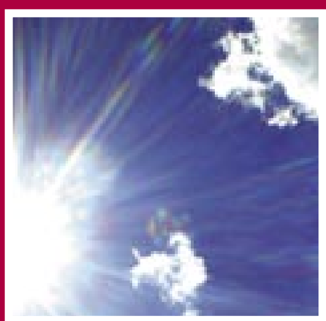
EEA Report | No 1/2005

Climate change and a European low-carbon energy system

ISSN 1725-9177



European Environment Agency

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Cover design: EEA
Layout: Brandpunkt A/S and EEA

Luxembourg: Office for Official Publications of the European Communities, 2005

ISBN 92-9167-765-5
ISSN 1725-9177

Front cover photo source: Pawel Kazmierczyk
Left smaller cover photo: © Glassman, stock.xchng 2004

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Acknowledgements

This report was prepared by the European Environment Agency and the European Environment Agency's European Topic Centre on Air and Climate Change (ETC/ACC). The contributing authors, in alphabetical order, were Andreas Barkman, André Jol, Stephane Isoard, Aphrodite Mourelatou and Tobias Wiesenthal (EEA) and Judith Bates, Marcel Berk, Bas Eickhout, Hans Eerens, Michel den Elzen, Bernd Gugele, Leonidas Mantzos, Jelle van Minnen, Dora Petroula, Bas van Ruijven, Rob Swart, Willemijn Tuinstra, Peter Taylor and Detlef van Vuuren (ETC/ACC) and Antonio Soria (JRC IPTS). The EEA project manager was André Jol, the ETC/ACC project leader was Hans Eerens. Peter Saunders assisted in editing the report. EEA acknowledges advice provided at various stages during the preparation of the report by an advisory group consisting of Lars Mueller, Matti Vainio (European Commission, Environment DG), André Berger (EEA Scientific Committee), Nebojsa Nakicenovic (IIASA), Juergen Schneider (EMEP) and Cedric Philibert (IEA). Comments provided by the national focal points and other country representatives as well as other members of the EEA Scientific Committee (Manfred Kleemann, Costas Cartalis) are also acknowledged.

Summary

This report presents an assessment of possible greenhouse gas emission reduction pathways made feasible by global action and a transition to a low-carbon energy system in Europe by 2030. It analyses trends and projections for emissions of greenhouse gases and the development of underlying trends in the energy sector. It also describes the actions that could bring about the transition to a low-carbon energy system in the most cost-effective way.

Key messages

- Many changes in climate, and the impacts of these changes, are already visible globally and in Europe, and these are projected to become more pronounced. In Europe, the Arctic region, mountain regions, coastal zones, wetlands and the Mediterranean region are particularly vulnerable.
- Limiting global mean temperature increase to 2 °C above pre-industrial levels (the EU target) would lead to the avoidance of many, but not all, adverse effects globally and in Europe. Adaptation strategies, in addition to mitigation strategies, are required at European, national, regional and local levels.
- In the long term (after 2100), achieving the 2 °C target would require atmospheric greenhouse gas concentration levels of well below 550 ppm CO_2-equivalent (broadly consistent with 450 ppm of CO_2 alone).
- For the analyses in this report, the 2 °C target has been translated into stabilisation of greenhouse gas concentrations at a level of 550 ppm CO_2-equivalent. This would require *global emissions* to be limited to an increase of 35 % above the 1990 level by 2020 and then decrease to 15 % below the 1990 level by 2050. However, to reduce the risk of overshooting the 2 °C target, recent scientific insight has shown that global emissions should possibly be reduced by 50 % by 2050. The range mentioned by the EU Environment Council of March 2005 is a decrease to 15–50 % below the 1990 level by 2050. Further research is needed to better quantify the required global emission reductions.
- The EU Environment Council has not yet fixed emission reduction targets for the EU, since these will be negotiated in future. However, the EU Environment Council, concluded that to achieve stabilisation in an equitable manner, developed countries should reduce emissions to about 15–30 % below the base year (1990) level by 2020 and to 60–80 % below by 2050. This report analyses assumed *EU emission reduction targets* of 20 % below the 1990 level by 2020, 40 % below by 2030 and 65 % by 2050.
- The climate action scenario shows that by domestic actions alone, based on a carbon permit price of EUR 65/t CO_2, the EU could reduce its greenhouse gas emissions to 16–25 % below the 1990 level by 2030. Thus a substantial share of the reductions needed to achieve the assumed target of 40 % by 2030 could be achieved by actions inside the EU, with international emissions trading providing the remaining reductions.
- Substantial low-cost emission reductions are projected in the climate action scenario for nitrous oxide and methane emissions from industry, waste management and agriculture. However these options will have been almost fully exploited by 2030.
- In the climate action scenario, substantial changes in the EU energy system are projected, leading to energy-related emissions of CO_2 (the most important greenhouse gas) in 2030 that are 11 % below the 1990 level, compared with 14 % above in the baseline scenario. The baseline scenario assumes modestly optimistic economic growth with a diverse development of the European energy system. Larger domestic emission reductions would lead to increasing marginal abatement costs, for example a reduction to 21 % below 1990 levels would require the permit price to more than double by 2030.
- Reductions in the energy intensity of the economy are expected to account for almost half of the emission reduction in 2010. Towards 2030, their contribution will decrease, requiring a shift of effort to further long-term

changes in fuel mix, mostly in the power generation sector.

- Towards 2030 more than 70 % of the CO_2 emission reductions (in the climate action scenario compared with the baseline) are expected to be realised in the power generation sector, mostly as a result of a shift to low or non-carbon fuels.
- The use of solid fuels is projected to decline substantially and of natural gas to increase rapidly. Renewable energy (mainly wind power and biomass use) shows the largest increase of all primary energy sources (42 % higher than in the baseline). Combined heat and power will increase its share of electricity production.
- The report analysed various climate action variants, including a higher share of renewables and a higher and lower share of nuclear power, and the largest emission reductions are expected in a scenario that assumes a high share of renewables in addition to a carbon permit price.
- Carbon capture and storage has not been part of the detailed European model analysis. Other scenarios, however, show that this could help to reduce CO_2 emissions considerably towards 2030 and serve as a transition technology towards a low-carbon energy system.
- Considerable reductions in CO_2 emissions are projected for the industry, services and household sectors, mainly from fuel switch in industry and efficiency improvements in heating, electrical appliances and lighting. CO_2 emissions from transport are projected to continue to grow in all climate action scenario variants (to 25–58 % above the 1990 level by 2030), because of the steady increase in passenger and freight demand.
- Achieving a low-carbon energy system requires further measures in addition to a carbon price, including the removal of potentially environmentally harmful subsidies, setting targets for renewables, and energy efficiency and increases in research and development and awareness-raising.
- The additional annual costs of the climate action scenario compared with the baseline scenario are projected to be about EUR 100 billion by 2030. This would represent about 0.6 % of EU GDP, which is projected to double between 2000 and 2030. For the industrial sector, the additional costs by 2030 represent on average about 1.6 % of the value added by the sector, with different costs for subsectors. For the services sector, the additional costs by 2030 represent about 0.2 % of the value added by the sector. For households, the additional costs by 2030 would be relatively small, about EUR 110–120 per household, compared with an increase in energy costs, under baseline assumptions, of EUR 1 900/household in the EU-15 and EUR 3 400 in the EU-10 by 2030.
- A low-carbon energy system is expected to result in additional benefits, including ancillary environmental benefits, enhanced security of supply, and potential beneficial effects for employment. The EEA will publish a report on ancillary benefits for air quality.

1. Introduction

1.1 Purpose and scope

This report presents an assessment of possible greenhouse gas emission reduction pathways made feasible by global action and a transition to a low-carbon energy system in Europe by 2030. It analyses trends and projections for emissions of greenhouse gases and the development of underlying trends in the energy sector. It also describes the actions that could bring about a transition to a low-carbon energy system in the most cost-effective way.

The report could contribute to the political debate on possible post-2012 European climate change strategies, which can feed into the global debate on post-2012 strategies that is starting within the UN Framework Convention on Climate Change (UNFCCC) in 2005. The report and the scenarios developed for it can be used as an input to other EEA reports, in particular a report on environmental outlooks and the EEA 2005 State of Environment and Outlook report.

The report builds on various EEA reports published in 2003 and 2004, technical papers and reports that contain detailed information on the scenario studies performed specifically for the EEA, to be published on the EEA website in 2005 (EEA, 2005), and a number of other national and EU-wide studies (e.g. Criqui *et al.*, 2003).

1.2 Climate change and energy use as sustainability issues

Climate change is one of the four key environmental priorities of the EU sixth environmental action programme (6EAP) (European Council, 2002). Climate change should also be seen in the context of sustainable development in both developing and developed countries (including the EU). In the EU strategy for sustainable development (European Commission, 2001a), climate change is mentioned as one of the main threats to sustainable development, and energy use is explicitly linked to this by proposing limitation of climate change and increase in the use of clean energy together as a priority objective.

Human activities have increased the concentration of greenhouse gases (GHGs) in the atmosphere. Over the past 100 years, global mean temperature has increased. There is new and stronger evidence that most of the observed warming over the past 50 years is attributable to emissions of GHGs from human activities (IPCC, 2001a), in particular to emissions of CO_2 (the most important GHG) from burning fossil fuels and land-use changes, and other GHGs from industry, transport, waste management and agriculture. The highly industrialised European economic system, as well as the economies of other industrialised countries, relies on a carbon-intensive energy system (supply and demand). Substantial amounts of fossil fuels (coal, oil and natural gas) are burned, both in power and heat production (supply) and in the sectors using energy (demand). Other important direct anthropogenic GHGs include methane (CH_4) from agriculture and waste management (landfills), nitrous oxide (N_2O) from agriculture and industry and industrial halogenated gases (CFCs and HCFCs). Tropospheric ozone is also a greenhouse gas; it is formed in the atmosphere from carbon monoxide, nitrogen oxides and non-methane volatile organic compounds emitted by human activities (industry, road transport, households, energy industries) and natural or managed ecosystems.

Impacts of temperature increases can already be observed globally and in Europe. In the past 100 years, the sea level has risen, at least partially as a result of the warming of seawater and the melting of glaciers. The coverage of the earth's surface with ice and snow has shrunk and precipitation patterns have changed. Recently, central and northern Europe received more rain than in the past. In contrast, southern and south-eastern Europe has become drier. Impacts of regional climate change on animal and plant populations can already be discerned, as well as impacts on human health and economic losses from weather and climate-related extreme events (EEA, 2004a; IPCC, 2001b; ACIA, 2004).

Climate change has consequences for many natural and societal systems and should therefore be analysed in an integrated way together with other key global and European environmental issues, in particular air pollution, depletion of water resources, deforestation and loss of biodiversity. Climate change can be regarded as an additional pressure on natural systems that are already subject to various other pressures such as land-use changes.

The European Community (EC) and its Member States are parties to the United Nations Framework Convention on Climate Change (UNFCCC). The ultimate objective of the UNFCCC (Article 2) is to *stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner* (UNFCCC, 1992). However, scientific uncertainties do not allow unambiguous determination of concentration levels below which this condition could be considered fulfilled. Furthermore, determination of 'safe' or 'sustainable' concentration levels is not only a scientific issue but is also related to the observed and projected impacts and to perceptions, values and political negotiations (Criqui *et al*., 2003; van Vuuren *et al*., 2003). It also depends on socioeconomic capacity to mitigate or adapt to climate change — and the need to strike a balance is reflected in the reference to sustainable development in the UNFCCC Article 2. Many developing countries with currently relatively low GHG emissions are expected to be most affected by climate change, but have the least socioeconomic capacity to adapt. Developed countries have more resources and capacity to develop and implement measures to reduce emissions.

IPCC's third assessment report (IPCC, 2001a) indicates that stabilisation at levels in line with the UNFCCC ultimate objective would require substantial reductions in global GHG emissions. This implies that future emission reductions will require substantial and increasing efforts on emission reduction or limitation in all countries, going far beyond the reduction targets for developed countries of the Kyoto Protocol (2008–2012). Many developing countries currently have lower average total and per-capita GHG emissions than most of the developed countries. However, emissions in developing countries are projected to increase much more rapidly in the near future, and some (including newly industrialising countries) are expected to reach per-capita emission levels similar to those in developed countries. Furthermore, total emissions from developing countries are projected to become larger than those from developed countries in the near future.

1.3 EU climate change policy developments

To achieve the UNFCCC Kyoto Protocol targets, the EU has adopted and started to implement EU-wide common and coordinated policies and measures, through the European climate change programme, in addition to the implementation of national policies and measures.

The EU (European Council, 2002) has set an indicative long-term global temperature target of not more than 2 °C above pre-industrial levels (before about 1750), as its interpretation of the UNFCCC ultimate objective. Several Member States, based on their view of 'sustainable' GHG concentration levels and associated global emissions, have set national indicative policy targets for future substantial reductions of global and national emissions. A political debate started in 2005 within the UNFCCC on possible future (post-2012) emission targets, guided by the ultimate objective of the UNFCCC. The European Commission launched a public consultation on possible post-2012 climate change strategies in 2004 and the results of this are an important guide for the EU in discussions within the UNFCCC.

The Environment Council of 20 December 2004 (European Council, 2004) welcomed the outcome of the 10th session of the conference of the parties to UNFCCC (COP10), including the Buenos Aires programme of work on adaptation and response measures and the decision to start a dialogue among all parties in 2005 on current and future actions on adaptation and mitigation to respond to climate change.

The Environment Council's conclusions included:

- a reaffirmation of the target of not more than 2 °C global temperature increase above pre-industrial levels;
- that stabilisation of concentrations well below 550 ppm CO_2 equivalent ([1]) may be needed and global GHG emissions would have to peak within two decades, followed by substantial reductions of the order of at least 15 % and perhaps as much as 50 % by 2050 compared with 1990 levels;
- the willingness of the EU, in the context of a global agreement, to commit to its fair share of the necessary global mitigation efforts;
- the need for significantly enhanced reduction efforts by all developed countries, if allowance is made for an increase in emissions from developing countries in pursuit of sustainable development goals;
- the need to propose medium and longer-term emission reduction strategies, including targets, at the March 2005 (Environment) Council, taking into account the Commission's report on costs and benefits;
- the importance of emissions trading and project-based mechanisms beyond 2012 within a global framework, as a cost-effective way of reducing emissions and to support sustainable development in developing countries;
- the need for additional policies to arrive at low GHG-emitting economies, thereby improving competitiveness, for example by building competitive advantage into new technologies;
- the need for further increases in energy efficiency, and to significantly enhance investments in research and development with regard to low-carbon-emitting energy technologies;
- the need to prepare for and adapt to the consequences of some inevitable climate change, even with significant emission reductions over the coming decades, in developing and developed countries, to complement mitigation policies;
- the need to incorporate considerations of climate risks into poverty-reduction strategies and national strategies for sustainable development, to minimise the vulnerability of developing countries to climate change;
- the need to limit climate-change effects in order to help achieve the millennium development goals and the Johannesburg Plan of Implementation goals and targets, and the importance of the EU action plan on climate change in the context of development cooperation, adopted by the Council in November 2004, in achieving these goals;
- that addressing climate change has costs but also brings opportunities and incentives for innovation in support of the Lisbon Agenda goals of economic growth, full employment and sustainable development;
- that it is vital, when evaluating the costs and benefits of future climate-change policies, to include monetary, non-monetary and non-tangible aspects of climate change policies in the costs of both action and inaction.

The European Commission had been requested by the European Council (March, 2004) to report on the costs and benefits of medium and longer-term emission reduction strategies, including targets, for the 2005 Spring European Council. The Commission published a communication in February 2005 (European Commission, 2005a and 2005b), with proposals for a EU post-2012 climate change strategy, in which it did not propose specific targets for emissions post-2012. The communication proposed five elements that should be part of the future (post-2012) climate change strategy of the EU:

- broadening participation: there is an urgent need for wider participation on the basis of common but differentiated responsibilities; in order to minimise negative economic impacts, further policy efforts by the EU need to be accompanied by similar action by other major emitting nations;
- including more emission sources: the scope of international action must be widened to cover all greenhouse gases and sectors; in particular, the fast-growing emissions from aviation and maritime transport should be included;

([1]) CO-equivalent allows the concentration of a gas (or particle) to be expressed in terms of the concentration of CO_2 that would have a similar global warming effect.

Box 1.1: Summary of EU Council conclusions on targets (March 2005)

To minimise adverse effects, the EU, in the sixth environmental action programme (2002), defined an indicative long-term global temperature target of not more than 2 °C above pre-industrial levels, and a long-term CO_2 concentration stabilisation level of 550 ppm. The EU Environment Council meetings of 20 December 2004 and 11 March 2005 both reaffirmed the temperature target. However, reference to a possible long-term concentration level target was revised, compared to the target mentioned in the sixth environmental action programme. The Council meeting of 20 December 2004 concluded: *stabilisation of concentrations well below 550 ppm CO_2-equivalent may be needed and global GHG emissions would have to peak within two decades, followed by substantial reductions of the order of at least 15 % and perhaps as much as 50 % by 2050 compared with 1990 levels*.

Furthermore the EU Environment Council of 11 March 2005 (European Council, 2005) concluded that: *the EU looks forward to exploring with other parties possible strategies for achieving necessary emission reductions and believes that, in this context, reduction pathways by the group of developed countries in the order of 15–30 % by 2020 and 60–80 % by 2050 compared with the baseline envisaged in the Kyoto Protocol should be considered*.

The EU Spring Council of 22 March 2005 concluded that: *without prejudging new approaches for differentiation between parties in a future fair and flexible framework, the EU looks forward to exploring, with other parties, strategies for achieving necessary emission reductions and believes that, in this context, reduction pathways for the group of developed countries in the order of 15–30 % by 2020, compared with the baseline envisaged in the Kyoto Protocol, and beyond, in the spirit of the conclusions of the Environment Council, should be considered*. The Spring Council did not confirm reduction targets for 2050.

The climate action scenario presented in this report was developed for EEA before these Council conclusions were adopted. The EEA scenario assumes global and EU targets that are within the range mentioned by the Councils in March 2005.

- enhanced innovation: transforming energy and transport systems will be a major innovation challenge; a portfolio of low-emission technologies is already available and needs to be disseminated more widely, and more research is needed to bring new technologies closer to the market;
- the continued use of market-based and flexible instruments: there is a need to include emissions trading based on emission limitations and project-based mechanisms as building blocks of an international carbon market;
- the inclusion of adaptation policies: more resources need to be allocated in the EU to adapt effectively to climate change; the adaptation efforts of the poorest and worst-affected countries should be financially supported.

The conclusions of the Environment Council of 10 March 2005 and the EU Spring Council of 22 March 2005 are summarised in Box 1.1.

1.4 Scenarios developed for this report

This report addresses the need for a transition to a European society with substantially lower emissions of GHGs and the possible shape of a more sustainable European energy system. A 'climate action' scenario with several variants has been developed by the European Topic Centre on Air and Climate Change (ETC/ACC) for EEA (see Box 1.2). The time horizon of these scenarios is 2030. Also additional global energy and CO_2 emission scenarios

Box 1.2: The scenarios in this report

The results of the following scenarios are described in this report (see Chapters 4 and 5 and the underlying technical report (EEA, 2005) and (Criqui *et al.*, 2003) ([2]) for more detailed information on the scenarios and models):

The baseline scenario
The baseline scenario is a modestly optimistic economic growth scenario with a diverse development of the European energy system. The European population is projected to be relatively stable in the short to medium term and even to decline in the longer term, and thus increases in energy consumption are caused mainly by income growth. The baseline scenario does not take into account climate policies related to implementation of the Kyoto Protocol. At global level, the scenario is based on various studies (van Vuuren *et al.*, 2003; Criqui *et al.*, 2003); at European level the 'long-range energy modelling' (LREM) results ([3]) have been used. A similar baseline scenario is used up to 2020 for the Clean Air for Europe (CAFE) programme ([4]). For the purpose of this report, the European scenario was extended to include non-CO_2 GHGs using a model developed by AEA (Bates *et al.*, 2004), and non-CO_2 energy emissions and carbon sinks using IMAGE, TIMER (IMAGE, 2001) and FAIR models developed by RIVM ([5]). The POLES model, developed by IPTS (JRC), was used for additional global energy and CO_2 emission scenarios.

Climate action scenarios
The climate action scenarios explore ways in which Europe can move towards long-term sustainable objectives, in particular the EU long-term target for global temperature increase. The scenarios include policies and measures to reduce emissions of all six Kyoto gases for all the relevant main emitting sectors. A global emissions pathway to achieve a GHG concentration of 550 ppm CO_2-equivalent has been used from (Criqui *et al.*, 2003) in order to provide the global context.

Since a large part of the emissions are from the energy sector, specific scenarios have been developed for this sector. The low carbon energy pathway (LCEP) scenarios form part of the climate action scenarios and are designed to illustrate the development of the energy sector in which carbon prices alone determine the development of the energy system. They explicitly analyse actions beyond those formally agreed to date. They assumed a CO_2 price increase from EUR 20/tCO_2 in 2020 to EUR 65/tCO_2 in 2030. In the 'core' LCEP scenario, CO_2 emission reductions are more or less evenly distributed over various technological options, in a least-cost approach. The choice between supply and demand options to reduce the emissions of GHGs is made on the basis of cost-effectiveness of measures only.

Scenario variants were developed, which explore the implications of different assumptions and actions on a future energy system, including a variant assuming a high share of renewable energies in addition to the permit price, a variant with a higher share of nuclear energy as well as a nuclear phase-out variant. In the 'renewables expanded' variant it is assumed that the share of renewables in total energy consumption increases through the introduction of a renewables premium, in addition to the carbon permit price. The 'nuclear accelerated' variant assumes that new nuclear technologies become mature by 2010, leading more Member States to choose the nuclear option. The 'nuclear phase-out' variant assumes that existing nuclear plants are decommissioned at the end of their technical lifetime in addition to the stricter decommissioning policies that apply in certain Member States, and that no further investment in nuclear power occurs.

([2]) Criqui *et al.* (2003) Greenhouse gases reduction pathways in the UNFCCC process up to 2025; Technical Report — European Commission, Environment DG, Brussels.

([3]) PRIMES is a partial equilibrium model for the EU energy system developed by, and maintained at, the National Technical University of Athens. The most recent version of the model used in this study covers all EU Member States, EU candidate countries, and neighbouring countries, uses EUROSTAT as the main data source, and isupdated with 2000 as the base year (Mantzos *et al*., 2003).

([4]) CAFE is a programme organised by the European Commission (Environment DG) to prepare a thematic strategy to reduce air pollution and also makes use of the LREM projections. For CAFE scenarios see Amann *et al.*, 2004.

([5]) IMAGE: Integrated model to assess the global environment. TIMER: Targets IMage Energy Regional model. FAIR 2.0: a decision-support model to assess the environmental and economic consequences of future climate regimes. These models have also been used for a project on greenhouse gas reduction pathways in the UNFCCC process up to 2025, for the European Commission, Environment DG (Criqui *et al.*, 2003).

were developed with a time horizon of 2050. In line with the targets mentioned by the Environment Council and the Spring Council of March 2005, the report analyses scenarios that could achieve an EU GHG emission reduction target of 40 % below the 1990 level by 2030.

The climate action scenario and variants (henceforward referred to as 'climate action scenarios') include policies and measures to reduce emissions of all six Kyoto Protocol gases for all relevant main emitting sectors. Since a large part of the emissions is from the energy sector, specific scenarios and analyses have been developed for this sector. They were designed to illustrate a development of the energy system determined only by carbon prices. The report presents these scenarios and compares them with similar recent studies.

1.5 Outline of the report

Chapter 2 summarises the climate change impacts that are already being observed, what can be expected in future in Europe and the reasons for concern about climate change. Chapter 3 describes the agreed short-term Kyoto Protocol targets for emission reductions and possible long-term targets derived from GHG stabilisation levels, which may avoid dangerous climate change, and global approaches to equitable distributions of emissions between different regions in the world. Chapter 4 summarises a potentially low-emission pathway to 2030, based on the indicative EU long-term global temperature target of a maximum increase of 2 °C above pre-industrial levels. Chapter 5 describes technological options (fuel switch, energy effiency, renewables, nuclear, carbon capture and storage) for changes in the European energy system, which could lead to a more sustainable emission pathway. Chapter 6 presents the costs of the climate action scenarios for the main sectors.

2. Climate change impacts

Key messages

- Many changes in climate and its impacts are already visible globally and in Europe, and these are projected to become more pronounced. In Europe, mountain regions, coastal zones and wetlands and the Mediterranean region are particularly vulnerable. Although there are some positive effects, like an increasing potential for agriculture at high latitudes and reduced cold stress to humans, most impacts are adverse.
- Globally, developing countries are expected to be among the most affected by climate change, and have the least socioeconomic capacity to adapt. The Arctic region is also likely to be seriously affected, since it is warming more rapidly, and larger changes are projected than in many other areas of the world. The indigenous communities in the Arctic are already facing major economic and cultural impacts, which are expected to increase.
- Even if society substantially reduces its emissions of GHGs over the coming decades, the climate system is projected to continue to change over the coming centuries. In addition to taking mitigation measures, society will therefore have to adapt to the consequences of some inevitable climate change.

2.1 Overview of impacts

Various studies show that the climate is already changing and various impacts are visible throughout the world (e.g. IPCC, 2001c; Hare, 2003; ACIA, 2004; EEA, 2004a; WHO-ECEH, 2003). According to the UN Intergovernmental Panel on Climate Change (IPCC), *there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities, in particular to the emission of greenhouse gases* (IPCC, 2001a).

Global and European air temperature
Globally, the temperature increase over the past 100 years was about 0.7 °C, while European average temperature increased by about 1 °C. The warmest year in Europe was 2000; the next seven warmest years were all in the last 14 years. Global mean temperature is likely to increase by 1.4–5.8 °C between 1990 and 2100 (IPCC, 2001a).

Precipitation
Precipitation in northern Europe increased by about 10–40 % in the past 100 years, and decreased by up to 20 % in southern Europe. Projections show an increase of about 1–2 % per decade in northern Europe and a decrease of up to 1 % per decade in southern Europe.

Extreme weather events
The frequency of droughts, heatwaves and extreme precipitation events in Europe has increased while the frequency of cold extremes has decreased. Projections for temperature and precipitation extremes are highly uncertain. Nevertheless, cold winters are projected to disappear almost entirely by the end of this century and hot summers are projected to become much more frequent. The frequency of both intense precipitation events and summer droughts is projected to increase.

Glaciers, snow and ice
Eight out of nine glaciated regions in Europe showed a significant retreat over the last century. Glaciers in the European Alps lost approximately one third of their area and one half of their mass. It is likely that by 2050 about three-quarters of today's glaciers in Switzerland will have disappeared. The extent and duration of snow cover across Europe has decreased. Snowfall in lower mountain areas is projected to become increasingly unpredictable and unreliable. Sea ice in the Arctic regions of Europe has been in decline.

The Arctic climate is warming rapidly and much larger changes are projected. Annual average temperature has increased at almost twice the rate of that in the rest of the world, and it is projected to increase by 4–7 °C over the coming century. Reductions in sea ice will shrink the habitats of polar bears and seals. Many coastal communities and facilities face increasing exposure to storms. Several coastal regions will experience increasing problems due to sea level rise and the thaw of permafrost, which will weaken coastal land. Thawing ground will disrupt transportation, buildings and other infrastructure. Indigenous communities are facing major economic and cultural impacts. Many indigenous people depend on hunting polar bears, herding reindeer and fishing, all affected by climate change.

