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Climate change: the cost of inaction and the cost of adaptation

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Executive summary

Significant changes in climate are already visible globally, and are expected to become more pronounced in the future. These will lead to wide ranging impacts on the natural and man-made environment across different sectors and regions, which in turn will lead to economic costs. These economic costs of climate change are often known as the 'costs of inaction' and are increasingly helping to inform the policy debate. It is also evident that even if emissions of greenhouse gases stop today, changes in climate will continue for many decades. Therefore, in addition to mitigation, it is essential to develop adequate adaptive responses (adaptation) as a means of moderating damages or realising opportunities associated with climate change.
To allow a fully informed debate on adaptation, there is a need to consider the economic aspects of adaptation. Against this background, the EEA has prepared this report with the aim:

- to identify and highlight methodological issues and uncertainties of cost estimation;
- to review existing information on economic costs of climate change at a European level;
- to highlight the need for improved information on impacts of climate change and the need to monitor the effectiveness of adaptation strategies and actions;
- to facilitate information sharing among EEA member countries and learning from 'good practice';
- to identify research needs.

It is stressed that this report has a different focus from other recent reviews (IPCC, 20007b; Stern, 2006): it concentrates on the European scale and investigates methodological aspects in detail.

Policy perspectives

EU climate policy has been progressing in line with the developments in the UNFCCC and the Kyoto Protocol over the past decade. While EU climate policy has mainly focused on mitigation, the EC Communications (EC, 2005: 2007a, 2007b) have widened the remit to consider the costs of inaction. Adaptation has also been progressed by the European Climate Change Programme II and the recent EC Green Paper on Adaptation (EC, 2007c). This report concentrates on a European policy perspective, considering a framework covering the full costs of climate change. The information on the economic costs of climate change impacts (if no further action is taken) provides a means to monitor and predict the changing state of the environment likely to be affected in Europe. This information is still developing, and major issues remain. Nonetheless, expressing such impacts in monetary terms provides a common metric to assess across sectors, and can help identify the key areas of concern, as well as providing a key indicator suite for measurement and monitoring. At the same time, there is a need for an economic perspective in European adaptation policy, to ensure cost-effective and proportionate adaptation, and to consider the wider economic costs and benefits of adaptation.

Country perspectives

There is an increasing amount of information and evidence on the impacts of climate change, and also on adaptation. However, information on the costs of inaction remains limited, and there is an even larger gap for the costs of adaptation. The EEA has reviewed the available information on economic costs, including academic literature, research studies, policy studies and insurance studies. The review has also considered the action being taken towards understanding or using this economic information in EEA member countries. Whilst almost all countries are making progress to consider impacts and adaptation, only the United Kingdom, Finland and the Netherlands are significantly extending to include economic perspectives. The work in these countries provides insights into the major challenges and opportunities for making progress in the economics of climate change. The diversity can be explained as different countries are at varying stages in developing and implementing impacts and adaptation policy. However, national adaptation policy is quickly developing in many countries and it would be beneficial for countries to exchange information, share experience and learn lessons from each other.

Methodological issues

The report reviews the main methodological issues in estimating the costs of inaction and the costs of adaptation. Understanding and improving these methodological issues, and the way they can affect the economic cost estimates, is essential to ensure that the information generated can be effectively used in European and national policy developments. The review shows that the definitions of the 'cost of inaction' and 'adaptation' vary significantly, and involve complex concepts that are often dealt with differently by studies. The evidence provided shows that our understanding of the costs of inaction is still incomplete and permeated by uncertainty. Different assumptions and choices in the methodology for cost assessment lead to a very wide range of estimates of costs of inaction to climate change. These differences are due to:

- treatment of scenarios (both climate and socio-economic projections);
- issues of valuation (market and non-market effects; indirect effects on the economy);
- the approach taken to spatial and temporal variation (discounting and distributional effects);
- uncertainty and irreversibility (especially in relation to large-scale irreversible events); and
- coverage (which climate parameters, and which impact categories, are included).

The above issues are also relevant when considering adaptation, along with additional aspects of:

- the type of adaptation (autonomous or planned);
- the level and timing of adaptation (e.g. anticipatory or reactive);
- the types of costs of adaptation (including direct costs and transition costs);
- the ancillary benefits of adaptation; and
- the distributional aspects of adaptation.

Sectoral perspectives

The costs of inaction and the costs of adaptation have been reviewed at sector level in Europe:

- Natural ecosystems. While valuation knowledge is improving in this area, the full economic benefits to users and non-users remain a major evidence gap. This is highlighted as a research priority given the goal to halt biodiversity loss by 2010.
- Coastal zones. There are estimates of the economic costs of coastal flooding in Europe, which indicate that these could be substantial. The same studies show that adaptation should substantively reduce these at low cost, though it will not fully protect vulnerable ecosystems.
- Agriculture. This sector has been extensively studied and adaptation has the potential to reduce negative economic impacts in the short to medium term, though issues are likely to remain in the Mediterranean region and southerly eastern European countries. The consideration of a wider set of effects, including extremes, may also lead to additional economic consequences.
- Energy. The net economic costs in Europe from changing energy demand are predicted to be modest in the short-medium term, but have a strong distributional pattern with rising cooling (electricity) demand in the south, compared to falling heating (energy) demand in the north. There may also be emerging issues of energy demand for water supply, issues with water abstraction for cooling plant and hydro-electricity. Adaptation has an important role.
- Tourism. At present, European tourist flows are from north to south, which helps to transfer capital, but these may change (at least seasonally) with a changing climate. There are emerging studies of these economic costs which show a relative redistribution across Europe. Rising temperature may also increase the costs of the winter sports industry in Europe.
- Human health. While heat related mortality in Europe will increase under a changing climate, this is likely to be offset by an equivalent or greater decrease in winter-cold related mortality. Valuation of health effects is progressing for these effects, and emerging studies also indicate food-borne disease and physiological impacts of floods could have important economic costs. Adaptation has the potential to reduce health risks at low cost.
- Water. Europe already has a diverse pattern of water availability between North and South, and this is predicted to widen with climate change: recent studies have shown that these will lead to economic costs due to an anticipated water deficit. Water will also have cross-sectoral effects (EEA, 2007b) with potential indirect economic effects.
- Built environment. There are a number of studies on the economic costs of extreme events, including predictive studies, which indicate that these may be significant for heavy precipitation events (floods) and storms. Adaptation will be

able to reduce some of these, though there will be a cost. There are emerging concerns over increasing risk premiums/uninsured assets.

Conclusions

The following conclusions are drawn for Europe's natural environment and its society:

- Projected changes in climate (including extremes and sea level rise), compounded by other environmental changes and ongoing socio-economic development, are expected to have wide ranging impacts and economic effects on natural and human systems in Europe.
- The overall net economic effects across Europe are uncertain, not least due to the limits on quantification and valuation, but are potentially very significant. Further work is needed to provide quantification and valuation across all sectors (but especially for biodiversity) for a range of risks from temperature and sea level rise, extreme events, and large-scale irreversible events.
- Whilst there is a range of positive and negative economic effects across sectors and regions, more adverse impacts in the Mediterranean region and South-eastern Europe are predicted compared to other regions in Europe (e.g. in relation to energy demand, agricultural productivity, water availability, health effects, summer tourism, and ecosystems).
- Adaptation has an extremely important role in reducing the economic costs of climate change across Europe. While adaptation has a cost, it significantly reduces the residual costs of climate change. However, there is currently very little quantified information on these costs, and further work is urgently needed to build the evidence base to facilitate informed, cost-effective and proportionate adaptation in Europe. There is a need for an integrated approach to progress this.

Challenges

There are a number of challenges which should be addressed to improve the information on the economic costs of climate change. The research challenges include:

- Despite recent progress, the incomplete understanding of climate change itself remains a major difficulty, in particular the regional effects of climate change, and specifically the coverage across the range of different climate change effects.
- Current scenarios and impact studies use relatively crude spatial and temporal resolutions. Despite a growing number of country-level case studies, the current knowledge of impacts is still incomplete and does not allow for a careful, detailed comparison across regions.
- Differences in assumptions often make it difficult to compare studies. Only a few studies provide a consistent picture, based on uniform assumptions on climate, socio-economics, etc. and many studies extrapolate between regions. There is a need for consistent European studies.
- Non-market damages, indirect effects, horizontal inter-linkages, and the socio-political implications of climate change are still poorly understood. There is a particular gap on the analysis of economic costs and benefits of biodiversity. Analysis of uncertainties, transient effects, and the influence of climate variability are other factors deserving more attention. There is a need for a move towards more dynamic analysis of assessment, for impacts and valuation.
- Major advances are needed to understand the economics of adaptation. Adaptation will entail complex behavioural, technological and institutional adjustments at all levels of society, and not all population groups will be equally capable of adapting. Such analysis is complicated by the strong link between adaptation and socio-economic scenarios/development. Further work is needed to progress the costs and benefits of adaptation, and the consideration of maladaptation.
- There is a need to progress the policy aspects (and the policy process) in relation to the costs of inaction and the costs and benefits of adaptation.

These challenges should not be considered a barrier to progress in this area, but highlight a need for an enhanced research priority. As improved information appears, this will further help policy analysis and decision making. Towards this, there is considerable scope for improving the economic assessment of impacts. These are outlined in the report but include:

- the need to give greater consideration to uncertainty and the implications for policy decisions;
- to increase the number of real case studies;
- to strengthen the degree of integration and completeness of existing studies;
- to improve the consideration of the dynamics of scenarios and climate change;

- to consider alternative temporal and spatial aggregation criteria (i.e. over time and location); and
- to expand the coverage of studies, to include non-market damages and the impacts of extreme events and major catastrophic events.

Many of these are also relevant for adaptation, along with additional areas including:

- identifying adaptation options at different levels across Europe, and assess costs (e.g. through a 'good practice' European assessment of adaptation costs, including ex post assessment);
- improving the aggregation from local studies up to regional (or even global) assessment;
- considering how rates and speeds of climate change affect adaptation;
- investigating 'realistic' adaptation options by different stakeholders in different socio-economic, cultural and political settings;
- progressing analysis of transition costs and indirect costs alongside direct costs;
- investigating the co-benefits of adaptation (notably reducing vulnerability to current climate);
- examining and present uncertainty — and the expand coverage to different climate risks; and
- examining the distributional aspects of adaptation, within Europe, and the rest of the world.

Further progress across these areas will further strengthen the scientific, technical and economic capacity for impacts and adaptation, and help to bring these together within common methodological approaches and consistent policy frameworks that consider an economic perspective.

1 Introduction

1.1 Background

Atmospheric build-up of greenhouse gases has altered the energy balance within the Earth's climate system and has resulted in significant changes in our climate.

The recent Fourth Assessment Report from Working Group I of the Intergovernmental Panel on Climate Change (the IPCC, 2007a) recently concluded that 'Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level'.

Furthermore, it states that 'most of the observed increase in globally averaged temperatures since the mid-20th century is very likely (i.e. > 90 %) due to the observed increase in anthropogenic greenhouse gas concentrations' ([1]). It also reports that 'Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns'.

The Fourth Assessment Report also assesses the likely range of changes for the future climate with increased confidence. Without drastic changes in the current production and consumption patterns, the trend in global emissions of greenhouse gases and subsequent global warming will continue. For example, by 2100, the best estimate of global surface temperature across the IPCC SRES scenarios (described in Annex I) is a rise of 1.8 to 4 °C with a likely range of 1.1–6.4 °C in relation to 1990 levels, and a global mean sea level rise of between 18 to 59 cm (the range for all scenarios is presented in Annex I). Moreover, the impacts of climate change are already being observed: the IPCC WGII (IPCC, 2007b) documented 75 studies with some 20 000 observations of current effects on physical and biological systems. Over 90 % of the changes are consistent with trends in observed climates.

In line with this global climate trend, the climate in Europe has been changing and this is considered to have had a wide range of impacts on the natural environment and on human society in the region. Temperature and other changes in the climate system are likely to induce profound changes in the functioning and services of European's natural and human systems, (EEA, 2004). The recent IPCC 4th Assessment on Europe (WG II, Chapter 12, Alcamo, *et al.*, 2007) reported that wide ranging impacts of changes in current climate have been documented: retreating glaciers, longer growing seasons, shift of species ranges, and health impacts due to a heat wave of unprecedented magnitude. The observed changes described above are consistent with those projected for future climate change.

In recognition of the significance of climate change, under the United Nations, countries have initiated action to reduce greenhouse gas emissions, and hence to mitigate global climate change. The ultimate objective of the United Nations Framework Convention on Climate Change (the 1992 established UNFCCC) (1) (Article 2)) is to 'stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. This has been progressed under the Kyoto Protocol. In response, the EU has implemented a number of common and coordinated policies and measures to reduce greenhouse gas (GHG) emissions (ECCP, 2006). A key measure, among other initiatives, is the EU-wide carbon trading scheme which started in 2005 (European Commission, 2004a).

However, much greater emission reductions are needed beyond those established by the Treaty to achieve the UNFCCC objective. The EU (European Council 1996: 2004; 2005) aims to limit global

([1]) Note this is an increase in the level of confidence since the previous Third Assessment Report (IPCC, 2001), which reported the increase as 'likely' (> 60 %).

temperature increase to 2 °C above pre-industrial levels to avoid severe impacts globally. This would help to avoid serious adverse effects to, for example, water resources, ecosystems, biodiversity and human health. It would also help to prevent large abrupt transitions (e.g. the large-scale climate events or 'tipping point's identified (Schellnhuber *et al.*, 2005) that have the potential to cause very large potentially irreversible impacts, especially after the 21st century.

Consistent with progress towards this objective, there has been significant discussion of Post-Kyoto action in Europe. This was set out in previous communications from the European Commission on climate change ('Winning the Battle against Global Climate Change': EC, 2005), and more recently the 'Limiting Global Climate Change to 2 degrees Celsius' (EC, 2007a), which led to policy proposals and ambition levels for Europe for 2020 including that 'the EU should now take on a firm independent commitment to achieve at least a 20 % reduction of GHG emissions by 2020' and that 'by 2050 global emissions must be reduced by up to 50 % compared to 1990, implying reductions in developed countries of 60–80 % by 2050'. The 2020 targets were agreed at the Council summit meeting on 8–9 March 2007.

The Commission proposals and the EU agreement of 8–9 March 2007 were informed by an increasing awareness of the economic costs of climate change impacts if no further action is taken — often known as the 'costs of inaction'. The European Council (2004, 2005) requested that the Commission investigate the benefits of climate change mitigation policies, recognising that monetised avoided impact benefits, estimated globally, but with a focus also on the European scale, will enable fully informed policy making.

The evidence of these social costs were reviewed in the earlier EC communication (EC, 2005), and more recently in the Stern review (Stern, 2006) and the EC 2007 communication. In the latter Communication on limiting climate change, the EC stated that 'the benefits of limiting climate change outweigh the costs of action'. It also cited recent research which confirms the broad range of impacts of climate change, including on agriculture, fisheries, desertification, biodiversity, water resources, heat and cold related mortality, coastal zones and damages from floods. These show a picture of very significant economic damages in the future. While this information is extremely valuable in looking at the economic benefits of climate change policy (i.e. of mitigation), the studies also reveal that there are many methodological issues involved in estimating such costs, particularly when addressing a more detailed spatial scale (e.g. Europe) across policy applications.

