solar radiation.

As regards the extent to which particles impact on the climate, this is calculated with greater accuracy today than in previous IPCC reports, but there is still considerable uncertainty resulting from insufficient understanding of the processes involved. This applies in particular to the impact of particles on the reflective capacity of clouds. In general, cloud description is the prime source of uncertainty in present-day climate projections (see Appendix 2.2).

Figure B2.2 Probability distribution of radiative forcing changes caused by greenhouse gases and particles respectively, and changes in cloud whiteness (reflective capacity)



Source: Figure based on IPCC (2007a).

NB: In the probability distribution of the cumulative effect, net impact, small contributions from surface reflectivity (albedo), condensation trails from aircraft and changes in stratospheric steam are also considered.

The illustration in Figure B2.2 shows that the cumulative outcome of rising greenhouse gas and particle concentrations between the years 1750 and 2005 is a warmer planetary surface, even when the cooling effect of approximately 1.2 watts per square metre caused by anthropogenic particle emissions is brought into the equation. The warming can be expressed as increased radiative forcing at the earth's surface, and it amounts to 1.6 watts per square metre.

Appendix 2.4 Climate sensitivity

Climate sensitivity is defined as *the increase in temperature at equilibrium obtained when the CO_2 concentration level is double the pre-industrial level.* Climate sensitivity is a way of expressing the estimated temperature rise attributable to increased emissions of greenhouse gases, and is determined with the aid of model simulations of a more or less idealised nature. The results are backed up by studies based on observed climate variations, including paleoclimatological data.

The IPCC has previously estimated a sensitivity level of 1.5–4.5 °C. Research findings in recent years, however, suggest that the climate system is more sensitive than that. Climate sensitivity is now thought likely to be somewhere between 2 °C and 4.5 °C. In the IPCC's estimate, it is very unlikely that climate sensitivity is less than 1.5 °C. The possibility that it may be higher than 4.5 °C has not been excluded.[94]

Climate sensitivity plays an important part in the simplified estimates of temperature change that are made in connection with economically based projections of emission scenarios. These are mainly found in Part 3 of the latest IPCC assessment report. In the temperature scenarios discussed in Part 1, complete circulation models of the climate system are used, and climate sensitivity there is a result of the estimates rather than of a prescribed parameter. Complete climate models, however, are highly resource-intensive, in terms both of computer power and of input from specialist research institutes. Consequently, the climate sensitivity parameter is used when calculating a large number of different emission scenarios.

Given a better understanding of climate sensitivity, the relationship between stabilisation levels for GHG concentration in the atmosphere and long-term global warming can be quantified (see Table B2.1). Note that the global mean temperature at equilibrium is not to be equated with the global mean temperature in 2100. Due to the inherent inertia of the climate system, equilibrium temperature is not achieved until several centuries after the stabilisation of GHG concentration.

[94] IPCC (2007a). It has been argued, however, that for statistical reasons the likelihood of the upper limit being reached is not quantifiable. See for instance Allen et al (2006).

Table B2.1 Projection of temperature increase at equilibrium relative to the pre-industrial level for different stabilisation levels of GHG content in the atmosphere

Stabilisation level [ppmv CO_2e]	Temperature increase at equilibrium [°C]		
	Most likely level	Very likely higher than	Likely interval
350	**1.0**	**0.5**	0.6–1.4
450	**2.1**	**1.0**	1.4–3.1
550	**2.9**	**1.5**	1.9–4.4
650	**3.6**	**1.8**	2.4–5.5
750	**4.3**	**2.1**	2.8–6.4
1000	**5.5**	**2.8**	3.7–8.3
1200	**6.3**	**3.1**	4.2–9.4

Source: IPCC, 2007a.

Appendix 2.5 IPCC emission scenarios

A1

The A1 scenario describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The main theme is convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario is divided into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2

The A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other scenarios.

B1

The B1 scenario describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in A1, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and with the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2

The B2 scenario describes a world in which the emphasis is on local solutions to economic, social and sustainable development of the environment. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in B1 and A1. While the scenario is also oriented towards environmental protection and social equity, it focuses more on local and regional levels.

An illustrative scenario was selected for each of the six scenario groups, A1B, A1FI, A1T, A2, B1 and B2. All are considered equally sound.

The IPCC scenarios do not include additional climate initiatives, which means that none of them explicitly assumes implementation of the UN Framework Convention on Climate Change or the emission targets in the Kyoto Protocol.