Water resources
Annual river discharge has changed over recent decades across Europe. River discharge is projected to increase in northern and north-western Europe and to decrease in parts of Mediterranean Europe. Climate change is projected to reduce water availability and increase irrigation withdrawals in the Mediterranean river basins.

Terrestrial ecosystems and biodiversity
Climate change has led to an increase of the length of the growing season, which is projected to increase further. The European terrestrial biosphere has been a carbon sink during the past 20 years, but the potential amount that can be sequestered in future is likely to be reduced. Climate change is an important additional stress factor on terrestrial ecosystems. Plant populations have decreased in some parts of Europe and increased in others (e.g. north-western Europe). In the Alps, tree species are moving upwards. Plant diversity has increased only in north-western Europe. Many plant species will have difficulties in responding to the projected temperature increase by migration or adaptation, and are likely to become more restricted in distribution or even extinct.

Marine systems and coastal zones
By 2100, the sea level is projected to rise by 0.09 to 0.88 m, with a central value of 0.48 m. Sea level rise will cause flooding, coastal erosion and the loss of flat coastal regions. Rising sea level increases the likelihood of storm surges, results in landward intrusion of salt water and endangers coastal ecosystems and wetlands. Sea surface temperature has increased, resulting in an increase in phytoplankton biomass, a northward movement of indigenous zooplankton species and an increasing presence and number of subtropical species in the North Sea.

Agriculture
Central and northern Europe could potentially benefit from increasing CO_2 concentrations and rising temperatures. The cultivated area could be expanded northwards, earlier sowing dates may be possible and growing seasons may be extended. In southern parts of Europe, agriculture may be threatened by climate change due to increased water stress. During the heat wave in 2003, many southern European countries suffered drops in yield, while some northern European countries profited from higher temperatures and lower rainfall.

Health
More than 20 000 additional deaths attributable to a combination of heat and air pollution, particularly among the aged, occurred in Europe during the summer of 2003. This is an example of what may happen more frequently in the future. The number of excess deaths due to heat is projected to increase if no adaptation measures are taken. Tick-borne diseases have increased. Ticks can transmit tick-borne encephalitis (TBE) and Lyme disease (in Europe called Lyme borreliosis). However many aspects of the link between human health and climate change are uncertain. The annual number of river flood events and the number of people affected by floods have increased, with adverse human health consequences.

Economic losses
Economic losses resulting from weather-related events have increased significantly in the last 20 years due to several reasons, including the increased frequency of extreme events as well as increased urbanisation and costly goods and infrastructure. Economic losses due to climate change may increase in the future because of the projected increase in extreme events, although this is uncertain.

Abrupt climate change
Various non-linear, abrupt changes with global and regional consequences may occur in future. Although the probability of occurrence of these changes is low, they are important because of the large impacts they may have. Abrupt climate change (IPCC, 2001a; Hadley Centre, 2005a) includes a slow down of the ocean thermohaline circulation, which may result in a general decrease in European temperature. There would, however, still be warming over parts of Europe and most other parts of the world due to increased greenhouse gas concentrations. Another abrupt climate change relevant for Europe would be the melting of large ice sheets (Greenland and the west Antarctic ice sheet), which together contain an amount of water that could lead to a 13-m increase in global sea level. Greenland alone could contribute to a 7-m sea level rise on a time scale of centuries.

2.2 Vulnerability and adaptation to climate change

Vulnerability is the extent to which a natural or social system is susceptible to sustained damage from climate change, considering the degree of exposure to climate change, the sensitivity of the system and its adaptive capacity. The impacts of climate change are not, and are not projected to be equally distributed between countries. Some natural systems, regions and sectors are more vulnerable than others. In Europe, the Arctic regions, mountain regions, coastal zones and wetlands and the Mediterranean region are particularly vulnerable.

Even if society substantially reduces its emissions of greenhouse gases over the coming decades, the climate system is projected to continue to change over the coming centuries. As well as taking mitigation measures, society therefore has to adapt to the consequences of some inevitable climate change. Adaptation strategies for affected systems are required at European, national, regional and local levels if severe damage to the environment, society and economies is to be prevented or limited.

Adaptation requires the participation of all stakeholders involved in any kind of policy, business or service that is or could be affected by climate change. There are several reasons why adaptation to climate change is needed and why planning should start now.

- Anticipatory and precautionary adaptation is more effective and less costly than forced, last minute, emergency adaptation or retrofitting.
- Climate change may be more rapid and pronounced than current projections suggest; there is a risk of under-adaptation and a potential for unexpected sudden events.
- Immediate benefits may be gained from better adaptation to climate variability and extreme climatic events.
- Immediate benefits may be gained by removing policies and practices that result in ineffective adaptation. An important aspect of adaptive management is to avoid the implementation of decisions that constrain or reduce the effectiveness of future options for adaptation.
- Climate change may bring opportunities as well as threats. Future benefits may result from climate change, and these opportunities could be realised or increased by appropriate adaptation and awareness. However, the faster the rate of climate change, the more difficult it will be to realise such benefits or adapt to its impacts.

Impacts of and adaptation to climate change, in addition to mitigation through reduction of GHG emissions and/or enhancement of 'carbon sinks', received considerable attention at the COP-10 meeting of UNFCCC (Buenos Aires, 6–18 December 2004). A Buenos Aires programme of work on adaptation and response measures was adopted (UNFCCC, 2004). This includes further scientific assessments of vulnerabilities and options for adaptation, support for the national action plans on adaptation of least-developed countries, and support for mainstreaming adaptation into sustainable development planning.

The need for adaptation to some inevitable climate change impacts has gained growing acceptance in Europe. Governments, businesses and nature conservation organisations have started to realise the relevance of climate change and to adopt new policies, regulations and standards that take account of projected climate change.

The EU Environment Council recognised the need to prepare for and adapt to the consequences of climate change in developing and developed countries. The EU supports vulnerable developing countries to adapt to climate change impacts through contribution to various adaptation funds under the UNFCCC and the Kyoto Protocol. A recent communication from the Commission sets out a EU framework on flood risk mapping. However, most EU policies (e.g. common agriculture policy) and environmental directives and policies (e.g. the water framework directive, the biodiversity strategy) do not include specific strategies or policies and measures to address climate change impacts.

National adaptation strategies are currently under preparation and are due to be finalised in 2005 in Denmark, Finland, Germany and the United Kingdom. In the Netherlands, the need to address climate change impacts and adaptation is incorporated in the national spatial policy. In many EU Member States, adaptation measures are taking place in the context of natural hazard prevention, environment protection, and sustainable resource management.

3. Climate change targets

Key messages

- The Kyoto Protocol entering into force on 16 February 2005 is a first small but vital step towards further global emission reductions. Ratifying industrialised countries are committed to an average reduction of 2.8 % by 2008–2012 (from the 1990 level). These countries represent about 64 % of total emissions from industrialised countries, since the US and Australia have not ratified.
- In the long term (after 2100), achieving the EU target of limiting global temperature increase to 2 °C above pre-industrial levels would require concentrations of well below 550 ppm CO_2-equivalent (broadly consistent with a concentration of 450 ppm of CO_2 alone).
- For the analyses in this report, the 2 °C target has been translated into stabilisation of greenhouse gas concentrations at a level of 550 ppm CO_2-equivalent. This would require *global emissions* to be limited to an increase of 35 % above the 1990 level by 2020 and then decrease to 15 % below the 1990 level by 2050. However, to reduce the risk of overshooting the 2 °C target, recent scientific insight has shown that global emissions should possibly be reduced by 50 % by 2050. The range mentioned by the EU Environment Council of March 2005 is a decrease to 15–50 % below the 1990 level by 2050. Further research is needed to better quantify the required global emission reductions.
- Reducing global emissions to achieve the EU global temperature target would lead to the avoidance of many, but not all, adverse effects globally and in Europe.
- The EU Environment Council (March 2005) adopted the conclusion that to achieve stabilisation in an equitable manner, developed countries should reduce emissions by about 15–30 % by 2020 and 60–80 % by 2050, below the base year levels (1990). This report analysed an EU emission reduction target of 20 % below the 1990 level by 2020, 40 % below by 2030 and 60 % by 2050. These assumed targets are within the ranges mentioned by the EU Environment Council of March 2005.

3.1 The Kyoto Protocol

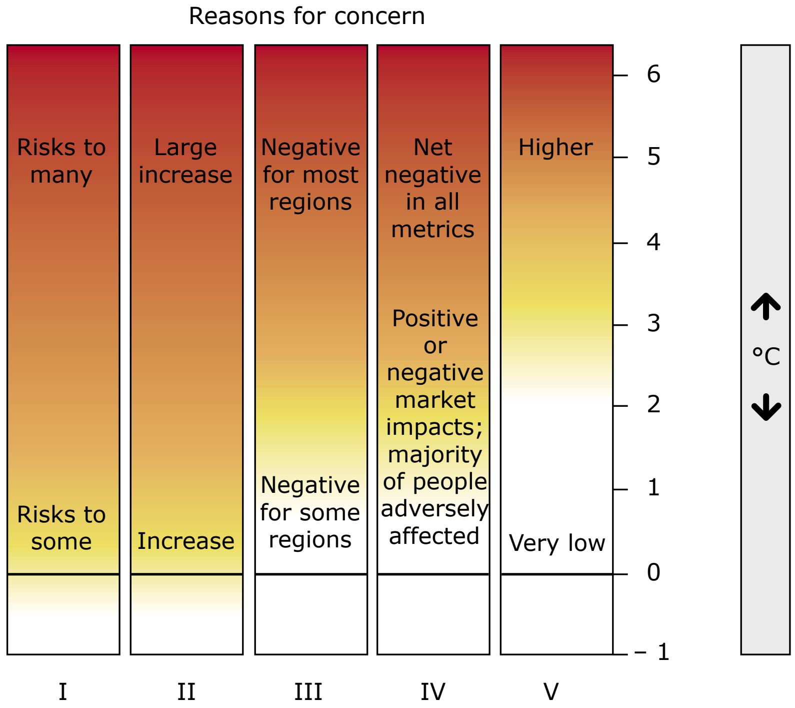
As a first step towards the UNFCCC ultimate objective of stabilising GHG concentrations, the third conference of the parties to the UNFCCC (COP3, Kyoto 1997) adopted binding targets for emissions of six GHGs (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorcarbons (HFCs), perfluorcarbons (PFCs) and sulphur hexafluoride (SF_6)) for industrialised countries in the Kyoto Protocol, which stated in Article 3: *The parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions,…, do not exceed their assigned amounts,...with a view to reducing their overall emissions of such gases by at least 5 % below 1990 levels in the commitment period 2008 to 2012.*

Although the Annex I parties agreed to an overall reduction of 5.3 % (960 million tonnes) from base year levels by 2008–2012, this implies a 4 % (720 million tonnes) reduction compared with 1990 emissions, due to the use of base years other than 1990 by several countries (den Elzen and de Moor, 2002). At the end of 2004, all Annex I parties, with the exception of Australia and the United States, had ratified the Protocol. The overall target of these parties (responsible for 64 % of the GHG emissions of the Annex I parties) was a reduction of 4.8 % (570 million tonnes) compared with their base year emissions and 2.8 % (330 million tonnes) compared with their 1990 emissions.

Under the Kyoto Protocol, the European Community, which at that time had 15 Member States, agreed to reduce its GHG emissions by 8 % ([6]) from base year levels by 2008–2012, a reduction of about 330

([6]) 7.7 % compared with 1990, taking into account that most EU-15 countries opted for 1995 as the base year for the F-gases, with the exception of Finland and France, which took 1990 as base year for the emissions of all six GHGs.

Figure 3.1 Risks for a range of global temperature increases



Note: Each column corresponds to a reason for concern, shown against increases in global mean temperature above the 1961–1990 average (°C). Category 1 represents the risk to unique and threatened systems; category II the risk of extreme climate events; category III the distribution of impacts; category IV aggregated impacts; category V the risk of large-scale discontinuities. White indicates small negative or positive impacts or risks, yellow indicates negative impacts for some systems or low risk, and red means negative impacts or risks that are more widespread and/or greater in magnitude.

Source: IPCC, 2001a and IPCC, 2001b.

million tonnes. The EU-15 and its Member States agreed in 2002 on different emission limitations and/or reduction targets for each Member State according to economic circumstances — the 'target-sharing' agreement. Eight Member States agreed to meet reduction targets, two to stabilise emissions, and five to limit their increases, in all cases by 2008–2012.

The new EU Member States belong to the UNFCCC group of countries undergoing the process of transition to a market economy (except Cyprus and Malta) and most of them have targets under the Kyoto Protocol. The eight Member States which joined the EU in 2004 keep their individually agreed reduction targets under the Kyoto Protocol, ranging from 6 to 8 % from the base year levels. In total, this means that the EU-23 ([7]) has to reduce emissions by 5.3 % compared with 1990. Two accession countries, Bulgaria and Romania, will probably join the EU in 2007. Both countries have a target of an 8 % reduction compared with their base year (respectively 1988 and 1989).

In addition to domestic measures, parties are also allowed to make use of so-called Kyoto mechanisms — emissions trading, joint implementation, the clean development mechanism — to achieve their targets by activities abroad (UNFCCC, 2002).

Reductions are for net emissions, i.e. gross emissions from sources minus captures by sinks (resulting from afforestation and reforestation). The Marrakech Accords (2001) allowed partial inclusion of carbon removal by managed forests in accounting for emissions.

With ratification by Russia, the Protocol acquired 64 % of the GHG emissions from Annex I countries, passing the necessary minimum of 55 %, and it entered into force on 16 February 2005. In total, 150 countries have ratified the Protocol (UNFCCC, 2005).

([7]) There are no targets for Cyprus and Malta.

3.2 Potential sustainable greenhouse gas concentration and temperature levels

3.2.1 Climate change risk assessment

The EU global temperature objective of a maximum of 2 °C above pre-industrial levels was first established in 1996 during preparations for the Kyoto negotiations, and reaffirmed subsequently in various Environment Council conclusions and in the sixth environmental action programme. The EU Environment Council meeting of 20 December 2004 reaffirmed the EU target of limiting global temperature increase to 2 °C above pre-industrial levels.

Assessment of the impacts and associated risks of climate change have improved over recent years, as presented in the third assessment report of the IPCC (IPCC, 2001b), and afterwards (e.g. Hadley Centre, 2005a; ECF, 2004; WBGU, 2003a; EEA, 2004a). However, the 2 °C target cannot be considered to be a safe level to avoid all adverse effects, and there are still several uncertainties in establishing such a target.

In its third assessment report, the IPCC identified five 'reasons for concern' (Figure 3.1) that summarise the differences in vulnerabilities between regions, natural systems and sectors which could help to determine what may be regarded as 'dangerous climatic change' (IPCC, 2001c). Leemans and Eickhout (2004) added an additional reason to the list, showing the risk to regional and global ecosystems. They concluded that the risk increases rapidly above a 1–2 °C increase in global mean temperature.

In general, impacts will increase as temperatures rise. For some types of impact the increase will be relatively smooth and it is difficult to identify global and regional damage thresholds. For others, such as heat wave mortality, coral reef losses and thawing of permafrost, a critical temperature threshold may be identified. The expected increases in temperature and climate impacts vary regionally, making some thresholds regional rather than global. In highly vulnerable areas, such as parts of Africa and the Arctic, serious regional impacts are already occurring. Significant global impacts on ecosystems and water resources are likely at global temperature rises of between 1 and 2 °C, and the risks of adverse impacts on global food production occur at temperature increases of 2–3 °C and more (Hadley Centre, 2005a).

Exceeding temperature thresholds could trigger climate feedbacks that strongly accelerate climate change, initiate irreversible changes to the climate system, or result in rapid exacerbation of impacts to which adaptation would be very difficult or impossible. The temperature changes at which these thresholds would be passed are uncertain. At a temperature rise above 2 °C, there is an increase in the risk of a shutdown of the thermohaline ocean circulation. The melting of the Greenland ice sheet may be initiated at a global temperature rise of 1.5 °C and could be irreversible (Hadley Centre, 2005b).

The German Advisory Council on Global Change defined 'dangerous climate change' in terms of tolerable changes to global mean near-surface air temperature. On the basis of an extensive evaluation of 'tolerable' limits to climate change for ecosystems, food production, water availability, economic development and human health, changes in the composition and functioning of today's ecosystems cannot be ruled out if the global mean temperature were to rise by more than 2 °C above the pre-industrial temperature and by 0.2 °C or more per decade (WBGU, 2003a).

3.2.2 Potentially dangerous concentration levels

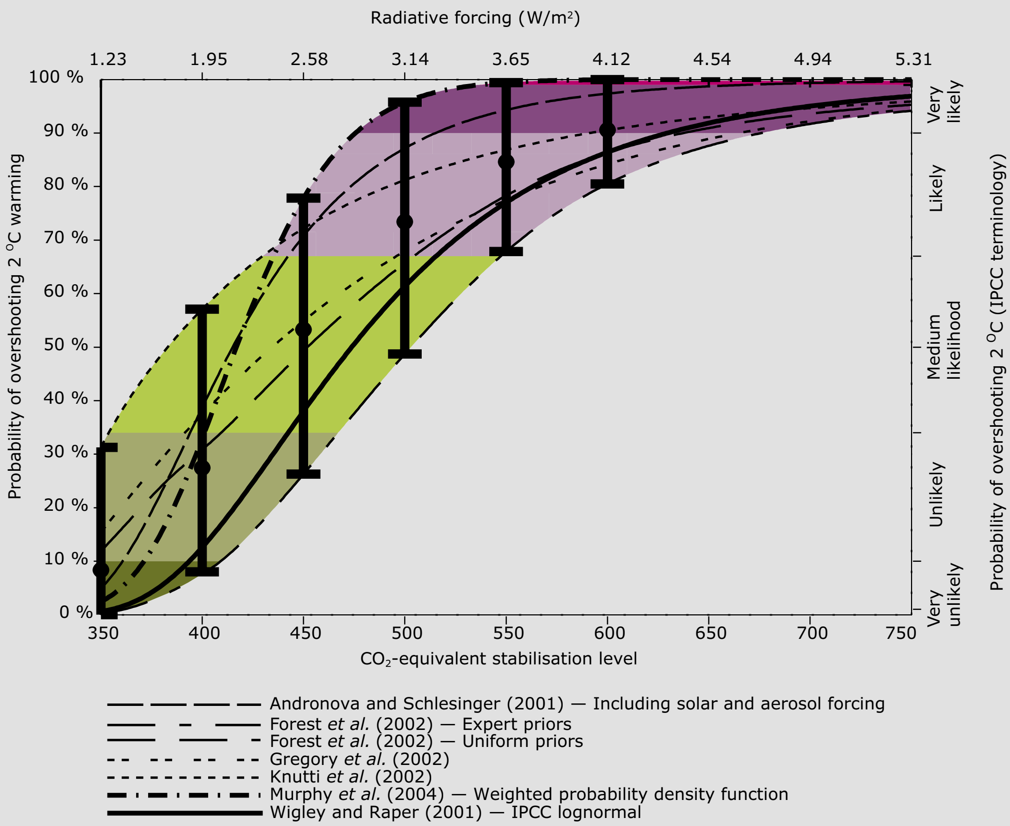
The UNFCCC ultimate objective is to *stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner*. Determining the meaning of 'dangerous' or 'safe' or 'sustainable' concentration levels depends on many factors. Important factors are the type and intensity of currently observed and projected impacts and the capacity to adapt, which varies between countries and regions. The capacity for, and costs attached to, mitigating emissions will also be elements to consider.

The time frame is a very important factor determining the concentration level that can be reached.

Box 3.1: The two degree target; recent insights

The probability of overshooting the EU temperature target at 550 ppm CO_2-equivalent has recently been estimated to be at least 70 % or to be 'likely' (see figure; CO_2-equivalents in this approach include non-Kyoto greenhouse gases, e.g. ozone and aerosols). In order to minimise the risk of overshooting the 2 °C target, the figure strongly suggests, according to these new insights, long-term sustainable targets of 450–500 ppm CO_2-equivalents or less to be reached well before 2400, providing a medium probability of the temperature target being achieved (Hare and Meinshausen, 2004; den Elzen and Meinshausen, 2005a and 2005b). The target of 550 ppm CO_2-equivalent by 2100, for the Kyoto GHGs, used as target for this report, can, according to this new information, be seen as a conservative upper estimate target for 2100 and requires concentrations to decrease further after 2100.

Figure CO_2-equivalent concentration levels and their associated probability of overshooting the global 2 °C target by 2400



Source: Hare and Meinhausen, 2004.

Note: The definition of CO_2-equivalent (Hare and Meinshausen, 2004) is derived from the net forcing of all anthropogenic radiative forcing agents including warming by tropospheric ozone and the cooling (dampening) effect of (sulphate) aerosols. In 2005, the CO_2-equivalent concentration of the Kyoto GHGs is approximately 425 ppm, while the net effect of all anthropogenic radiative forcing agents, including aerosols, is estimated to be 368 ppm CO_2-equivalent.

There is no simple link between the level at which greenhouse gases are to be stabilised and the allowable increase in global temperature. This is due to limitations in the understanding of the climate system and the accuracy of modelling future climate change and future socioeconomic developments. The main uncertainty factors when modelling the future global temperature are the climate sensitivity ([8]) and the assumptions on emissions of non-CO_2 greenhouse gases and their reduction potential.

([8]) The expected global mean temperature increase associated with GHG emissions depends on the uncertainty with respect to 'climate sensitivity', which is defined as the equilibrium global temperature increase over pre-industrial level that would result from a doubling of CO_2-equivalent concentrations. IPCC (2001a) estimates the range of this climate sensitivity between 1.5 and 4.5 °C, with a median value of 2.5 °C.

The original EU 2 °C maximum temperature target (European Council, 2002) related to stabilisation of atmospheric CO_2 concentrations (i.e. not all Kyoto gases) below 550 ppm. However, several studies since then have shown that for low to medium estimates of the sensitivity of the climate system, the temperature target is consistent with 550 ppm CO_2-equivalent rather than CO_2 alone, or approximately 460 ppm CO_2 alone, by 2100 (Eickhout *et al.*, 2003; WBGU, 2003a).

The uncertainty about climate sensitivity is unlikely to be resolved conclusively in the near future. Some recent scientific work has taken a probabilistic approach to estimating the probability of overshooting a given temperature objective for different stabilisation levels of greenhouse gases (see Box 3.1). The main conclusion of this approach is that there is still a large probability of overshooting the 2 °C target at a stabilisation level of 550 ppm CO_2-equivalent by 2100.

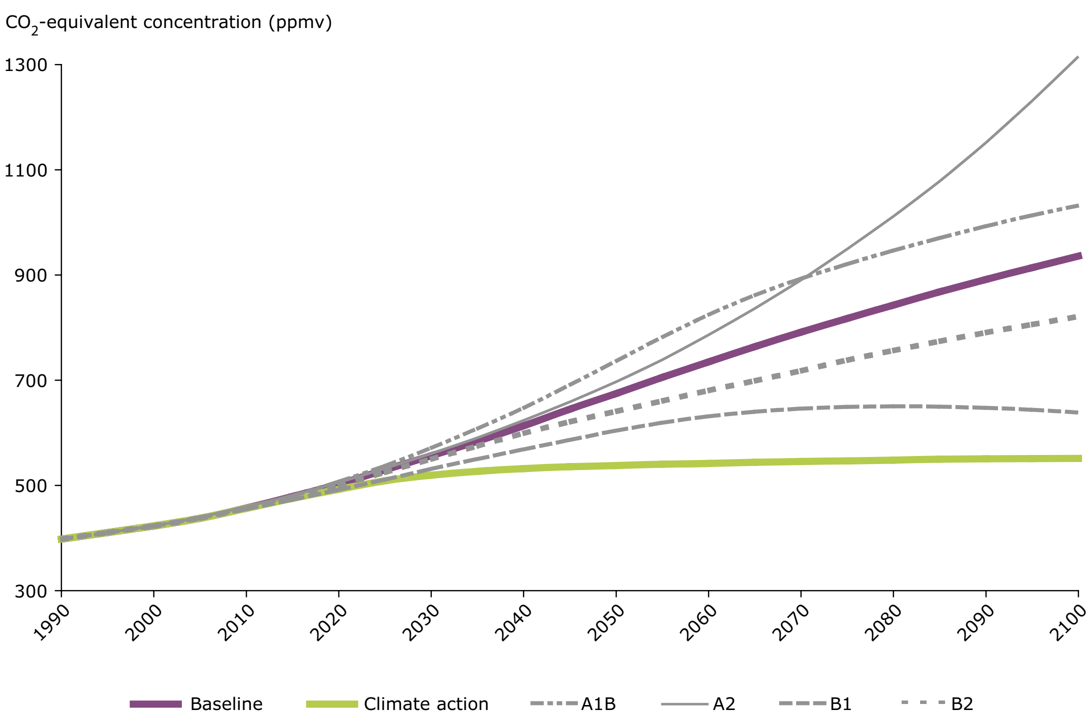
Taking such recent scientific research into consideration, the EU Environment Council (December 2004) recognised that recent scientific research and work under the IPCC indicates that it is unlikely that stabilisation of GHG concentrations above 550 ppm CO_2-equivalent would be consistent with meeting the EU temperature target. It recognised that stabilisation at well below 550 ppm CO_2-equivalent may be needed and noted that global GHG emissions would have to peak within two decades if this was to be achieved, followed by substantial reductions of the order of at least 15 % and perhaps as much as 50 % by 2050 compared with base year levels (European Council, 2004).

Further research is needed to better quantify the thresholds and risks of various global temperature increases and the risks of overshooting the EU temperature target at different levels of GHG concentration.