It is also evident that even if emissions of greenhouse gases stop today, changes in climate will continue for many decades and in the case of sea level for centuries. This is due to the historical build up of the gases in the atmosphere and time lags in the response of climatic and oceanic systems to changes in the atmospheric concentrations. For example, even under the B1 scenario (based on the most 'environmental friendly' storyline compared to all scenarios presented in the IPCC report), the IPCC 4th Assessment Report considers the best estimate of global surface temperature is a rise of 1.8°C by 2100 with a likely range of 1.1–2.9 °C, and global mean sea level rise of between 18 to 38 cm, in relation to 1990 levels.

Therefore, in addition to GHG emission reduction measures (mitigation), and the consideration of the benefits of climate change mitigation policy, it is essential that natural as well as human systems also develop adequate adaptive responses (adaptation) to avoid the risks posed by, and to take advantage of the opportunities arising from, unavoidable global climate change.

It is recognised both scientifically (IPCC, 2007a; 2007b) and politically that a global temperature increase of 2 °C could have potentially severe impacts which will need adaptation, in both developing and developed countries. It is also recognised that developing countries will be affected most by climate change, but have the least socio-economic capacity to adapt. Hence, adaptation is important especially in the developing and in particular the least developed countries, including small island states. The EU has initiated policies to integrate climate change into development aid and also contributes to various funds on adaptation under UNFCCC and the Kyoto Protocol. However this report focuses on adaptation and costs of adaptation in Europe, since various other reports cover a global scale.

As the impacts of climate change have become more evident, countries in Europe have started to plan for and implement measures to adapt to projected climate change and impacts. The Environment Council meeting in December 2004 and subsequent meetings in 2005 highlighted the need to prepare for and adapt to the consequences of some inevitable climate change, and the 2005 EC Communication highlighted 'the role of the EU in reducing vulnerability and promoting adaptation'.

And further, that 'EU climate policy should aim to reduce vulnerability of European society and economy to the adverse effects of climate change and improve its resilience'.

In late 2005, the EEA documented the wide ranging impacts of climate change for Europe, provided information on vulnerability, and highlighted the need for adaptation (Vulnerability and Adaptation in Europe (EEA, 2005)). The European Commission has made progress on this in 2006 through the European Climate Change Programme (ECCP) II group on 'Impacts and Adaptation', which has the remit to 'define the EU role in adaptation policies so as to integrate adaptation fully into relevant European policy areas, to identify good, cost-effective practice in the development of adaptation policy and to foster learning'. The information from the working group was used by the Commission to prepare a Green Paper on adaptation published on 29 June 2007 (EC, 2007c).

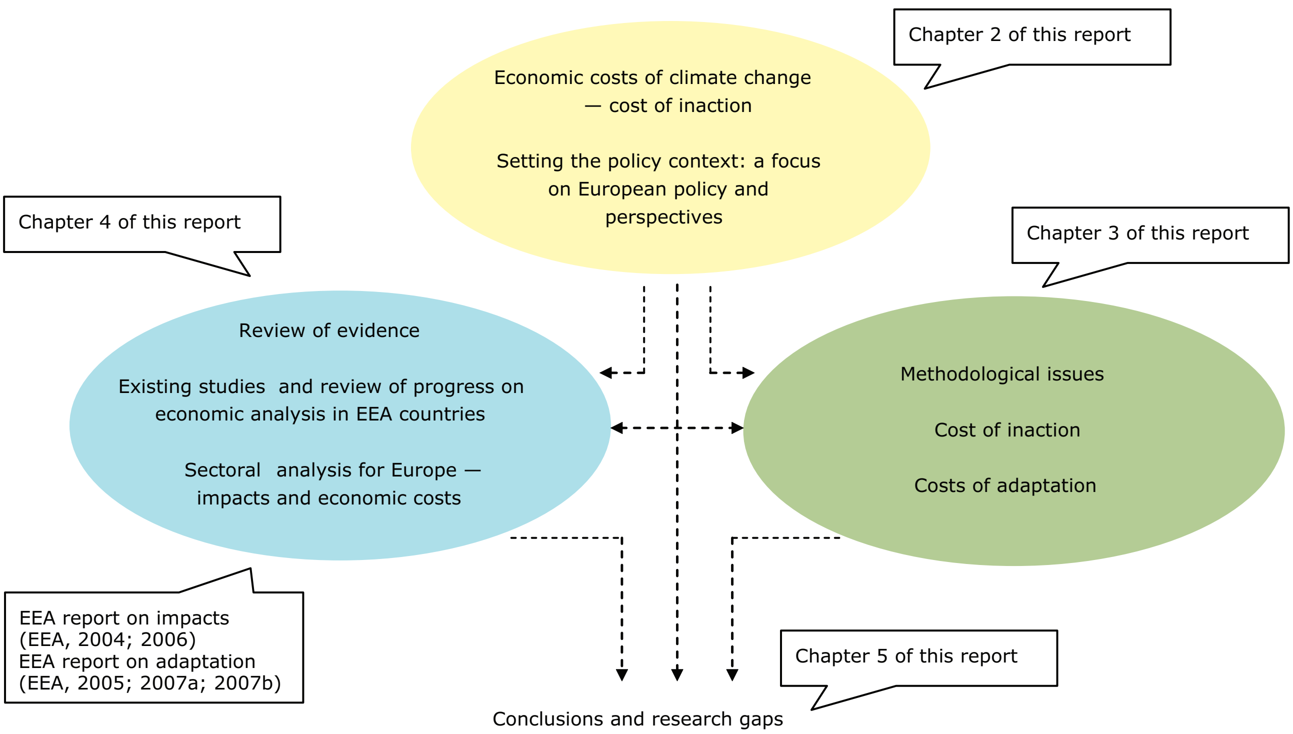
Strategies for adaptation need to be embedded within existing national policy and institutional frameworks, as well as within sectoral policies. Some progress is being made in this area (e.g. in the water sector through the recognition that the Water Framework Directive (WFD) is a powerful tool to introduce climate change impacts into water resources management and river basin planning (see main conclusion of Time to Adapt — Climate Change and European Water Dimension, held as part of the German EU presidency activities). Similar moves are needed across EU environmental and wider policy areas.

Finally, to provide a fully informed debate on adaptation, and to make progress towards cost-effective and proportionate adaptation policy, there is a need to consider the economic costs of adaptation: and the economic benefits that adaptation achieves (i.e. in reducing the cost of residual climate change damage after mitigation). Information on the costs of adaptation will help the design and implementation of successful adaptation policy in Europe. However, there remains an evidence gap on the costs of adaptation, and major methodological issues on how best to assess them.

1.2 Objectives of the report

Against this background, the EEA has commissioned two working papers to investigate the economic costs of climate change (EEA, 2006; 2007a). The first of these — Climate Change: the Cost of Inaction — has reviewed the economic impact studies with a focus on the methodologies

Figure 1.1 Major components of this report in relation to the key subjects of the economic costs of climate change impacts, and costs of adaptation



used. The second — Costs of Adaptation to climate change: a review of assessment studies with a focus on methodologies used — complemented the first specifically focusing on adaptation, reviewing studies and assessing methodological issues. This report compiles the findings of these working papers. The report and discussion has the following objectives:

- to identify and highlight methodological issues and uncertainties of cost estimation;
- to review existing information on economic costs of climate change at European level;
- to highlight the need for improved information on impacts of climate change and on the need to monitor the effectiveness of adaptation strategies and actions;
- to facilitate information sharing among EEA member countries and learning from 'good practices' in assessments of economic costs of climate change; and
- to identify research needs.

The report has a different focus from other recent reports and reviews (Stern, 2006; IPCC, 20007b). The Stern review takes a global perspective on the economics of climate change and focuses on the aggregate total costs and benefits (with benefits derived from integrated assessment models, and based on implicit methodological assumptions). The IPCC Working Group II (IPCC, 2007b) presents the current scientific understanding of impacts of climate change on natural, managed and human systems and the capacity of these systems to adapt and their vulnerability. In contrast this report focuses specifically on Europe (and the regional level), and explicitly explores the methodological issues over the costs of inaction and the costs of adaptation at this level.

1.3 Definitions

With the rapid growth of literature on climate change vulnerability, impacts and adaptation, concepts and definitions continue to be re-defined.

Within the context of climate change, the IPCC TAR (2001) defines vulnerability in climate change terms as: the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. Adaptation is defined as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities associated with climate change.

In earlier EEA documents (2005), vulnerability is defined as 'a state induced from adverse impacts of climate change, including variability and extremes, and sea level rise, of both natural and human systems.' In other words, vulnerability of natural and human systems to unmanaged climate change is presented and discussed. Adaptation is defined as 'policies, practices, and projects with the effect of moderating damages and/or realising opportunities associated with climate change', including climate variability and extremes and sea level rise.

The main focus of this report is on two specific areas of the full costs of climate change — the 'costs of inaction' and the 'costs of adaptation'.

The EC communication (2005) termed the economic effects of climate change as the 'costs of inaction'. 'Inaction' is defined as the counterfactual or reference from which the costs and benefits of different policy or actions can be evaluated. Strictly speaking the 'costs of inaction' can reflect many different possible future reference scenarios, but in practice, the term is usually taken to represent the future baseline without mitigation (and planned adaptation), and so more closely relates to an IPCC A1 or A2 scenario.

From this baseline, it is possible to assess the benefits of climate change policy, i.e. the benefits of achieving a greenhouse gas stabilisation target (e.g. 450 to 550 ppm CO_2-equivalent) or a global warming target (e.g. the EU's 2 °C temperature target). This is estimated by assessing the economic costs of climate change under the baseline (if no further action is taken), and 'with' the policy scenario in place. The difference between the two provides the benefits of policy intervention. The residual economic costs provides a key input for the consideration of adaptation (note that climate change policy does not avoid all economic costs — only reduces them).

The costs of inaction are often expressed as the social cost of climate change, or the social cost of carbon (the latter especially in relation to marginal social costs). Even within these definitions there are different ways that the costs of inaction can be expressed, depending on assumptions on the given baseline, scenario, the level of adaptation (whether included or excluded), and whether these costs refer to total or average costs, or marginal costs (see Box 1.1).

Box 1.1 Total vs. marginal costs

Total social costs
The total (social) costs of climate change reflect the total economic costs of the baseline scenario, either in a given future year (e.g. 2100), or as a total net present value over, e.g. the next 100 years or longer. By dividing by the total emissions of carbon, it is possible to assess the average cost of GHG emissions.

Marginal social costs
The marginal social costs of climate change are usually estimated as the net present value of all climate change impacts over the next 100 years (or longer) of one additional tonne of carbon or other GHG emitted to the atmosphere today. They are the marginal global damage costs of carbon emissions. The marginal social costs are usually estimated by assessing the economic costs of climate change under the given baseline, and then rerunning the analysis with an additional pulse of carbon emissions (e.g. an additional tonne). The difference between the two scenarios (over all future years) provides the marginal social cost.

Marginal abatement costs
The marginal abatement cost (MAC) reflects the marginal technology and represents the cost of abating an additional tonne of carbon. These metric is often used for the assessment of mitigation policy costs.

Cost-benefit analysis (CBA)
CBA is designed to help policy makers choose the best option by calculating the net benefits as the balance of total benefits and total costs of alternative projects or policies. It quantifies costs and benefits in monetary terms, including values not captured by markets (i.e. the full social or economic costs). CBA also has the capacity to determine the optimal policy, i.e. where net benefits are maximised: this occurs when marginal abatement costs are equated to marginal abatement benefits.

Cost-effectiveness analysis.
CE analysis compares the costs of alternative ways of producing the same or similar outputs. It is therefore a relative measure, i.e. it only provides comparative information between choices and cannot show whether the chosen project will have a net benefit to society, as CBA does. It is typically used in one of two ways — it can be used to identify the highest level of achievement given available resources, or it can be used to assess the least-cost approach of reaching a given target (e.g. a threshold level) ([2]).

There is a wide diversity in the definitions of adaptation. One of the key differences is whether adaptation extends only to 'planned' adaptation, i.e. as developed through public or private agents, or whether it also includes 'autonomous' adaptation, including in natural systems and human systems.

What is clear is that adaptation has a cost, e.g. as in IPCC (2001), the 'Cost of planning, preparing for, facilitating and implementing adaptation measures, including transition costs'. This is countered by the benefits of adaptation (IPCC) as 'the avoided damage cost or the accrued benefits following the adoption and the implementation of adaptation measures'. If, net of adaptation costs, the negative consequences induced by climatic stimulus are reduced, or its positive consequences are enhanced, there are benefits from adaptation. If not, then this potentially leads to mal-adaptation. These elements are discussed further in Chapter 2 (policies).

It is often difficult or impossible to distinguish between impacts of, and adaptation to, climate change. For instance land abandonment due to sea level rise — or increased health care expenditure due to higher incidence of heath-related diseases — could be labelled also as impacts of climate change. However, all these processes are reactions that agents put in place to respond to it. Moreover, without them the costs of climate change will be

([2]) Note cost-benefit analysis and cost-effectiveness analysis are not necessarily mutually exclusive, and recent European impact assessment analysis has used both approaches to help inform policy.

higher. Accordingly we have described them here as adaptation. There is also often overlap between autonomous and planned adaptation.

1.4 Scope of the report

This report aims to provide an overview of key economic costs of climate change (impacts) and adaptation, and to identify and discuss methodology challenges in the analysis of the costs of inaction and the costs of adaptation. This report is a follow-up to the EEA reports on climate change impacts (EEA, 2004a), and climate change vulnerability and adaptation (EEA, 2005). Since this is the first EEA technical report on the economic costs of climate change and adaptation, it should be regarded as a scoping study. A more detailed analysis may be considered at a later date. The IPCC Fourth Assessment Report (AR4) WGII (IPCC, 2007b) contains much information on impacts of climate change and adaptation at the global level.

1.5 Sources of information

This study used a combination of methods to collect and analyse information. It has primarily focused on and reviewed the literature on climate change impacts and adaptation in Europe (e.g. IPCC reports, publications of EU-funded research, academic literature and research journals), but has also benefited from discussions with a wide range of experts across Europe (see Annex II).

1.6 Outline of the report

The policy context for the costs of inaction and the costs of adaptation are set out in Chapter 2. Chapter 3 introduces the methodological issues in the analysis of these costs. The literature on these costs is reviewed in Chapter 4. Finally, Chapter 5 presents the conclusions and identifies the research gaps.

2 EU policy frameworks

Current EU climate change policy was set out in the previous chapter. This chapter investigates the policy frameworks with a focus on an economic perspective.

2.1 Policy frameworks and applications

The assessment of the costs of inaction, and the costs of adaptation, are useful for policy decisions across different geographical spatial scales, across different time periods and for different types of policy applications. These range from assessments:

- to inform the international (global) debate on climate change policy;
- to inform European policy making on climate change and adaptation; and finally
- to inform and assist local responses to mitigate, plan and adapt to climate change.

In light of the diversity of applications, it is useful to frame the policy perspectives for different users of the costs of inaction and the costs of adaptation. This section discusses all three, but focuses on the European scale to put these economic issues in context in relation to European climate change policy and the role of the EEA.

2.1.1 A global perspective

At the most strategic level, the costs of inaction, and the costs and benefits of mitigation and adaptation are useful for a global policy perspective on climate change, i.e. in informing international negotiations or in developing European commitments for international targets or reductions. Both metrics are part of the overall consideration of what constitutes the full (economic) cost of climate change, as well as the residual costs as set out in the below equations.

To date, most of the discussions around global policy have been made based on consideration of defined ambition levels (to prevent dangerous levels of climate change) and from the costs of mitigation, i.e. the costs of reducing greenhouse gas emissions. However, it is increasingly apparent that information on the economic benefits of climate change policy itself can help inform decisions over long-term stabilisation targets and emission reduction goals.