Estimates of available fossil coal, oil and natural gas

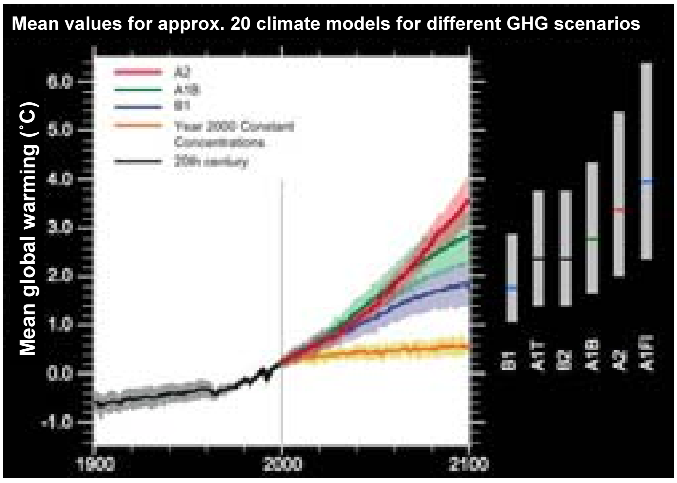
Fossil fuel access is not a limiting factor for further emissions in the 21st century. According to estimates (IPCC, 2007c), there are larger amounts of fossil coal, oil and gas in conventional and non-conventional deposits than are specified for consumption in the IPCC scenarios. Even if it will gradually become costlier to bring up first oil and then natural gas using the technology currently available when known reserves are depleted, the same can scarcely be said of available coal reserves, which are very extensive.

Scenario outcomes

The IPCC's principal scenarios as described above are divided into four different groups or 'families' (A1, A2, B1, B2), each with their own assumptions concerning demographic, social, economic, technological and environmental trends. In these reference pathway scenarios, GHG concentration in the atmosphere increases to different extents, depending largely on the development path chosen.

According to these scenarios, GHG levels in the atmosphere, calculated as carbon dioxide equivalents, will increase by the year 2100 to between 600 and 1 550 ppmv CO_2e. No scenario is identified as being more likely than any other. It should also be noted that these scenarios do not include any assumptions concerning climate policy measures for reducing emissions.

Figure B2.3 Mean values for various scenarios



Source: IPCC (2007a).
NB: The continuous curves are what are termed multimodel averages for global warming at the earth's surface in approximate relation to the year 1990 for four emission scenarios. The orange curve shows the outcome when concentrations are kept constant at the levels pertaining in the year 2000. The shading shows the spread between models (plus/minus a standard deviation). The grey columns on the right show the most likely value as a horizontal line, and also represent the range of uncertainty estimated for six different reference pathway scenarios.

The lowest emission scenario in climate simulations for the period 1990–2095 gives an increase in global mean temperature of 2.3°C compared with the pre-industrial era (1.8°C compared with 1990), with a range of uncertainty of between 1.6°C and 3.4°C (see Figure B2.3). The highest emission scenario (A1F1) gives a temperature increase of 4.5°C compared with the pre-industrial era (4.0°C compared with 1990), with a range of uncertainty of between 2.9°C and 6.9°C. The other emission scenarios lie between these two, in terms of both emissions and increases in temperature. It should be noted that changes in temperature would continue beyond the year 2100 as well.

Besides rising temperatures, the climate simulations indicate that the sea-level will also continue to rise. The lowest emission scenario shows a rise of between 18 and 38 centimetres between 1990 and 2095, while the higher scenario puts the figure at 26–59 centimetres. These estimates do not take into account the possibility that ice-melting may accelerate as a result of further warming, since our understanding of these processes is inadequate. Accelerating ice-melting could raise the sea-level by between 10 and 20 centimetres.

Appendices to Chapter 5

Appendix 3.1 Models for sharing emission allowances and reduction commitments

Discussions on international climate policy after 2012 have generated a large number of proposals for models for framing and sharing emission reduction commitments in the climate field. Table B3. 1 presents a brief description of the most widely debated models. Models marked with an asterisk (*) are included in the analysis undertaken by Ecofys at the behest of the UK Government. Its findings are set out in Chapter 5.3. The models are described in greater detail in Ecofys reports.[95] These are available on the Environmental Advisory Council website.[96]