3.2.3 *Greenhouse gas concentrations: trends and projections*

The concentration of greenhouse gases has fluctuated considerably in the past, but has currently reached unprecedented levels. GHG concentrations in the atmosphere have increased from the pre-industrial level

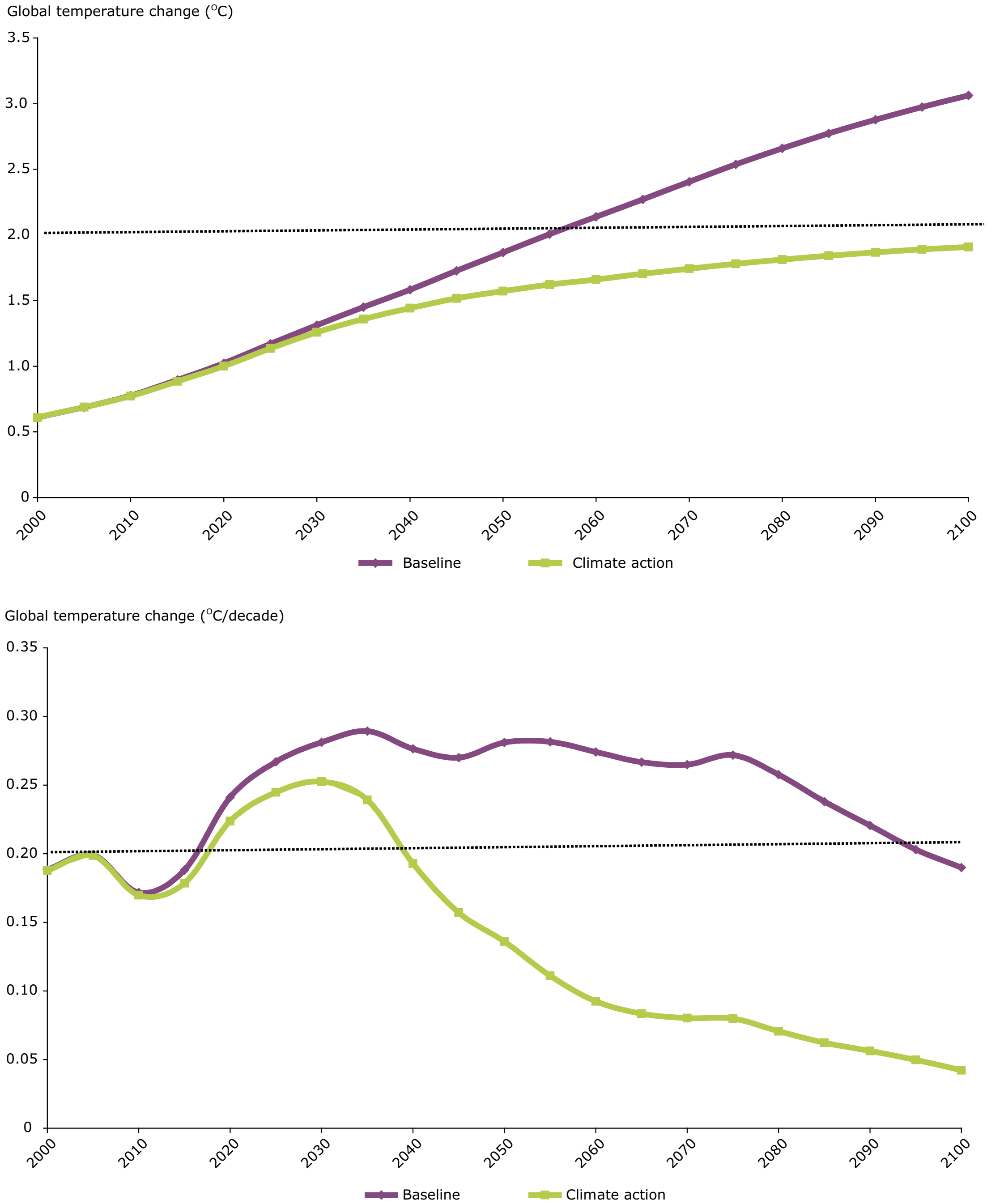
Figure 3.2 Atmospheric Kyoto greenhouse gas concentration (in CO_2-equivalents) between 1990 and 2100



Note: Baseline (blue line), EEA climate action scenario (green line), compared with four IPCC (SRES) scenario's (described in IPCC's Special Report on Emissions Scenario's, 2000) (grey lines).

Source: IMAGE model (EEA, 2005).

Figure 3.3 Changes in global mean temperature (top) and rate of change (bottom) for the base line and the climate action scenarios, compared with pre-industrial



Note: Dotted lines show EU long-term sustainability objective (top) and the proposed rate of change objective (bottom).

Source: IMAGE model (EEA, 2005).

of 278 to 425 ppm CO_2-equivalent ([9]). The concentration of CO_2 in the atmosphere has increased from 278 (pre-industrial) to 375 ppm. Projected emissions under the baseline scenario are for an increase in GHG concentration from 425 ppm in 2005 to 675 ppm CO_2-equivalent (or 528 ppm CO_2 alone) by 2050 and 935 ppm by 2100 (or 695 CO_2 alone).

This shows that the EU target of keeping the GHG concentration below 550 ppm

([9]) By definition, the CO_2-equivalent concentration includes the pre-industrial level of CO_2 while for non-CO_2 (Kyoto) GHGs only the changes after pre-industrial levels are taken into account.

CO_2-equivalent will not be met by a large margin. In the climate action scenarios, the concentration stabilises in about 2050 at approximately 550 ppm CO_2-equivalent (or 460 ppm CO_2 alone). CO_2 remains by far the most important GHG, contributing about 80–85 % of the total concentration (in both the baseline and the climate action scenarios, for all years). All non-CO_2 GHGs show increasing concentrations in the baseline scenario and also in the climate action scenario, in varying degrees, despite emission reductions in the climate action scenario. Currently CH_4 is the second most important GHG. Its contribution remains high in the baseline, but declines in the climate action scenario due to effective policy measures and the short lifetime of methane in the atmosphere. N_2O currently contributes only about 2 %, and the current contribution of F gases covered by the Kyoto Protocol is smaller. However, the contribution of N_2O and 'Kyoto F gases' doubles up to 2100 due to their long lifetime. The contribution of F gases covered by the Montreal Protocol (currently more important than N_2O) over the next 50 years diminishes due to the implementation of policies to protect the stratospheric ozone layer.

3.2.4 Global and European temperature: trends and projections

Globally, the temperature increase over the past 100 years was about 0.7 ± 0.2 °C (EEA, 2004a), and the current global rate of change is about 0.18 ± 0.05 °C per decade (IPCC, 2001a). These changes are unusual in terms of both magnitude and rate of change. The observed global temperature change is about one third of the EU target of 2 °C global average temperature increase above the pre-industrial level, thus leaving only a maximum temperature increase of 1.3 °C from current levels. The indicative target for maximum global rate of change (0.2 °C per decade, WBGU, 2003a) may be exceeded in the near future. Current emissions of GHGs will already lead to a substantial additional temperature increase and make meeting the EU target a challenging task (Hare and Meinshausen, 2004). Global mean temperature is likely to increase by 1.4–5.8 °C between 1990 and 2100, depending on the scenario (IPCC, 2001a). The baseline scenario used in this report shows a global mean temperature increase of 3.1 °C between pre-industrial levels and 2100 (Figure 3.3). The EU global temperature increase target (maximum 2 °C above pre-industrial levels) is thus likely to be exceeded by about 2050 (Figure 3.3), within the range estimated by IPCC of 2040 to 2070 (IPCC, 2001a).

European average temperature increased by about 1 °C in the past 100 years (CRU, 2005; Klein-Tank, 2004). The warmest year in Europe was 2000; the next seven warmest years were all in the last 14 years. The mean temperature in Europe is projected to increase by 2–6.3 °C between 1990 and 2100, slightly more than the global mean temperature (Parry, 2000). The largest warming is projected for the southern and north-eastern parts of Europe.

Under the climate action scenarios, the global average temperature increase to 2100 remains just below the 2 °C maximum target. The increase to 2050 is about 1.6 °C (compared with pre-industrial), so the largest increase is projected for the first half of the century. However, because the temperature increase does not show a clear stabilisation, a temporary exceedance of the EU objective can be expected in the 22nd century, followed by a decrease due to falling concentration levels. Analysing the rate of global average temperature change, a peak at 0.25 °C per decade is projected, followed by a considerable decrease down to 0.05 °C per decade. Thus an exceedance of the indicative target of 0.2 °C per decade is also projected in the climate action scenarios for some decades during the 21st century.

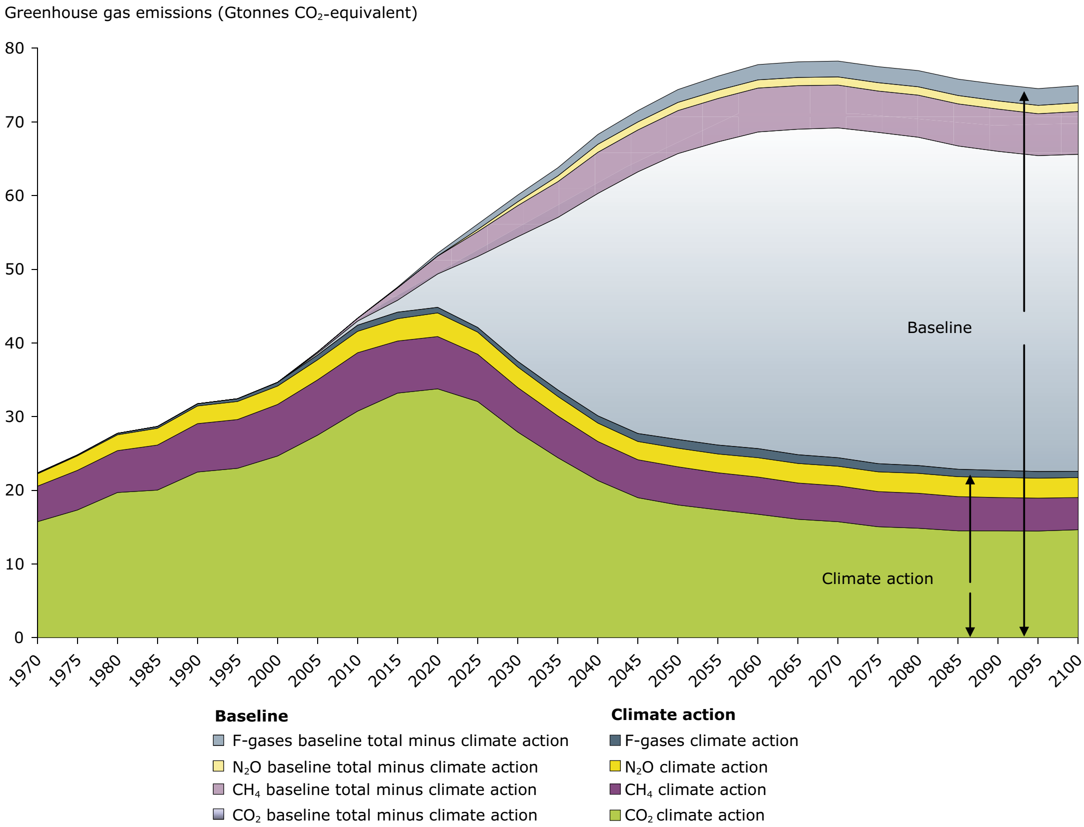
3.3 Long-term global and regional emission targets

3.3.1 Global emission reduction targets

The EU Environment Council (March 2005) concluded that global greenhouse gas emissions should peak by around 2020 and then decrease, to at least 15 %, or possibly even 50 %, below the 1990 level by 2050. This target was the result of a political debate in which several sources of information were used. Some of the relevant sources are summarised here.

The WBGU (2003b) has proposed reducing global CO_2 emissions from fossil fuels by 45–60 % from 1990 levels by 2050 (based on a stabilisation goal of 400 ppm CO_2). Different emission pathways would reach the same stabilisation level for GHG concentrations, even if the same target year

Figure 3.4 Global greenhouse gas emissions for the baseline and climate action scenario (1970–2100)



Note: See Chapter 4 for explanations on the assumptions for these scenarios.

Source: IMAGE model (van Vuuren *et al*., 2003).

is chosen. If lower reductions are allowed in earlier decades, steeper reductions would be necessary in later decades.

Other studies (Criqui *et al*., 2003; Eickhout *et al*., 2003) showed that for stabilisation of CO_2 concentration at 450 CO_2 ppm (approximately 550 ppm CO_2-equivalent), global GHG emission levels should be limited to 35 % above the 1990 levels by 2020 and decrease thereafter to 15 % below the 1990 level by 2050, and 30 % below by 2100.

In this report, the same global emission pathway (Criqui *et al*., 2003; Eickhout *et al*., 2003) was used for further analysis. The indicative global emission reduction target (of 15 % below 1990 by 2050) analysed in this report is within the range mentioned in the conclusions of the EU Environment Council.

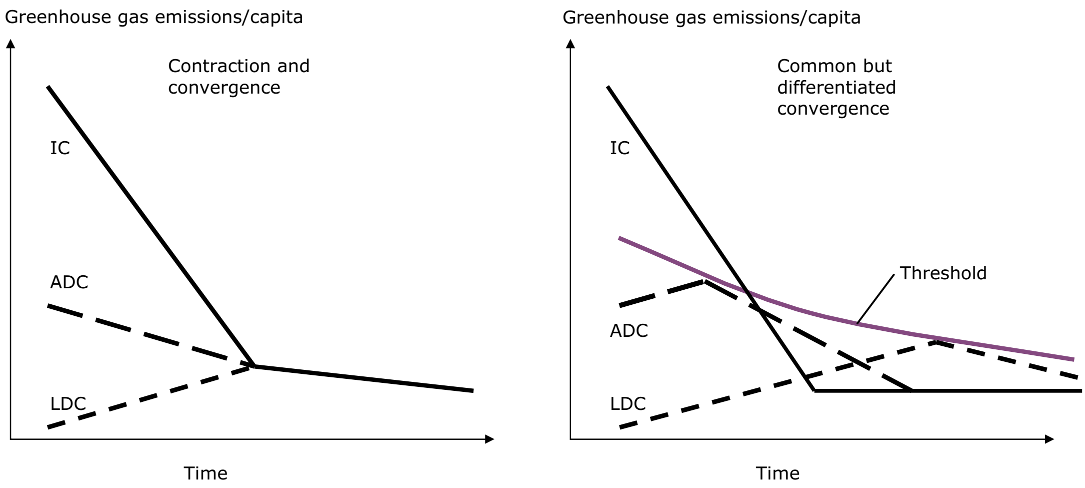
However, as indicated in Section 3.2.2, recent insight has shown that there is still a large probability of overshooting the 2 °C target at a stabilisation level of 550 ppm CO_2-equivalent by 2100 and global emissions should possibly be reduced by as much as 50 % by 2050. Further research is therefore needed to better quantify the global emission reductions required to minimise the risk of overshooting the EU temperature target.

Considering the many uncertainties in the impacts of climate change and emission reduction costs, the IEA has advocated a more flexible approach which involves adopting ambitious short-term as well as long-term objectives while making implementation of measures to achieve such targets dependant on actual abatement costs. The targets could be relaxed if the costs of full achievement appear excessive (IEA, 2002).

3.3.2 Different approaches to define national targets

In a long-term global climate change strategy, global emission reduction targets would have to be shared between countries, taking into account 'common

Figure 3.5 Schematic representation of GHG emissions per capita for three countries under contraction and convergence (C&C, left) and under common but differentiated convergence (CDC, right)



Note: IC = industrialised country, ADC = advanced developing country, LDC = least-developed country.

Source Höhne *et al*., 2005.

but differentiated responsibilities' between developed and developing countries, as stated by the UNFCCC. Such sharing of efforts could imply distribution of targets to countries either as emission reductions or as emission limitation targets.

There are various approaches to defining national contributions, which are currently being discussed within various science policy frameworks in anticipation of a more formal discussion within the UNFCCC. Several of these approaches have been presented at side events (informal meetings) of UNFCCC in recent years. Depending on the method used, different emission allowances for Europe would result. A key element of any proposal for differentiation of future commitments should be equity or fairness. Equity considerations include the distribution of the costs of mitigating GHG emissions and adapting to impacts of climate change. IPCC (2001b) has indicated that developing countries will be particularly damaged by climate change because they are more vulnerable. These countries, in particular the least-developed countries (LDCs), have the least socioeconomic capacity to cope with climate change impacts, especially the observed and projected increases in the frequency and intensity of extreme events (floods, droughts, etc). The distribution of the costs of the impacts and of adapting to them can be dealt with via policy instruments such as the adaptation fund adopted in the Marrakesh Accords (UNFCCC, 2002), when that is funded. Capacity to adapt to and mitigate climate change is likely to form part of the discussions in UNFCCC on a fair and equitable future differentiation of future mitigation efforts from 2005 onwards.

Most approaches either assume or result in a continuing growth in emissions from developing countries for some time and reductions in emissions from developed countries, a peaking of global emissions in the near future and an overall decrease in global emissions thereafter. Developing countries may stabilise and then reduce their emissions at different times in the future.

A number of approaches to the sharing of global emission targets among countries have been proposed internationally (see also den Elzen *et al.*, 2003a and 2003b; Höhne *et al*., 2005):

Historical contribution to climate change (the Brazilian proposal)
During negotiation of the Kyoto Protocol, Brazil proposed linking the relative contribution of industrialised parties to their relative contribution to the global mean temperature increase (UNFCCC, 1997). This proposal was not adopted but did receive support, especially from developing countries, and is still under consideration by the Subsidiary Body for Scientific and

Technological Advice of the UNFCCC for evaluation of its methodological aspects (e.g. UNFCCC, 2002). While the original proposal only involved defining targets for industrialised countries, several authors have sought to extend it to developing countries. In a recent study (den Elzen *et al.*, 2005), the Brazilian proposal approach is applied in combination with an income threshold for participation of the non-Annex I regions (see Section 3.3.3).

Per-capita contraction and convergence (C&C)
This approach was initially developed and promoted by the Global Commons Institute under the term 'contraction and convergence' (Meyer, 2000). It defines emission quotas on the basis of a convergence of per-capita emissions, under a contracting global GHG emission profile. In such a convergence regime, all countries participate, with emission allowances converging to equal per-capita levels over time (e.g. C&C50 stands for convergence over 50 years).

Common but differentiated convergence (CDC)
This approach (Höhne *et al.*, 2005) is based on the principle that the per-capita emissions of Annex I countries converge within several decades to a low level. Individual non-Annex I countries also converge to the same level over the same period, but starting when their per-capita emissions are a certain percentage above the global average. Until then, they may voluntarily take on 'positively binding' targets (non-binding targets allowing emissions trading, see below). This approach combines aspects of the contraction and convergence (C&C) approach with others from multi-stage approaches, but it eliminates a concern often mentioned regarding C&C. Under CDC, advanced developing countries start reducing emissions later than Annex I countries, avoiding the excess emission allowances for low emission countries that occur under C&C (see Figure 3.5).

Multi-stage approach
This is an incremental but rule-based approach, which assumes a gradual increase in the number of Annex I parties involved which are adopting binding quantified emission intensity targets (see *indexed and intensity targets* below) or reduction objectives, whether absolute or dynamic. It consists of a system that divides countries into different groups, with different types of commitment (stages). The number of countries involved and their level of commitment gradually increases according to pre-defined participation rules (Gupta, 1998; Berk and den Elzen, 2001; den Elzen and de Moor, 2002; den Elzen *et al.*, 2004; den Elzen *et al.*, 2005).

The triptych approach
This is a method of sharing emission allowances among a group of countries, taking into account the main differences in national circumstances. It was originally developed as an approach to sharing emission allowances within the EU for the first commitment period under the Kyoto Protocol (Philipsen *et al.*, 1998). It distinguishes three broad categories of emissions and suggests three different rules for allocation:

- convergence of GHG intensity of electricity production in the power sector;
- convergence of energy intensity in energy-intensive industries;
- convergence of per-capita GHG emissions in 'domestic' sectors.

The allowances for each category are added up to a national target for each country. Only one national target per country is proposed and no sectoral targets, to allow countries the flexibility to pursue any cost-effective emission-reduction strategy.

Global compromise approach
This combines a 'grand-fathering' entitlement method with a per-capita approach (Bartsch and Müller, 2000). A 'preference score share' to be reached by each country is calculated by adding the relative emission shares of each method, weighted by the share of world population that is assumed to prefer the Brazilian or the C&C approach (basically Annex I industrialised countries versus non-Annex I developing countries).

Ability to pay or Jacoby rule
This consists of a set of rules (Jacoby *et al.*, 1999) for progressively integrating non-Annex I countries into a system of global emission reductions and defining subsequent levels of reduction commitments for meeting long-term climate targets, depending basically on GDP per capita in each country.

Indexed and intensity targets
While the above proposals have all focused on how to allocate emission allowances

to the various countries, others have focused on the possibility of differentiating the nature or form of the targets or commitments (see IEA, 2002; Philibert *et al*., 2003). The concept of indexed or dynamic targets allows assigned amounts to be based on an economic projection that can be adjusted at a later stage if economic reality deviates significantly from the projection. Indexation can be 'less than proportionate' and take a great variety of forms. One 'pure' form would be 'intensity targets' in which the target is expressed as a ratio of emissions to GDP. Intensity targets are suggested as being particularly appropriate for developing countries, since they impose fewer constraints on economic growth than an absolute cap. In one approach, an equal right to emit is combined with an equal (proportional) ability to pay or an equal distribution of the commitment. Intensity targets could cover CO_2 emissions from fossil fuels only, or also other GHGs (see also Pew, 2004). Intensity targets would presumably vary from country to country as the departure points and national circumstances are very different.

Price caps
In a context of uncertain abatement costs and uncertain mitigation benefits, and given the cumulative nature of the climate change problem, it has been suggested that capping the marginal abatement cost could prevent excessive costs that do not outweigh additional benefits (Pizer, 2002). It would also facilitate the adoption of more ambitious policies while making full achievement of the targets dependant on actual costs (IEA, 2002). The price cap (or 'safety valve') would take the form of supplementary permits available in unlimited supply at a given price.

Non-binding targets
It has been suggested that developing countries should be allowed to adopt non-binding targets open to emissions trading. Countries could sell surplus emission allowances if they exceed their target but would not have to cover a possible deficit by buying permits on international markets. This would provide developing countries with an incentive to achieve emission reductions while alleviating their legitimate concerns for economic development (Philibert, 2000; IEA, 2002).

Global tax and price stability
The agreed global GHG emission reduction could also be achieved by introducing a global carbon/GHG tax on primary energy use to stimulate the transition to a low-carbon energy system. In the climate action scenario presented in this report, this approach has been used to calculate the amount of expected 'domestic action' in various global regions using a least-cost approach. This outcome is used as a 'benchmark' to compare the effects of the various proposed target-sharing regimes (for example by calculating the additional costs/benefits of a region compared with the global least-cost solution). In practice, the distribution of costs and benefits of such an approach would probably be unequal. Compensation would require the establishment of a global institution/bank to collect the revenues and redistribute them to the participating countries.

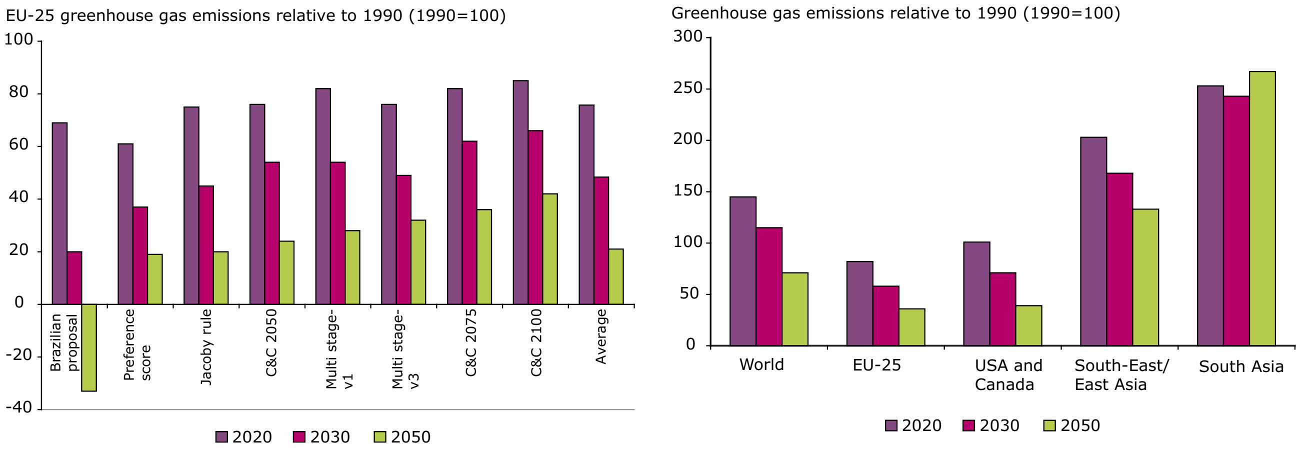
Another way of ensuring a global, stable and efficient carbon market may also require the establishment of a 'climate change bank' (CCB) in order to smooth disproportionately large price spikes. This could limit the uncertainty in the future costs of mitigation by increasing planning certainty (lowering the risk premium) for companies and private households, which ultimately bear the costs. A CCB, with the task of ensuring price stability in the market for CO_2 permits and the right to buy and sell carbon permits, could give long-term assurance to investors and support the realisation of the long-term reduction commitments (WBGU, 2003b). Funding of a CCB could be ensured in various ways, by countries (as shareholders), through the revenues of a global carbon tax, and by selling and buying permits. The right to sell carbon permits is seen as an important 'safety valve' (see price caps above) for preventing excessive prices for carbon permits while the obligation (intervention) to buy permit prices at a certain minimum would reduce the 'risk premium' for investors in low-carbon technologies.

3.3.3 EU and national emission reduction targets

Emission reduction targets for the EU, mentioned by the Environment Council (March 2005) were presented and discussed above (Box 1.1, Chapter 1.3).

Several individual EU Member States have expressed their intention to achieve substantial GHG emission reductions in the longer term, beyond those agreed in the Kyoto Protocol. The following have national

Figure 3.6 Potential emission reduction targets for the EU-25 under various approaches (left) and the impact of a 75 year convergence and contraction approach on various world regions (right)



Note: South Asia includes a.o.: India, Pakistan, Bangladesh. South-East/East Asia includes a.o.: China, South Korea, Thailand, Indonesia.

Source: FAIR model (EEA, 2005).

reduction targets (all compared with 1990 levels):

- UK: reduction target of 60 % by 2050 (CO_2);
- Germany: reduction target of 40 % by 2020 (all GHGs), under the condition that the European Union agrees a target of a 30 % reduction;
- France: reduction target of 75 % by 2050 (all GHGs).

For the EU as a whole, the EU Environment Council of 11 March 2005 concluded that reduction pathways by the group of developed countries of the order of 15–30 % by 2020 and 60–80 % by 2050 should be considered.

For this report, an analysis was performed, using the same model (FAIR) as used for other studies (van Vuuren *et al*., 2003; Criqui *et al*., 2003; den Elzen *et al*., 2003a and 2003b). Potential reduction targets for the EU-25 and other world regions for the period 2020–2050 (Figure 3.6 right) were compared using various approaches for defining national targets (as described in Section 3.3.2). Developed countries should reduce emissions to at least 65 % below 1990 by 2050. Developing countries would by 2050 be allowed an increase compared with 1990, but some would need to reduce emissions between 2020 and 2050.

If the more extreme cases, which are the preference score (or 'global compromise') and the Brazilian proposal, are left out, the reduction targets for the EU-25 would be 18 to 25 % by 2020 and 35 to 38 % by 2030 and at least 65 % by 2050 (Figure 3.6 left).

Based on this analysis, for the purpose of this report, indicative targets for EU-25 GHG emission reductions of 40 % by 2030 and 65 % by 2050, compared with 1990, are assumed and the implications are further analysed. These targets are broadly consistent with the range of targets mentioned by both the Environment Council and the Spring Council of March 2005, for 2020 and 2050 (the Councils did not mention targets for 2030).

4. A global and European low greenhouse gas emission pathway

Key messages

- Achieving a global emission reduction of 15 % below the 1990 level by 2050 may need increases in the carbon permit price to EUR 65/t CO_2 by 2030.
- The climate action scenario shows that by domestic actions alone, based on a carbon permit price of EUR 65/t CO_2, the EU could reduce its greenhouse gas emissions to 16–25 % below the 1990 level by 2030. Thus a substantial share of the reductions needed to achieve the assumed target of 40 % by 2030 could be achieved by actions inside the EU, with international emissions trading providing the remaining reductions.
- Substantial low-cost emission reductions are projected in the climate action scenario for nitrous oxide and methane emissions from industry, waste management and agriculture. However these options will have been almost fully exploited by 2030.