These benefits are estimated based on knowledge of the costs of inaction (i.e. the costs of inaction under the business as usual scenario with no mitigation), and the benefits that the policy achieves (i.e. in reducing the costs of inaction, from mitigation policy) ([3]) .

In theory this information could be used in a cost-benefit analysis to justify long-term climate change policy, or to select the optimal policy choice from different options (e.g. by comparing

The full costs of climate change = Costs of mitigation + Costs of adaptation + Residual costs

Residual costs = Costs of inaction – Benefits from mitigation – Benefits from adaptation

([3]) Whilst adaptation is also part of this overall analysis, for simplicity it is not included in this simple description.

the marginal mitigation costs of achieving different stabilisation levels against the marginal economic benefits obtained). However, recent reviews (e.g. Watkiss and Downing, 2007) have guarded against such a use of CBA at present, due to the uncertainties in the current cost of inaction estimates ([4]), though they do stress that the information on the economic benefits of climate change policy have an important input in to long-term climate change policy.

The economic costs and benefits of adaptation also have an important role in this global perspective. Adaptation (autonomous or planned) will reduce the baseline costs of inaction, even without mitigation policy. Adaptation also can reduce down the residual costs of inaction after mitigation policy has been introduced, e.g. reducing the impacts of climate change even if, say, the 2 °C target is achieved (or on the path towards the target over time).

In both cases there are economic benefits from adaptation as it reduces the economic costs that would otherwise occur from climate change. In considering this global perspective, it is often the role for adaptation in developing countries that is highlighted: developing countries are more vulnerable to the effects of climate change ([5]) and they have less capacity to adapt, and the 2007 EC Communication recognises that the 'EU should enhance its alliance-building with developing countries in the areas of climate change adaptation'.

Furthermore, it is possible to consider the interaction between the costs and benefits of adaptation and mitigation in a purely economic framework, where along with the residual costs of inaction (see equation above), all three can be considered potential partial substitutes, e.g. where further action on mitigation reduces the need to adapt, and vice versa. Thus it is possible to frame a trade-off between adaptation and mitigation as part of an optimal economic decision on how best to react to climate change. However, it is not currently possible to do this due to the uncertainties and the partial coverage of integrated assessment models, and because these frameworks do not explicitly consider the potential role of large-scale, irreversible climate impacts that could be triggered past certain temperature increases. Nonetheless, there is emerging evidence that shows that mitigation and adaptation are complements and the discussion about substitutability is explored further in the underlying working paper on the costs of adaptation. Irrespective of these issues, adaptation will be essential, and there is a need to develop an economic perspective to adaptation policy.

2.1.2 A European perspective

Moving to a European policy perspective, there are a number of potential applications for the costs of inaction ([6]) and the costs of adaptation.

First, information on the costs of inaction can provide a means to monitoring and predicting the changing state of the environment (both natural and human systems) that is likely to be affected by climate change in Europe. Expressing these in monetary terms (economic costs) provides a common metric to assess the impacts of climate change across sectors, countries and over time. This can help prioritise the key areas of concern, and can provide a key indicator suite for measuring and monitoring the effects of climate change (consistent with the role of the EEA).

Second, the cost of inaction is also relevant for European policy making as an input to policy appraisal (in Impact Assessment or cost-benefit analysis — see Box 2.1). Irrespective of any long-term ambitions or targets for climate change policy, there are a range of current policy areas or proposals that will either:

- be part of a wider package of measures as part of European climate change policy in the near term, involving for example greenhouse gas emissions reductions in different sectors;

([4]) The economic benefits of climate change policy should be considered when setting long-term targets and goals, but a wider framework is needed (i.e. simple cost-benefit analysis should be avoided). It is recommended that this framework should include a disaggregated analysis of economic winners and losers by region and sector, and a disaggregated analysis of the impacts of climate change including key indicators such as health and ecosystems. It should also include a full and explicit consideration of the risk matrix (including consideration of major events including non-marginal events and irreversible effects) and the analysis should include extensive uncertainty and sensitivity analysis (e.g. over key decision variables such as discount rate and equity weighting). Given the status of the knowledge on economic effects, alternative decision frameworks (e.g. risk based approaches) enhance the knowledge available for such decisions (Watkiss and Downing, 2007).

([5]) Because these countries are exposed to significant climatic threats, their economies often rely more heavily on climate-sensitive activities, and because in many cases they are already close to environmental tolerance limits (Tol *et al.*, 2005).

([6]) Cost of inaction is taken in this report as the total cost due to climate change in the absence of mitigation and adaptation policies and measures.

- be associated with policy areas that have the potential to reduce greenhouse gas emissions, but that are not explicitly part of climate change policy, e.g. air quality policy and transport policy. Note that in some cases there can also be policy areas that can potentially increase greenhouse gas emissions (which also need to be considered).

In appraising such policies, there is a need to consider the economic, social and environmental costs of greenhouse gas emissions (or phrased the other way round, the economic benefits of greenhouse gas emission reductions). In theory this should use the costs of inaction: in practice a range of values are used (if values are indeed used at all), which often include use of the costs of mitigation as a surrogate or proxy value.

Related to this, it is also important to note that the European Union has identified the need to address external cost ([7]) as one of it's key sustainability indicators, under the policy agenda of 'getting the prices right' ([8]). It is also aiming to address this through a greater use of economic instruments in European policy (including taxes, charges and other market based instruments such as trading) as referenced in the EC Green paper on market based instruments (EC, 2007b).

Box 2.1 Impact assessment (policy appraisal)

Impact assessment (also known as regulatory impact assessment or appraisal) is a set of logical steps which structure the preparation of policy proposals. It is undertaken prior to policy implementation (*ex ante*) as a form of policy appraisal. IA is a tool that informs policy decisions ([9]), and provides an assessment of the impact of policy options (or more usually alternative policy choices) in terms of the costs, benefits and risks of a proposal.

The European Commission has issued guidance on Impact Assessment (SEC(2005) 791). Following the earlier communication on European Governance (COM(2001)428) these set out that 'Proposals must be prepared on the basis of an effective analysis of whether it is appropriate to intervene at EU level and whether regulatory intervention is needed. If so, the analysis must also assess the potential economic, social and environmental impact'. While this includes a comparison of costs and benefits, the IA guidance does not require cost-benefit analysis.

Other EEA member countries have more explicit recommendations for cost-benefit analysis in impact assessment. As an example, the United Kingdom provides guidance on the appraisal of government action in the Treasury Green Book (HMT, 2006). As well as requiring that appraisal be based on an assessment of how any proposed policy, programme or project can best promote the public interest, the Green Book identifies two key questions:

- Is the rationale for intervention clear?
- Are the benefits of intervention expected to exceed the costs?

The technique recommended to address the latter question is cost-benefit analysis (CBA), whereby all relevant costs and benefits to government and society of all options are valued, and the net benefits or costs calculated ([10]). CBA should explicitly consider the economic costs and benefits of greenhouse gas emissions for relevant policies. Note that CBA also has the capacity to determine the optimal scale of the policy, i.e. the point where net benefits are maximised — specifically optimal scale is where the marginal social benefits of the project/policy are just equal to the marginal costs of the project policy (Pearce *et al.*, 2006).

([7]) Environmental pollution has a number of important impacts on human health, as well as on the natural and man-made environment. These include impacts on our health, the man-made and on the natural environment. These impacts have a number of important economic costs — known as external costs or externalities (or full social costs), as they are not included in the price of goods or services.

([8]) http://europa.eu/bulletin/en/200112/p104035.htm.

([9]) Impact assessment is an aid to political decision-making, not a substitute for it. Project or policy appraisal is one strand of information that informs whether to proceed with a particular course of action.

([10]) Though note we are unlikely ever to be able to value all the important costs and benefits of a particular project.

It is widely acknowledged that incorrect signals occur when external costs are not reflected in prices, and that the appropriate way to handle this is by passing through these costs (internalising them). This is consistent with the Polluter Pays Principle. While the setting of taxes and charges is often a complex political decision, information on external costs (in this case the cost of inaction associated with greenhouse gas emissions) can be used to help inform and set these taxes and charges.

While many of these policy concepts are still evolving at an EC and Member State level, some countries have adopted and followed through the economic theory to policy making, notably the United Kingdom with the Social Cost of Carbon (the marginal cost of inaction), see Box 2.2.

Finally, there is a European perspective for adaptation policy, which can be considered separately to mitigation. This looks at adaptation policy (policies, practices, and projects) as a means of moderating damages or realising opportunities associated with climate change (or residual climate change). If an economic perspective is also included, then such adaptation policy also compares adaptation to the European costs of inaction.

The policy framework on European adaptation is still evolving, though recent progress has been made with the Green Paper (published 29 June 2007) (EC, 2007c). However, policy frameworks for European adaptation are emerging (e.g. UKCIP (Willows and Connell, 2003); Watkiss, 2005), which have used the traditional policy appraisal cycle and set out according to the following steps:

1 define the overall (European) policy aim of adaptation;
2 determine priority sectors for adaptation action;

Box 2.2 The UK Social Cost of Carbon

In early 2002 the UK Government Economic Service (GES) presented a review of the available literature on the social cost of climate change (the cost of inaction), termed in the United Kingdom as the social cost of carbon (SCC). The SCC is the marginal global damage cost of carbon emissions, estimated as the net present value of the impact over the next 100 years (or longer) of one additional tonne of carbon emitted to the atmosphere today.

This suggested a value of GDP 70/tC (within a range of GBP 35 to GDP 140/tC — approximately 28 EUR/tCO_2, with a range of 14 to 56)) as an illustrative estimate for the global damage cost of carbon emissions ([11]). These are for a year 2000 emission in year 2000 prices. It also suggested that since the costs of climate change are likely to increase over time, the estimates should rise in real terms by GBP1/tC per year (i.e. so for a 2005 emission, in 2005 prices, the values would be GBP 45, GBP 85 and GBP 164/tC (approximately 34 EUR/tCO_2, with a range of 18 to 66). It is recommended that this value is used across Government in the UK in Regulatory Impact Assessment (which is mandatory) and guidance is available on how to do this (Defra, 2006). These values are high in relation to many estimates in the literature, though lower than reported in the recent Stern review.

The values have been used in a large number of UK regulatory policy appraisals and used in consultations for taxes in the United Kingdom, for example a recent review (Watkiss *et al.*, 2006) found examples of the use of the SCC for cost-benefit analysis of proposed greenhouse gas policies (e.g. F gas regulation), other policies with the potential to affect GHG (e.g. renewable energy targets, building regulations, air quality policy), in project based schemes considered by the economic regulators in the United Kingdom (e.g. in gas and electricity infrastructure), and in consultation on economic instruments (e.g. in potential charges for the carbon component on aviation and road user charging).

The GES paper recommended periodic reviews of these illustrative figures above as evidence became available. Two recent review studies were undertaken (Downing *et al.*, 2005; Watkiss *et al.*, 2006a). This recommended broadly similar values to the GES paper. There has also been some additional information from the Stern Review, and there is likely to be an updated set of values released in 2007.

([11]) 1t C = 3 664t CO_2. So, a value of GBP 100/tC would be equivalent to GBP 27/t CO_2.

3 characterise priority risks/opportunities (in each sector);
3a identify potential adaptation options;
3b appraise adaptation options;
4 propose adaptation objectives;
5 define adaptation targets and indicators;
6 link up policy framework at the EU, national and sectoral level;
7 implement;
8 monitor, review and revise.

This type of traditional policy construct can be used for assessing the likely roles of different European organisations, including the EEA, in European adaptation policy (see Box 2.3).

Within such an adaptation framework, the costs of adaptation form the basis for prioritising risks and opportunities (step 3). If appraisal is based only in terms of cost-effectiveness analysis, then these adaptation costs allow the identification of the least cost way of achieving given ambition targets for adaptation ([12]). If appraisal is based on cost-benefit analysis, then as well as considering the costs of adaptation, analysis is also made of the economic benefits that adaptation achieves. The benefits relate to the reduction in the cost of inaction, which can be compared to the costs of adaptation (note consistent with CBA, the costs and benefits here should include both market costs and non-market costs and benefits) ([13]).

Key to this overall process is ensuring that adaptation policy is cost-effective and proportionate, and that maladaptation is prevented (see Box 2.4).

A number of EEA member countries have produced national adaptation plans (see EEA, 2005). Many of these are now moving to develop adaptation policy frameworks, and increasingly adaptation policy implementation is being discussed in terms of 'mainstreaming'. No common definitions of mainstreaming exist as yet, but the term is widely used (Levina and Tirpak, 2006) to refer to the integration of adaptation policy into mainstream policy, i.e. such that adaptation becomes part of national and regional policies and processes at all levels and stages (or such that potential climate change impacts are considered when making investment decisions).

2.1.3 *A local perspective*

Finally, it is possible to consider the costs of inaction and the costs of adaptation at a project (local) based perspective. The most obvious application here is project appraisal. As with policy appraisal above, the information on the costs of inaction (as a marginal social cost, or proxy for this) can be used to help inform the justification for projects, or help in choosing between alternative policy options, for individual mitigation projects.

For adaptation, project based appraisal can also follow the scheme outlined above for European adaptation policy. It can work within a cost-benefit framework, assessing the costs of inaction (for perhaps different scenarios, with and without mitigation) and then looking at adaptation options and assessing the costs and benefits (or even optimal adaptation policy for a local decision). The consideration of a smaller-scale, with more detailed information on climate and impact predictions has allowed a more detailed analytical framework to be developed

2.1.4 *Summary*

The difference between the three policy perspectives (global, European, and local) is important for many reasons. Many of the methodological issues with the economic costs of climate change differ for each level (both for the costs of inaction, and the costs of adaptation). Moreover, there are differences in the potential uncertainties introduced by impact assessment or valuation. Many (but importantly not all) uncertainties are reduced as one moves from global policy level down to project level, not least because in some respects the time-frame for analysis tends to be shorter ([14]). However, analysis at a local level may be complicated by the need to integrate policies and measures with other (sometimes contradictory) objectives (singling out the adaptation part of these policies and measures is not always easy), and because a higher level of accuracy may be required for a local project.

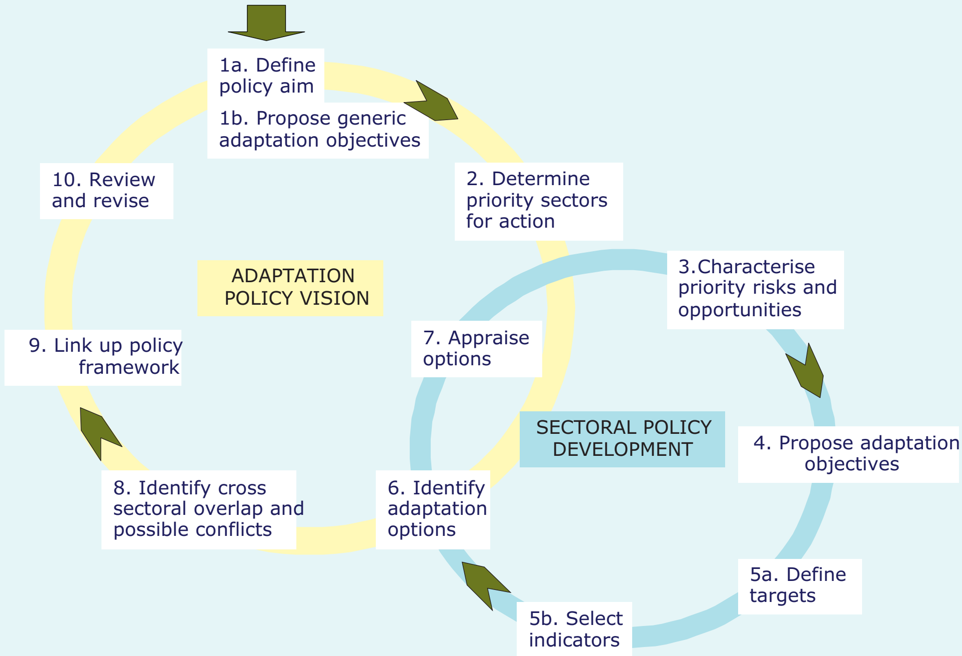
([12]) For example, looking at critical climate change impacts across sectors, and then setting ambition levels for protection to be achieved through adaptation. The information on the costs of adaptation of different options allows a cost-effectiveness analysis to identify identification of the least cost way of achieving these ambition levels. In this context, the economical optimal decision only applies to achieving the target as cost-effectively as possible — at lowest (least) cost. Benefits are not treated explicitly in economic terms, as they are already fixed based on the ambition levels.