Table B3.1 Climate policy burden-sharing models

Model	Description
Common but Differentiated Convergence*	Only countries whose per capita emissions exceed/reach a given threshold level need reduce emissions. Thereafter (e.g. within 40 years), these countries must reduce their per capita emissions to an equitable level. The threshold level is lowered over time.
Contraction & Convergence*	From a certain point in time onwards (e.g. 2050) per capita emissions from all countries must be the same. A country's emission reduction requirement up to the convergence point will depend on how its emission levels compare with current mean global per capita emissions. Total emission allowances are reduced over time.
Fish Trap	All Annex I countries and non-Annex I countries whose per capita GDP exceeds/reaches a given threshold level must reduce emissions. Expected emissions from countries that do not need to reduce emissions are deducted from the global ceiling. Emission allowances for countries required to reduce emissions are shared in proportion to the country's share of global GDP. Thereafter, emission allowances (emissions per GDP) are adjusted upwards or downwards depending on whether the country's per capita GDP is lower or higher than the global mean. Annex I countries are subject to upper and lower reduction requirement limits relative to 2002 levels at different points in time.
Historical Responsibility*	Emission allowances for all countries within a given period are determined by each country's historical contribution to the greenhouse effect. A range of indicators can be chosen.

[95] Höhne et al (2007), Höhne & Moltmann (2007).
[96] www.sou.gov.se/mvb

Model	Description
Intensity targets*	All countries must reduce emissions per unit of GDP by the same percentage.
Multistage*	Countries take part in four differentiated stages on the basis of their level of development (per capita GDP) and emission levels (per capita emissions): (1) Least developed countries have no commitments, (2) commitments on sustainable development measures, (3) non-binding commitments on absolute emission limitation measures, (4) binding commitments on absolute emission reductions to a low per capita emission level. Countries in stage 4 are subject to the same percentage reduction requirement, adjusted in accordance with per capita emissions.
Triptych*	Allocation of emission allowances within a group of countries is determined on a sectoral, bottom-up basis. Allowance is made for differences in national conditions of relevance to emission levels and reduction potential, such as the structure of national energy systems. Limit conditions are set for emission growth in different sectors, e.g. per capita emission convergence in the household sector and energy efficiency convergence in the industry sector.

The models, some of which are linked to proposals on the general architecture of a future international climate regime, differ mainly on two issues of principle: 1) participation, that is to say which countries should be covered by commitments on emission limitation; and 2) fairness, i.e. equitable burden-sharing among those taking part.

Some models, for example *Triptych*, *Contraction & Convergence*, *Intensity-based Targets* and *Historical Responsibility*, are based on the principle that all countries take part – with binding emission reduction commitments. Other models, for example *Multistage*, *Common but Differentiated Convergence* and *Fish Trap* advocate differentiated participation, i.e. developing countries are subject to binding commitments to some form of emission reduction (absolute or dynamic) when they have reached a given threshold level, defined for example in terms of per capita GDP or per capita emissions. These models thus indirectly take particular account of the needs of developing countries on the basic principle of fairness.

With respect to sharing reduction requirements among the participating countries, some models, e.g. *Contraction & Convergence* and *Common but Differentiated Convergence*, which are based on a fair and equal distribution perspective, propose that per capita GHG emissions in different countries should converge at a given point in time – usually 2050. *Fish Trap*, devised by the Swedish energy group Vattenfall and based on a combination of the principles of equality and equilibrium with convergence of per capita GDP and per capita emissions by 2100, allocates emission rights mainly on the basis of a country's share of global GDP (adjusted for purchasing power) at different points in time.[97] Some models such as *Intensity-based Targets* and *Multistage* propose that countries with binding commitments on absolute emission reductions should be allocated emission rights in accordance with a uniform annual reduction rate. The most complicated model, *Triptych*, allocates emission rights on the basis of national conditions, e.g. a country's industrial structure and the composition of its energy systems, for example. Unlike other models, which are based mainly on assumptions about future conditions, the Historical Responsibility model, submitted by Brazil ahead of the Kyoto 1997 climate negotiations, proposes that allocation of emission rights should be made on the basis of countries' historical responsibility for global warming.