4.1 Introduction

Projections of energy supply and consumption and associated emissions of

Table 4.1 Total EU GHG emissions and sinks under baseline assumptions ([10])

	Mt CO_2-equivalent/year				% change from 1990 levels	
	1990	**2000**	**2020**	**2030**	**1990–2020**	**1990–2030**
EU-25						
CO_2 (Energy)	3 769	3 665	4 041	4 304	7.2 %	14 %
CO_2 (Non-energy)	133	131	145	147	9.1 %	10 %
CH_4	535	419	410	376	– 23 %	– 30 %
N_2O	459	403	397	382	– 14 %	– 17 %
F gases	48	61	144	150	200 %	210 %
Sinks	0	0	0	0		
Total	**4 945**	**4 680**	**5 140**	**5 360**	**3.9 %**	**8.4 %**
EU-15						
CO_2 (Energy)	3 082	3 118	3 444	3 669	12 %	19 %
CO_2 (Non-energy)	110	112	122	122	10 %	11 %
CH_4	414	335	325	300	– 22 %	– 28 %
N_2O	409	350	339	327	– 17 %	– 20 %
F gases	46	58	131	137	180 %	190 %
Sinks	0	0	0	0		
Total	**4 062**	**3 970**	**4 360**	**4 550**	**7.3 %**	**12 %**
EU-10						
CO_2 (Energy)	687	547	597	635	– 13 %	– 7.6 %
CO_2 (Non-energy)	23	19	23	25	2.4 %	7.6 %
CH_4	121	84	85	76	– 30 %	– 37 %
N_2O	51	53	58	56	15 %	10 %
F gases	1	3	13	14	900 %	950 %
Sinks	0	0	0	0		
Total	**883**	**710**	**780**	**810**	**– 12 %**	**– 8.9 %**

Source: EEA, 2005.

([10]) Sinks are not assumed in the scenario with existing policies and measures (the baseline scenario).

GHGs and air pollutants show that, without further action, Europe will not meet many of its existing short-term sustainable energy and environmental objectives and, in the longer term, is heading for an unsustainable future far removed from the kinds of sustainability goal outlined in Chapter 3. Because most of the GHG emissions in the EU are energy-related (81 % of EU-15 emissions in 2002), the way in which the energy sector evolves will to a large extent determine future GHG emissions; this chapter therefore focuses on that sector. It also includes sections on the abatement of non-CO_2 GHGs, which can still contribute substantially to the reductions required in the EU-25 during the coming decades. A detailed analysis of a European low-carbon energy system by 2030 is presented in Chapter 5.

4.2 EU emissions in the baseline scenario

The environmental policies assumed in the baseline scenario are essentially a continuation of current policies in the EU, with new policies only being introduced in developing countries to improve air quality, e.g. by means of desulphurisation in power plants to ensure a reasonable living environment. The scenario assumes that no climate policies are introduced. It describes a world in which globalisation and technology development continue to be important for economic growth. The world is open to international collaboration and trade, and major international conflicts are avoided.

Total GHG emissions in the EU-25 fell between 1990 and 2000, and, under the baseline assumption of existing measures only, are projected to be still slightly (2.3 %) below 1990 levels by 2010. After 2010, however, emissions rise steadily, to just over 8 % ([11]) above 1990 levels by 2030.

The fall in emissions to 2000 was due to a reduction in CO_2 emissions driven by the restructuring of economies in the new EU Member States and Germany, and a reduction in CH_4 emissions (from landfill, coal mining and livestock) and N_2O emissions. These were the result partly of structural changes (e.g. reductions in underground coal mines and declines in livestock numbers) and partly of abatement measures (e.g. recovery of landfill gas and abatement of N_2O emission in the chemical industry). From 2000, CO_2 emissions begin to rise, with substantial increases after 2010. This is the main cause of the rise in total GHG emissions, although there is a contribution from F gas emissions which double between 1990 and 2020. The downward trend in CH_4 and N_2O emissions continues, although at a much slower rate.

4.3 The climate action scenarios

4.3.1 A global low-carbon energy system

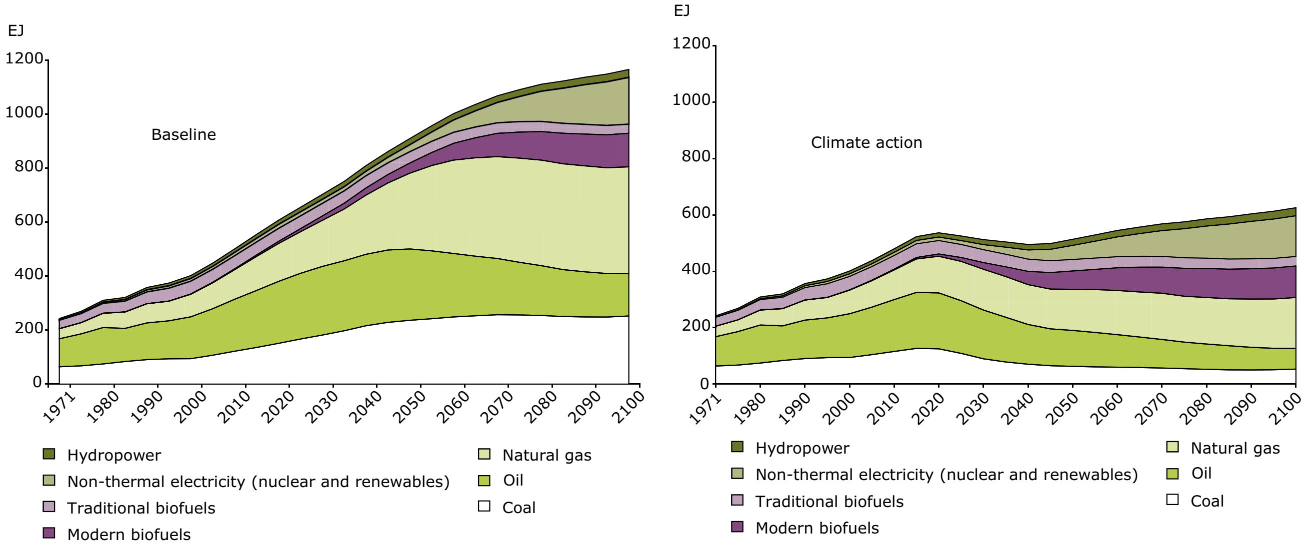
Without further action to tackle climate change, the baseline scenario shows global primary energy consumption increasing by more than 2½ times by 2050, and continuing to rise to 2100. These results are consistent with projections by IEA (IEA, 2004a), which show an increase of almost 60 % in global primary energy demand between 2002 and 2030. Fossil-fuel use rises even more quickly to 2050, although its consumption then starts to stabilise as other fuel sources, most notably non-thermal electricity sources (solar/wind and nuclear power) grow rapidly. In the climate action scenarios, the objective of limiting global GHG emissions to a 550 ppm CO_2-equivalent stabilisation level leads to substantial changes in the energy system compared with the baseline. Global energy use increases slowly over the 2000–50 period. Compared with the baseline scenario, global primary energy use is reduced by more than 40 % by 2050 (van Vuuren *et al.*, 2003).

The largest reductions (see Figure 4.1) compared with the baseline are for coal (by 70 % in 2050), with the remaining coal consumption being used mainly in electric power stations using carbon capture and storage. Instead of an increase compared with 2000, coal use now actually declines over the whole period. Reductions in oil and natural gas use reach 50 % (compared with the baseline). In absolute terms, oil use grows till 2020 and starts to decline afterwards. Natural gas use increases up to 2030 and stabilises afterwards. Other energy carriers gain market share, in particular wind, nuclear-based electricity and modern biomass.

Over the whole simulation period, but particularly in the first two decades, most of

([11]) CO_2 emissions from energy sources in the same period rise by 14 % in the EU-25 and 19 % in the EU-15.

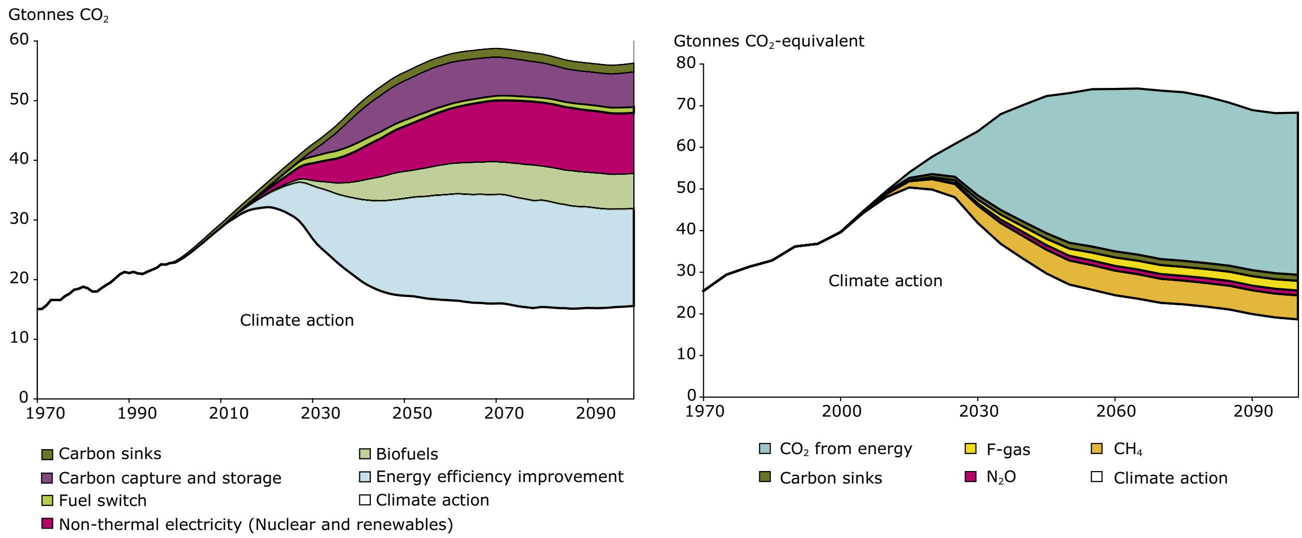
Figure 4.1 Global development in energy use



Note: Left baseline, right climate action scenario.

Source: IMAGE/TIMER model (EEA, 2005).

Figure 4.2 Global emission reductions by mitigation measure (left) and greenhouse gas (right) for the climate action scenario compared with the baseline



Note: Figure left includes only CO_2; figure right includes all greenhouse gases.

Source: van Vuuren *et al.*, 2003 (IMAGE model).

the reductions come from energy efficiency improvements (particularly outside the OECD regions). By 2030, other options start to become important: using biofuels instead of fossil fuels, and non-thermal electricity modes (solar/wind and nuclear power) instead of fossil-based electricity. The largest reductions are likely to occur in the electrical power sector. Several non-carbon-emitting options are deployed in the climate action scenario at global level, i.e. renewables, nuclear and thermal power using carbon capture and storage.

4.3.2 Global emissions and carbon sinks

Under the climate action scenario, global anthropogenic GHG emissions peak around 2020 and decline to below 1990 levels around 2040. The contribution of non-CO_2 abatement action to the total reduction decreases sharply after about 2030, because the potential for relatively cheap emission reduction options is limited. Non-CO_2 gases represent about 25 % of total global GHG emissions and low-cost emission reductions are almost fully exploited around 2030.

Another important source of emissions of CO_2, besides energy sources, is deforestation. CO_2 land-use emissions (deforestation) change from 19 % of energy and industry-related GHG emissions in 1990, to 4 % in 2050, and to minus 25 % (that is a substantial carbon sink) in 2100, due to substantial afforestation in the later period. Total land-use GHG emissions (including methane and N_2O) range from 40–45 % of energy and industry-related emissions in the period 1990–2050 (EEA, 2005).

For carbon sinks, the results also indicate a declining relative contribution to the overall emission reduction (from 40 % in 2010 to less than 5 % in 2050). The total potential for enhancement of sinks is assumed to be limited to about 2–4 $GtCO_2$ per year. Furthermore, only a small share of the total potential (10–30 %) is likely to be used because of socioeconomic barriers. Taking both limitations into account results in a total of 0.2–1.1 $GtCO_2$-equivalent sinks per year by 2050, which is an important but small contribution to the 40 $GtCO_2$-equivalent emission reduction needed at that time (van Vuuren *et al.*, 2003).

4.3.3 European emissions

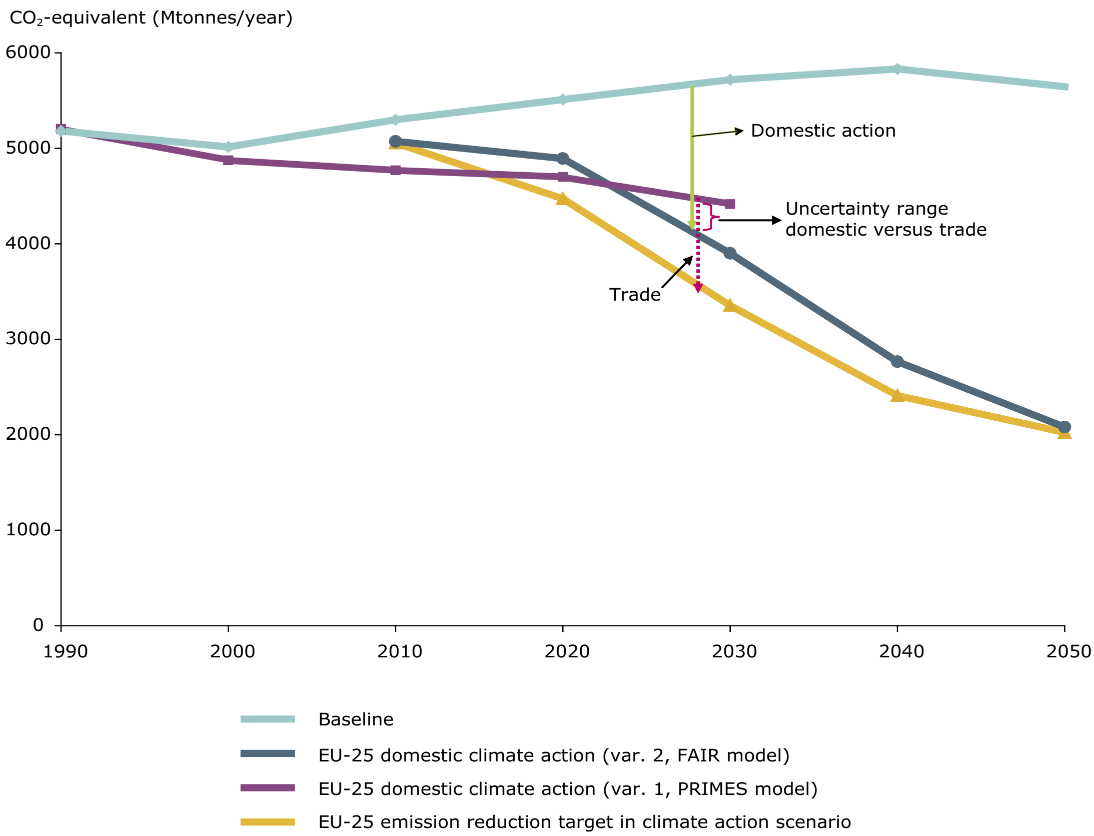
Reductions originating outside Europe (through flexible mechanisms)

The climate action scenario suggests that, in principle, the long-term sustainability objectives for climate change in Europe can be met most cost effectively by continuing to use the Kyoto mechanisms in the period 2012–2030 and/or implementing additional options that cost more than EUR 65/t CO_2-equivalent, including a EUR 5/t CO_2-equivalent premium for domestic action (see Table 4.2).

In the global cost-effective approach used for this report, total global mitigation costs are minimized. This approach has been used to calculate the amount of expected 'domestic action' in various global regions.

The expected domestic emission reduction in the EU-25 would be 16 to 26 % in 2030, compared with 1990 levels. This represents

Figure 4.3 Reduction of EU GHG emissions domestically within the EU and outside through 'flexible' mechanisms



Note: Share of domestic action EU is estimated using two models; var. 1 (PRIMES model up to 2030) and var. 2 (FAIR model up to 2050), with EU emission reduction targets of 40 % in 2030 and 65 % in 2050.

Source: EEA, 2005.

Table 4.2 Assumed permit and renewable certificate prices in the climate action scenarios 2015–2100

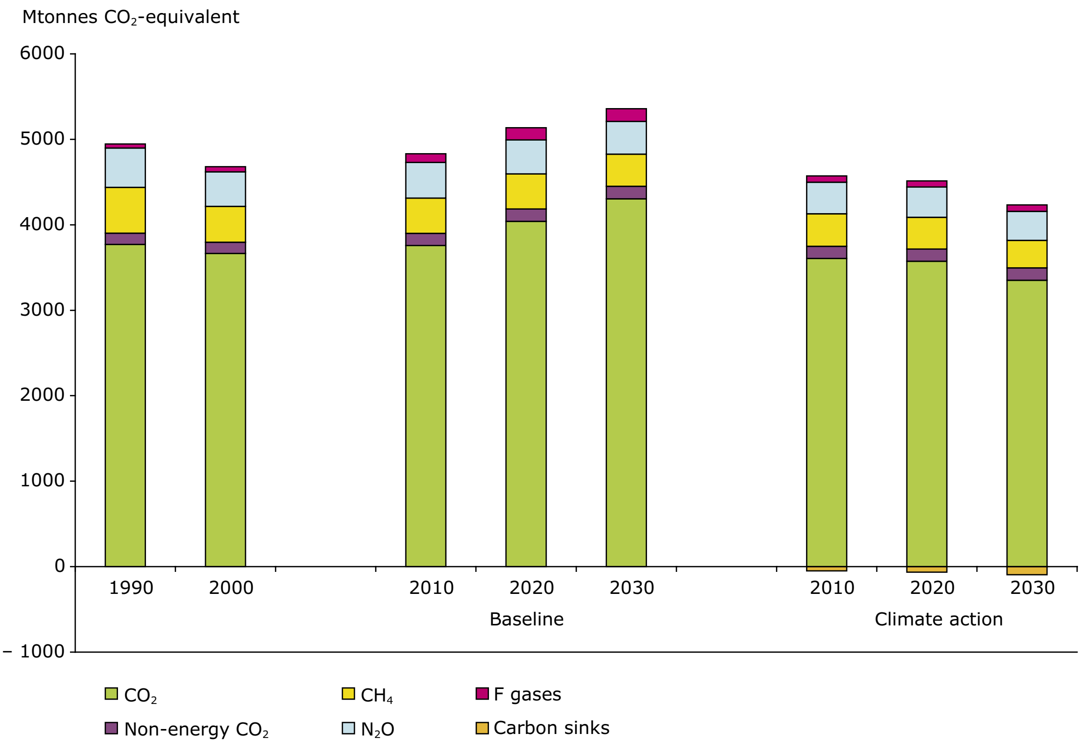
	Permit price (Euro/tonne CO_2-equivalent) European level				Green certificate value renewable variants (Euro/Kwhe)	Permit price global level	
Year	Climate action	Low economic growth	Renewables/ combined climate action	Renewables on top of climate action		Climate action	Low economic growth
2015	20	6	16	20		6	1
2020	30	20	24	30	0.024	25	15
2025	50	40	41	50	0.03	45	35
2030	65	55	49	65	0.045	60	50
2040						105	80
2050						115	95
2075						165	105
2100						190	105

50 to 70 % of the gap between the baseline projection for 2030 and the assumed target of 40 % reduction for 2030. For 2050 the expected domestic emission reduction is 61 % compared with 1990 levels. This represents 95 % of the assumed target of 65 % reduction for 2050.

Domestic reductions within the EU
To achieve the 40 % target in 2030 it is assumed that the remaining part of the required emission reductions (about 30 to 50 % of the gap between baseline emission projections and the target) would be achieved outside the EU-25, through mechanisms that could be similar to the current Kyoto mechanisms (see also Chapter 5). Whether and how much Europe would opt to buy emissions allowances abroad to meet sustainability objectives (for 2030) will be a political decision.

Under the climate action scenario, total domestic GHG emissions in the EU-25 fall gradually over the coming decades so that by 2030 they are more than 16 % lower than in 1990. The fall in CO_2 emissions is less significant, but a decrease of 11 %

Figure 4.4 Total GHG emissions in EU-25 (baseline and climate action scenarios)



Source: Bates *et al.*, 2004 and EEA, 2005.

Table 4.3 Total EU GHG emissions and sinks in the climate action scenarios

	Mt CO_2-equivalent/year				% change from 1990 levels	
	1990	**2000**	**2020**	**2030**	**1990–2020**	**1990–2030**
EU-25						
CO_2 (Energy)	3 769	3 665	3 570	3 350	– 5.2 %	– 11 %
CO_2 (Non-energy)	133	131	144	145	8.0 %	9.4 %
CH_4	535	419	372	322	– 31 %	– 40 %
N_2O	459	403	352	339	– 23 %	– 26 %
F gases	48	61	72	76	51 %	58 %
Sinks	0	0	– 64	– 94		
Total	**4 945**	**4 680**	**4 450**	**4 140**	**– 10 %**	**– 16 %**
EU-15						
CO_2 (Energy)	3 082	3 118	3 060	2 900	– 0.7 %	– 6.0 %
CO_2 (Non-energy)	110	112	121	121	9.4 %	10 %
CH_4	414	335	305	265	– 26 %	– 36 %
N_2O	409	350	302	291	– 26 %	– 29 %
F gases	46	58	64	67	39 %	45 %
Sinks	0	0	– 42	– 64		
Total	**4 062**	**3 972**	**3 810**	**3 580**	**– 6.2 %**	**– 12 %**
EU-10						
CO_2 (Energy)	687	547	510	450	– 25 %	– 34 %
CO_2 (Non-energy)	23	19	23	24	1.1 %	6.3 %
CH_4	121	84	67	57	– 45 %	– 53 %
N_2O	51	53	50	48	– 0.3 %	– 4.1 %
F gases	1	3	8	8	490 %	530 %
Sinks	0	0	– 22	– 30		
Total	**883**	**708**	**640**	**560**	**– 28 %**	**– 37 %**

is still seen over this period ([12]). About three-quarters of the reductions achieved, compared with the baseline scenario, are of CO_2 emissions. The downward trend in CH_4 and N_2O emissions in the baseline scenario is amplified slightly as a number of additional abatement measures are implemented. Abatement measures for F gases significantly reduce emissions compared with the baseline but are unable to reverse the upward trend: F gas emissions are still 58 % above 1990 levels by 2030. In addition, roughly 10 % of the net emission reductions in the climate action scenario will be through carbon sinks, which will however just compensate for the increase in emissions of fluorinated gases in the EU-15.

In the new EU-10, however, the historic reduction in CO_2 emissions in the 1990s, combined with the reductions achieved from 2000 onwards, means that total GHG emissions are 34 % below 1990 levels by 2030.

Industrial fluorinated gases

Across the EU-25, total emissions of fluorinated gases are expected to increase by 146 % between 2000 and 2030 with existing policies and measures (baseline scenario) ([13]). Growth is rapid until 2020 but then slows as the market becomes saturated. Growth is higher (320 %) in the EU-10 than in EU-15 (137 %), due mainly to the projected increased penetration and use of HFCs in several key sectors within the EU-10, notably refrigeration and air-conditioning, and aerosols. In absolute terms, however, emissions of fluorinated gases from the EU-10 are only about 10 % of

([12]) Assuming a higher share of non-carbon energy sources (i.e. renewable energies, nuclear power) leads to higher emissions reductions than the climate action scenarios. The relevant scenario variants are described in Chapter 5.

([13]) Not including the proposed regulation on F-gases (see Chapter 5).

those from the EU-15. Significant reductions (by 50 %) in total emissions of fluorinated gases are projected in the climate action scenario through implementation of a number of relatively low-cost measures to reduce leakages and use alternative gases. While these measures more than offset the rises in PFC and SF_6 emissions, HFC emissions still more than double by 2030, giving an overall increase in fluorinated gas emissions of almost 60 %.

Chemical industry
Abatement plants to reduce N_2O emissions from large adipic acid plants have already been installed so that N_2O emissions in the baseline scenario remain broadly constant. In the climate action scenario, the introduction of abatement technology at nitric acid plants and remaining smaller adipic acid plants is projected to reduce emissions by more than 60 %.

Coal, oil and gas fugitive emissions
Emissions from coal production decline as production levels in deep mines continue to fall. Significant reductions (60 %) are achieved as a number of low-cost measures to recover and utilise methane from mines are implemented. In the gas sector, emissions increase as gas use increases in the climate action scenario, measures in the oil production reduce emissions by about 20 % in 2010. After 2010, measures to reduce emissions from gas production and distribution are also introduced and are projected to reduce emissions by about a third in 2030.

Waste management
There are three main ways of reducing CH_4 emissions from landfill:

- reduce the amount of biodegradable waste going to landfill by using other waste management options (e.g., incineration, anaerobic digestion, composting, recycling);
- recovery and combustion of landfill gas, either in a flare or more usefully to produce heat and/or electricity;
- reduce methane venting from closed sites through improved capping.

The existing landfill directive (European Council, 1999), which requires the diversion of biodegradable wastes from landfill and recovery of landfill gas, should more than halve emissions from waste by 2030 in the baseline scenario. In the climate action scenario, it is assumed that improved capping is implemented from 2025 and that landfilled biodegradable waste will be reduced by a further 20 % in the EU-15 and between 2020 and 2030 and a further 10 % in the EU-10. The climate action scenario gives an additional 16 % reduction in projected emissions by 2030, compared with the baseline.

Agriculture, methane (CH_4)
Enteric fermentation emissions show a steady decline due to declining animal numbers, and are projected to be almost 25 % below 1990 levels by 2030 in the baseline scenario. In the climate action scenario, a small additional reduction (3 %) is achieved, mainly by optimising diets and improving animal productivity. Emissions from manure are also projected to decline in the baseline scenario because of declining animal numbers, falling by 5 % by 2030. In the climate action scenario, manure management options (stable adaptation and anaerobic digestion of manure to provide heat) are also applied, and an additional 18 % reduction is achieved by 2030.

Agriculture, nitrous oxide (N_2O)
Emissions from soils are projected to decline slowly, as nitrogenous fertiliser consumption falls to about 8 % below 1990 levels by 2030 if only existing policies are implemented (the baseline scenario). In the climate action scenario, a small additional reduction (2 %) is achieved because of improvements in fertiliser use and set-aside of land leading to reduced applications of nitrogenous fertiliser.

Carbon sinks
As carbon sinks are not part of existing policies and measures, they are not taken into account in projections for existing policies (the baseline scenario). However they are included in the climate action scenarios ([14]). In total, the EU-25 is projected to be able to sequester about 50 and 95 Mt CO_2 in 2010 and 2030 respectively, about 1 and 2 % of the 1990 emissions. For the EU-25 this is small compared with the emission reductions needed in the climate action scenario).

([14]) Strictly speaking, counting carbon sinks cannot be seen as part of emission reduction policies. However, counting carbon sinks is part of future climate policies.

4.4 Comparison with other scenarios

The scenarios presented in this report include many uncertainties of different kinds. A comparison with other studies illustrates some of these uncertainties. Table 4.3 includes some of the key characteristics of four recent climate change response scenarios, including the EEA climate action scenarios.