([13]) Cost-benefit analysis allows the identification of optimal adaptation policy (and provides the answer to whether adaptation policy in a specific area is justified).

([14]) Time-scales for long-term climate change policy need to have a horizon that considers at least the next 100 years, and preferably more: project appraisal will tend to be associated with shorter term projects that have a lifetime measured over decades (though there are some exceptions).

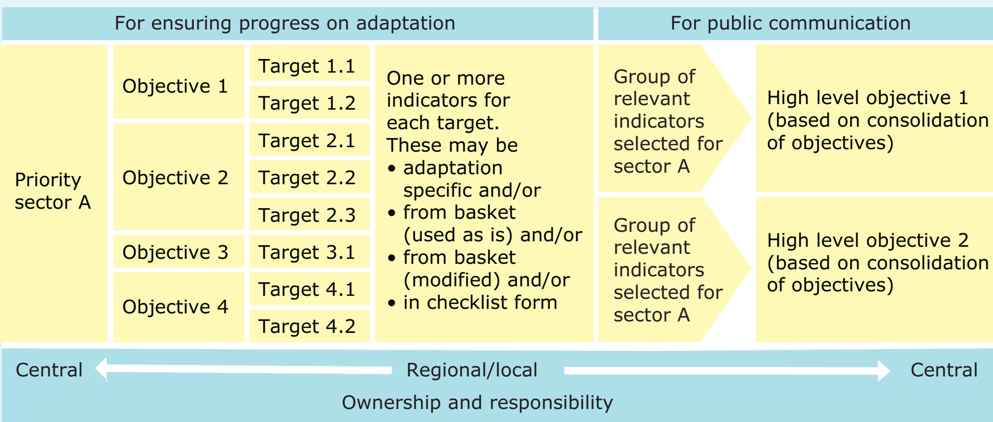
Box 2.3 Adaptation policy

A number of adaptation policy frameworks are now developing. These include the United Nations Development Programme (UNDP) and Global Environment Facility (GEF) adaptation policy framework (Lim *et al.*, 2005), the UKCIP Climate Adaptation: risk, uncertainty and decision-making (2003), and others. Many of these share common features. A synthesis of these frameworks was used to provide a template for national level adaptation policy (Horrocks *et al.*, 2006), shown below. The process starts with the setting of the overall adaptation goal — set in the ECCP II as 'to identify good, cost-effective practice in the development of adaptation policy and to foster learning'. To accommodate the challenges posed by adaptation, the method developed is circular and iterative. It allows for input from individual sectors to occur, and requires engagement with a range of stakeholders at various stages in its application.



Source: Horrocks *et al.*, 2006. Objective Setting for Climate Change Adaptation Policy. Report for Defra.

Following down from the high level goal, there is a need to develop adaptation objectives, targets and indicators — the latter is a potential indicator suite at national and EU level (e.g. for the EEA). Whilst thinking on adaptation indicators is at an early stage, it is clear that there are potentially two types of indicators: process-based targets that form the basis for the early steps towards adaptation (e.g. building capacity) and outcome-based targets that actually set targets that can be tracked and monitored (explicit outcome or end point of adaptation — note that these are more difficult given the time-scales of climate change). Consistent with mainstreaming, there is a need to consider how these link with existing indicator sets.



Box 2.4 Adaptation implementation and maladaptation

Recent work has developed the potential development of the adaptation policy cycle at a European level through a three tiered approach. This is centred around 1) building capacity, 2) adopting no regrets adaptation opportunities, and 3) assessing other adaptation options through appraisal.

A key element of this latter stage of appraisal (Watkiss and Downing, 2006a) is the recognition that climate proofing all human activities through adaptation would be extremely expensive (and there will be many cases where benefits will certainly exceed costs). At the other extreme is a policy of do nothing, i.e. living with the risks of climate change. Optimal policy will be somewhere between these two extremes (i.e. 'cost-effective and proportionate').

Whilst there has been much attention focused on the effectiveness of adaptation in reducing climate change vulnerability, and so potential impacts, it is rarely appreciated that if done badly, (adaptation) responses can actually exacerbate the effects of climate change. This is termed maladaptation. The IPCC (2001) defines maladaptation as 'any changes in natural or human systems that inadvertently increase vulnerability to climatic stimuli; an adaptation that does not succeed in reducing vulnerability, but increases it instead'. A more pragmatic explanation (Downing *et al.*, 2005) is the kinds of action that might involve:

- inefficient use of resources compared to other options (e.g. the principle that all actions should be climate-proof through adaptation would be an extremely expensive tax on current investment that is unlikely to provide good value for society as a whole);
- ineffective (e.g. relying on scenarios of future climatic risks that are not subsequently realised and actions that have no other benefits);
- displacing vulnerability (from one actor to another); and/or
- reducing the possibility for future adaptations.

Maladaptation can be placed more explicitly in an economic framework. If, net of adaptation costs, the negative consequences induced by the climatic stimulus are reduced, or its positive consequences are enhanced, there are benefits from adaptation; vice versa adaptation produces damages, in which case it becomes maladaptation. It is important to stress that adaptation which can be successful at a specific temporal or spatial scale can become maladaptation at a different spatial and temporal scope.

Perhaps more importantly, however, is that the perceived role for economics varies significantly between the three levels. Recent stakeholder survey in the United Kingdom (e.g. Watkiss *et al.*, 2006) has found considerable resistance by many consultees to the use of the cost of inaction values for cost-benefit analysis of (long-term) climate policy, though nearly all recognise the need for some form of benefits analysis in this decision making context. This partly reflects the variation in views over policy appraisal and CBA, but it has also highlighted that the explicit use of such framework values for climate change policy remains controversial. Similarly, many commentators disagree with a purely economic optimisation framework considering global mitigation vs. adaptation as substitutes. In contrast, far fewer are likely to disagree (at least in principle) to a greater role for economic analysis and even economic optimisation for project design e.g. for adaptation at a local level. However, in all cases, there are important methodological issues that are relevant, which are set out in the next chapter.

3 Methodological issues

This section outlines the methodological issues with estimates of the costs of inaction, and the costs of adaptation. The consideration of these issues has been one of the primary aims of the underlying working papers. Understanding these methodological issues, and the way they can affect the cost estimates, is essential to the progress in this area, and to ensure that the information generated on the economic effects of climate change can be effectively used in the European policy frameworks from the previous section. This section first addresses the methodological issues with estimating the costs of inaction (focusing on impacts of climate change), and then looks at the additional issues which arise when looking at the costs of adaptation.

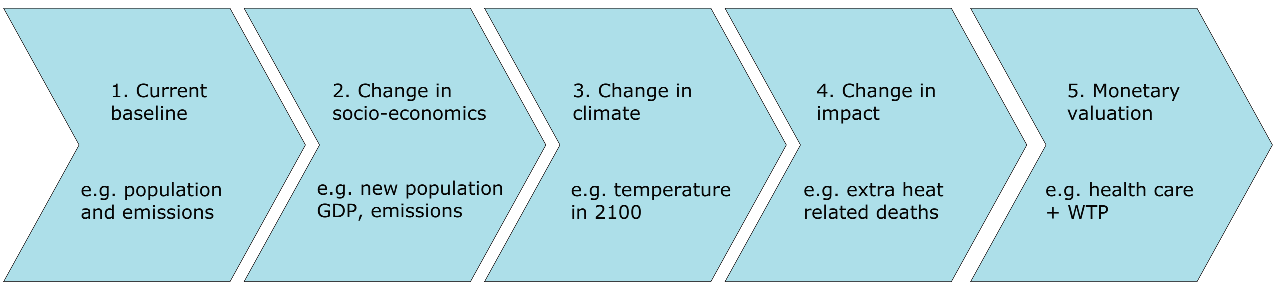
3.1 Estimating the cost of inaction

While the costs of mitigation policies and measures can be relatively well identified, the economic costs of climate change impacts are not so easily assessed. This is because of the difficulties in both estimation of physical impacts from climate change, as well as the economic valuation of these impacts.

In general, the assessment of the costs of inaction progresses through a series of integrated steps (simplified in Figure 3.1, and summarised below):

1. The current baseline climate and socio-economic scenario are assessed. This provides information on the 'stock at risk' (e.g. population, crops, etc.);
2. A future socio-economic scenario is modelled for a future time period, e.g. 2041 to 2070, for a future business as usual scenario (or an alternative scenario). This provides the future stock at risk (i.e. how population will change over time with a constant climate). It also provides the information on technology, production, consumption and emissions;
3. In addition to the future socio-economic scenario (in 2), a future climate scenario is added. Note that the future climate is also dependent on the socio-economic scenario above (the link with emissions, atmospheric concentrations and radiative forcing). There are many climate parameters that need to modelled (e.g. average temperature, temperature variations, average and temporal precipitation), though there are different levels of confidence attached to each — whilst the prediction of average temperature is often fairly constant between models, estimates of extreme events such heavy rainfall events of concern for floods are much more variable. For these reasons, different models are often used in inter-comparison, or an ensemble of model outputs is used;
4. The impacts of the future socio-economic and climate change are quantified (e.g. by impact category and sector). This is usually undertaken using either physical impact relationships between climate and impacts (for example using crop models to assess the effects of future temperature, rainfall, CO_2 concentrations,

Figure 3.1 Potential steps in the assessment of the costs of climate change impacts (no mitigation or adaptation)



etc. on crop yields, or through the use of relationships from epidemiology studies which show levels of health impacts with given levels of temperature), or through econometric analysis. The end result is a quantified set of impacts (preferably split into those that arise from the changing socio-economic signal and those that arise from the changing climate signal ([15])). While there is emerging evidence for relationships across sectors, the full links between climate and impacts are not fully understood in such a detailed way. This step should also consider adaptation (autonomous), and as part of a wider analysis, planned adaptation;

5. The impacts are valued in monetary terms. The valuation is generally undertaken from the perspective of 'willingness to pay' (WTP). For some effects, such as damage to crops, this can be done using appropriate market data. For non-market areas alternative approaches are needed, such as the use of contingent valuation.

It is clear that such an analysis, especially when undertaken across multiple sectors, is extremely complex. Most of the reported estimates of the total social costs of climate change (and especially the marginal social costs — see Chapter 3) have undertaken this type of analysis with Integrated Assessment Models (IAMs). These combine the scientific and economic aspects of climate change within a single, iterative analytical framework (i.e. essentially linking the elements above together ([16]) . The advantage of these models is that they have an additional element where climate impacts feed back to the socio-economic module thereby linking emissions, climate modelling, climate change impacts and the economy (Hope, 2006). However, to make analysis manageable, they often use simplified analysis of climate projections (e.g. rather than full-scale climate models) and simplified impact relationships (e.g. rather than sector based models) (see Warren *et al.*, 2006) ([17]).

It is also clear that the resulting economic costs ([18]) of climate change will occur to different individuals, in different sectors, in different places, and at different times (see Downing *et al.*, 2006). This leads to complex issues on aggregation, and how to treat costs in different time periods and geographical locations.

These two issues above explain much of the variation in the literature for the costs of inaction (Tol, 2005). Given the complexity of analysis, there will be methodological differences in the approach used for quantifying and valuing effects. However, there will also be differences due to the choice of parameters used for aggregation and especially in relation to treatment of values in different times and locations (Watkiss and Downing, 2007).

Finally, it is stressed that there are different levels of action (and so different definitions of inaction). Action in climate change can refer to any or all of: mitigation, autonomous and planned adaptation — and so the costs of inaction can refer to baselines for each of these ([19]). Referring back to the full costs of climate change in the earlier section, the same approach is also used to quantify the residual costs of climate change (i.e. after any or all of mitigation or adaptation) ([20]) .

This section focuses on the key methodological issues involved in estimating the costs of inaction, i.e. associated with the steps in the diagram above, but also the choice of parameters and how these influence values. These are discussed below.

3.1.1 Scenarios

In the assessment of the future damages of climate change, assumptions have to be made on future conditions of the climate and of the natural and social systems that are potentially affected by it. This requires scenarios. A scenario is a set of assumptions on future conditions that is coherent, internally consistent, and plausible. The IPCC makes

([15]) This is necessary to split out the effect of climate change, from those effects that would have occurred anyway (from changing socio-economic conditions).
([16]) IAMs for social cost of climate change typically include an energy/economy/emissions module, a climate module and an impact/valuation module. The latter looks at the impacts of climate change on different sectors, e.g. agriculture, human health, sea level rise, etc. They often explicitly consider adaptation, as part of the overall framework, for both autonomous and planned adaptation.
([17]) Some models do not undertake physical impact assessment *per se*, but instead directly link changes in climate to economic values, using relationships between climate change and economic damage.
([18]) The term 'social' costs are also used as an alternative, to indicate that we refer to the costs to society as a whole, not to one particular group of agents.
([19]) Moreover, the actions/inactions are often not independent of each other, so that inaction in one area (e.g. mitigation) will have implications for other areas of action (e.g. for autonomous adaptation).
([20]) Note that the baselines against which total costs and marginal costs may differ: the baseline against which to measure total costs is often no climate change, while the baseline against which to measure marginal costs is a reference rate of climate change, usually derived from one of the IPCC emissions scenarios.

a distinction between climate scenarios on the one hand, and non-climate scenarios on the other hand (IPCC, 2001: 2007).

Climate scenarios are usually derived from modelling experiments with Global Circulation Models (GCM). An important distinction can be made between models that compare two equilibrium states of the climate (e.g. a doubling of atmospheric CO_2 concentration or its radiative equivalent), or models that dynamically track transient changes in climate variables (using so-called coupled Atmosphere-Ocean Global Circulation Models: AOGCM).

An extremely important issue for damage assessment is the spatial aggregation of climate models and scenarios. A simple mean global change in temperature may hide important regional variations. In impact assessments, the results of low-resolution GCM can be regionalised by regional climate models or by statistical methods.

Another important distinction is inclusion in the climate scenarios of extreme weather events (hurricanes, tornadoes, storm surges, droughts, floods), and low-probability, high-impact events (major climate signals), such as a disruption of the thermo-haline circulation in the Atlantic Ocean, or the collapse of the West Antarctic ice sheet (Lenton *et al.*, 2006: IPCC, 2007b). These latter types of scenarios have a much higher uncertainty than the scenarios for 'average' climate change (see later discussion of uncertainty and coverage).

Non-climate scenarios are centred on socio-economic scenarios, but also include land-use and land-cover. These non-climate scenarios are important as they determine the vulnerability of social and economic systems to climate change in the future (i.e. when climate change occurs). Consistent with the scheme above, they describe the changes in the 'stock at risk', with respect to size, and subsequent sensitivity to climate change, adaptive capacity and vulnerability. Note that the future socio-economic scenario can provide a significant change in vulnerability or exposure, even without future climate change: as an example, the impact of extreme events such as floods or storms will be determined by the increased wealth of potential infrastructure affected, but also changes in relation to location (e.g. from building in areas that are most susceptible to flood risk). These socio-economic changes can affect the size of the impact from climate change, and can even affect the signs (+/–) of damages. There are also strong linkages between socio-economic development and adaptation (discussed later).