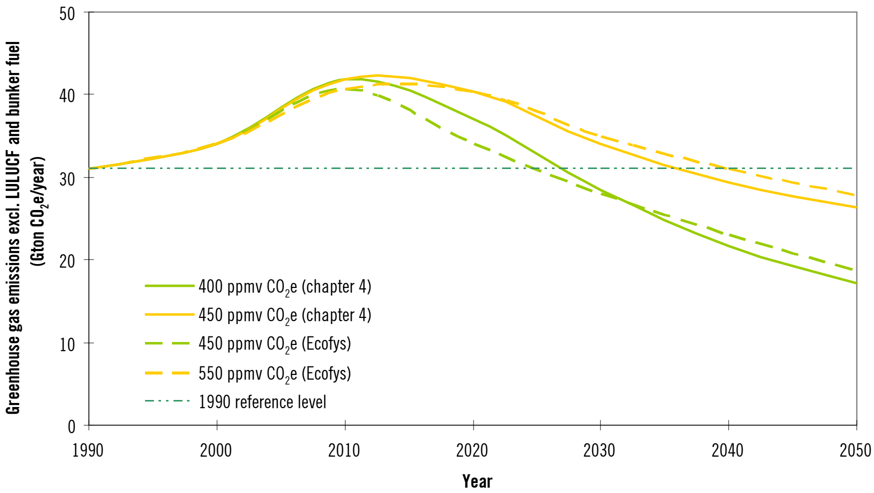
[97] However, allocations of emission rights to rich countries, i.e. countries with a high per capita GDP, are adjusted downwards somewhat, while allocations to poor countries are adjusted upwards.

Appendix 3.2 Comparison of emission pathways as a basis for sharing the two-degree target global reduction requirement

Estimates of the global reduction requirement set out in Table 5.1 (see Chapter 5) and background reports by Ecofys are based on global emission pathways that differ somewhat from those presented in Chapter 4. Burden-sharing does not extend to emissions from the burning of bunker fuel (external aviation and shipping), land use and forestry. Furthermore it is designed for emission pathways which for a given stabilisation of atmospheric GHG concentrations call for bigger emission reductions in the period up to 2050. This is because, unlike the emission pathways presented in Chapter 4, they do not allow for the fact that atmospheric GHG concentrations can exceed the stabilisation level for a transitional period and fall thereafter without raising the mean global temperature more than 2°C above pre-industrial levels.

However, as shown in Figure B3.1, emission pathways for stabilisation at 450 ppmv CO_2e according to the burden-sharing estimates (broken green curve), and at 400 ppmv CO_2e according to Chapter 4 (excluding emissions from external aviation and shipping, and land use and forestry – continuous green curve) respectively are relatively similar for the period 1990–2050. The same applies to emission pathways for stabilisation at 550 ppmv CO_2e according to Ecofys (broken yellow curve) and at 450 ppmv CO_2e according to Chapter 4 (corrected to include the same emission sources – continuous yellow curve) respectively.

Figure B3.1 Emission pathways for selected stabilisation scenarios



Source: Based on data from den Elzen & Meinshausen (2006) and Höhne et al (2007).

On the whole, therefore, the outcomes for stabilisation at 450 ppmv CO_2e according to Ecofys (and Table 5.1) give a good approximation for burden-sharing in the period up to 2050 for the emission pathway for stabilisation at 400 ppmv CO_2e according to Chapter 4 (corrected to include the same emission sources – continuous yellow curve). Similarly, the outcomes for stabilisation at 550 ppmv CO_2e according to Ecofys (and Table 5.1) give a good approximation for burden-sharing in the period up to 2050 for the emission pathway for stabilisation at 450 ppmv CO_2e according to Chapter 4 (corrected to include the same emission sources).

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Glossary of terms

The following terms are defined as they are used in the present report

Activity target

Target relating to a special measure, activity or criterion that may be expected to help reduce emissions, e.g. an energy efficiency enhancement measure or the share of renewable energy sources in a given primary energy supply system.

Adaptability

The ability of a system to adapt to climate changes, including climate variation and climate extremes, by mitigating potential damage, recognising and exploiting opportunities, or dealing with their effects.

Annex I countries

Mainly industrialised countries and countries with economies in transition that have special commitments under Article 4.2 of the Climate Convention (UNFCCC). Annex I countries are broadly the same countries that have quota commitments under Annex B in the Kyoto Protocol.

BAU scenario

(Business-as-usual) scenario for future development assuming that current trends continue.

Buffering capacity of ecosystems

Ecosystem resilience, i.e. the ability of an ecosystem to cope with disturbances without irreversible damage to its structures or functions, and adapt to stresses and changing conditions.

Burden-sharing model

A model for quantifying the sharing of emission rights among countries.

Carbon cycle

Term referring to the flow of carbon (in different forms, e.g. carbon dioxide) in the geobiosphere, i.e. the lithosphere, the hydrosphere, the atmosphere and the biosphere.

Carbon intensity

The amount of carbon dioxide emitted relative to a given economic activity, e.g. emissions per unit input of primary energy or emissions per unit of GDP.