4.4.1 Scenario objectives

Scenarios developed for the German WBGU study (WBGU, 2003b), the study (Criqui *et al.*, 2003) and the climate action scenario (this report), all have the same long-term climate goal: a maximum of 2 °C increase in global mean temperature. All three roughly translate the temperature goal into the same goal for stabilisation of GHGs: 450 ppm for CO_2 alone and 550 ppm for CO_2-equivalent. Because of the relative small uncertainties in the carbon cycle, these concentration targets translate into similar cumulative global emissions, the emission paths over time depending on the timing of emission reductions and possible target-sharing regimes.

The WBGU study, however, also has some additional ambitious goals, notably a predefined target path for renewable energy and the requirement of globally substantially improved access to energy (at least 500kWh/person/year by 2020 at the latest), targets which are similar to those considered in the sustainable development vision of the 'Energy to 2050' study of the International Energy Agency (IEA, 2003a). The IEA vision does not contain an explicit concentration or temperature target. Instead, a target of 60 % of total world primary energy supply to be from zero-carbon sources (renewables, nuclear and also taking account of CO_2 storage) by 2050 is adopted, compared with the constraint of 50 % (only renewables) in the WBGU study also for 2050.

The main variables that determine regional emission constraints over time are the timing of global and regional emission reductions and the distribution of constraints between different regions. The three studies (WBGU, Criqui *et al.*, and EEA climate action scenarios) all conclude that very significant reductions in emissions from the industrialised countries in the medium term are needed compared with their baselines, of the order of 15–40 % by 2025. The three studies elaborate a contraction and convergence (C&C) example in more detail for different years (2050, 2075 and 2100), which leads to results well within the possible range of outcomes (up to 60 % emission reduction for industrialised countries by 2050), without prejudging the outcome of international negotiations.

4.4.2 Driving forces

The WBGU, Criqui *et al.*, IEA and EEA climate action scenario studies all use similar, intermediate population scenarios, leading to a world population of approximately 9 billion by 2050. The economic growth assumptions are also similar across the Criqui *et al.* and EEA climate action scenarios, leading to world GDP growth of about 3 % per year, while for the WBGU and the IEA studies the GDP growth assumption is about 4 % per year.

4.4.3 Energy system

The largest differences between scenarios emerge in changes in the energy system. The WBGU study assumes an almost complete shift away from coal use, while the EEA climate action scenarios, Criqui *et al.*, and IEA SD (sustainable development) vision scenarios allow for a continued though decreasing use of coal (70 % reduction by 2050, compared with the baseline). The WBGU study also has the fastest growing use of renewable energy (mainly biomass in the medium term and solar in the longer term), and assumes a relatively fast transition to an electricity/hydrogen economy; the study is very optimistic about the feasibility of such a transition. The IEA SD vision scenario target of a global 60 % share of zero-carbon sources in primary energy supply also requires a fundamental transition in the global energy system (46 % nuclear and renewables, adding carbon storage to meet the 60 % target by 2050), comparable to the WBGU outcome for renewable energy. On the other hand, the Criqui *et al.*, and EEA climate action scenarios have fewer constraints (e.g. more relaxed outcome for the share of zero-carbon technologies in primary energy use, of the order of 35 % by 2050) and can therefore more safely assume that a hydrogen economy will take more time to develop.

4.4.4 Costs

The WBGU study shows that abatement costs are more dependent on the

Table 4.4 Comparison of EEA climate action scenario results with other studies

	WBGU	IEA, 2003a	Criqui *et al.*, 2003	EEA climate action scenario
Targets	Temperature Rate of temperature change Concentrations Access to electricity Renewable energy supply	Share of zero-carbon energy sources Access to electricity	Temperature GHG concentrations Rate of emission reductions	Temperature GHG concentrations Rate of emission reductions
Time horizon	1990–2100	1990–2050	1990–2100	1990–2030 (Europe) 1990–2100 (world)
Ref. baseline	SRES A1T, B1, B2	SRES A1T	CPI	LREM-E up to 2030/CPI after 2030
World population	9 to 7 billion by 2050–2100	8.7 billion in 2050	9.5 billion by 2100	9.5 billion by 2100
World economic growth	High	High	Modest	Two variants, modest and modest/pessimistic
Primary Energy use (in EJ) in 2050	App. 800–1 200	App. 1 000	App. 600	App. 600
Target sharing regime examined	Contraction and convergence (C&C) by 2050 and 2100	Not analysed	C&C by 2050 and 2100; Multi-stage approach	C&C by 2075
Emissions ($GtCO_2$) by 2050	App. 9–22	App. 37	App. 18 (550 CO_2-equivalent) — 38 (baseline)	18
Permit price by 2050 per tCO_2	USD 280–400 (1990)	Not analysed	120–130 (S550e) EUR 35 (S650e)	EUR 120–150
Fossil fuel by 2050	Global coal use phase-out	Large reduction in global coal use	S550e: large reduction in global coal use. Smaller reductions in S650e	Large reduction in global coal use
Nuclear	Nuclear energy phase-out in some scenarios, dominant in others	Increased share of nuclear	One of the non-fossil energy sources (not separately quantified)	Variants explored
Share of zero-carbon sources in energy supply	Dominant role of solar energy and biomass use below max limit in some scenarios. Biomass growth, subordinated role for solar energy in others	46 % of world TPES ([15]) from zero-carbon sources (including nuclear) by 2050	In S550e (including nuclear) 2050 35 % 2100 55 %	(Including nuclear) 2050 35 % 2100 55 % + variants explored
Hydrogen	An electricity/hydrogen economy in all scenarios	Further research needed	Option not explored	Hydrogen not affordable up to 2030

economic growth assumptions of the baseline scenario than on the climate regime selected. The Criqui *et al.*, and the EEA climate action scenarios show that emission reduction objectives (e.g. concentration targets) are more important for abatement costs than the target-sharing regime considered. All three studies have found comparable costs of stabilising GHG concentrations at 550ppm CO_2-equivalent, ranging from 1 to 1.5 % of GDP by 2050. The costs of mitigation depend on the stringency of the target and the economic growth of the world economy in the underlying baseline scenario as well as on assumptions regarding the techno-economical development of low or zero-carbon energy sources, in particular renewables and carbon capture and sequestration. Bollen *et al.*, 2004, concluded, for a similar 550 ppm GHG stabilisation scenario and a baseline called 'Strong Europe', that GDP losses would be less than 2 % globally and less than 1 % for Europe by 2040. Income losses in this scenario are 1.6 % globally and 2.2 % in Europe but income is projected to increase threefold (by 200 %) in the baseline ('global economy') scenario. See Chapter 6 for estimates of the costs of the EEA climate action scenarios.

([15]) Total primary energy supply, which is the same as primary energy demand.

5. Policies and technologies for a transition to a European low-carbon energy system

Key messages

- The introduction of a carbon permit price that rises up to EUR 65/t CO_2 by 2030 is projected to result in European energy-related CO_2 emissions falling by 11 % between 1990 and 2030. Under baseline developments, emissions would increase to 14 % over this period. Higher domestic emission reduction levels would lead to increasing marginal abatement costs: a 21 % reduction would more than double the permit price in 2030.
- While improvements in energy intensity account for almost half of the emission reduction in 2010 in the LCEP scenario, their contributions decrease to one third in 2030. This shifts the effort to further changes in fuel mix in the long run, which would mostly occur in the power generation sector. As a result, power generation would become responsible for more than 70 % of emission reduction in 2030, whereas the share of the end-use sectors' (i.e. transport, households, services and industry) in overall emission reduction would fall from 43 % in 2010 to 28 % in 2030. However, in the case of a higher domestic emission reduction and a related increase in the carbon permit price, energy intensity improvements would increase again as other options are becoming increasingly exploited.
- The use of solid fuels would decline substantially as a result of the introduction of the carbon permit price. In the LCEP scenario, renewable energies show the largest increase compared with the baseline, driven by a significant increase in wind power and biomass. Combined heat and power contributes to improving efficiency and increases its share in electricity production to 17–28 % in 2030.
- Final energy consumption in 2030 is 7.3 % lower in the LCEP than in the baseline scenario, resulting in emission reduction of almost 190 $MtCO_2$. The services and household sectors are the most sensitive to the imposition of a carbon constraint and show the highest reductions in final energy used for heating, electrical appliances and lighting.
- Achieving a sustainable energy system requires further measures in addition to a carbon price, including removal of potentially environmentally harmful subsidies, setting of targets for renewables, increase in R & D and awareness-raising. The modelling results demonstrate that additional policies have to be introduced in addition to a carbon permit price if the European indicative 2010 target for the share of renewable energies is to be met.

5.1 Introduction

Introducing a carbon permit price is expected to result in substantial changes to the present energy system. It will stimulate improvements in energy efficiency in both supply and use of energy and the further expansion of technologies and fuels with low or zero carbon dioxide emissions. This chapter explores the expected changes to the present energy system and discusses some of the key changes in energy supply and consumption compared with a *baseline development* **([16])**. Some consideration is also given to the type of actions and institutional framework and additional investment that will be needed to promote such changes.

The PRIMES model was used to analyse possible future developments of the European energy sector, including a baseline scenario without a permit price and the *low-carbon energy pathway (LCEP ([17])*) scenario. It describes the least-cost response of the EU-25 energy system to the introduction of a carbon permit price that rises to EUR

([16]) The baseline scenario is broadly consistent with that published as 'European energy and transport — Trends to 2030' (Mantzos *et al*., 2003).

([17]) The low carbon energy pathway (LCEP) scenarios are designed to illustrate the development of the energy sector in which carbon prices determine the development of the energy system. They form part of the low greenhouse gas emission pathway (LGEP) scenarios.

65/t CO_2-equivalent by 2030. The model differentiates between the energy supply (e.g. power and heat generation) and energy demand sectors (services [18]), industry, transport, households). It is important to note that the choice between supply and demand options to reduce the emissions of GHGs is made on the basis of cost-effectiveness only, in line with the introduction of a uniform carbon tax. The analysis therefore provides an indicator of the 'elasticity' of a particular sector, i.e. how much it is flexible and can shift to low or zero-carbon fuels and more efficient technologies, or even reduce its energy demand.

The LCEP scenario does not take into account the wider benefits of a sustainable energy system, such as reduced emissions of air pollutants and increased energy security. For this reason, scenario variants were developed, which explore the implications of different assumptions and actions on a future energy system. These include a variant assuming a high share of renewable energies in addition to the permit price and variants with a higher share of nuclear energy and a nuclear phase-out variant.

- The *renewables expanded* variant assumes that the share of renewables in total energy consumption meets the indicative target of 12 % in 2010 and then future targets are set to increase this to 16 % in 2020 and 20 % in 2030. This is achieved through the introduction of a renewables premium in the power sector and tax regulation in transport. This chapter will focus on the case, where the renewables premium is introduced in addition to the carbon permit price.
- The *nuclear accelerated* variant assumes that new nuclear technologies become mature by 2010, leading more Member States to choose the nuclear option (including re-evaluations of declared nuclear phase-out policies).
- The *nuclear phase-out* variant assumes that existing nuclear plants are decommissioned at the end of their technical lifetime in addition to the stricter decommissioning policies that apply in certain Member States, and no further investment in nuclear power occurs.

Key results for the development of the European energy sector are summarised in Table 5.1. They are discussed in more detail in Sections 5.2 and 5.3.

In the following, the results of the analysis of the LCEP pathway and its variants will be presented. In some cases, a reference to other scenario results will be made, in particular to a set of scenarios prepared for the European Commission Directorate-General for Energy and Transport (Mantzos *et al.*, 2004) ([19]). This set of scenarios includes a baseline development (i.e. no carbon permit price) plus an increased share of renewables and energy efficiency measures respectively, and a number of climate change scenarios. The climate change scenarios differ in their assumptions for the use of flexible mechanisms and non-CO_2 GHG emissions and thus result in different domestic emission reductions. While the scenario assuming that the EU will make intensive use of flexible mechanisms is mostly in line with the LCEP scenario (and results in CO_2 emissions being 10.5 % below 1990 levels), another scenario assumes that a 21 % reduction in energy-related CO_2-emissions will be achieved domestically ('Gothenburg domestic scenario'). This results in significantly higher marginal abatement costs, with a carbon permit price rising to EUR 136.6/t CO_2 in 2030.

5.2 Overall changes in the energy system in the climate action scenario

Since 1990, energy-related CO_2 emissions in the EU-25 have fallen slightly, mainly as a result of significant decreases in the new Member States. However, as a result of rising total energy consumption and continued reliance on fossil fuels, EU-25 emissions are projected to rise by 14 % in 2030 under baseline assumptions. Introducing a carbon permit price under the LCEP-scenario is projected to lead to energy-related CO_2 emissions being 11 % lower in 2030 than in 1990. The higher share of renewable energies in the renewables expanded variant scenario results in emissions being 21 % below the 1990 level, the nuclear accelerated variant leads to CO_2 emission being 14 % below 1990 while

([18]) The service sector includes agriculture.
([19]) As they are also based on the PRIMES model, their results can be compared to the LCEP results to a large extent.

Table 5.1 Main characteristics of the EU-25 energy system in relevant scenarios

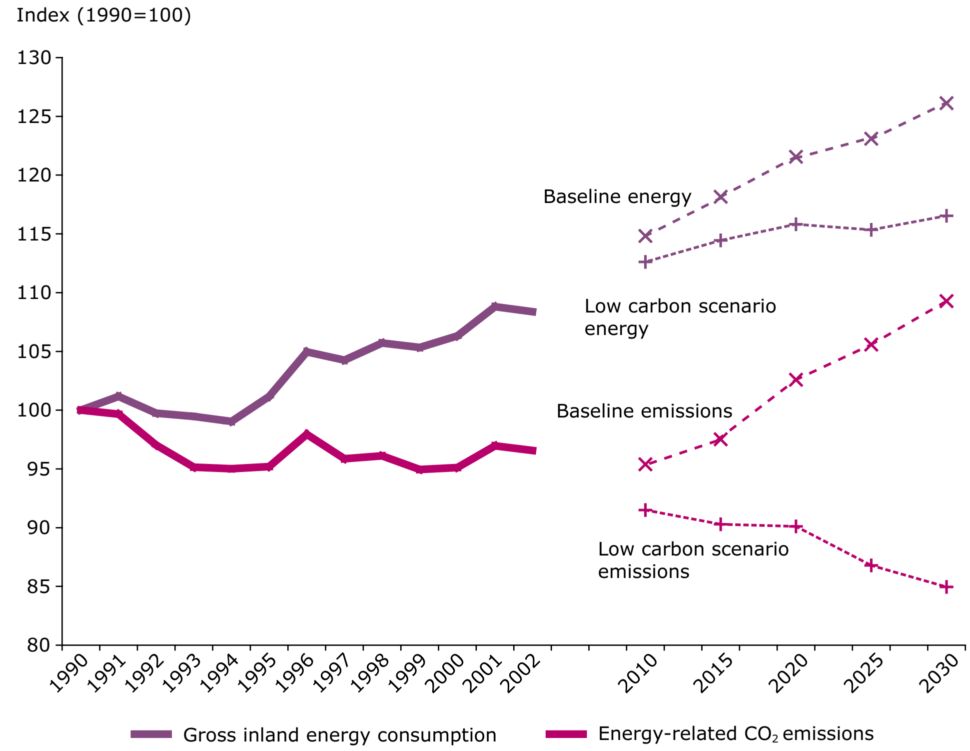
	1990	2000	2030				
			Baseline	LCEP	Renew-ables expanded	Nuclear acceler-ated	Nuclear phase-out
CO_2 emissions ($MtCO_2$)	3 770	3 665	4 304	3 346	2 984	3 230	3 455
Electricity and steam production	1 341	1 228	1 613	927	772	822	1 044
Energy branch	144	164	139	132	121	132	133
Industry	713	606	552	475	489	474	468
Households	520	463	488	433	409	427	428
Services	257	237	250	215	204	210	214
Transport	795	968	1 258	1 164	990	1 167	1 167
EU-25 energy-related CO_2 emissions; index 1990 = 100	100	97.2	114.2	88.8	79.2	85.7	91.6
Gross inland energy consumption (Mtoe)	1 554	1 651	1 960	1 811	1 827	1 871	1 774
Solids (%)	27.7	18.4	15.3	4.9	4.2	4.5	6.3
Oil (%)	38.4	38.5	34.4	34.7	30.5	33.7	35.6
Gas (%)	16.7	22.8	32.1	35.1	32.6	31.6	36.0
Nuclear (%)	12.7	14.4	9.5	12.0	11.1	17.5	7.9
Renewables (%)	4.5	5.8	8.6	13.1	21.5	12.5	13.9
Carbon intensity (t CO_2/toe)	2.4	2.2	2.2	1.8	1.6	1.7	2.0
Final energy consumption (Mtoe)	1 009	1 074	1 394	1 292	1 290	1 290	1 286
Electricity generation (TWh)	2 456	2 898	4 397	4 208	4 130	4 271	4 145
Renewables in electricity generation (%)	-	14.6	18	28	39	27	30
Nuclear in electricity generation (%)	-	31.8	17	21	20	30	13
Electricity produced by CHP (%)	-	12.6	16	17	28	17	18
Efficiency of thermal electricity production (%)		37.1	48.7	50.6	48.6	49.5	50.7
Carbon intensity of power generation (t CO_2/MWh)		0.34	0.29	0.17	0.15	0.15	0.20
Import dependency %	44.8	47.2	67.3	62.4	55.5	57.8	65.0

Note: 'Renewables' include waste. CO_2 emissions from electricity and heat production include district heating. The split of CO_2 emissions by sectors follows Eurostat energy balances definition (i.e. consumption for non-marketed steam used on site in industry allocated in the demand side). Import dependency excludes import of uranium.

the nuclear phase-out variant results in emissions being 8.4 % below 1990, all in 2030. Compared to the baseline, the CO_2-emissions of these variants are between 17 % and 31 % lower in 2030.

These projected emission reductions are due to changes in the energy system due to the introduction of a carbon permit price. The system has various means of responding to binding reductions on GHG emissions and maintaining the same level of GDP. It can reduce the level of energy used per unit of GDP (*the energy intensity*) or it can change the fuel mix in favour of low- or non-carbon fuels in order to reduce *the carbon intensity*. The division of the system's response between these two approaches is an important indication of where most of the flexibility in the system is to be found

Figure 5.1 Total energy consumption and energy-related carbon dioxide emission in EU-25



Note: Index 1990=100; 1990–2002 historical data; 2010–2030 baseline and LCEP projections.

Source: EEA, 2005. Eurostat (past energy data).

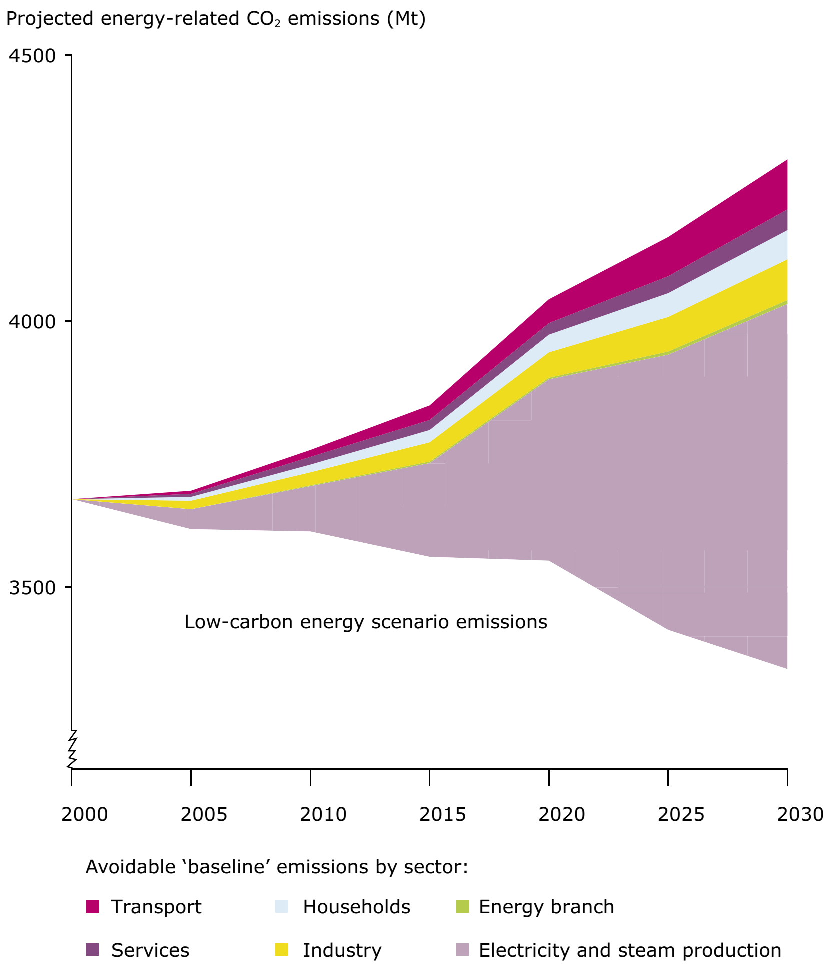
within the assumptions made in the model (see Section 6.3 on uncertainties). Changes in the economic development are also expected to influence energy demand and CO_2 emissions, as presented in a high- and a low-growth case in Mantzos *et al*., 2004.

A reduction in the carbon intensity of the energy system signifies that fuel substitution opportunities (i.e. fuel switch towards less carbon-intensive fossil fuels or non-carbon fuels) is more cost effective than substitution of energy by other goods. For the year 2010, CO_2 emissions in the LCEP are 4 % less than in the baseline scenario while gross inland energy is only 1.9 % less than in the baseline scenario; almost half of the emission reductions between the baseline and the LCEP-scenario is realised by improvements in energy intensity. In 2030, gross inland energy consumption will be 7.3 % lower than in the baseline with CO_2 emissions being 22 % lower than in the baseline (Figure 5.1).

Towards 2030, the contribution of energy intensity improvements to achieving CO_2 emission reductions decreases to one third. This reflects the increased difficulty that the European energy system will face in further reducing energy requirements, thus shifting the effort to further changes in fuel mix in the long run. However, in the case of a higher domestic emissions reductions and a related increase in the carbon permit price, improvements in energy intensity become more important and account for 40 % of the total emissions reductions in 2030. This is indicated by scenario results prepared for the European Commission Directorate-General for Energy and Transport (Mantzos *et al*., 2004, 'Gothenburg domestic scenario').

The fuel mix of gross inland energy consumption is projected to change considerably in 2030 both compared with 1990 and between the baseline and the LCEP scenario and its variants. The use of solid fuels is 70 % lower in the LCEP scenario than in the baseline (and 80 % below 1990). The share of gas, which has become the fuel of choice for new power plants in the past decade, is projected to increase further but in the long term, this growth is projected to decline as a result of higher natural gas import prices, enhanced by concerns about security of supply. The share of renewable energies is 40 % higher than in the baseline (and 340 % higher than 1990). This will also lead to a reduced import dependency compared with the

Figure 5.2 Energy-related carbon dioxide emissions, EU-25



Source: EEA, 2005.

baseline (a reduction of 4.9 percentage points for the LCEP, even more with – 11.8 percentage points for the renewables variant) ([20]).

Most of the changes in fuel mix occur on the supply side (in particular in power generation), while emission reductions on the demand side, i.e. in the end-use sectors transport, industry, services and households, are due mainly to improvements in energy intensity. The contribution of the end-use sectors to overall emission reductions falls from 43 % in 2010 to 28 % in 2030 in the LCEP scenario, showing the increasing difficulty that the end-use side will face in the long run in reducing CO_2 emissions. Towards 2030 more than 70 % of the CO_2 emission reductions (56 % in 2010) will be realised in the power generation sector, demonstrating the flexibility of this sector (Figure 5.2). If higher domestic emissions reductions than in the LCEP were assumed, low-cost options on the supply side would become increasingly exploited, thus resulting in higher emission reductions on the demand side (Mantzos *et al.*, 2004, 'Gothenburg domestic scenario').

5.3 Developments in the energy sector and key technologies

The developments in the energy sector over the next 30 years depend crucially on the role of some key technologies and fuels on both the demand and the supply side. They act to lower CO_2 emissions through a combination of:

- improvements in energy intensity by e.g. increasing the energy efficiency on the demand and supply side, a substitution

([20]) Import dependency excludes import of uranium. This approach is in line with the Green Paper on energy security (European Commission, 2000a).

of energy-intensive products, and lower demand;
- switching from fossil fuels to fuels with lower carbon content, e.g. from coal to natural gas;
- increasing the share of non-fossil fuels and technologies, e.g. renewable energies and nuclear power.

This section explores some of the key technologies modelled in the LCEP scenario and its variants. Some technologies that were not included in the scenario (hydrogen, carbon capture and sequestration and some technologies in road transport) but may help reduce CO_2 emissions in the future are also described.

5.3.1 Improvements in energy efficiency

Improvements in the efficiency of both energy production and consumption will be central to any transition towards a more sustainable energy system in Europe, since a key requirement for sustainability is to minimise the energy needed to meet the demands for energy-related services that originate from economic and social drivers (e.g. economic growth, demand for freight transport, personal mobility, warmth and comfort in the home). The projections show that energy intensity improvements could deliver almost half of the required total emission reduction in 2010 and one third in 2030 ([21]). In 2030, gross inland energy consumption in the LCEP-scenario is almost 150 Mtoe less than in the baseline scenario and final energy consumption is 102 Mtoe less (see Table 5.1). That means that in 2030, gross inland energy consumption is projected to be 10 % above 2000 levels in the LCEP scenario instead of rising to 19 % above 2000 levels in the baseline scenario.

Cost-effective improvements in the way we use energy can also contribute to other goals of energy policy such as security of supply and improving competitiveness. Past experience shows, however, that cost-effective potentials remain unused, especially on the demand side. To increase energy efficiency and reduce energy demand will thus require further policies, especially in the area of awareness-raising of consumers, and the removal of barriers to energy efficiency. In addition, changes in process management and substitution of energy-intensive materials can lead to further improvements in energy intensity. The European Commission's communication for an action plan to improve energy efficiency in the European Community (European Commission, 2000b) outlines a wide range of policies and measures aimed at removing existing market barriers to energy efficiency. The proposed directive on energy end-use efficiency and energy services (European Commission, 2003a) sets a target for the Member States to save 1 % per year of energy supplied between 2006 and 2012 (and 1.5 % for the public sector) compared with business-as-usual.

The CO_2 emission reductions that would result from a dedicated energy efficiency policy even in the absence of a carbon permit price are modelled in a scenario being prepared for Directorate-General for Energy and transport (Mantzos *et al*., 2004, 'Energy Efficiency Case'). This scenario assumes that energy efficiency policies and measures are implemented along the lines of the action plan on energy efficiency (European Commission, 2000b). As a result, EU-25 gross inland energy consumption would remain almost stable between 2000 and 2030 instead of increasing by 19 % under a baseline scenario. The services sector shows the highest decrease in energy consumption compared with the baseline development, followed by households and transport. Compared with 1990 levels, the CO_2 emissions would decrease by 4.5 % instead of increasing by 14 % as in the baseline, underlining the importance of energy efficiency improvements in reducing CO_2 emissions.