These socio-economic scenarios also determine the global GHG emissions leading to the range of emissions scenarios used in GCMs. In studies that make use of non-climate scenarios, a distinction can be made between studies that use exogenous (external) scenarios and studies that employ an Integrated Assessment Model (IAM) to generate scenario values.

3.1.2 Valuation approach

As outlined above, a wide range of approaches are needed for the full monetary valuation of climate change. Some values can be directly based on market values (e.g. crops where the values of foregone crop yields can serve as a measure of the environmental damage), whereas other values can be indirectly valued on the basis of market prices for surrogate products or services (e.g. the costs of alternative fuel sources to replace fuel wood loss arising from deforestation). In both examples, market prices are directly or indirectly indicative for the effect of climate change.

There are, however, much greater challenges in valuation. First, to find future market prices that are consistent with the underlying socioeconomic scenario, for example the future price of (foregone) crop yields may be higher as high-quality farming land becomes scarcer as a result of climate and land-use changes. Second, to provide valuation estimates where there are no market values, as is the case for human health or non-commercial ecosystems.

The techniques for the valuation of non-market effects (OECD, 2006) are generally classified into methods that are derived from 'revealed preferences' and values that are based on 'stated preferences' ([21]). Revealed preference methods calculate valuation indirectly by using the relationships between environmental goods and expenditures on market goods. Typical examples include hedonic pricing and averting behaviour method. Stated

([21]) Other approaches have been used. Many older environmental economic studies used marginal abatement costs as a proxy for environmental damage, through the assumption that political decisions reveal the price that society is willing to pay for environment improvements. An alternative has been valuing environmental goods using the costs required to protect or replace these goods. Both approaches are not recommended because they have no basis in welfare economic theory (and can lead to other problems in analytical frameworks).

preference methods ask individuals their WTP for the environmental good directly, by using structured questionnaires ([22]). The contingent valuation method (CVM) is the most important technique belonging to this category.

Such non-market estimates are usually derived through primary valuation studies or surveys, which produce values that are specific to particular conditions and locations. Because it is not possible to undertake these primary studies for every location, nor for future conditions, the unit values are used more generally in different regions or times: a technique known as 'benefit transfer'. This involves transferring unit values, e.g. by adjusting WTP estimates according to income, or transferring the complete valuation function using meta-analysis to include other socio-economic and demographic factors (see Navrud, 2007). Virtually all studies of the economic impact of climate change rely on benefit transfer — though this is needed since climate change is a future phenomenon, for which data are not yet available.

3.1.3 Direct and indirect effects

Economic impacts of climate change can be divided into direct impacts and indirect impacts.

- Direct impacts concern primary effects from climate change on production or consumption.
- Indirect impacts reflect changes in production or consumption on the whole economy, through their effects on relative prices, including factor prices (income). This requires assessing how climate change impacts will affect other sectors or regions (that are different from those initially impacted) and the feedbacks between sectors.

Most studies have only estimated direct costs under the assumption that indirect effects would be negligible. Whether through the use of market or non market techniques, impacts are assessed multiplying a 'price' by a 'quantity' (e.g. price of land per km^2 multiplied by the area of land lost; value of statistical life multiplied by additional cases of mortality, etc.).

Indirect costs are more complex to assess, some modelling of sectoral interdependencies is needed, but can be undertaken using a partial equilibrium or general equilibrium approach ([23]).

A limited number of studies have used a partial equilibrium approach for climate change effects, which includes the indirect effects for the sector or market in question, but do not look at wider economy effects. General equilibrium analysis has only recently received attention in climate change modelling of impacts (though have been used more in analysis of mitigation). A number of recent studies have examined the economy-wide implications of sea level rise, extreme events, climate change impacts on tourism, and on health. These suggest that indirect effects of climate change can have both positive and negative effects on climate change ([24]), and will also lead to changes in the distribution of gains and losses, i.e. whereas direct costs are limited to those directly affected, markets would spread the impact to their suppliers, clients, and competitors as to financial markets.

3.1.4 Temporal aggregation (discounting)

The economic costs of climate change, and also the costs of mitigation and adaptation, all occur at different times in the future. Mitigation and adaptation measures are typically undertaken in the short-medium term, whilst many of the benefits of climate change policy occur in the more distant future.

In order to directly compare economic costs and benefits at different times, a technique called discounting is usually used. This expresses all economic costs in a common base year. Discounting is different to inflation, and is based on the principle that, generally, people (and society) prefer to receive goods and services now rather than later, and also

([22]) Theoretically, there is an additional distinction in valuation between the willingness to pay (WTP), and the willingness to accept compensation (WTAC/WTA) as a measure of the welfare loss. Empirical studies show that WTA may be up to a factor of 20 greater than WTP. From a climate policy perspective, the difference is potentially important. All climate studies to date use WTP.

([23]) Partial equilibrium approaches/models are constructed around one specific sector (or a few sectors) of the economy. The strength of these models is that they enable a relatively high degree of dis-aggregation and a detailed representation of the specific economic and institutional factors. The drawback is their inability to capture the effects on other markets and other feedbacks. General equilibrium approaches (and computable general equilibrium models, CGEs) take account of all sectors of the economy, and the links between them. Their advantage is that they allow consideration of effects from one sector to all others (i.e. the entire economic system, for example from a localised shock onto the global context via price and quantity changes and vice versa). The weakness of CGE models is over the assumptions and calibration made, and the lack a detailed bottom-up representation.

([24]) For example, a loss of land due to sea level rise would reduce overall productivity of the economy, a negative effect that is not captured in the (change in) land price. In such cases, the direct costs are an underestimate of the true economic impact. However, direct costs also ignore that markets would adapt to minimise the adverse effects; for example, a loss in agricultural production may be compensated by an increase in imports. As any adaptation, this would work to reduce the negative direct impact, at least in the short term.

that costs and benefits in the future count less because they affect a larger expected future income. A discount rate is used to convert economic costs to so called 'present values'.

The issue of discounting is particularly important in the economic analysis of climate change, because of the very long time frames involved. The choice of the appropriate discount rate, however, has been a source of controversy and heated debate, both in academic and policy circles. While there are standard discount rates used in project and policy appraisal across Europe ([25]), the debate has centred on which values are appropriate for climate change ([26]). Climate change has some attributes that make it unique (or certainly unusual) — it involves very long-time scales, consideration of costs and benefits across all geographical world areas, inter- and intra-generational issues, and potential consideration of non-marginal (catastrophic) changes to society. Details of discounting are provided in Box 3.1.

The choice of discount rate dramatically affects the economic costs of climate change (Tol, 2005; Downing *et al.*, 2006). In moderate climate change scenarios, climate change often generates a mix of both positive and negative impacts in the short to medium term, moving to predominantly negative impacts in the longer term. A higher discount rate therefore leads to lower economic costs (as larger future negative effects are reduced through discounting).

Many studies use a social rate of time preference for discounting (as used in public policy by Governments), rather than a private investment rate used in industry. More recent studies (e.g. Tol, 2006; Hope, 2006) tend to use explicit assumptions about growth in each world region, and look at alternative values for the Pure Rate of Time Preference (PRTP) only. Values of a PRTP of between 0 % and 3 % are typically used. Note that when studies use a PRTP of 0 %, they are still discounting, but only to account for the extra wealth of future generations.

Box 3.1 Discounting

The discount rate used in public policy appraisal is a social rate of time preference (STRP). This is defined as the value society attaches to present, as opposed to future, consumption, and is based on comparisons of utility (an economic term referring to the total satisfaction received from consuming a good or a service) across different points in time or different generations. It is constructed from two elements:

- the rate at which individuals discount future consumption over present consumption, on the assumption of an unchanging level of consumption per capita over time. This is the so-called 'pure rate of time preference' (PRTP);
- an additional element for the growth of per capita consumption over time, reflecting the fact that these circumstances imply that future consumption will be plentiful relative to the current position and thus have lower marginal utility. This effect is represented by the product of the annual growth in per capita consumption (g) and the elasticity of marginal utility of consumption (μ) with respect to utility.

The SRTP is the sum of these two components

$$SRTP = PRTP + \mu \times g$$

In Europe, a pure rate of time preference of 1.5 or 2 % is usually adopted, and with typical values of 2 % for g (growth) and 1 for μ (so a marginal increment in consumption to a generation that has twice the consumption of the current generation will reduce the utility by half), the resulting social discount rate is 3.5 % to 4 %.

Source: Adapted from HMT, 2006.

([25]) For example, EC Impact Assessment guidance recommends a 4 % discount rate.
([26]) The literature distinguishes between a prescriptive and a descriptive approach. The prescriptive approach to discounting starts by asking how trade-offs between present and future generations should be made, the descriptive approach, by contrast, starts by asking what choices involving trade-offs across time do people actually make, implying, in practical terms, that the prescriptive approach advocates a lower rate of discount than the descriptive approach.

There has been a recent recognition that the discount rate should not be constant over time, especially over very long time-periods, but instead should fall with time. So called 'declining' discount rates have the advantage that short-term decisions (e.g. investments in education and pensions) may be based on relatively high rates of time preference, while long-term decisions (e.g. greenhouse gas emission reduction), can use lower rates. Some EEA member countries (e.g. the United Kingdom) have already introduced declining discount rates for conventional policy appraisal (see HMT, 2006). The marginal damage costs of carbon dioxide are higher with declining discount rates (Downing *et al.*, 2005).

One other element, partly related to discounting, is the study time horizon chosen. Extending the time horizon, even with discounting, can substantially increase the economic cost of climate change, not least because it captures some of the larger impacts in the far future. Constraining the time-scale — even to the next 100 years — only gives a partial view of the future effects of climate change (though predicting climate and socio-economic scenario over these time-scale is extremely challenging). Many of the latest IAMs extend the time-scale for analysis significantly past 2100 ([27]).

3.1.5 *Spatial aggregation (equity and distributional effects)*

Just as the effects of climate change occur at different times, they also occur in different places.

The recent IPCC Fourth Assessment (WG II summary for policy makers, IPCC, 2007b) makes it clear that the impacts of future climate change will be mixed across regions. It is now commonly understood that most climate change damage (at least in the short to medium term) will be felt in developing countries (e.g. see IPCC, 2001; Stern, 2006; IPCC, 2007b). There are several reasons for this: many of the largest changes are projected to occur in these countries; their economies rely more on climate-sensitive activities; many operate close to environmental and climatic tolerance levels; and their ability to adapt may be limited because of technical, economic and institutional limitations (Tol *et al.*, 2004). The effects are likely to be greatest for the poor persons within these countries, and they potentially exacerbate inequities in health status and access to adequate food, clean water, and other resources.

There are increasing concerns about how best to compare economic damages from climate change across countries with very different levels of impacts and also very different income levels. An aggregate estimate of the economic costs of climate change inevitably implies combining benefits and dis-benefits across winners and losers over different regions (Eyre *et al.*, 1999). The way this is done strongly influences the resulting costs of inaction.

As with discounting, this issue has been a major source of contention in the climate change valuation discussion, and there remains no consensus on how best to do this. As an example, the value of public goods affected by climate change may vary across countries. An economically correct application of valuation techniques might for instance produce estimates of the Value of a Statistical Life that would be 20 times higher in Europe than in Bangladesh, which is ethically contentious.

There are a number of ways of addressing these potential problems. One is to apply distributional weights (equity weights). These allow the impact of a policy on an individual's well-being to be adjusted according to his or her income; the rationale being that an extra euro will give more benefit to a person who is deprived than to someone who is well off (or conversely the loss of a euro will have a greater effect on someone who has less). The use of equity weights increase the aggregate economic costs of climate change, as it gives greater emphasis to the (larger) impacts that occur in developing countries. However, there is no consensus on whether equity weighting should be used for climate change, and which approach is best ([28]). The 'correct' approach may also change according to the policy perspective and application (see Watkiss *et al.*, 2006) ([29]) .

([27]) For example, the FUND model (Tol, 2006) uses a 2300 time horizon and the PAGE model (Hope, 2006) a 2200 time horizon. The effect of major impacts post 2100 can be significant in the overall results (e.g. see Hope, 2006).

([28]) In a pure utilitarian framework, equity weighting is based upon the diminishing marginal utility of consumption. A value of $\varepsilon = 1$ is commonly employed in the literature. Note that some commentators have highlighted that this is not consistent with the current rate of spending on foreign aid, nor consistent with action on other policies in the areas of agriculture, trade, etc (e.g. Pearce, 2003).

([29]) A number of additional issues are emerging. Firstly, that the equity weights in each time period depend upon the assumption about growth rates in different countries, and whether it is assumed that per capita incomes are converging. Under convergence, the impact of equity weights is significantly reduced in the future, compared to the unequal incomes of today. This can be addressed through dynamic (or time varying) equity weighting. Second, there are potential inter-relationships between discount rate and equity weighting, as the elasticity of marginal utility of consumption appears in both approaches.

3.1.6 *Uncertainty and irreversibility*

Climate change is uncertain. This is partly because our understanding of climate change and its impacts is incomplete, but it is also because climate change will take place in the future, driven by future emissions, and impact upon a future world. Future research and observations may reduce this uncertainty, although surprises may increase the uncertainty as well.

In looking at model and climate variation, one extremely important aspect of uncertainty is climate sensitivity, i.e., the warming expected with a doubling of carbon dioxide concentrations ([30]). This parameter links the greenhouse gas emission scenarios to temperature change, and is extremely important in the overall analysis, but is still uncertain. The latest IPPC WG1 report cites that climate sensitivity 'is likely to be in the range 2 to 4.5 °C with a best estimate of about 3 °C, and is very unlikely to be less than 1.5 °C (though values substantially higher than 4.5 °C cannot be excluded' (IPCC, 2007a). The assumed climate sensitivity, or the consideration of the range of uncertainty, can significantly alter results (indeed, some IAMs report that this parameter has more influence on the size of results than any other input parameter (Hope, 2006)).

Learning and irreversibility play a crucial role in how to deal with uncertainty. If an effect is irreversible (e.g. species extinction), we may want to prevent it regardless of how uncertain it is and regardless of what future research will show (according to the 'precautionary principle'). In contrast, events that may or may not occur in some distant future, but whose consequences can be alleviated once apparent, are unlikely to worry us as much. The concept of large-scale climatic events (Schellnhuber *et al.*, 2005; Lenton *et al.*, 2006), often expressed in the climate literature as major irreversible events or 'tipping points', is undoubtedly one of the major areas driving international concern over climate change. It is these concerns that have led many (e.g. Chichilnisky, 2000; Azar and Lindgren, 2003; Tóth 2000) to conclude that the preferred evaluation framework for a very long-term problem such as climate change, with a large inertia in the biogeophysical system (such that mistakes cannot be swiftly corrected), and the possibility of extreme and irreversible changes in the climate system, might not be cost-benefit analysis, but cost-effectiveness analysis with respect to a given climate target (or a 'tolerable climate window').

Some of the uncertainty aspects can be incorporated in economic analysis through risk aversion. This determines how much weight we place on negative surprises. A risk-neutral decision-maker would cancel negative surprises against positive ones, but a risk-averse decision-maker would not. Including risk aversion does increase the economic costs of climate change.