Carbon sink

A process or activity that removes carbon dioxide from the atmosphere, e.g. uptake of carbon dioxide by growing forests or crops through photosynthesis. See also under Net emissions.

Clean Development Mechanism (CDM) project

Emission reduction project implemented in a non-Annex I country with funding from an Annex I country. CDM projects can generate emission rights subject to approval under internationally established rules. The rights can then be used by the investor to meet international climate regime targets.

Climate Convention

The United Nations Framework Convention on Climate Change (UNFCCC). An international UN treaty ratified by 191 countries committed to cooperation on action to prevent the global temperature from rising. The Climate Convention was signed at the 1992 Earth Summit in Rio de Janeiro and came into force in 1994. It was supplemented at a conference in Kyoto in 1997 by the Kyoto Climate Protocol, which secured binding commitments by a number of countries to reduce emissions of six greenhouse gases.

Climate sensitivity

See Appendix 2.4.

Climate neutrality

A unit (industrial installation, enterprise or country) can neutralise its impact on the climate by reducing its emissions by 100 per cent or by buying emission rights equivalent to the total emissions produced by that unit.

Concentration of carbon dioxide equivalents

The concentration of carbon dioxide that would cause the same amount of radiative forcing as a given mixture of carbon dioxide and other greenhouse gases. Expressed in ppmv CO_2e.

Concentration target

Represents the highest acceptable concentration of atmospheric greenhouse gases (stabilisation level).

Cost-benefit analysis

Method used to compare alternative courses of action; their costs and revenues (benefits) are calculated and compared.

Discounting/discount rate

A recognised method for comparing present and future economic quantities. A discount rate is used to estimate the monetary value of future costs and revenues.

Economic potential

Emission-reducing potential that reflects the economic costs involved but does not take account of possible market barriers to the implementation of a given measure.

Ecosystem services

Services provided by nature and regarded as beneficial to human beings and human society. These include food provisioning, pollinating insects, water purification, natural pest control, carbon sequestration and the formation of fertile soil.

Emission of carbon dioxide equivalents

The quantity of emitted carbon dioxide that would cause the same amount of radiative forcing over a given period as emissions of another well-mixed greenhouse gas or a mixture of well-mixed greenhouse gases. The equivalent amount of carbon dioxide is obtained by multiplying the various greenhouse gases by their respective global warming potential to allow for the different lengths of time the gases remain in the atmosphere. Expressed in tons of CO_2e.

Emission pathway

Description of the required development of emissions over time if a given concentration target is to be met.

Emission target

Represents the highest acceptable emission level. May also be expressed as a reduction requirement over a given period.

Emission target with deductible emission allowances

National emission target that focuses on emission rights initially allocated for activities within an emission rights trading system, as opposed to actual emissions arising from such activities.

Energy intensity

Level of energy consumption, e.g. measured as the ratio of energy consumption to economic or physical output in an industry or country. At national level, energy intensity is the ratio of total domestic primary energy consumption or final energy consumption to GDP product.

European Union Greenhouse Gas Emission Trading Scheme (EU ETS)

Europe-wide EU scheme for trading carbon dioxide emission rights. The scheme, launched in 2005, enables enterprises within the EU to buy and sell emission rights. Approximately 12,000 industrial and energy installations in all 27 EU member states were involved in emission trading in 2005–2007 (the first trading period).

Global energy system

The total system of supply and consumption of electricity, heating and fuel at global level.

Greenhouse gases

Atmospheric gases capable of absorbing infrared radiation (heat) and thereby contributing to the greenhouse effect. Although most of these gases occur naturally, some are anthropogenic, i.e. the result of human activity. Anthropogenic emissions, where these arise, increase the atmospheric concentration of naturally occurring gases. Examples of greenhouse gases are water vapour, carbon dioxide, methane, dinitrous oxide, ozone and halocarbons (e.g. fluorocarbohydrates, fluorocarbons and sulphur hexafluoride). Greenhouse gases covered by the Kyoto Protocol are carbon dioxide, dinitrous oxide, methane, fluorocarbohydrates, fluorocarbons and sulphur hexafluoride.

Ground-level ozone

See Appendix 2.3.

Halocarbons

See Appendix 2.3.

Joint Implementation (JI) project

Emission reduction project implemented in an Annex I country with funding from another Annex I country. JI projects can generate emission rights subject to approval under internationally established rules. The rights can then be used by the investor to meet international climate regime targets.