Energy efficiency in final energy consumption
Final energy consumption in the EU-25 has increased at an average annual rate of just over 0.5 % since 1990 and is projected to continue to increase by 30 % between 2000 and 2030 in the baseline scenario and by 20 % in the LCEP scenario. However, final energy intensity (final energy consumption per unit of GDP) is projected to decline. The baseline projections show substantial reductions in final energy intensity in all sectors over the period 1990 to 2030 and further decreases are seen under all LCEP scenarios (see Tables 5.1 and 5.2). Given that

([21]) The contribution of energy intensity improvement to the overall emission reduction would increase if higher domestic emission reductions were to be achieved as low-cost fuel switch options become increasingly exploited (see scenario results in Mantzos *et al.*, 2004, Chapter 8).

Table 5.2 Improvements in final energy intensity (22), EU-25

	1990	2030				
		Baseline	Core LCEP	Renewables expanded	Nuclear accelerated	Nuclear phase-out
Industry	100	51	49	49	49	48
Households	100	52	49	48	48	48
Services	100	58	52	52	52	52
Transport	100	67	62	62	62	62

Note: Index 1990=100.

the baseline assumptions result in significant improvements in energy intensity in all demand sectors, additional improvements in the LCEP scenario are rather modest but still important, since total final energy consumption in 2030 is around 7.3 % lower than in the baseline, equivalent to an emission reduction of almost 190 $MtCO_2$.

The structure of final energy consumption has undergone significant changes in recent years, with the rapid growth of a wide range of service sectors and a shift to less energy-intensive manufacturing industries. Rising personal incomes have permitted higher standards of living, with resultant increases in the ownership of private cars and domestic appliances. Rising comfort levels, reflected in increased demand for space heating and cooling, have also contributed to higher final energy consumption. As a result, final energy consumption increased in every sector except industry between 1990 and 2002. The transport sector was the largest and fastest growing consumer of energy in the EU-25. Under both the baseline and the LCEP scenarios, services and transport are the sectors with the highest increases in final energy consumption. The overall performance in improving the final energy consumption intensity is shown for each sector and for all the scenarios in Table 5.2.

The services and household sectors are the most sensitive to the imposition of the carbon constraint. In the LCEP scenario, their final energy consumption is 10 % (services) and 8 % (households) less than in the baseline, reflecting the existence of a significant potential for a more rational use of energy as a result of changes in consumer behaviour and the adoption of more efficient technologies. The largest reduction in 'absolute' terms, both for the services and the household sector, is in energy used for heating and cooling as a result, for example, of better thermal insulation of buildings. Compared with the baseline, final energy use for heating and cooling is 9 and 7 % lower in the LCEP scenario for services and households respectively. The highest 'relative' reductions between the baseline and the LCEP scenario are achieved in electricity for electrical appliances and lighting; they are 16 % (services) and 13 % (households) below the baseline. This demonstrates the enormous potential for energy efficiency improvements in electrical appliances that can to some extent be mobilised by standard setting and labelling. The higher relative reductions in the services sector reflect the fact that the services sector benefits from economies of scale due to a larger unit size than individual households and that energy investment decisions are often taken by firms instead of by individuals, as in the household sector (see Mantzos *et al*., 2004).

In the industry sector, additional improvements in final energy intensity are modest as this sector already shows significant improvements under the baseline, due to more efficient production and a restructuring of production towards less energy-intensive industries (see Mantzos *et al*., 2004).

Despite an absolute increase in final energy consumption for transport, the final energy intensity decreases by 5 percentage points as a response to the introduction of a carbon permit price. This is mainly the consequence of reductions in road transport fuel use, which accounts for around 80 % of transport final energy consumption in 2030. While the average fuel consumption of private cars (trucks) in the baseline scenario decreases by 35 % (20 %) in 2030 compared to 1990,

(22) Final energy consumption per unit of GDP, value added or private consumption.

Table 5.3 Use of combined heat and power, EU-25

	2000	2030				
		Baseline	Core LCEP	Renewables expanded	Nuclear accelerated	Nuclear phase-out
% of electricity from CHP	12.6	16.3	17.1	28.0	16.5	17.8

they are 37 % (24 %) below 1990 levels in the LCEP scenario (see also Section 5.3.8). Aviation shows a drastic decrease of 19 % in final energy consumption between the baseline and LCEP scenarios in 2030, due both to lower transport activity (a reduction of 4.4 %) and a substantial improvement in efficiency.

Efficiency in energy supply
Under the LCEP scenarios, improvements in the overall efficiency of energy supply are driven mainly by an increase in the efficiency of electricity production based on fossil fuels. These arise due to developments in the technology used for any given fuel, through alternative combinations of technologies and fuels and changes in the allocation of available plants in the merit order of dispatch. The further use of combined cycle gas turbines (CCGT) rather than conventional thermal coal plant plays an important role. The result of these changes is that the overall efficiency of thermal electricity production in 2030 increases from 48.7 % under the baseline scenario to 50.6 % under the LCEP scenario. While this does not sound very much, because of the significant emissions from electricity production, it is sufficient to reduce CO_2 emissions by around 60 $MtCO_2$.

Use of combined heat and power (CHP) can also help to increase the efficiency of energy supply as it combines electricity production technologies with heat recovery, which results in an increase in the overall efficiency of electricity and heat production. In conventional thermal power plants, around 45–70 % of the input energy is lost as heat. In CHP plants, which make use of some of the heat that would otherwise be lost, only around 15 % of the input energy is lost. The combined efficiency of heat and electricity production from CHP schemes is typically 85 %. CHP plants are often located close to where the heat can be consumed, limiting transmission and distribution losses and so further helping to improve efficiency.

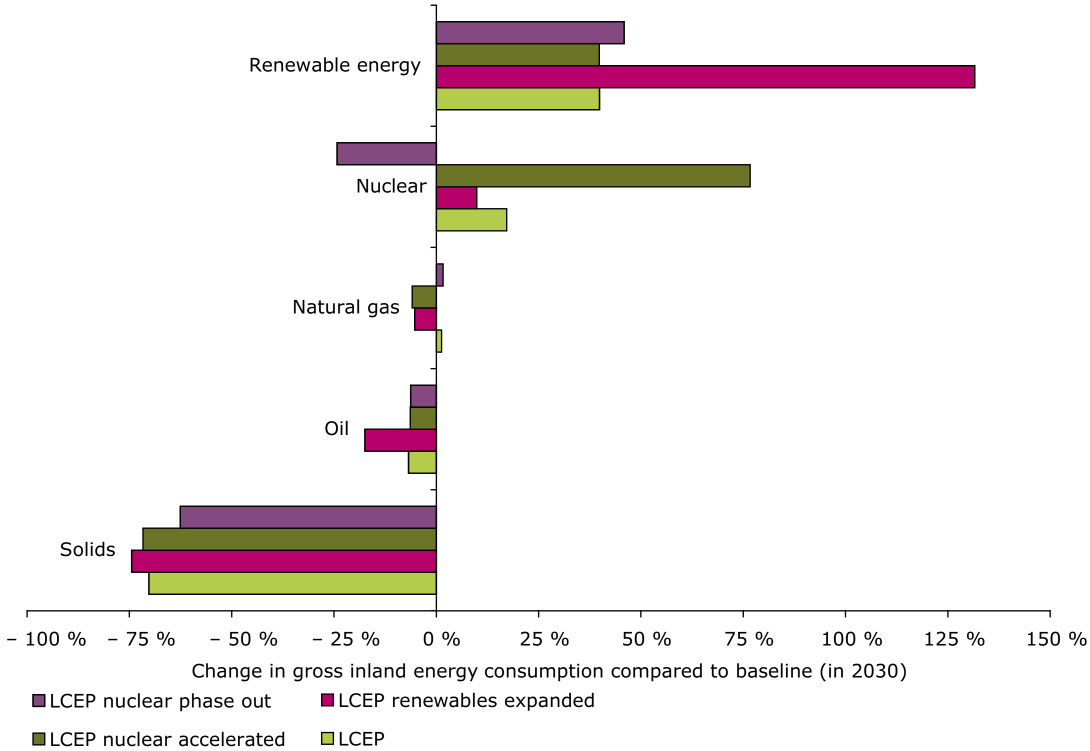
The share of electricity from CHP in total gross electricity production was around 12.6 % in 2000, and under the baseline scenario this share is expected to increase slightly to reach 16.3 %. Under many of the LCEP scenarios, there is little further increase in CHP, however, for the renewables expanded scenario, the share of CHP increases to 28 % by 2030, following the assumed implementation of the directive on the promotion of cogeneration in this scenario and the increased use of biomass in CHP-plants.

5.3.2 *Fuel mix in gross inland energy consumption*

The use of fossil fuels has considerable impact on the environment and is the main cause of emissions of GHGs and acid gas pollutants. The environmental impact of the energy system depends on the relative share of non-fossil and different fossil fuels in total energy consumption and the extent to which pollution abatement measures are used. Natural gas, for instance, has about 40 % less carbon content than coal and 25 % less than oil (IPCC, 1996) and contains only marginal quantities of sulphur.

In recent years, the fossil fuel mix has been gradually changing. Oil and oil products continue to be the most important fossil fuel, mainly because of their use in the transport sector. However, the share of gas has increased rapidly, largely at the expense of coal and lignite, which has seen its contribution to total energy consumption reduced by one third. Gas now represents almost one quarter of total energy consumption and its use as a fuel for producing electricity has tripled since 1990. The baseline scenario shows that oil consumption is expected to continue to increase, but the rate of increase slows as demand from the transport sector decelerates and liquids become almost exclusively a fuel for transport and the petrochemical industry. Gas use is expected to continue to grow strongly in the short term, driven by its continued penetration into the electricity production sector, supported by the liberalisation of electricity markets. In the longer term, this rate of

Figure 5.3 Changes in the fuel mix of EU-25 gross inland energy consumption compared with the baseline in 2030



Source: EEA, 2005.

increase is expected to decline under baseline assumptions, as higher import prices lead to a loss of competitiveness of gas-based electricity production, enhanced by concerns about security and diversity of supply.

The introduction of a carbon permit price under the LCEP scenario results in a continuing fuel switch over the entire projection period until 2030 (see Figure 5.3). Gas use in 2030 is slightly higher than in the baseline scenario while solid fuel use decreases by 70 %. The use of renewable energies increases by 40 % and nuclear by 17 %. Fuel switching is most important in the power generation sector and thus described in detail in Section 5.3.3.

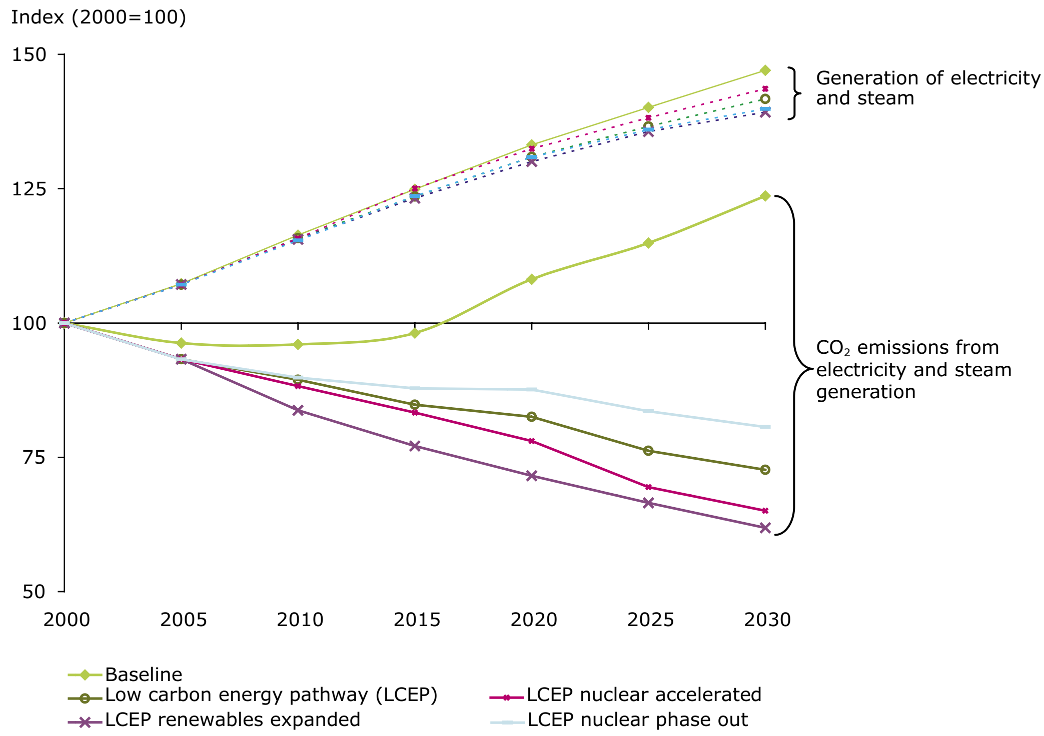
5.3.3 Power generation

The power generation system (i.e. electricity and steam) in Europe appears to be the area that can adjust in the most cost-effective way to emission constraints. More than 70 % of the CO_2 emissions reductions in 2030 between the baseline and the LCEP scenarios occur in this sector. Compared with 2000, CO_2 emissions from public power generation will decrease by 25 %, or even 40 % in the case of additional targets for the introduction of renewable energy, instead of increasing by 31 % compared with 2000 levels in the baseline scenario ([23]). Compared with the baseline, the emissions of this sector in the LCEP scenarios are between 36 % (nuclear phase-out) and 53 % (renewables expanded) lower in 2030.

These emission reductions are achieved despite electricity consumption being only slightly under baseline scenario levels and well above 2000 levels. The rise in electricity consumption is due not only to a growing economy, but also to an increase in the share of electricity in final energy consumption. The attractiveness of electricity is due to its flexibility in use and the importance placed by consumers on the variety of energy services that it provides. In the baseline scenario, electricity generation from public and industrial producers increases by 52 % between 2000 and 2030 (and by 36 % from public producers). The LCEP scenario

([23]) CO_2 emissions from electricity and heat generation by 'both' public and industrial producers will be 27.3 % below 2000 in the LCEP instead of growing by 23.6% in the baseline (Figure 5.4).

Figure 5.4 Development of electricity and steam generation by public and industrial producers and related CO_2 emissions according to different scenarios, EU-25



Source: EEA, 2005.

results show an increase of 45 % compared with 2000 (and 30 % for public generation only). Electricity generation declines at rates well below those of reductions in total final energy consumption, since efficiency gains on the demand side are largely counterbalanced by shifts in the fuel mix towards the use of electricity.

There are many reasons for the high flexibility of the generation system: high carbon fuels in electricity generation such as coal can be replaced by low carbon fuels such as gas; generation using carbon-free fuels can increase; and the system can respond by increasing the overall efficiency of generation based on fossil fuels. This last option could be achieved by improving the technology used for any given fuel, through alternative combinations of technologies and fuels (such as the use of gas-turbine combined cycle units rather than conventional thermal coal plant) and through changes in the allocation of the available plants in the merit order of dispatch.

Fossil fuels remain the dominant fuel for electricity production. However, while their share is projected to remain almost constant in the LCEP scenario (51 % in 2030), it would increase to 64 % in the baseline scenario.

Natural gas, which causes less pollution than other fossil fuels, is becoming the fuel of choice for new fossil-fuelled power plants and increases its share from 9 % in 1990 to 35 % and 42 % in the baseline and LCEP respectively by 2030. In the baseline scenario, the share of electricity produced from hard coal and lignite decreases in the short term but increases after 2015 to return to its current level in 2030. This is the result of coal playing a predominant role in the replacement of retired nuclear plants as clean coal technologies gain maturity and the competitiveness of coal-fired plants increases as a result of the forecasted increase in the relative price of gas. In the LCEP scenario, coal use declines substantially over the entire period.

The share of non-fossil fuels (i.e. renewable energies and nuclear power) grows moderately compared with 1990 as a response to the permit price. However, it will be 14 percentage points higher in the LCEP scenario than in the baseline scenario, in which the share of nuclear energy declines steadily and the share of renewable electricity only increases slightly. Assuming a higher share of renewables in electricity production — 38.6 % in the renewables expanded variant compared with 28 % and 18 % in the LCEP

Table 5.4 Share of renewables in gross inland energy consumption and electricity production, EU-25

	2000	2030				
		Baseline	Core LCEP	Renewables expanded	Nuclear accelerated	Nuclear phase-out
Renewable energy consumption	5.8	8.6	13.1	21.5	12.5	13.9
Renewable electricity	14.6	18.2	27.9	38.6	27.4	30.1

Note: Share in %.

and baseline scenario respectively — would result in substantially higher emission reductions. In addition, other low- or zero carbon power generation technologies can contribute to higher emission reductions. The nuclear accelerated variant leads to additional emission reductions as shown in Table 5.1.

5.3.4 *Renewable energies*

Under all LCEP scenarios (except for the nuclear accelerated variant) renewable energies experience the largest increase relative to the baseline scenario. This demonstrates that the further development of renewable energy could make a major contribution to a more sustainable energy system as most renewable energy technologies produce very little GHG emissions and generally have much lower environmental impacts than other fuel sources. The renewables expanded variant demonstrates how strong support for renewable energy could have a significant impact on CO_2 emissions. In this scenario, emissions in 2030 are reduced by 362 $MtCO_2$ compared with the least-cost LCEP scenario and 1 319 $MtCO_2$ compared with the baseline.

A significant expansion of renewables would also make a useful long-term contribution to diversity, security and self-sufficiency of energy supply. Continued growth in the EU renewables industry could also create employment (particularly amongst SMEs), increase export earnings, and promote social and economic cohesion, particularly in remote and rural regions. It could also provide a platform for long-term cooperation with developing countries, where energy consumptions are expected to grow dramatically in the coming years. As these wider benefits of renewable energies may become increasingly important, their contribution to gross inland energy consumption may develop even faster than assumed in the LCEP scenarios, where (except for the renewables expanded variant) the growth of renewable energy occurs as a result of the introduction of carbon prices.

In all LCEP scenario variants (except for the renewables expanded variant) and the baseline, the share of renewables in gross inland energy consumption would fall short of the indicative EU target of 12 % by 2010 and the potential future targets ([24]). It would as well fall short of the 21 % target for the share of renewables in gross electricity consumption; European Council, 2001. The renewables expanded variant assumes that the indicative target for 2010 is reached in the entire EU-25 even in the absence of carbon prices and that further targets for 2020 and 2030 of 16 and 20 % respectively are also achieved, which would require additional incentives both to energy consumers and energy producers. If current best practice policies were applied in all countries, other studies show that even more ambitious targets (around 19 % in 2020) could be achieved (Ragwitz *et al*., 2004).

In the renewables expanded variant, most of the increase in renewable energy occurs in the electricity production sector, where the share of renewable energy in 2030 increases from 18.2 % under the baseline to 38.6 %. The expansion of renewables for electricity production is driven mainly by increases in the deployment of wind energy (increasing its share in 2030 from 7 % in the baseline scenario to 13.1 % in the renewables expanded variant) and biomass, with the role of solar energy becoming increasingly important only in the long term. The share of biomass in electricity generation in 2030 increases from 1 % in the baseline scenario to 12.7 % in the renewables expanded variant, of which a high share is used in combined heat and power plants. In

([24]) This target applies to the pre-2004 EU-15 Member States only.

contrast, large and small hydro show a less pronounced growth over baseline levels since their additional potential is relatively low due to site restrictions and environmental concerns. The total amount of electricity produced in large hydropower plants will remain almost constant between 2000 and 2030. Under all scenarios, the increase in the share of renewables is mainly at the expense of coal as its share of total energy consumption falls to between 4.2 and 6.3 %. The significant expansion of nuclear under the nuclear accelerated scenario does not affect the deployment of renewables to any large extent.

Renewable energy on the demand side (including biofuels in transport) also increases over baseline levels both in absolute terms and in terms of market share, an increase that is less pronounced than on the supply side, but still important given the overall decline of energy consumption due to the introduction of carbon prices. Thus the market share of renewables on the demand side reaches 10.3 % in the renewables expanded variant and 5–5.5 % in the other LCEP variants compared with 4.5 % in the baseline scenario. Most of the growth occurs in rising quantities of biofuels mixed in petrol and diesel fuel. However, while expanding the growth of biomass for energy purposes in agricultural and forestry areas, attention should be given to conflicting land use, in particular to nature conservation requirements. The use of solar thermal and other renewables in the household and services sector increases its share to 4.3 % and 3 % respectively in 2030 in the renewables expansion variant, while it would remain at very low levels (1 % and 0.2 %) in the baseline scenario. Biomass and waste experience show a large growth in the final energy consumption of the industry sector.

It should be noted that the introduction of carbon prices leads to an increased contribution of co-generated steam in overall steam demand, as this is a more cost-effective option than heat production, and thus limits the potential use of biomass on the demand side, which would then be used on the supply side.

The scenario results demonstrate that the introduction of a carbon price alone would not be sufficient to mobilise the potential of renewable energies and meet the EU indicative 2010 target for renewables and ambitious targets beyond 2010. Post-2010 European targets for renewable energies will be formulated in 2007. A future EU target of a 20 % share of renewable energies in gross inland energy consumption by 2020 has already been proposed (see EREC, 2004; Berlin European Conference for Renewable Energy, 2004). In addition, some European countries have announced renewable energy targets that go beyond the time horizon of the EU 2010 indicative target. Germany aims to increase the share of renewable electricity from 7.9 % in 2003 (BMU, 2004) to 20 % in 2020 and to provide half of gross inland energy consumption by renewable energies by the year 2050 ([25]). The UK announced in its White Paper the aspiration to double the share of renewable in electricity production from the 2010 target to 20 % by 2020 (DTI, 2003a). At the World Summit on Sustainable Development in Johannesburg in 2002, an agreement was reached to increase the global share of renewable energy sources. The German Advisory Council on Global Change recommended a 20 % share of renewable energy in the global energy mix by 2020, increasing to more than 50 % by 2050 (WBGU, 2003b).

Reaching these targets would require specific policies and measures such as direct price support and loans or market-based mechanisms such as calls for tenders for electricity from renewable sources, trading of 'green certificates' or voluntary payments of premium rates for renewable electricity by consumers (EEA, 2001). In the renewables expanded scenario, further penetration of renewable energy on the demand side is achieved through promotional policies for the use of biomass and waste in industry and solar thermal panels for water heating in services and households. This scenario also assumes implementation of the biofuels directive (European Council, 2003) that sets indicative shares for biofuels in petrol and diesel for transportation purposes of 2 % in 2005 and almost 6 % in 2010. This is achieved through a favourable tax regulation. On the supply side, the 21 % renewables electricity target for the EU and targets by Member State as defined in the EC renewables electricity directive (European Council, 2001) and for beyond 2010 are achieved through support schemes that provide subsidies

([25]) The target of 20 % renewable electricity and the indicative target of 50 % renewables in GIEC are given in the Renewable Energy Sources Act from 21 July 2004 and the national sustainability strategy respectively.

Table 5.5 Use of nuclear power, EU-25

	2000	2030				
		Baseline	Core LCEP	Renewables expanded	Nuclear accelerated	Nuclear phase-out
Nuclear capacity (GW)	140.3	108	134	130	209	71
Share of electricity production (%)	31.8	17.4	22.1	20.4	29.5	13.2

for electricity generation from renewable energy, i.e. a renewables premium of 2,4 and 4.5 cent/kWh in 2020 and in 2030, respectively. It is further assumed that the electricity tariffs for all electricity consumers increase to reflect the higher costs of greater renewables deployment. However, the large increase in renewable energies between the renewables expanded variant and the core LCEP scenario would increase the energy bill for households by only EUR 10–20 in 2030 (see Chapter 6).

The effect of dedicated renewable energy actions in the absence of a carbon permit price was analysed in an additional scenario variant. A higher contribution from renewable energy sources than in the baseline, increasing to 20 % of total energy consumption in 2030, results in CO_2 emissions of the energy system being almost stable between 1990 and 2030 compared with growing by 14 % in the baseline scenario. The increase in renewable energies is most important in the electricity sector, contributing 35 % of total electricity generation in 2030. It is interesting to note that gross inland energy consumption in this scenario remains unchanged compared with the baseline development, indicating that the influence of dedicated renewable support policies and measures have only limited influence on energy efficiency. Synergies can mainly be found in a higher share of biomass-fired combined heat and power plants.

5.3.5 Nuclear power

The future role of nuclear power in helping to reduce GHGs and limit climate change is one of the most hotly debated topics in European energy policy and also regarding the export of nuclear energy technology outside Europe. To reflect a range of future outcomes, two variants have been developed to illustrate different actions with respect to the long-term role of nuclear power in Europe.

Under the baseline scenario, which is based on the phase-out policies of some European member countries, the share of nuclear power in electricity production falls from current levels as some plants are retired and no new nuclear power stations are built. In contrast, under the core and the nuclear accelerated LCEP scenarios, new nuclear power stations are built in the EU-25 from 2015 onwards in response to the increased carbon permit price. These are mostly new nuclear designs (such as the European Pressurised Water Reactor (EPR) and the Westinghouse AP technology).

In the core LCEP scenario, there is 26 GW of additional capacity compared with the baseline scenario by 2030, which brings the total installed capacity of nuclear power in Europe almost back to the level seen in 2000. In the nuclear phase-out variant, nuclear capacity is retired more quickly than under the baseline scenario with the result that by 2030 there is almost 64 GW less capacity than under the core LCEP scenario and 37 GW less than under the baseline scenario. There is also an increase in the share of renewable energy from 27.9 to 30.1 % to partially compensate for the reduced nuclear output, but even so total carbon emissions under this scenario are 3 % (109 $MtCO_2$) higher in 2030 than in the core LCEP scenario. In the nuclear accelerated variant, nuclear capacity is 75 GW higher in 2030 than in the core LCEP scenario and 68.5 GW higher than in 2000. This results in total CO_2 emissions in 2030 being 3.5 % (116 $MtCO_2$) lower in 2030 than in the core LCEP scenario.

Other studies describing the transition to a sustainable energy system highlight the necessity of taking into account not only the cost of nuclear power but also public concerns and waste disposal (WBGU, 2003b). The problem of nuclear waste management and the risk of proliferation are not fully integrated into the LCEP analysis. Today, the quantities of highly

Table 5.6 Possible carbon dioxide capture technologies for power generation

Technology	Plant adaptation required	Type
Integrated gasification combined cycle (IGCC)	New	Pre-combustion capture
Gas turbine combined cycle with catalytic shift	New	Pre-combustion capture
Pulverised fuel (PF) with flue gas scrubbing	Retrofit	Post-combustion capture
PF + oxyfuel combustion + flue gas scrubbing	Retrofit	Oxyfuel combustion
PF + supercritical boiler + flue gas scrubbing	Retrofit/New	Post-combustion capture
PF + supercritical boiler + oxyfuel combustion + flue gas scrubbing	Retrofit/New	Oxyfuel combustion
GTCC with flue gas scrubbing	Retrofit	Post-combustion capture
GTCC with new coal gasifier to effectively produce an IGCC plant	Retrofit	Pre-combustion capture

Source: DTI, 2003b.

radioactive waste from nuclear power production continue to accumulate and a generally-acceptable disposal route for this waste has yet to be identified. Scenarios with increasing shares of nuclear energy would thus have to consider the increasing quantities of nuclear waste. The cost of decommissioning is also becoming an increasingly important issue at Member State level for economic reasons and due to public concern. The cost of nuclear decommissioning is included in the analysis. However, the cost of returning nuclear power plant sites to their initial conditions is not taken into account. The cost of nuclear waste management is taken into account (through the price of nuclear energy) but no consideration is made for the problem of increasing quantities of nuclear waste.