A relevant issue is that when risk or uncertainty analysis has been undertaken for climate change valuation, the resulting distribution is strongly right skewed (see Tol 2005, Downing *et al.*, 2006), i.e. the mean is much higher than the median (because pleasant surprises are less likely than unpleasant surprises). This latter point is important as the cited values of the costs of inaction can vary according to the metric used to express the central tendency (mean or median).

One final issue that is usually considered alongside these other wider issues is substitutability. It is important to understand that aggregate estimates of economic costs have trade-offs implicit in the numbers, i.e. between different regions, or between different positive and negative effects. The use of a single aggregated value implies an assumption about substitution between categories of impact. The existing models assume full substitutability, i.e. between very different impact categories (so called weak sustainability). This means that the aggregated economic cost is the net of the losses from, for example, damages to natural ecosystems, against the pluses, for example, from reduced energy for heating. It is clear that different stakeholders will have different views on whether such substitution is acceptable. As a minimum, it seems sensible that future work should show the balance of positive and negative effects, by region, (rather than single global values), to help examine these issues.

3.1.7 *Coverage/completeness*

Climate change is comprised of numerous types of climatic parameters, which in turn affect many sectors (market and non-market) in different ways. This leads to the issue of coverage (or completeness). It is clear that different estimates of the costs of climate change are based on different types of climate effects, and include different impacts across varying sectors.

([30]) The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is not a projection but is defined as the global average surface warming following a doubling of carbon dioxide concentrations (IPCC, 2007).

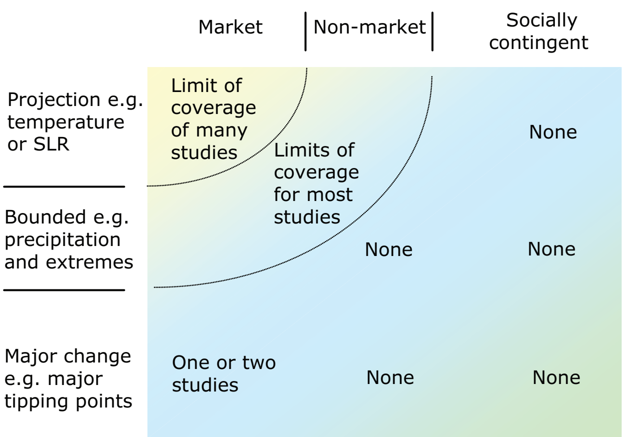
In order to look at the consistency of estimates, it is necessary to assess the coverage of the study.

Recent work (Downing and Watkiss, 2003; advanced in Downing *et al.*, 2005; Watkiss *et al.*, 2006) has framed this issue of coverage in a risk matrix, see Figure 3.2 below, based on:

1) the different types of climate change impacts and their uncertainty, covering:
   - impacts that can be predicted with relative confidence (e.g. average temperature);
   - impacts where prediction is more uncertain, and where models often give different results (even a different sign) as with for example regional estimates of levels of precipitation, or frequency or magnitude of extreme events;
   - impacts where prediction is highly uncertain, notably around the major 'tipping points' commonly identified (major climate discontinuities).

2) the uncertainty in valuation, covering:
   - market effects (e.g. estimates captured through markets such as energy and agriculture);
   - non-market effects (e.g. estimates for health and ecosystems);
   - a sub-category of non-market effects (termed socially contingent effects) defined as large scale dynamics related to human values and equity that are very poorly represented in cost values, e.g. from regional conflict, famine, poverty.

Figure 3.2 The coverage of marginal economic costs of climate change against the risk matrix



Source: Adapted from Watkiss *et al.*, 2006.

Mapping the literature estimates onto this matrix shows a large difference in coverage between studies — and also reveals that most studies focus on the top left area reflecting market damages from predictable events. A few studies do assess non-market damages, and only a few (scoping studies) have considered major catastrophic events.

All current estimates of the costs of inaction are incomplete, as they do not cover all effects of climate change, across all impact categories, though we do not know by how much (because the probability and consequences of many of the boxes in the matrix are unknown). While the missing categories are likely to include both positive and negative effects, there is a general view that the missing effects are likely to have net damages, which could be potentially very large. A clear research priority is to investigate the missing elements of the risk matrix — to fill the evidence gaps.

3.1.8 Adaptation

Adaptation is an important part of the costs of inaction. It is included in many of the baseline assessments of the costs of inaction, e.g. in IAM output (even with scenarios without mitigation), and has a strong effect in reducing these costs (e.g. Hope, 2006).

However, adaptation is difficult to capture adequately in impact assessment. The degree to which adaptation is included — and the types of adaptation included — therefore affect estimates. Many impact studies only take autonomous adaptation into account (Warren *et al.*, 2006): i.e. adaptations that occur without explicit policy interventions by governments. But governments are already embarking on adaptation policies, and are starting such policies well before critical climate change occurs.

Clearly, different adaptation goals lead to different adaptation costs and to different residual impacts. Various approaches are used to model adaptation (e.g. spatial analogues, micro-economic optimisation), but they all tend to either underestimate or overestimate its effectiveness and costs (Tol, 2005).

Given the range of types of adaptation (as in the definitions earlier) and the complexity across different types of adaptation to different climate parameters in varying sectors, it is not surprising that adaptation is not always handled consistently across studies ([31]). As discussed earlier, it is often not possible to distinguish neatly between impacts of and adaptation to climate change.

While the issues of forecasting the benefits of adaptation policy (i.e. in reducing the costs of inaction) are bound up with the discussion above, there is also an additional issue around the consideration of adaptation and the costs of adaptation. This is considered in more detail below.

3.2 The costs of adaptation

This section outlines the economic issues for adaptation, in relation to the aggregate costs of inaction (above), but also in relation to the costs of adaptation. Many of the factors above for the costs of inaction are also relevant to adaptation — though differences also occur. For example:

- Scenarios. The scenario chosen will also have a strong influence on adaptation (through changing vulnerability, levels of impacts and adaptive capacity). There are also strong links between adaptation and socioeconomic trends, as the capacity to adapt increases with development, so that degree and type of adaptation (e.g. planned versus autonomous, public versus private) will depend on the kind of socioeconomic scenario assumed. The types of analysis needed to combine climate, socio-economics and adaptation are included in Box 3.2.
- Valuation approach and indirect effects. As with the costs of inaction, adaptation has the potential to lead to direct and indirect costs, and these could be potentially important
- Temporal variation (discounting). The present value of adaptation is dependent on the discount rate. However, in the case of adaptation, the role of discounting is usually less controversial, as the costs and benefits of adaptation measures are usually less far apart in time.
- Geographical variation (equity). Similarly, the costs and benefits of adaptation tend to occur in the same region. There is therefore not a need to compare between developed and developing regions. Note, however, that there are still distributional effects for adaptation (discussed later).
- Uncertainty and irreversibility/coverage. The same areas of uncertainty that affect the costs of inaction affect adaptation. In theory, adaptation measures need to be considered across all climate parameters across all sectors and across the entire risk matrix (for predictable and extreme events for example). To date, analysis has been limited to a few sectors, for the most predictable climate outputs.

However, there are a number of additional methodological issues for adaptation that are discussed below.

3.2.1 Types of adaptation

All natural and social systems are, to some degree, adapted to the climates they experience. Climate change imposes new pressures on those systems. In natural ecosystems these pressures will be experienced as new selection pressures, affecting the relative chances of species' survival. In social systems, these pressures will also be experienced as selection pressures, but in addition there is scope for innovation and change as people and organizations adjust to the new climatic conditions (Berkhout, 2006).

Individuals, households and businesses will make many of these adjustments privately, and they are likely to yield principally private benefits. However, because of the public good character of some types of adaptation, these types of adaptation will be underprovided in private markets. From an economic perspective, this is the primary reason for governments to provide adaptation services.

As in the definitions section earlier, we differentiate autonomous and planned adaptation ([32]), but highlight that both are relevant. Note the planned public adaptation services include changes in major infrastructures, as well as changes in standards and regulations that will give private actors the freedom and incentives to adapt (facilitating adaptation or enhancing adaptive capacity).

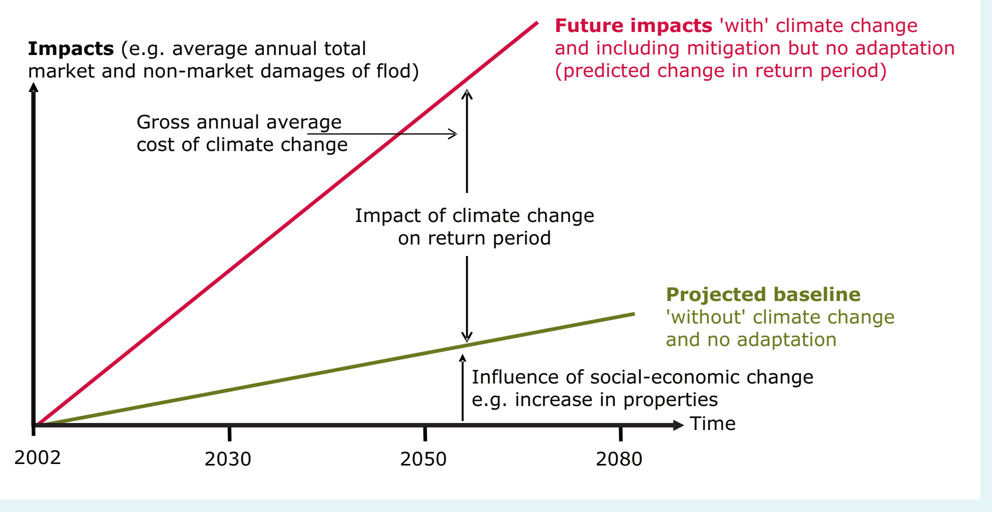
([31]) For example with agriculture, in some studies the (implicit) goal of adaptation is to maintain current cropping patterns, others want to maintain current farmers' incomes, or adjust existing practices in the most efficient manner.
([32]) The distinction between planned and autonomous adaptation can be blurred. Firstly, autonomous and planned adaptation often coexist. Secondly, adaptive behaviours characterising social economic systems are often put in place by rational or informed economic agents who follow specific strategies. But unless these strategies are the outcome of a plan by a public agency or administration, these are considered autonomous.

Box 3.2 Consideration of an economic framework for project adaptation

For adaptation, it is important to be clear about the different elements that are needed for a full economic analysis. The figures below highlight the ideal approach for looking at the costs and benefits of adaptation. They show that the analysis is a two-stage approach — first identifying the impact of the socio-economic signal (and differentiating it from the climate signal) and then looking at the net reduction that adaptation can achieve, vs. the residual climate impacts.

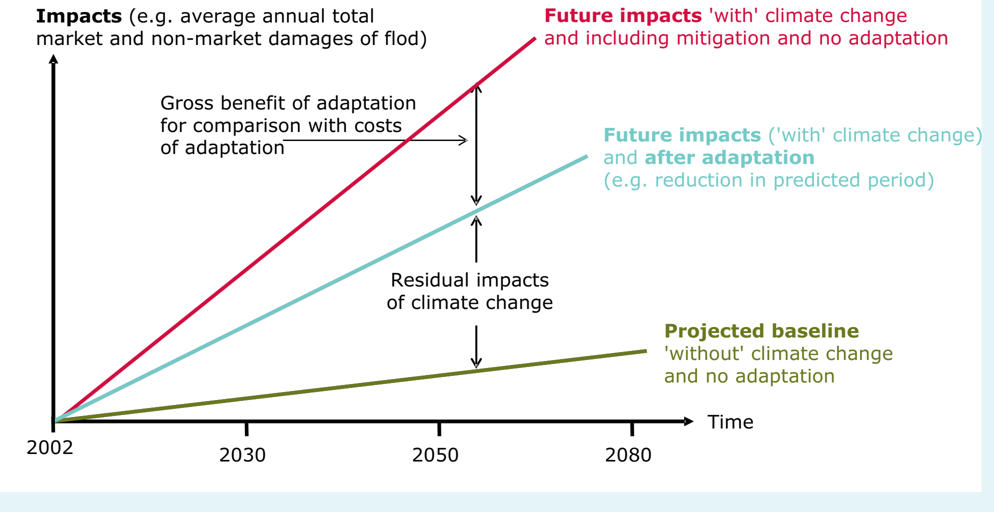
The analysis of the contribution of the climate signal and socio-economic signal is first needed (without adaptation), illustrated below in relation to a change in return period and the impacts of flood: the changing socio-economic background over time (shown in green) is combined with the climate signal to give the overall future impacts (in red).

Adjusting for socio-economic change and estimating total costs of inaction



Adaptation reduces the total impacts, shown as the reduction to the pink line below, but it does not completely remove all impacts. The gross benefits of adaptation are the impacts avoided, but there will still be residual impacts of climate change (the cost of climate change impacts, after adaptation).

Costs and benefits of adaptation



Source: Boyd R. and Hunt A. (2006) Climate Change Cost Assessments Using the UKCIP Costing Methodology. Report for Stern Review.

Without adaptation, the costs of climate change would be considerably higher. However, adaptation entails costs ([33]).

It is increasingly clear that an understanding is needed of adaptation processes, together with a reliable quantification of their costs and benefits. Disregarding the capacity of natural and of socio-economic systems to adapt can lead to a serious overestimation of mitigation costs and residual damages, whereas overly optimistic assumptions on adaptation costs can bias downward the total cost of climate change. Moreover, the assessment of costs and benefits of adaptation is relevant from a policy perspective. In a world of scarcity, resources need to be allocated efficiently between different adaptation strategies and between adaptation and mitigation strategies. This can be done only if costs and benefits of the different options are clearly determined.

What is apparent, however, is that the research on adaptation methodologies available for the quantification of their benefits, and particularly of costs, is currently very limited. Some of the emerging issues in providing these cost estimates are outlined below.

There are different types of costs, associated with different adaptation actions. These include:

- direct costs of implementing a specific adaptation measure;
- general costs of enhancing the broad adaptive capacity of an impacted system (the cost of facilitative adaptation); and
- transition costs, associated with the adjustment process triggered by adaptive responses.

Public (planned) adaptation may be in the form of investments in major infrastructures (such as strengthening sea defences), as well as in changes in standards and regulations that will give private actors the freedom and incentives to adapt. While the opportunity costs of the first type of investment is recordable and relatively easy to assess in advance, the opportunity costs of the second type of 'investment' (in regulatory change) is difficult to estimate.

Transition costs ([34]) are particularly relevant for the assessment of the costs of both planned and autonomous adaptation processes (note autonomous adaptation does entail costs): they are also the most difficult to assess (and are often omitted from modelling analysis).

3.2.2 *Level and timing of adaptation*

Adaptation to climate change is very much dependent upon the way in which impacts appear, whether as gradual changes or by catastrophic events. Adaptation strategies can also be very diverse — specific to given time and location. While adaptation to gradual changes is relatively easy to undertake, and may not cost much, adaptation to low-probability catastrophic events may be very costly and anticipatory adaptation may even be impossible.

The level of adaptation (how much to adapt), be it private or public, anticipatory or reactive, basically depends on an evaluation of the (expected) costs and benefits of adaptation by the relevant decision-maker. Of course, this evaluation does not have to be in the form of a formal cost-benefit analysis, but some evaluation of gains and losses may be assumed.

Decision-making in governments is more likely to make use of formal decision support tools such as cost-benefit analysis and cost-effectiveness analysis, but here the analysis will often be confounded by large uncertainties, complexities and unknowns of various (market and non-market) costs and benefits. Moreover, efficient adaptation is often hindered by social, legal or political barriers.

Some forms of facilitation adaptation, enhancing the adaptive capacity of a sector, region or country, are often considered to be (almost) no-regret measures because they would in many cases make societies less vulnerable to many different pressures, including present climate variability. The fact that those no-regret measures have not been taken yet, indicate the presence of barriers of some sort.