Kyoto Protocol

See under **Climate Convention** and **Greenhouse gases**.

Kyoto Protocol mechanisms

Collective term for the three mechanisms – international emission trading, Joint Implementation (JI) and the Clean Development

Mechanism (CDM) – introduced into the Kyoto Climate Protocol to boost the cost-effectiveness of reducing greenhouse gas emissions and give countries with binding commitements greater flexibility to meet their emission quotas.

Market potential

Expected emission reduction potential under assumed market conditions, taking account of current measures and policy instruments as well as possible constraints hindering their implementation.

Montreal Protocol

The Montreal Protocol on Substances that Deplete the Ozone Layer, an international treaty within the UN framework was adopted in Montreal in 1987 and came into force in 1989. Its purpose is protect the ozone layer by phasing out the production of a number of damaging substances, primarily freons and halons.

Natural system

An ecosystem, biological system, water system or system characterised by air, snow, ice or permafrost.

Net emissions

Difference between greenhouse gas emissions and uptake in a specific sector, e.g. land use and forestry. Net emissions are negative if the uptake exceeds the amount of greenhouse gases emitted, in which case the sector in question is a (net) coal sink, as in the case of land use and forestry in Sweden.

Non-Annex I countries

All (mainly developing) countries that have ratified the Climate Convention but are not classified as Annex I countries.

Particle

See Appendix 2.3.

Peer review

See Appendix 1.2.

Primary energy

Energy that has not been converted or transformed, e.g. energy contained in crude oil, coal, natural gas and water in rivers developed for hydropower. Examples of converted energy include electricity and heating.

Project-based mechanisms

Collective term for the Joint Implementation (JI) scheme and Clean Development Mechanism (see also under Kyoto Protocol mechanisms).

Radiative forcing

A measure of the extent to which a factor can perturb the balance between incoming and outgoing radiation in lower-lying atmospheric layers (closest to the ground). It is also an indication of the potential significance of that factor as a climate change mechanism. See also Chapter 2.2.2 and Appendix 2.3.

Reference pathway scenario/reference pathway

Description of the way emissions develop over time based on assumptions regarding population, technological and economic development, but with no assumptions concerning any emission reduction measures beyond those already implemented.

Regulated feed-in tariffs

Scheme for subsidising initial development costs in connection with new technologies for renewable energy sources such as solar cells and windpower. As knowledge is gained and development and production methods and techniques improve, these technologies are increasingly able to stand on their own.

Sectoral target

Emission and/or activity target for a social sector or industry at national as well as regional level.

Stratospheric ozone

See Appendix 2.3.

Temperature target

Represents the highest acceptable increase in global mean temperature. Target specification may also include the highest *rate* of increase in global mean temeperature.

Terrestrial ecosystem

An ecosystem on land, as opposed to a marine, i.e. ocean, ecosystem.

Vulnerability

Measure of a system's sensitivity to, or inability to cope with, adverse effects of climate change, including climate variation and climatic extremes.

Abbreviations

AAU	Assigned Amount Units
GDP	Gross Domestic Product
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent(s)
COP	Conference of the Parties
EEA	European Environment Agency
EMEC Economic	Environmental Medium Term Model (used by the Swedish National Institute of Economic Research)
EU	European Union
EU ETS	European Union Greenhouse Gas Emission Trading Scheme
FAO Organization	The Food and Agriculture of the United Nations
Gton	Gigaton (billion tons)
IEA	International Energy Agency (Autonomous organisation for energy cooperation. Linked with the OECD)
IPCC	Intergovernmental Panel on Climate Change (UN Climate Panel)
JI	Joint Implementation Mechanism
Mton	Megaton (million tons)
NGO	Non-Governmental Organisation
ppmv	parts per million by volume
PPP	Purchasing Power Parity

SCC	Social Cost of Carbon
SMHI	Swedish Meteorological and Hydrological Institute (*Sveriges meteorologiska och hydrologiska institut*)
SOU	Swedish Government Official Reports (*Statens Offentliga Utredningar*)
UN	United Nations
UNDP	United Nations Development Programme
UNEP Programme	United Nations Environment
UNFCCC	The United Nations Framework Convention on Climate Change
USD	Dollar (USA)
WBGU	German Scientific Council of Global Change (*Wissenschaftlicher Beirat der Bundesregierung Globale Umweltver änderungen*)
WG1-3	Working group 1–3
WMO	World Meteorological Organization (UN body)
WTO	World Trade Organization