5.3.6 Carbon capture and storage

Carbon dioxide capture and storage (CCS) offers the possibility of continuing to use fossil fuels while dramatically reducing the amount of CO_2 that enters the atmosphere from their use (by 85–95 %). It is best applied to large stationary sources, which offer economies of scale in construction and minimise the extent of the supporting transport network. Most current work on CCS has therefore focused on its application to power generation and other large process plant such as oil refineries and coal gasification plant, and, looking to the longer term, hydrogen production facilities from fossil fuels.

Carbon capture and storage was not considered as an option for carbon abatement in the country-specific LCEP scenarios by PRIMES. Calculations by IMAGE/TIMER and POLES showed however that it could have a key role as a transition technology for the 21st century in helping to move towards a lower-carbon energy system. The IPCC is currently working on a special report on carbon capture and sequestration because of the high mitigation potential of this technology (IPCC, 2002). A recent IEA study underlines that CCS could play an important role in reducing CO_2 emissions worldwide (IEA, 2004b). This would be the case especially in regions with ample coal reserves, such as North America, Australia, China, India, and some parts of Europe. IEA modelling results suggest a potential of 400–800 Mt of CO_2 capture in Europe by 2030. The use of CCS in China and India may depend on technology transfer from industrialised countries and global CO_2 mitigation efforts.

CCS involves three processes, capture, transport and storage. Capture involves the separation of the CO_2 from the gas stream, which can be done either post- or pre-combustion. This process requires energy and as a result the overall efficiency of a power plant equipped with CCS is reduced. The efficiency loss is highest for post-combustion capture in conventional coal power plants and ranges from 12 percentage points for existing coal-fired plants to 4 percentage points for future designs with fuel cells (IEA, 2004a). Pre-combustion capture in combination with an integrated gasification combined cycle coal power plant is considered to be promising as well as oxyfuel combustion. There are a

Table 5.7 Capacity of carbon dioxide storage — estimates for the North Sea

	Estimated storage capacity (Gt CO_2)			
	Depleted oil fields	Depleted gas fields	Deep saline aquifers ([26])	
			Closed	Open
North Sea				
Denmark	0.1	0.4	0	0
Netherlands	0	0.8	0	0
Norway	3.1	7.2	10.8	476
UK	2.6	4.9	8.6	240
Total	**5.8**	**13.3**	**19.4**	**716**

Notes: i) The potential for storage in deep unmineable coal seams has not been included in the table because this remains at the research stage.

ii) Estimates for the United Kingdom apply only to the North Sea with further potential in other areas including West of Shetland and the Irish Sea.

Source: British Geological Survey, 1996.

number of technologies available for carbon sequestration with the choice depending on the state (concentration, pressure, volume) of the CO_2 captured.

Once captured from the flue gases, the CO_2 can be transported in gaseous form by pipeline or by tanker (road, rail or water), but with the large volumes involved in a typical CCS scheme (10–30 $MtCO_2$ per year), pipeline transport is the only practical option. Most experience of pipeline transport of CO_2 has been gained in the United States where the gas is used extensively for enhanced oil recovery (EOR). This practical experience shows that CO_2 transport by pipeline is an established commercial technology.

Various methods have been proposed for storing or managing captured CO_2 including injection into geological formations, deposition into the water column on the deep ocean floor and conversion into solid minerals. In the medium term, geological storage seems one of the most promising options for Europe because understanding of the processes is more advanced. Disposal into the water column may have environmental impacts on the marine ecosystem and is not appropriate for relatively shallow waters such as the North Sea. Geological storage requires permeable rock strata that provide space for the gas to be stored. These strata must be sealed by rock that is impermeable to CO_2. There are three main options for geological storage:

- depleted oil and gas reservoirs (this option may offer some financial return if the CO_2 can be injected as part of an enhanced oil recovery operation in non-depleted reservoirs);
- deep saline aquifers ([27]);
- unmineable coal seams.

For the last two options, research to estimate the storage potential is continuing. It is not yet determined to what extent *open* deep saline aquifers offer a potential for long-term safe storage. In Norway, about 1 $MtCO_2$ from the Sleipner oil field is captured and stored annually into the Utsira aquifer. Estimates of the storage capacity of selected north-west European countries are given in Table 5.7. It should be noted that these storage potentials are geographically unequally distributed across Europe. Depleted oil and gas fields can be found in particular in e.g. the UK, the Netherlands and Norway, with a similar distribution of saline aquifers. Since the transport of huge quantities of CO_2 leads to transport costs, which depend on the distances between the source and the storage site, CCS might be more competitive in countries with large storage capacities nearby.

([26]) It is not yet sure to what extent open saline aquifers can be used for safe long-term storage of CO_2, while a long-term storage is likely to be possible in closed saline aquifers.

([27]) An aquifer is a layer of sedimentary rocks saturated with water and from which water can be extracted through pumping or into which fluids can be injected (IEA, 2004a). An open aquifer has no natural barriers to water flow.

5.3.7 Hydrogen

The widespread use of hydrogen as a fuel for both stationary and transport applications is often seen as a long-term key element in the transition towards a low-carbon energy system, with the term 'hydrogen economy' being used to describe a future world in which hydrogen has largely taken the place of carbon-based fossil fuels. It is expected that a higher share of hydrogen will contribute to enhancing energy supply security, reducing GHG emissions and strengthening the European economy by acquiring a leading position in this technology (European Commission, 2003b). Developing a low-carbon energy system based around hydrogen would be a major undertaking and the EU recently (2003) started a research programme to collect the required information covering the technical, social and economic impacts of hydrogen production and use.

Hydrogen can be produced from virtually any primary energy source and can then be used chemically in fuel cells to deliver electricity to power engines for transport applications or for heat production or directly as a fuel. It is also possible to mix hydrogen with natural gas (to produce 'hythane'). Production of hydrogen from electricity causes efficiency losses but has the advantage that hydrogen, unlike electricity, can be stored.

The production of hydrogen using fossil energy sources results in emissions of CO_2. In the case of centralised production, with almost pure CO_2 flows, capture and sequestration of carbon may become an attractive option (Blok *et al*., 1997). The production of hydrogen from renewable energy sources has the biggest environmental benefits, but is likely to remain very expensive over the next decades. Since the production of hydrogen, in particular from electricity, is combined with considerable conversion losses, the direct use of renewable electricity is — with today's technologies — in many cases more favourable. The use of hydrogen in fuel cells produces only water, and although some NOx emissions result when used in combustion engines, these can be abated through the use of catalytic converters (Akansu *et al*., 2004).

There are varying views on the timescale over which hydrogen could be introduced and the extent to which it may be applied. The LCEP scenarios show very little penetration over the next 30 years, which is consistent with the view that widespread use of hydrogen is unlikely for 20 to 50 years or more. In the baseline scenario, the use of fuel cells for electricity generation will remain at a very low level. The introduction of a carbon price in the LCEP scenario significantly increases the share of fuel cells in particular between 2025 and 2030, with the share of electricity generated by fuel cells reaching 0.4 % of total electricity generation in 2030. The installed capacity of fuel cells grows to 4189 MWe in 2030 with all of it being installed between 2025 and 2030. It will, however, not reach the 'snapshot 2020' proposed by the European Hydrogen and Fuel Cell Technology Platform (2004), which envisages a newly installed capacity of stationary fuel cell in the order of 2 000 to 4 000 MWe in 2020. The use of liquefied hydrogen in transport reaches a share of 0.15 % both in the baseline and LCEP scenarios. Small fuel cell appliances such as in handheld computers may reach a higher market share earlier (European Hydrogen and Fuel Cell Technology Platform, 2004), but were not modelled.

If a higher share of hydrogen is to be realised (e.g. as proposed by the Hydrogen and Fuel Cell Technology Platform), additional policies and measures would have to be implemented in order to overcome the barriers to a widespread use of hydrogen. These barriers include:

- lack of markets for centralised production and distribution of hydrogen;
- storage is still inefficient, voluminous and expensive;
- on-site production requires relative expensive converters (natural gas, ethanol);
- fuel cells face high production costs and the lifetime of fuel stacks needs to be improved, although costs are expected to decrease rapidly once fuel cells can be mass-produced;
- there are concerns in society about safety;
- the development of infrastructure will require large investments;
- lack of EU-wide regulations and standards for fuel cells.

Additional policies and measures include further research and development in order to reduce the costs of the fuel cell

Table 5.8 Attributes of alternative engine and fuel technology

Attribute	Engines			Fuels	
	Advanced ICE	Hybrid	Fuel cell electric	Biofuels	Hydrogen
Vehicle emissions	Reduces CO_2 & regulated pollutants	Reduces CO_2 & regulated pollutants	Virtually no tailpipe emissions, may be upstream emissions	Tailpipe emissions reduced; fuel- cycle CO_2 emissions reduced, but may be some N_2O and PM increase	Tailpipe emissions reduced or eliminated; fuel- cycle emissions vary greatly according to production method
Speed and drivability	Probably improved	Probably improved	Probably improved	Some types may adversely affect performance of conventional engines	Engine-dependent
Refueling infrastructure	Uses existing infrastructure	Uses existing infrastructure	Probably requires major new infrastructure	Significant new infrastructure	Major new infrastructure
Cost of motoring	Potentially higher, but lower fuel consumption	Potentially higher, but lower fuel consumption	Uncertain	Probably increased costs	Probably increased costs
Timescale for widespread deployment	Short (from 2005)	Short and medium (2005–2030)	Long (post 2030)	Short and medium (2005–2030)	Long (post 2030)

Source: Adapted from Kroger *et al*., 2003.

systems and increase their lifetime, large-scale demonstration projects and the establishment of codes and standards (Hydrogen and Fuel Cell Technology Platform, 2004).

5.3.8 Transport sector — low carbon emission vehicles

Analysis of the LCEP scenario and the variants show that the transport sector will be one of the most difficult areas in which to reduce CO_2 emissions in the short to medium term (see Section 5.3.1). This is because of the rapid increase in passenger and freight demand projected over the next 30 years and the difficulty in replacing oil as the fuel on which the transport sector is almost totally dependent (except for biofuels in the renewables expanded variant, see below). The impact of these two factors is that the transport sector is the only sector that shows continuously growing CO_2 emissions over the next 30 years in all the scenarios that have been considered. Emissions will rise to being 58 % above 1990 levels in the baseline and 46 % above in the LCEP scenario (Table 5.1).

Road transport

Road transport is expected to be responsible for more than 80 % of transport final energy consumption in 2030, showing the need to decrease the emissions from cars and trucks. In the medium to long term, there are a number of engine technologies and fuels that could substantially reduce carbon emissions from road transport. These include for engines:

- improvements to internal combustion engines, including advanced fuel injection systems, and downsizing;
- hybrid vehicles, which have an internal combustion engine used in combination with an electric motor;
- fuel cell vehicles, which have a dedicated electric motor;

and for fuels:

- hydrogen for fuel cells from one of a wide range of possible sources;
- biofuels, including alcohols made out of starch crops and diesel made from oilseeds as well as advanced fuels based on the gasification of biomass (for example biomass-to-liquids).

The advantages and disadvantages of these technologies and fuels are shown in Table 5.7.

The recent well-to-wheels evaluation of energy and GHG emissions by the JRC

EUCAR and CONCAWE (JRC *et al.*, 2004) concluded that a shift to renewable/low-fossil carbon routes in transport may offer a significant GHG reduction potential, but that no single fuel pathway offers a short-term route to high volumes of 'low carbon' fuel. Consequently, the report noted that contributions from a number of technologies/ routes will be needed and a wider variety of fuels may be expected in the market.

The scenario results demonstrate that efficiency increases in car and truck fuel consumption are an important way of reducing CO_2 emissions from road transport. Already in the baseline, the average fuel consumption of private cars and trucks decreases by 35 % and 20 % respectively compared with 1990 levels. A further decrease by 2 and 4 percentage points for cars and trucks respectively is achieved as a result of the imposition of a carbon constraint in the LCEP scenario.

As shown in the renewables expanded variant, incentives for a higher share of biofuels in petrol and diesel fuel can lead to a slowdown in the growth of CO_2 emissions, with emissions in 2030 increasing by 25 % above 1990 levels compared with 58 % in the baseline scenario. The share of biofuels in both petrol and diesel fuels rises to more than 20 % in the year 2030 as a result of the assumed favourable tax regulation. This number does, however, not take into consideration the impacts of the growth of biofuel crops on land use, farmland habitats and biodiversity.

Overall, the increasing CO_2 emissions from road transport in all scenarios demonstrate the need for more effective policies to reduce CO_2 emissions from the transport sector. These include taxation measures tied to CO_2 performance or a stronger focus on biofuels; the introduction of CO_2 emission limits may also be considered (EEA, 2004b). There is also a need for awareness-raising since car parameters such as mass, engine power and the amount of energy-consuming equipment (air conditioning, electric windows), which influence specific CO_2 emissions, depend strongly on consumer choice. Improvements in urban planning might also contribute to reducing passenger transport activity.

Modal shift
Behavioural change combined with investment in public transport and pricing mechanisms could also result in a shift to alternative transport modes, which is generally beneficial (though not in all cases as positive as it may seem (EEA, 2004b). The LCEP scenario results do not, however, show a significant shift in transport modes, for example there is no shift in passenger transport towards rail or public transport. The role of inland navigation also remains low in all scenarios. These findings indicate that a carbon price alone would not be sufficient to initiate a modal shift and that additional policies would be needed.

Aviation is the transport mode that is most sensitive to the imposition of a carbon constraint. Aviation passenger transport activity in 2030 in the LCEP scenario is 4.4 % less than in the baseline scenario and the final energy consumption 19 % below, as average fuel consumption improves considerably.

The impact of a modal shift on transport energy consumption and related CO_2 emissions is analysed in a scenario being prepared for Directorate-General for Energy and Transport (Mantzos *et al.*, 2004, Chapter 6). It assumes that the share of rail and public road transport remain stable at the 1998 level up to 2010 instead of decreasing as in the baseline scenario, and that load factors increase significantly. These assumptions correspond to a successful implementation of policies proposed in the White Paper on common transport policy (European Commission, 2001b). As a consequence, rail transport increases by 21 % above the baseline scenario in 2010. Transport energy consumption in this scenario is 13 % below that in the baseline scenario, resulting in CO_2 emissions being reduced by 13.4 % (compared with the baseline scenario) in 2010 and 9 % in 2030.

5.4 Future actions

Earlier sections of this chapter have described the kind of changes in technologies and fuels that would be necessary in Europe's energy system to facilitate a transition to a low-carbon energy pathway, and have shown that such changes are technically possible. However, given that the baseline scenario shows that with current trends Europe's supply and consumption of energy is likely to remain far from sustainable, there is clearly a need for new policies and institutional structures to help achieve a change in direction. The policies and measures need to go beyond the introduction of a carbon permit price in order to achieve the transition towards a more sustainable, low-carbon energy system. They also have to take into account the wider benefits and impacts of such a transition.

From the results presented here and from other similar studies it can be concluded that there are a number of broad areas that will require further action.

First, it is important that potentially environmentally harmful subsidies on energy are removed and that the true costs of energy are reflected in the prices paid by consumers. Subsidies to energy in the EU-15 amounted to more than EUR 29 billion in 2001 with more than 73 % oriented towards the support of fossil fuels (EEA, 2004c). In addition, the external costs that arise from the social and environmental impacts of energy supply and use are not adequately reflected in energy prices. For electricity production alone these are estimated to be up to 1 % of GDP in the EU-15 (ExternE, 2004). By removing environmentally harmful subsidies and internalising external costs into energy prices, producers, consumers and decision-makers will get accurate price signals on which to base their decisions about how best to use resources.

Second, much more attention needs to be placed on reducing the demand for energy and promoting more sustainable sources of supply. In both cases, long-term targets should be set which clearly demonstrate the EU's commitment to using less energy per unit of economic activity and supplying an increasing proportion of this energy from sources that have minimal impacts on the environment. Detailed policies can then be developed to help achieve these targets. The adoption of long-term targets for increasing energy efficiency and the share of energy production in the EU to come from renewable sources would provide clear signals about the direction of energy policy, so providing long-term investment security. They would then need to be backed by enhanced policies such as support schemes (e.g. feed-in tariffs), non-discriminatory access for renewables to electricity grids and similar support mechanisms for renewable energy in heat markets and transport (EEA, 2001). Similar long-term goals should also be set for limiting and eventually reducing energy consumption, including in the transport sector where demand is growing rapidly. This should be complemented by awareness-raising (e.g. by labelling) and the setting of stricter standards for energy-using products.

Third, there needs to be greater support for research, development and demonstration into sustainable energy technologies in order to support and promote innovation. Total spending on energy research and development in EU Member States has fallen significantly since 1990 (IEA, 2004c), yet many studies show that R & D on the emerging sustainable energy technologies such as renewable energy, carbon capture and storage, energy efficiency, hydrogen and fuel cells could yield significant cost reductions and performance improvements over time. R & D expenditure should address a variety of low-carbon technologies on the supply and the demand side in order to keep different options open. As with changes in behaviour, decision-making routines and status symbols can have a considerable potential for saving energy, and technology research should interact with social and economic research (German Council for Sustainable Development, 2004). An analysis of 22 successful case studies for creating markets for energy technologies concluded that the combined effect of technology performance and customer acceptance has a positive impact on the market (IEA, 2003b). Successful deployment of new technologies should therefore focus on both.

Making commitments to innovation in low-carbon technologies would have the added benefit of introducing a new element to the international dialogue on policies for addressing climate change, which may appeal to some of the countries that are sceptical of the Kyoto Protocol. An innovation-oriented technology and climate action could also contribute to the creation of a lead market, resulting in future economic benefits ('first-mover advantage').

Finally, there needs to be a more integrated approach to tackling climate change in the EU. This means that other policy areas, such as transport, development and regional and structural funds, need to be aligned with the climate change policy framework. New institutional structures are also needed to meet the changing priorities.

6. Costs of a global and European low-carbon energy system

Key messages

- According to the global analysis in this report, the additional 'financial' costs of reducing GHG emissions in the climate action scenario, compared with the baseline scenario, increase to about 0.45 % of GDP by 2030 and 0.8 % by 2040, after which total abatement costs increase more slowly than global GDP. For Europe, the projected costs, as a percentage of GDP, are somewhat less than the global average.
- In the European analysis in this report, the additional 'economic' ([28]) costs of a European low-carbon energy system (the LCEP scenario), compared with the baseline, would be about EUR 100 billion in 2030. This corresponds, in 2030, to 0.6 % of EU GDP, which is projected to double between 2000 and 2030. The average cost of power generation increases by 25 % over these three decades.
- For the European industrial sector the additional costs in the LCEP scenario by 2030, compared with the baseline, represent on average about 1.6 % of the value added of the sector. However, different costs are projected for subsectors depending on their energy intensity. For the services sector, the additional costs by 2030, compared with the baseline, represent about 0.2 % of the value added of the sector.
- The additional energy bill for European households in the LCEP scenario by 2030, compared with the baseline, is projected to be relatively small, about EUR 110–120 per household per year. This should be compared with an increase in the energy bill, in the baseline scenario, of EUR 1 900 per household per year in the EU-15 and EUR 3 400 in the EU-10 in 2030, compared with 2000. The renewables expanded variant, which leads to substantial additional CO_2 emission reductions, could increase the energy bill by another EUR 10–20 per household per year by 2030.
- Additional benefits of a low-carbon energy system can be expected, including ancillary environmental benefits, enhanced security of supply, and potential beneficial effects on employment.

6.1 Global low-carbon energy system

This section explores the consequences of the low-carbon energy pathway scenario in terms of abatement costs, taking into account the impacts of emissions trading. In general, the net regional costs or gains of a post-2012 climate regime result from the costs of domestic abatement, combined with the costs or gains from the use of international mechanisms such as international emissions trading (IET), clean development mechanism (CDM) and joint implementation (JI). Given the large differences in incomes and purchasing power between regions, GDP is presented not in real exchange rates but in purchase power parities (PPP).

By expressing the costs (or gains) as a percentage of regional GDP levels, an indication can be given of the costs as compared with the 'carrying capacity' of the local economy.

Estimates of the costs of future policies depend critically on the assumptions made. The global costs presented here are calculated 'bottom-up' as the sum of investment costs and additional fuel and operating costs in the LCEP scenario compared with the baseline and do not include the macroeconomic costs and benefits of adjustments in the wider economy. These global costs are financial (see Box 6.1) and do not include macroeconomic feedbacks. They should be regarded as lower boundary costs, given the least-cost approach and the assumptions of fully effective emissions trading, removal of implementation barriers and no strategic behaviour of suppliers in international

([28]) The global costs reported are financial costs and the European estimates are economic costs (see Box 6.1 for definitions). Because of this different definition and because of other differences between global and European costing methodologies, the global and European numbers are not directly comparable.

Box 6.1: Representation of costs in scenarios

Major distinctions can be made between *economic* and *financial/production* costs and between *private* and *social* costs. An assessment in terms of financial costs is based on actual payments and market prices. This approach is used for the cost estimates presented in this chapter. A monetary analysis of a mitigation option based on the true scarcity values is called economic cost assessment. It implies that, if market prices are distorted, corrections are made. These corrected prices are called *shadow prices*. The 'global' costs analysed for this report are 'financial' costs, while the 'European' costs calculations are can be regarded to resemble 'economic' costs, which implies that they are not directly comparable.

External costs, such as the damage costs of climate change impacts, for example on human health or ecosystems, were not analysed for this report.

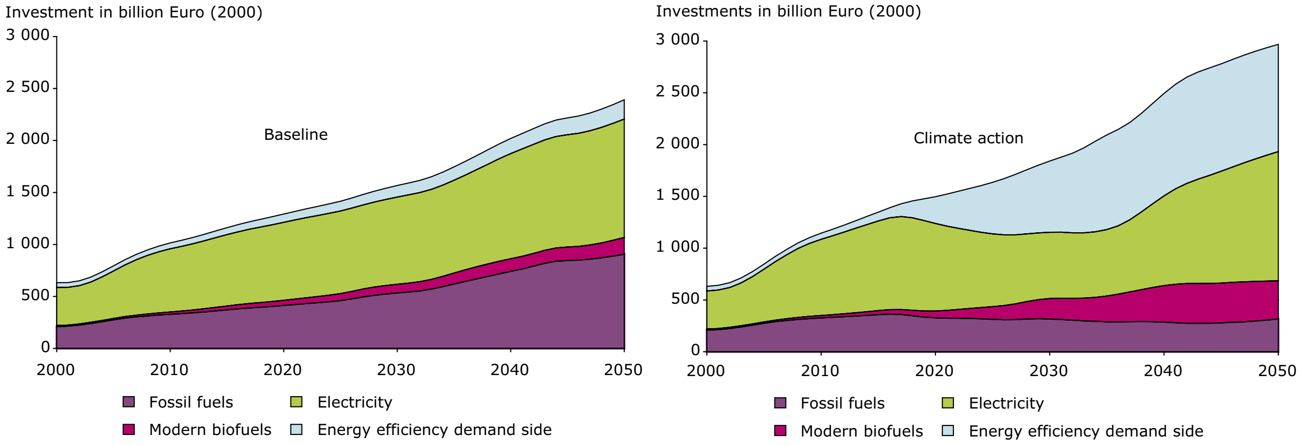
Private versus *social* costs reflect the perspective from which the costs are considered. Costs that influence an individual's decision-making are called private costs. Social costs are usually defined as all the relevant costs of an activity considered from the national or the global perspective. The major distinction between social and individual costs is the 'external costs' and the discount rate used.

The CO_2-equivalent permit price is the cost of the most expensive measure needed to reach the target. The effort rate (as a percentage of GDP), as presented in this report, describes the expected average costs, over all measures, of reducing GHGs.

emissions trading after the first commitment period of the Kyoto Protocol. Included, however, is the assumption that the costs of zero and low-carbon energy technologies will continue to fall, even in the baseline scenario. This is a result of learning-by-doing, application in niche markets, and continuous research and development, often already supported by existing policies and subsidies.

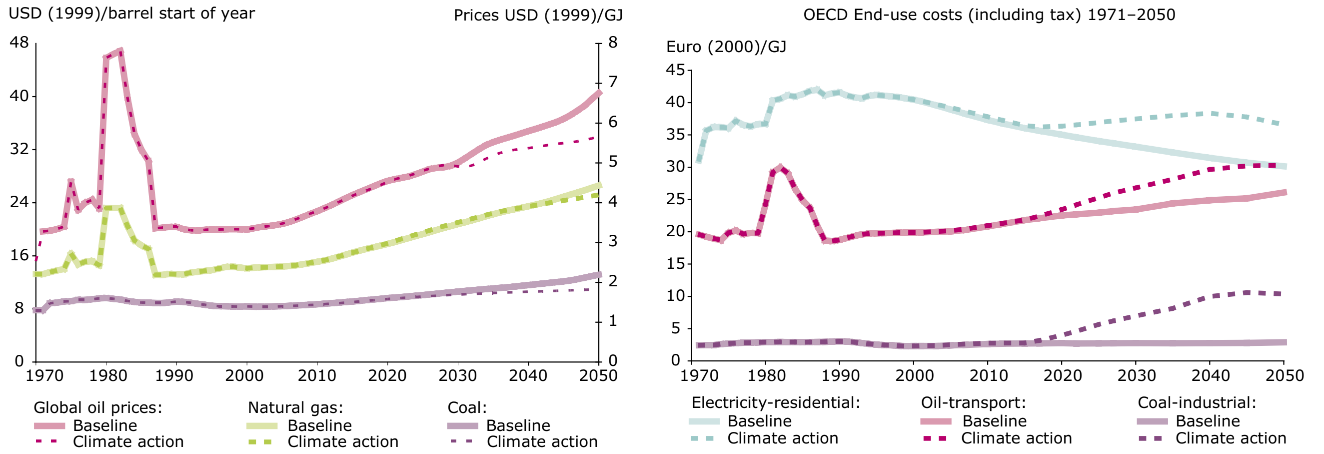
Figure 6.1 shows the projected global annual investment (in 2000 prices) for energy systems assumed in this study for the LCEP and the baseline scenarios. Investment in the baseline scenario rises from EUR 600 billion/year in 2000 to EUR 2 300 billion/year by 2050. The largest investments are expected in the electricity sector (growing to EUR 1 000 billion/year) and in fossil fuels (growing to EUR 900 billion/year). For modern biofuels and electricity saving, investment is expected to stay at EUR 160 billion and EUR 190 billion/year respectively. In the LCEP scenario the situation changes: investment in fossil fuels drops to EUR 330 billion/year, while investment in modern biofuels increases to EUR 350 billion/year. The largest change occurs in energy savings, expected to increase to EUR 1 000 billion/

Figure 6.1 Projected global energy investment 2000–50, baseline (left) and climate change action scenario (right)



Source: IMAGE/TIMER model (EEA, 2005).

Figure 6.2 Past and projected prices of fossil fuels and electricity 1970–2050 in the baseline and LCEP scenarios



Source: IMAGE/TIMER model (EEA, 2005).

year. In total, investment is expected to increase in the LCEP to EUR 2 900 billion/year in 2050, or EUR 600 billion/year more than in the baseline scenario.