Apart from the level of adaptation, the timing of adaptation is of crucial importance from an economic point of view. Fankhauser (2006) examines the timing of adaptation analytically. He distinguishes three components in the decision to

([33]) All economic actions that deal with the allocation of scarce resources have opportunity costs in the sense that if one allocates resources to one activity, these resources cannot be allocated to another (the next best) activity, and potential benefits from that activity are missed.

([34]) An example of transition costs is that farmers have to allocate time resources to learn new management techniques or that they have to be trained for new, off-farm employment.

adapt early or to wait: 1) the costs of adaptation always favour waiting; 2) short-term benefits of adaptation may justify early action if action has immediate benefits (e.g. with respect to current climate variability) or strong ancillary benefits (e.g. health, resilience of natural ecosystems); and 3) longer-term effects of early adaptation may justify early adaptation if it locks in lasting benefits for example by preventing long-term damage to ecosystems.

Further to this there are differences at the temporal or spatial scale. The temporal scope defines long-term and short-term adaptation, which can relate to instantaneous versus cumulative, or short-term vs. strategic approaches. The spatial scale can be localised or widespread, even though it is often noted that adaptation has an intrinsic local nature (Fussel and Klein, 2006).

The feasibility and costs of adaptation will be influenced by the rate of climate change, especially for major adjustments in physical infrastructures or land use. Adaptations in response to rapid changes in climate or changes in variance are difficult to predict (Callaway, 2004), but are likely to be costly. Nicholls (2004) notes in this respect that an important argument for early mitigation of greenhouse gas emissions is that it would 'buy time' for adaptation to sea level rise, allowing adjustments to tap into natural investment cycles and thereby reducing their costs.

The feasibility and costs of adaptation will also be influenced by technical, socio-economic and political change over time. The adaptation literature has suggested a positive correlation between economic development and adaptive capacity (cf. Yohe and Tol, 2002).

Finally, the timing of adaptation measures needs special attention if the adaptation measure itself influences climate change in a negative or positive way. If an adaptation measure reduces both climate change (e.g. lower greenhouse gas emissions from new practices in agriculture) and the vulnerability to climate change damages, both aspects need to be considered in the climate cost equation.

A distinction can also be made between anticipatory vs. reactive adaptation, i.e. adaptation that occurs before or after the impacts of climate change are observed.

There can be circumstances when an anticipatory intervention is less costly and more effective than a reactive action (a typical example is that of flood protection), and this is particularly relevant for planned adaptation ([35]). There is also an increasing view that in order to prevent major damages, a purely reactive strategy will not be sufficient (especially for larger and more complex adaptation measures need to be planned in advance). However, this view needs to be thoroughly tested for EU country contexts across all sectors to provide an indication of the most appropriate time scales for adaptation, particularly in order to ensure cost-effective adaptation and avoid mal-adaptation. There are some studies that show that reactive responses are not always cost-effective or adequate.

3.2.3 The ancillary benefits of adaptation

Adaptation to climate change often has benefits beyond a reduction of residual damages of climate change. One important benefit of many adaptation measures is that it also reduces vulnerability with respect to current climate variability (see Fankhauser, 2006), i.e. the reduction of damages due to current climate variability is an ancillary benefit of adaptation to climate change.

There may be more ancillary benefits of adaptation measures. As was noted above, facilitating adaptation is often intimately connected to overall macroeconomic or development goals, making economies less vulnerable to both climatic as well as a range of other economic and natural pressures. In some cases, adaptation policies are explicitly targeted to provide ancillary benefits in the areas of nature and landscape protection, recreation, and a host of other policy areas (see case study from the Netherlands in the next section).

3.2.4 The distribution of costs and benefits of adaptation

The costs and benefits of adaptation are likely to be unevenly distributed among sectors, socio-economic groups and countries. Whereas mitigation (greenhouse gas emissions reduction) serves a global public good, adaptation can both be private and public and the scope of its benefits will seldom exceed the national level. Given that adaptive capacity is positively correlated with economic development, it follows that access to efficient adaptation is greater for high-income groups and

([35]) Reactive adaptation is a major characteristic of unmanaged natural systems and of autonomous adaptation reactions of social economic systems.

Table 3.1 A classification of the most recent studies (post year 2000) based on key methodological issues

Post-2000 Selected studies	Dynamic scenario	Valuation approach		Estimation approach		Adaptation costs			Temporal aggregation		Spatial aggregation		Uncertainty and risk		Completeness	
		WTP/ WTA	Benefit transfer	Direct impacts	Indirect impacts	Dis-entangled from residual impacts	Lumped together with residual damage	Trade-off with mitigation	Constant discount rate	Declining Discount rate	With equity weighting	Without	Sensitivity analysis	Statistical uncertainty	Source of impact	Impacted sector
Bosello *et al.*, 2004a,b			X	X	X		X					X	X		Sea-level rise/extreme events/ temperature increase	Tourism/ health
Bosello, 2005	X			X	X	X	X	X				X	X		Temperature increase	
Darwin and Tol, 2001			X	X	X	X	X		X			X	X		Sea-level rise	Land and capital lost
Li *et al.*, 2004		X											X			
Newell and Pizer, 2004							X		X	X		X	X	X	CO_2 emissions scenarios	
Nordhaus and Boyer, 2000	X			X	X		X			X		X	X		Temperature increase	
Rive *et al.*, 2005			X	X	X		X					X			Change in temperature and precipitation	Forestry
Stern *et al.*, 2006	X		X	X			X		X			X				
Tol, 2005							X		X	X	X	X		X		
Tol and Dowlatabadi, 2001	X		X	X	X	X		X				X	X		Temperature increase	Health (vector-born diseases)

Source: Kuik *et al.*, 2006.

richer countries, and less for the poor. This poses a potential problem of equity and distribution, and raises the issue of whether planned adaptation should specifically try and target such groups, or apply distributional analysis to ensure equitable adaptation strategies.

3.2.5 Classification of methodological issues in the literature

A classification of whether the recent literature covers the above issues is shown in Table 3.1. This shows that while progress is being made, the coverage remains partial.

3.3 Conclusions

The definition of inaction to climate change is in itself a complex concept, and is dealt with differently by the different studies. The evidence provided shows how our understanding of the costs of inaction is still incomplete and permeated by uncertainty, and also how different assumptions and choices in the methodology for cost assessment lead to a very wide range of estimates of costs of inaction to climate change, notably in the areas of:

- scenarios;
- valuation and direct/indirect effects;
- spatial and temporal variation;
- uncertainty and irreversibility;
- coverage.

Similarly, these issues are also relevant when considering adaptation. However, an additional set of methodological issues arise when assessing the costs of adaptation. These include:

- defining the type of adaptation and the types of costs;
- the level and timing of adaptation;
- ancillary benefits of adaptation;
- distributional aspects of adaptation.

4 Review of the evidence on the costs of inaction and costs of adaptation

4.1 Review literature

There is a wide and increasing literature on the impacts of climate change, and on adaptation. However, the literature on the costs of inaction remains limited, and there is an even larger evidence gap on the costs of adaptation.

This section provides a review of the literature in the field. A number of different lines of evidence have been investigated including:

- academic research literature;
- research studies (Member State and European research);
- policy studies;
- insurance studies.

These are discussed in turn below. The section then goes on to provide some analysis of the economic costs and relevant issues by sector. Finally, it sets out the key research challenges and summarises the findings.

4.1.1 Research literature

While there are a large number of sectoral studies (especially on impacts), there are very few studies that have considered the costs of inaction, especially in relation to total or marginal cost estimates. This is in large part due to the complexity of such studies, and the need to use detailed integrated assessment models linking emissions — climate — impacts — economic costs — and adaptation.

The recent IPCC Fourth Assessment (WG II summary for policy makers, IPCC, 2007b) has collated recent studies.

There are a number of studies on the economics of climate change in the literature. These studies have typically considered total economic costs (of climate change impacts) and marginal economic costs. It is highlighted that the comparison of these studies is extremely difficult — because of the issues raised in the methodological chapter — and there are particular issues of coverage. A recent comparison for this report (by Tol, updated from Tol, 2005), reviewed the literature on the marginal economic (social) cost estimates of climate change and found only around 30 studies. They reveal a wide range of estimates, not least because of the decision parameter used ([36]).

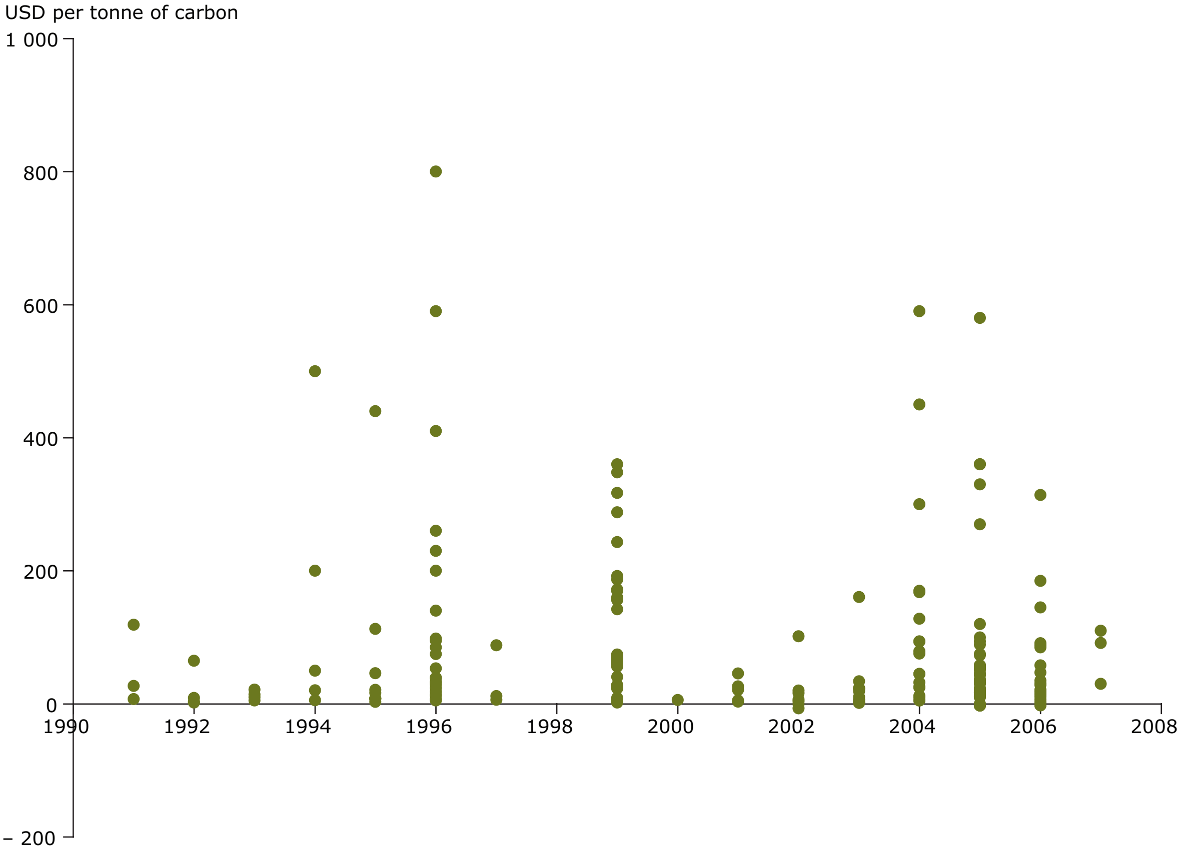
The numerical results remain speculative, but they can provide insights on signs, orders of magnitude, and patterns of vulnerability. Results are difficult to compare because different studies assume different climate scenarios, make different assumptions about adaptation, use different regional disaggregation and include different impacts (as well as the choice of parameters and approach for discount rate and equity weighting).

The trend in the estimates is shown in the figure and has indicated lower values over time. This is because of the TAR climate scenarios, consideration of explicit socio-economic reference scenarios (generally of wealthier futures), inclusion of benefits as well as impacts, and notably due to autonomous adaptation. It should be noted that such trends may change in future analysis. A number of emerging findings are that climate sensitivity and likelihood of severe impacts increases at lower temperature thresholds may be higher than previously expected (see IPCC, 2007a, b).

The key studies in the past few years (post 2003) are highlighted below. These centre on the four main

([36]) The earlier Tol (2005) review shows that If all studies are combined, the mode is USD 2/tC, the median USD 14/tC, the mean USD 93/tC, and the 95 percentile USD 350/tC. Using the weights favoured by authors, the mean is USD 129/tC. Studies with a lower discount rate have higher estimates and much greater range. Similarly, studies that use equity weighting have higher estimates and a larger range. Peer reviewed studies have lower values. Tol's conclusion in the 2005 paper is that 'the marginal damage costs of carbon dioxide emissions are unlikely to exceed USD 50/tC, and are probably much smaller'. Note, however, that recent reviews (e.g. Stern, 2006) have used the existing models (e.g. PAGE) and derived much high estimates, e.g. USD 312/tC, mostly due to the choice of input parameters over climate sensitivity and discount rate (PRTP).

Figure 4.1 Estimates of the marginal costs of inaction



Note: One 1992 study, and a number of points from a 2005 study are excluded, as these have values above the scale used here.

Source: Updated from Tol, 2005.

IAMS (FUND; PAGE; RICE/DICE; MERGE), as well as more recent IAM-energy models (WIAGEM). For a review of the main IAMs and an inter-comparison, see Warren *et al.*, 2006 ([37]). While these models do include (some) adaptation, the coverage is partial: most assume autonomous adaptation in the agricultural sectors, and some have adaptation factored in to combat sea level rise. The consideration of adaptation is mostly in relation to the benefits in reducing impacts: there are some estimates of adaptation costs (in some sectors, for some models) but they are not always included in the net outputs from the models.

The current generation of aggregate estimates may understate the true cost of climate change because they tend to fully capture extreme weather events, to underestimate the compounding effect of multiple stresses, and to ignore the costs of transition and learning. However, these studies may also have overlooked positive impacts of climate change and not adequately accounted for the way development could reduce impacts of climate change (Tol, 2005b). Our current understanding of (future) adaptive capacity, particularly in developing countries, is still too limited to allow firm conclusions about the direction of the estimation (bias).

The need for synthesis and aggregation in the assessment of the costs of climate change poses challenges with respect to the spatial and temporal comparison of impacts. Aggregating impacts requires an understanding of (or assumptions about) the relative importance of impacts in different sectors, in different regions and at different times. There is a need to move from a static analysis to a dynamic representation of impacts as a function of shifting climate characteristics, adaptation measures and exogenous trends like economic and population growth. There is growing recognition that the climate

([37]) The review found that all the models are based on literature from 2000 and earlier. Since this time, some predictions of climate impacts have become more pessimistic.

Table 4. 1 Key recent studies in the academic literature on costs of inaction

Study	Description
Tol, (e.g. 2006, 2005, 2004, 2004, 2003, 2002, 2001)	Analysis of total and marginal social costs of climate change (costs of inaction) including adaptation using the FUND integrated assessment model. This is a sectoral model looking at impacts in specific sectors using reduced form equations. FUND also has a monte carlo module to allow analysis of uncertainty.
Hope/Plambeck and Hope (e.g. 2006, 2004, 2001, 1996, 1993)	Analysis of total and marginal social costs of climate change (costs of inaction) including adaptation using the PAGE integrated assessment model. This is an aggregate model using relationships for economic costs in aggregate sectors (market and non-market), but doing so in a probabilistic approach through integrated monte carlo analysis. Includes some consideration of major (catastrophic) events.
Nordhaus/Nordhaus and Boyer (e.g. 2000, 1994, 1993, 1991) Note also development from Bosello *et al.*, 2006.	Analysis of total and marginal social costs of climate change (costs of inaction) including adaptation using the RICE/DICE integrated assessment model. This is an aggregate model using relationships for economic costs in aggregate sectors (market and non-market). Includes some consideration of major (catastrophic) events.
Mendhelsohn *et al.* (e.g. 2003, 1996)	Analysis of economic costs of climate change including adaptation using the MERGE integrated assessment model.
Kemfert *et al.* (e.g. 2006, 2002)	Analysis of costs of inaction and costs of action using the WIAGEM integrated assessment model.

impact dynamics, i.e. the conjunction of climate change, societal change, impact, and adaptation, is non linear, and might be quite complex.