Another study, IEA, 2004a, also projects substantial increases in global energy supply investment (almost 60 % between 2002 and 2030). IEA estimates that this will require cumulative investment in energy infrastructure of about USD 16 trillion (10^{12}) over the period 2003–2030, or USD 568 billion per year. This investment is needed to expand supply capacity and replace existing and future supply facilities that will be exhausted or become obsolete during this period. Most (about 70 %) of this investment is projected to take place in the electricity sector. Developing countries will require about half of the global investment of the energy sector as a whole. Financing these large investments, especially in developing countries, is a big challenge. The total annual investment needed is about 1 % of global GDP, however for some regions it is much higher, up to 4 to 5 % of GDP (IEA, 2004a).

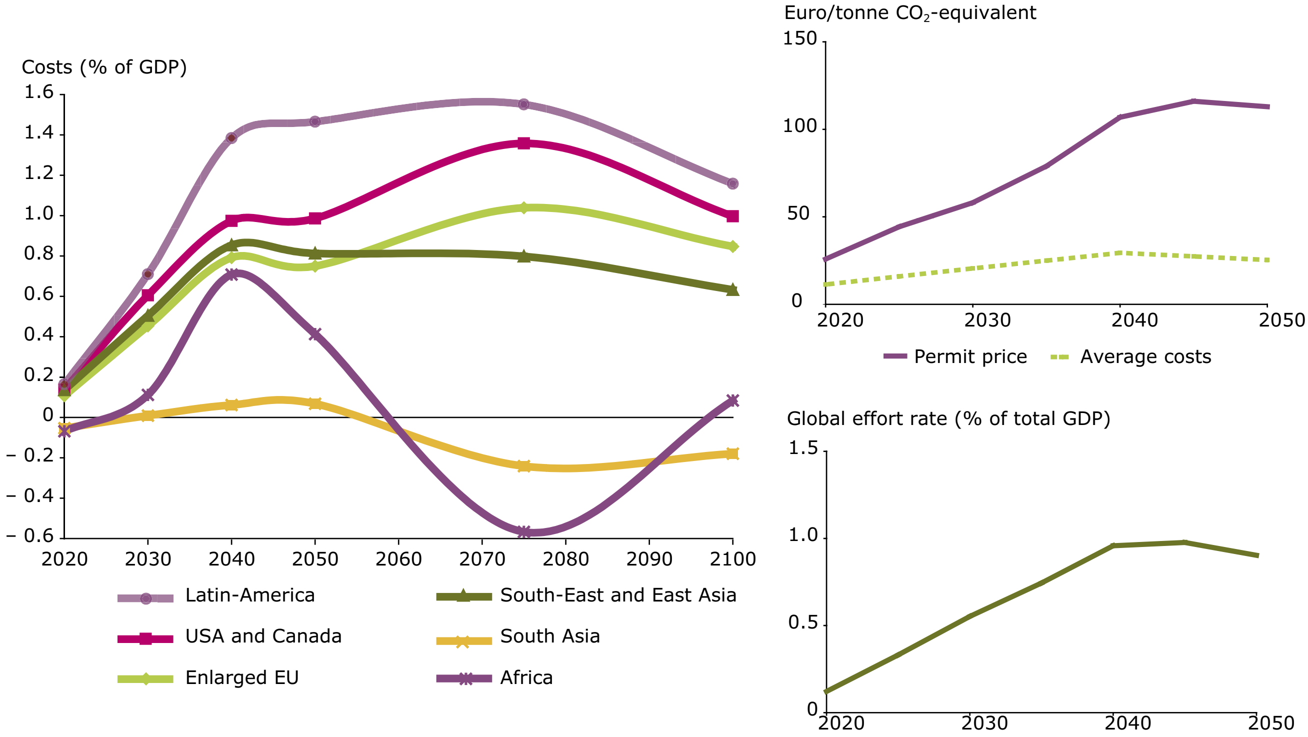
The costs of fuel (coal, oil and gas) rise to EUR 2.3, EUR 4.9 and EUR 4/GJ ([29]) respectively in 2030 in the baseline scenario and (including carbon mitigation costs) to EUR 7.5, EUR 8.9 and EUR 7.2/GJ respectively in 2030 in the climate action scenario. In 2050, the costs for coal and oil in the baseline are still low at respectively EUR 2 and EUR 5/GJ, but rise in the climate action scenario to more than EUR 12/GJ for coal, and EUR 14/GJ for oil. As natural gas has the lowest carbon content of the three types of fossil fuel, it becomes the most attractive form of fossil-based energy. The increases in end-use prices are substantially less dramatic, since most include taxes and refining costs that change very little or not at all.

Uncertainties in the development of future oil prices and resources are not fully integrated into the model. The risk of fluctuations in oil price may increase in the future, since of the 99 countries that have produced significant amounts of oil (more than 1 000 barrels a day), production in 72 has already peaked or is near to peaking (Bentley and Smith, 2004). The uncertainty in the use of alternatives to conventional oil contributes to this uncertainty. World resources of unconventional oil: oil sands (1.7 trillion barrels at USD 5–20/barrel), heavy oil (2 trillion barrels at USD 8/barrel), shale oil (3–6 trillion barrels at more than USD 60/barrel) and coal (fuel conversion) are large ([30]) and the development of unconventional oil production depends on the future behaviour of the Middle East oil producers and post-2012 climate change agreements. Increases in oil prices would

([29]) EUR 4.9/GJ is approximately equivalent to EUR 28/barrel.

([30]) By 2030, the global use of oil, in the baseline scenario, is estimated at almost 40 billion barrels a year. With an estimated 8 trillion (10^{12}) barrels of unconventional oil reserves this could supply the world oil demand, at 2030 levels, for 200 years.

Figure 6.3 Costs (% of GDP) for various world regions to achieve climate change targets 2020–2100 under the LCEP scenario (left), and the global permit price and global costs (right)



Note: South Asia includes a.o.: India, Pakistan, Bangladesh. South-East/East Asia includes a.o.: China, South Korea, Thailand, Indonesia.

Source: FAIR 2.0 model (EEA, 2005).

make new low-carbon energy technologies more competitive and thus accelerate their introduction.

Over 2020–2050, the calculated price of carbon permits in the LCEP scenario shows a sharp increase (from EUR 25 to EUR 120 per ton CO_2-equivalent) due to the rapid increase in the annual global emission reduction objective (from 1Gt CO_2-equivalent to 45Gt CO_2-equivalent), while the average costs of reducing CO_2 are estimated to grow less dramatically, from EUR 11 to EUR 21–25. Moreover, the costs of reducing GHG emissions as a proportion of GDP (see Figure 6.3) show the same trend as the international permit price. These increase rapidly to 2040, to a level of 1 % of GDP, after which total abatement costs increase more slowly than global GDP. At regional level, Africa and southern Asia face the least costs with even potential gains after 2050. The costs in Europe, expressed in GDP terms, are expected to stay just below the global average costs (about 0.45 % of GDP by 2030 and 0.8 % by 2040) and the costs in the United States and Canada are similar to the global average. Latin America is expected to be confronted with costs rising above the global average. These are financial costs (see Box 6.1) and do not include macroeconomic feedbacks.

6.2 European low-carbon energy system

This section explores the additional costs of a low-carbon energy system (the LCEP scenario) compared with those in the baseline scenario, based on the PRIMES model results. It should be noted that the CO_2 permit price describes the expected highest cost of reducing GHG emissions, while the effort rate (as a percentage of GDP) is a measure of the expected average cost.

This section does not include a complete presentation of the costing methodologies used in various integrated assessment methods and approaches. It concentrates on the issues that are important for the comparison of costs calculated by energy models at international level. In different contexts, other methods of cost (and benefit)

Table 6.1 Projected costs of primary fossil fuels for the EU

EU-25	Baseline			LCEP	Ren max	Nuc-	Nuc+
	2000	2020	2030	2030			
Coal (EUR/GJ)	1.4	1.3	1.3	1.3	1.3	1.3	1.3
Incl. cost CO_2 permit price:				7.5	7.5	7.5	7.5
Oil (EUR/GJ)		4.5	5.3	5.3	5.3	5.3	5.3
Incl. cost CO_2 permit price:		30	35	9.3	9.3	9.3	9.3
Oil (EUR/barrel)				35	35	35	35
Incl. cost CO_2 permit price:				62	62	62	62
Gas (EUR/GJ)	2.9	3.9	4.3	4.4	4.4	4.4	4.4
(EUR cent/m^3)	10.8	14.5	16.0	16.4	16.4	16.4	16.4
incl. cost CO_2 permit price				8.0	8.0	8.0	8.0
(EUR/m^3)				29.8	29.8	29.8	29.8
Permit price							
(EUR/tonne CO_2-equivalent)	0	0	0	65	65	65	65

Table 6.2 Projected costs for the EU energy sector (power and heat generation) ([31])

EU-25	Baseline			LCEP	Ren max	Nuc-	Nuc+
	2000	2020	2030	2030			
	(Billion EUR (2000))						
Investment costs	61	61	91	94	102	99	97
Yearly operational and transmission costs	100	130	140	133	133	135	135
Fuel costs	48	76	87	154	155	170	148
Total (billion EUR (2000))	209	267	318	381	390	404	380
Green certificate value	0	0	0	0	4.5	0	0
Green certificate costs as increase in electricity price	0	0	0	0	1.2	0	0
Average production cost (ct/kWh)	5.3	5.0	5.4	6.8	7.1	7.3	6.7

assessment may be appropriate. In this report, we have distinguished between the additional costs of a low-carbon energy system for the supplier and those for the consumer.

Sections 6.2.1 and 6.2.2 report the supply-side and demand-side energy costs, respectively (i.e. all fuel and technology costs) for the baseline and the LCEP scenario. Note that supply-side and demand-side energy costs cannot be added since the former are partly passed on to end-users.

6.2.1 *Costs on the supply side (electricity and heat generation)*

On the supply side (including electricity and heat generation but excluding refineries), the imposition of carbon permit prices results in an increase in energy system costs, reflecting the increase in investment requirements, increased tariffs, etc. These costs are not purely economic since most of the additional costs will be recycled within the overall economy, reducing the burden on the total economy. The additional costs

([31]) The EU energy sector includes electricity and heat generation and electricity transmission, but excludes refineries.

Table 6.3 Projected EU-25 energy costs for households, industry, services and total

	2000	2020	2030	2030			
	Baseline			LCEP	Ren max	Nuc-	Nuc+
	(% of value added (32))						
Industry	9.2	7.1	6.4	7.9	8.1	8.2	8
Services	1.6	1.4	1.4	1.6	1.6	1.6	1.6
Households	5.6	7.9	8.2	8.5	8.5	8.5	8.5
All categories	**6.2**	**6.9**	**6.9**	**7.5**	**7.6**	**7.6**	**7.5**
Households (absolute values; EUR (2000)/household/year)							
EU-15	1 660	2 940	3 580	3 690	3 710	3 720	3 710
EU-10	930	3 280	4 340	4 460	4 470	4 490	4 480
EU-25	1 550	2 990	3 700	3 800	3 810	3 820	3 810
Transport (EUR per pkm or tkm travelled per year)							
Passenger	0.21	0.22	0.24	0.25	0.25	0.25	0.25
Freight	0.27	0.3	0.32	0.32	0.32	0.32	0.32

are represented by the increase in primary energy costs due to the introduction of a CO_2 permit price. Based on initial experiences with the EU trading system and the allocation plans presented by the EU countries, the assumption is made that the energy and industrial sector will be granted CO_2 emission rights proportional to the projected energy produced minus the agreed reduction targets. For the transport sector, it assumed that the additional costs of biofuels will not increase end-use prices (according to current practice, the EU countries stimulate the introduction of biofuels by (partial) tax exemptions).

The additional costs on the supply side of a European low-carbon energy system (LCEP scenario) compared with the baseline scenario in 2030 are projected to be about EUR 63 billion. This would correspond to 0.35 % of EU GDP, which is expected to more than double between 2000 and 2030. The average electricity generation cost would increase by 20 % in 2030 in the LCEP scenario (33). Table 6.1 shows that the primary fuel costs between LCEP (variants) and baseline scenario differ only slightly, in line with the conclusions of the former chapter where it is shown that baseline and LCEP primary energy prices start to differ only after 2030. Because of different fuel inputs the total fuel costs vary considerably between the variants, from a slight decrease in the nuclear accelerated to a significant increase in the nuclear phase-out variant (See Table 6.2).The increase in fuel costs, including the CO_2 costs, between baseline and LCEP scenario reflects the introduction of the carbon permit price. The costs for coal, expressed as additional fuel costs, increase by more than a factor five in the LCEP (see Table 6.1), compared with the baseline scenario, while oil and gas fuel prices almost double. Average electricity and steam generation cost in the LCEP increase by 5.9 % in 2010 to 27.0 % in 2030 compared with those in the baseline scenario, while the average electricity tariff increases by 5.7 % in 2010 and 28 % in 2030.

6.2.2 Costs to energy consuming sectors

On the demand side, the consumer bears the additional direct costs in the form of increased energy prices (e.g. electricity, petrol) and the indirect costs through increased prices for goods (increased energy costs for the production of goods and the costs of producing goods that use less

(32) For households: relative to private income.
(33) In the increased share of renewables variant, the energy system costs would increase further by EUR 9 billion compared with the core LCEP, mostly due to an increase in investment costs. The average production cost would increase by 4 % or 0.3 ct/kWh. In the variant with increased nuclear capacity, the costs are projected to decrease by 0.3 %; in the variant with decreasing nuclear capacity, it increases by 7 %.

Table 6.4 Projected costs for the EU-25 energy system (demand side, excl. transport)

EU-25	Baseline			LCEP	Ren max	Nuc-	Nuc+
	2000	2020	2030	2030			
	(Billion EUR (2000))						
Industry total	157	195	220	271	278	281	273
Energy technologies costs	44	62	76	75	75	75	75
Fuel Costs	113	132	144	195	203	205	198
Services	90	138	168	191	197	196	191
Energy technologies costs	9	21	29	29	29	29	29
Fuel Costs	81	117	139	161	168	167	162
Agricultural	16	21	24	28	28	28	28
Energy technologies costs	4	6	7	6	6	6	6
Fuel Costs	12	15	17	21	22	22	22
Households	288	650	839	864	868	870	867
Energy technologies costs	138	463	632	628	625	624	628
Fuel Costs	149	187	207	236	242	246	239
Total	**551**	**1 004**	**1 251**	**1 354**	**1 371**	**1 375**	**1 359**

energy). As well as the costs, there are also benefits for the consumer (e.g. reduced climate change effects, security of energy supply). In this section, the increased costs to the consumer are presented by calculating the average additional energy costs for industry, services and the consumer (increased prices minus reduced energy use).

Different economic sectors are affected differently in the LCEP scenario, with costs depending on the sector's energy intensity.

Average energy costs as a percentage of the valued added will increase especially in the most energy-intensive industrial sectors. Among the industrial subsectors, the energy costs as a percentage of value added, increase in LCEP from 0.9 to 4.5 % in 2010 to 3.6 to 18.7 % in 2030. The average costs in the industrial sector increase to 7.9 % (see Table 6.3) of the value added, about 23 % higher compared to the baseline (6.4 %) in 2030. In all scenario variants, energy costs as a percentage of the value added are expected to drop from 2000 to 2030, from 2.8 percentage points (baseline) to 1.3 percentage points (LCEP). The additional costs in the LCEP scenario, compared with the baseline in 2030, represents about 1.6 % of the value added. The costs for non-energy-intensive (sub)sectors as a percentage of value added range in the LCEP scenario from 0.05 to 0.3 % in 2010 and from 0.2 to 1.4 % in 2030.

For the services sector, the additional costs in the LCEP scenario, compared with the baseline in 2030, represents about 0.2 % of the value added of the sector.

Spending by households on energy-related costs in the baseline scenario increases from about 5.6 % in 2000 to 7.9 % in 2020 and 8.2 % in 2030. In the LCEP scenario, the energy costs rise further, by 0.3 % to 8.5 % of the valued added in 2030.

This means an increase in the baseline scenario of EUR 1 900/household in the EU-15 and EUR 3 400 in the EU-10 in 2030 compared with 2000. The additional energy bill for households in the LCEP scenario is projected to be relatively small, compared with the projected increases in total energy bills, about EUR 110–120 per household per year. The renewables expanded variant, which leads to further CO_2 emissions reductions, would further increase the energy bill, by another EUR 10–20 per household in 2030.Overall, the European energy bill on the demand side (excluding the costs of transport) increases from a total of about EUR 550 billion per year in 2000 to about EUR 1 250 in 2030 in the baseline scenario, an increase of about EUR 700 billion per year. The additional costs of the core LCEP scenario are about EUR 100 billion per year in 2030 and up to EUR 124 billion per year in 2030 in the variants. All these are in year 2000 prices.

These costs correspond to increases of from 6.2 to 6.9 % of GDP between 2000 and 2030 in the baseline scenario, and from 6.2 to 7.5–7.6 % in the LCEP variants. Thus the additional costs of the LCEP on the demand side (excluding transport) are about 0.6 % of GDP (core LCEP) to 0.7 % (LCEP variants) compared with the baseline, with minor differences between the variants. These costs are comparable to estimates from other studies (see Chapter 4.4.4).

Fuel purchase costs in the transport sector also rise in the baseline in the period 2000–2030, from 11 % for passenger cars to 16 % for freight transport.

6.2.3 Wider benefits of a sustainable energy system

These cost calculations take no account of the wider benefits of a low-carbon energy system, which could result in avoided costs. The IPCC (IPCC, 2001c) highlights that policies aimed at mitigating GHGs can have positive and negative side-effects on society, apart from the benefits of avoided climate change. However, it also notes that there is little agreement on the definition, extent, and size of these wider benefits or disbenefits, or on methodologies for integrating them into climate policies. Three areas where the benefits may be positive are air pollution, security of energy supply and the creation of employment in some sectors.

Ancillary environmental benefits: many of the traditional air pollutants and GHGs have common sources, and policies and technologies aimed at mitigating climate change can have a direct impact on air pollution. Examples are changes in the energy system towards increasing energy efficiency and a switch to less CO_2-intensive fuels. Climate change policies may thus have ancillary benefits for air pollution, which could partly offset the direct costs of climate policies (EEA, 2004d). For more information see also an upcoming EEA report on ancillary benefits of climate actions for air quality.

Other ancillary benefits that can be expected from using less energy include reduced wastes from mines and coal-fired and nuclear plants, water contamination from mining, oil spills and discharges to marine waters, soil damage from spills and leakages of liquid fuels, and impacts on ecosystems from the construction and operation of large dams (EEA, 2002).

Security of energy supply: in the Green Paper on security of supply, the European Commission highlighted that the EU will become increasingly dependent on external energy sources and that enlargement will not change the situation. Based on current projections, dependence will reach 70 % ([34]) in 2030 (European Commission, 2000a). Increased energy efficiency and increased use of renewables and nuclear power can both have an important role in reducing and managing the risks imposed by high import dependency. Under the LCEP scenarios, import dependency is reduced, with demand for imported fuels (in Mtoe) in 2030 being around 15–23 % lower ([35]) than in the baseline scenario, due partly to a reduction in the total consumption of energy (which falls by 7.5 %), but also because of the higher share of renewables and nuclear power in the primary energy fuel mix. The import dependency reduces hereby from 67 % in the baseline to 56–62 % in the LCEP scenarios. In addition, some climate-change technologies (in particular most renewable energy technologies) are well suited for distributed generation. This could contribute to decreasing the risk of transmission disruptions.

Employment impacts: many studies have examined the wider economic impacts of moving to a more sustainable energy system and have concluded that there may be benefits in terms of job creation in some sectors. These include research, manufacturing and installation and distribution of renewable energy devices. The extended use of biomass may also create employment in rural areas. Nevertheless, the net employment benefits for society as a whole may be considerably smaller.

([34]) In the EEA baseline, 67 % is assumed, see Table 5.1. Import dependency excludes import of uranium. This approach is in line with the Green Paper on energy security (European Commission, 2000a) and is based on the fact that sources of uranium are more diversified than oil and gas and the further steps of the nuclear cycle are largely domestic.

([35]) Total demand also decreases, therefore the import dependency ratio will not decrease with the same percentage.

6.3 Uncertainties and assumptions

Scenario analysis always includes many uncertainties:

- uncertainties related to future socioeconomic developments (e.g. GDP) and human choices;
- uncertainties in the underlying statistical and empirical data (e.g. on future technology costs and performance);
- uncertainties in the choice of indicators (representativeness);
- uncertainties in the dynamic behaviour of systems and its translation into models.

Some of these uncertainties have been explored through the use of sensitivities to test the impacts of different assumptions in key areas. A key uncertainty is economic development. It was found that, compared with the range of other projections, the economic growth assumptions were relatively optimistic. A lower economic growth variant was therefore explored (EEA, 2005). Lower economic growth leads to lower activity levels and thus lower emissions, but also to slower technological advances, leading to higher emissions. The combined effects result in lower emissions compared with the baseline, making it easier to meet the assumed 2030 targets.

The discount rate allows economic effects occurring at different times to be compared. The assumptions on the discount rate play an important role in analysing actions with varying time paths of costs and benefits. For the energy system costs, where the models simulate the investment behaviour of various actors, different discount rates have been used for the various models used (EEA, 2005).

Other uncertainties have to do with technological changes, the assumed rate of technological learning (i.e. the decrease in investment costs because of wide-scale implementation of the technology) and future policies to influence such changes. To look at these changes, scenarios have been developed that incorporate a number of technology variants (renewables, nuclear) to explore alternative ways of meeting the EU's sustainability objectives.

Other studies demonstrate the considerable potential for net CO_2 emission reduction after 2030 by carbon capture and storage (IEA, 2004a). This transition technology could lower the costs of achieving the climate change mitigation targets (see MIND model of the Potsdam Institute on Climate Impact Research).

Uncertainties related to modelling were studied by coupling different energy models. Implementing harmonised driving force assumptions in models like TIMER/FAIR, PRIMES and POLES resulted in different model outputs in terms of energy system parameters and associated emissions. For example, for the same level of carbon prices in the LCEP scenario, European emissions calculated with the global model TIMER after 2025 were significantly lower than those calculated with PRIMES. This may result from a wider number of technology options (e.g. carbon capture and storage) available in the TIMER/IMAGE model.

Assumptions on future fuel costs also have an important impact on the model results. Increases in oil prices would make low-carbon energy technologies more competitive and thus accelerate their introduction.

7. Acronyms

CAFE	Clean Air For Europe (European Commission thematic strategy)
CDM	Clean development mechanism
ETC/ACC	European Topic Centre on Air and Climate Change
FAIR	Framework to assess international regimes for differentiation of commitments (model maintained by RIVM)
GDP	Gross domestic product
GHG	Greenhouse gas
IMAGE	Integrated model to assess the global environment (model maintained by RIVM)
IPCC	Intergovernmental Panel on Climate Change
IPTS (JRC)	Institute for Prospective Technological Studies
LCEP	Low carbon energy pathway (included in the climate action scenario)
LREM	Long-range energy modelling (using the PRIMES model)
NEC(D)	National emissions ceilings (directive)
POLES	Long-term energy supply and demand projections (model maintained by JRC-IPTS)
ppm	Parts per million
PRIMES	Energy system model for the EU (model maintained by NTUA)
RAINS	Regional Air Pollution INformation and Simulation (model maintained by IIASA)
SoEOR	State of the Environment and Outlook report (EEA)
TIMER	Targets IMage Energy Regional (model maintained by RIVM)

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9. Annex 1 — Emissions of greenhouse gases by country for baseline, climate action base and extended renewable scenarios

Change compared with Kyoto target

Country	Kyoto target 2008–2012 from base year [36]	Required reduction by 2008–2012	2020 baseline	2020 LCEP	2020 LCEP–REN	2030 baseline	2030 LCEP	2030 LCEP-REN	Change baseline to LCEP	Change LCEP to LCEP-REN
	%	(Mtonnes CO_2-equiv.)	%	%	%	%	%	%	%	%
Austria	– 13,0	68	40	17	10	44	9	0	36	9
Belgium	– 7,5	136	13	– 2	– 5	31	0	– 5	32	5
Denmark	– 21,0	54	16	5	0	17	– 1	– 10	18	9
Finland	0,0	77	– 8	– 24	– 28	– 4	– 32	– 39	27	7
France	0,0	564	13	– 1	– 8	14	– 7	– 17	21	9
Germany	– 21,0	989	4	– 13	– 18	4	– 20	– 27	25	7
Greece	25,0	137	5	– 6	– 9	6	– 12	– 16	17	4
Ireland	13,0	60	27	11	1	26	– 5	– 17	32	11
Italy	– 6,5	475	15	3	– 3	20	– 2	– 11	22	9
Luxembourg	– 28,0	8	89	70	67	113	71	60	42	11
Netherlands	– 6,0	200	18	5	0	30	2	– 7	29	9
Portugal	27,0	74	43	26	15	59	17	5	42	12
Spain	15,0	330	35	17	11	40	9	– 1	31	11
Sweden	4,0	75	19	– 2	– 8	64	– 8	– 14	72	6
United Kingdom	– 12,5	653	6	– 8	– 14	12	– 12	– 20	24	8
Czech	– 8	177	– 32	– 48	– 50	– 29	– 53	– 56	24	2
Estonia	– 8	40	– 58	– 71	– 74	– 58	– 78	– 82	20	4
Hungary	– 6	106	– 14	– 28	– 29	– 5	– 34	– 36	29	2
Latvia	– 8	27	– 46	– 71	– 73	– 44	– 79	– 83	35	4
Lithuania	– 8	46	– 33	– 53	– 59	– 26	– 57	– 64	31	6
Poland	– 6	531	– 22	– 35	– 41	– 21	– 40	– 46	19	6
Slovakia	– 8	67	– 17	– 39	– 44	– 11	– 48	– 52	37	4
Slovenia	– 8	19	14	– 16	– 22	15	– 30	– 38	45	7
Cyprus	n.a.	n.a.	16	3	0	16	– 2	– 4	18	2
Malta	n.a.	n.a.	6	– 6	– 7	11	– 1	– 3	11	2
Bulgaria	– 8	130	– 38	– 50		– 38	– 55		17	
Romania	– 8	242	– 32	– 49		– 27	– 51		24	
Turkey	n.a.	n.a.	31	24		76	56		20	
Switzerland	– 8	49	32	15		50	13		37	
Norway	1	53	40	5		38	– 7		45	
EU-15	– 8	3 900	13	– 2	– 8	18	– 8	– 16	26	8
EU-10		1 013	– 23	– 39	– 43	– 20	– 44	– 49	24	5
EU-25		**4 912**	**5**	**– 10**	**– 15**	**10**	**– 16**	**– 23**	**26**	**7**

Notes: Cyprus, Malta and Turkey: these countries have no Kyoto targets. The scenario results are presented compared with the 2010 LCEP scenario.
LCEP: Low Carbon Energy Pathway.
LCEP-REN: LCEP, renewables expanded.

(36) 2010 national targets are derived from the 2004 national CRF (common report format) reports to the conference of the parties of the UNFCC as downloaded from the UNFCC website (October 2004): http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/2761.php

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9 789291 677658

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