4.1.2 European research projects

A large number of regional research programmes have been undertaken to develop and/or advance the knowledge on the climate related risks and strategies to manage them, in multiple sectors and at different scales.

A large body of knowledge and information has resulted from these efforts, especially on the potential impacts of projected climate change on different sectors, systems, communities and regions, and possible options to adapt to projected changes and their impacts, though in many cases the evidence on economic costs is still at an early stage.

In response to the growing need for improved knowledge, guidance and decision-making, research efforts have been gradually moving from science-driven, single sector/system-focused analysis towards a more policy-driven, multi-disciplinary integrated assessment. Part of this latter approach is to consider the economic issues — either within a framework towards cost-effectiveness, or explicitly to start looking at costs and benefits. The research activities are also increasingly adopting a strong stakeholder involvement component.

A selection of major projects that are relevant for the costs of inaction and costs of adaptation are presented in Table 4.2.

Although progress is being made, many aspects are not sufficiently studied. These include consistent and harmonised projections of impacts, economic costs and adaptation across sectors (accounting for climate and socio-economic scenarios), cross-sectoral interactions and linkages, full coverage of impacts and opportunities (including more difficult climate change in relation to extreme events and major events), and integration of different spatial scales (see also the research recommendations from the methodology chapter).

Overall, a robust methodological framework for evaluating the economic impacts and adaptation options is still to be developed and demonstrated.

4.1.3 Policy projects — progress of EEA member countries

The EEA report (2005) on vulnerability and adaptation collated information on existing and planned adaptation measures in EEA member countries. This information is not repeated here.

Instead, this review has looked at the additional action towards the economic costs of climate change, particularly with a focus on direct policy support for the costs of inaction and the cost of adaptation. This includes studies being undertaken to support the European Commission, and studies at EEA member country level. Of course this leads to a much shorter list — whilst almost all countries are making progress on consideration of impacts and adaptation, only the United Kingdom, Finland and the Netherlands are progressing the analysis

Table 4.2 Examples of recent European research projects which provide relevant support of climate change costs of inaction, and costs of adaptation

Project	Funding	Objectives	Participants	Policy relevance	Links
ADAM project (Adaptation and Mitigation)	EC (6th FP)	To lead to a better understanding of the trade-offs and conflicts that exist between adaptation and mitigation policies	26 research institutes across Europe	ADAM will support EU policy in post-Kyoto discussion and will inform emergence of new adaptation strategies for Europe	www.adamproject.eu
AMICA (Adaptation and Mitigation — an Integrated Climate Policy Approach)	INTERREG IIIC — project-part financed by the EU	To combine measures to promote climate change adaptation with preventive strategies to maintain and protect the global climate	Germany, Austria Italy, France, the Netherlands	Local and regional strategies to climate change (mix of short- and long-term preventive and reactive measures, to planning risks)	www.amica-climate.net
ASTRA (Developing Policies & Adaptation Strategies to Climate Change in the Baltic Sea Region)	INTERREG IIIB — project-part financed by the EU	To assess regional impacts of climate change and develop strategies and policies for adaptation	Finland, Germany Latvia, Estonia, Lithuania, Poland	Focus on Baltic Sea Region (BSR) and on stressors such as extreme temperatures, droughts, forest fires, storm surges, winter storms, floods	www.astra-project.org
cCASHh (Climate Change and Adaptation Strategies for Human Health)	EC (5th FP)	Identification of vulnerability; estimate the health benefits of combinations of adaptation strategies; estimate of costs of damages and adaptation measures	WHO (Europe); the United Kingdom, Sweden, Italy, Czech Republic, Germany, Netherlands	Information on health impacts and adaptation strategies from climate change in Europe	www.euro.who.int/ccashh
COMCOAST (Combined functions in Coastal defence zones)	INTERREG IIIB — project-part financed by the EU	To explore coastal defence strategies in the North Sea, plus new methods to evaluate flood defence zones; to develop new flood defence solutions	The Netherlands, Germany, the United Kingdom, Belgium, Denmark	Best practice multifunctional flood management solution	www.comcoast.org/
DINAS-COAST (Dynamic and Interactive Assessment of National, Regional and Global Vulnerability of Coastal Zones to Climate Change and Sea Level Rise)	EC (5th FP)	To develop a CD based tool to produce information on a range of coastal vulnerability indicators, for climatic/socio-economic scenarios and adaptation policies, on national, regional and global scales, for all coastal nations	Germany, the United Kingdom, the Netherlands	Practical use to policymakers and other stakeholders	www.dinascoast.net
ESPACE (European Spatial Planning: Adapting to climate Events)	INTERREG IIIB; North West Europe Prog.UK ODPM	To develop a dynamic approach to CC adaptation for spatial planning; to recommend approach at European, national, regional and local levels	The United Kingdom, Belgium, the Netherlands, Germany	Directly linked to inform policy decision for spatial planning adaptation	www.espace-project.org/index.htm
ExternE series (ExternE/MethodEx/GreenSense/NEEDS		To develop a consistent 'bottom-up' methodology to evaluate the external costs with range of activities	Over 50 research institutes across Europe	Estimates of costs of inaction and demonstration of implications for policy (external costs)	www.externe.info/
INTARESE (Integrated Assessment of Health Risks of environmental stressors in Europe)	EC (6th FP)	Developing and applying new, integrated approaches to the assessment of environmental health risks and consequences.	33 research institutes across Europe	Support of EU policy on environmental health for the assessment of the impacts, vulnerability, and the options to adapt to climate	www.intarese.org/
MICE: Modelling of the Impacts of Climate Extremes	EC	Identify and assess current and future changes in climate extremes and the impact of these changes	8 Research institutes across Europe	Provides information on the impacts of extremes	www.cru.uea.ac.uk/cru/projects/mice/index.html
PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects)	EC (6th FP)	To quantify confidence and uncertainties in predictions of future climate and impacts	25 research institutes across Europe	Will interpret these results in relation to European policies for adapting to or mitigating climate change	http://prudence.dmi.dk/
SEAREG (Sea Level Change Affecting The Spatial Development In Baltic Sea Region)	INTERREG IIIB — project-part financed by the EU	Assess impacts of future sea level rise in several case study areas in the BSR	Finland, Sweden, Germany	Information on impacts, plus the Decision Support approach is being developed to look at adaptation strategies	www.gtk.fi/projects/seareg/doc.html

towards economic dimensions. The main studies are summarised in Table 4.3.

The work by the EEA on impacts and adaptation has been set out earlier. At a European scale, the major policy based project is the PESETA project, co-ordinated by JRC in Seville. This is undertaking detailed bottom-up analysis of the economic costs of climate change in Europe for agriculture, energy, tourism, coasts, river flooding and health. This material was used in the recent EC Communication (2007) and also included in the Green Paper on adaptation (EC, 2007c).

Relevant research projects on impacts (some with consideration of economic costs) and programs have been carried out in member countries such as Finland, France, Germany, Hungary, the Netherlands, Norway, Portugal and the United Kingdom. Particularly relevant to impact and cost assessment are the research projects carried out in Finland by Finadapt, in the United Kingdom (several organisations), and in the Netherlands.

In Finland, impacts and adaptation assessment are being progressed through the FINESSIR project (which developed a computer-based evaluation framework for investigating the impacts of global change on various natural and managed systems in Finland making use of the global change scenarios developed in the FINSKEN project) and the FINADAPT consortium (which seeks to address both scientific and policy needs by conducting the first in-depth investigation of the adaptive capacity of the Finnish environment and society to the potential impacts of climate change). The Finnish adaptation plan is one of the most advanced in Europe, and the final report (Carter, 2007) is now available.

It outlines the current knowledge about climate variations; describes future changes in climate and other environmental and socio-economic factors projected for the 21st century; characterises adaptive capacity to cope with present-day climatic conditions; provides estimates of potential impacts under future climate change, including costs; lists potential measures/strategies for adapting to climate change, including costs; assesses the relative vulnerability of different systems, regions, sectors or communities to climate change, identifying priority areas for attention; and identifies the major gaps in knowledge and needs for new research. The wide-ranging strategy for adaptation to climate change recommends that long-term investments should already consider likely impacts of global warming, particularly in the construction, hydropower, transport infrastructure and forestry sectors. For agriculture and forestry in particular, the strategy suggests that in the short term economic benefits of climate change may outweigh disadvantages due to longer growing seasons and increasing plant productivity. However, it warns that negative impacts could grow more serious in the longer term.

In support of the national adaptation plan, the FINADAPT study aims to produce a systematic listing and ranking of estimated costs and benefits of climate change by sector in Finland, projected in a time frame of 2010–2100; a systematic qualitative overview of the risks and uncertainties attached to the estimations; an overall appraisal of the macro-economic impact of climate change and identification of major risk in Finland; an overview and clarification of the development needs of socio-economic evaluation tools for the assessment of climate change adaptation impacts and climate adaptation policy instruments.

In the United Kingdom, there are a number of initiatives on both impacts and adaptation. The UK Climate Impacts Programme (UKCIP) has been building the evidence and provides information on climate impacts and emerging adaptation options in the United Kingdom (to help UK organisations assess how they might be affected by climate change, to prepare for its impact). Various tools have been developed within UKCIP, such as the UKCIP adaptation wizard and the risk, uncertainty and decision making framework. UKCIP has also advanced economic analysis through a specific methodology for costing the impacts of climate change in the UK (Metroeconomica, 2004). This has 'step-by-step' guidelines for costing the impacts of climate change in the UK, and the costs/benefits of adaptation responses to these impacts. The study also applies the guidelines to case studies in the following sensitive sectors: coastal zones, water resources, buildings/infrastructure, agriculture and habitat, looking for example at irrigation restrictions, transport disruptions and flooding risks. This shows how cost-benefit thinking can be used to produce better decision-making on responses to climate change risks, as well as pointing out the contribution that other methods such as multi-criteria analysis and cost-effectiveness analysis can make.

The UK Government (Defra) has also been advancing the knowledge based on economic impacts, and looking at the application of the costs of inaction in policy appraisal (Downing *et al.*, 2005; Watkiss *et al.*, 2006; see also Box 2.2 on the UK social costs of carbon). This is important in explicitly

Table 4.3 Examples of policy projects in support of climate change costs of inaction, and costs of adaptation, in Europe

Project	Funding source(s)	Objectives	European countries	Policy relevance	Links to details
EEA climate change impacts EEA vulnerability and adaptation		Overview of key vulnerabilities to climate change in member states and current/potential impacts, ongoing adaptation activities	Europe	Indicators for climate change impacts in Europe and to identify priorities, opportunities, and barriers to adaptation in Europe	www.eea.europa.eu/
PESETA	EC/JRC IPTS Seville	Bottom up analysis of economic costs of climate change impacts in Europe for energy, agriculture, health, tourism, coasts and rivers, including adaptation	Europe	PESETA will provide estimates of the future impact of climate change in Europe, for informing climate change policy and adaptation strategies	http://peseta.jrc.es/index.htm
Assessing the Adaptive Capacity of the Finnish Environment and the Society under a Changing Climate	Finnish Environmental Cluster Research Programme	In-depth investigation of the adaptive capacity of the Finnish environment and society to the potential impacts of climate change	Finland	Analysis of estimated costs and benefits of adapting to climate change by sector in Finland, 2010–2100	www.ymparisto.fi/default.asp?contentid=165496&lan=EN
Stern Review on the Economics of Climate change	UK Treasury	Contribution to assessing the evidence and building understanding of the economics of climate change	The United Kingdom	Evidence on economic impacts of climate change and economics of stabilising GHGs. Policy challenges for transition to a low-carbon economy	www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change
Quantifying the Costs of Impacts and Adaptation. Research. Project E:	UK Defra CC Cross Regional Research	Estimates of costs of climate change in retailing and manufacturing; health; transport; agriculture; water resources and quality; built environment manufacturing; tourism and energy	The United Kingdom	Analysis of economic costs of summer of 2003. Analysis of future economic costs of inaction in UK, plus costs and benefits of adaptation	http://www2.defra.gov.uk/research/project_data/More.asp?I=GA01075&SCOPE=0&M=PSA&V=EP %3A030
Social Cost of Carbon Review 1) Downing *et al.*, 2005 2) Watkiss *et al.*, 2006	UK Defra	1) Provide a risk assessment of uncertainty in climate change impacts/valuation 2) To provide an assessment of the social cost of carbon in decision making	The United Kingdom	Estimates of costs of inaction, and recommends how values can be used in policy at different levels and applications (short and long-term action)	www.defra.gov.uk/environment/climatechange/carboncost/aeat-scc.htm
Costing the impacts of climate change in the UK: guidelines	UKCIP	Guidelines for costing climate change impacts, with case studies application to key vulnerable sectors	The United Kingdom	Provides guidance on how to undertake assessment of costs of inaction	www.ukcip.org.uk/
Climate for Space	Dutch government (Economic Affairs)	To face the challenges of living in a changing climate by providing sectors in spatial planning a sound scientific base in a participatory way	The Netherlands	Identifies and examines adaptation options	www.klimaatvoorruimte.nl
ARK (Adaptation, Space and Climate)	Dutch government, four ministries	To develop an adaptation agenda for the Netherlands	The Netherlands	Identifies and examines adaptation options, especially spatial planning	www.programmaark.nl
Living with Water	Dutch government (Economic Affairs)	To examine future options for water management. Collaboration between water management and spatial planning, science, economy and sociology.	The Netherlands	Amassing new knowledge and experience. The programme functions as a catalyst for innovations	www.levenmetwater.nl
IMAGE Integrated Model to Assess the Global Environment (IMAGE-2)	Netherlands Environmental Assessment Agency	Ecological-environmental framework to simulate consequences of global human activities. Interactions of society, biosphere and climate system to assess issues inc climate change	The Netherlands	To explore global impacts of climate change scenarios	www.mnp.nl/image/
Impacts des changements climatiques en Belgique	Marbaix and van Ypersele (ed), 2004 for Greenpeace	Assessment of changes in climate for Belgium and risk of inundation, plus risks in other sectors	Belgium	To assess risks at country scale	www.climate.be/impacts

directly translating consideration of these economic costs into cross-sectoral policy.

Other work includes detailed economic cost assessments (impacts and adaptation) for the United Kingdom based on bottom-up analysis (Metroeconomica, 2006) for retailing and manufacturing; health; transport; agriculture; water resources; water quality; built environment manufacturing; tourism and energy. The United Kingdom has also advanced the global level discussion on the economic costs of climate change through the Stern Review (Stern, 2006), which examines the evidence on the economic impacts of climate change and economics of stabilising GHGs. Investigates policy challenges for transition to a low-carbon economy.

The Netherlands Environmental Assessment Agency (MNP) has developed an Integrated Assessment Model, IMAGE, with the aim to explore the long-term dynamics of global environmental change, and in particular the dynamics related to climate change. The main objectives are to contribute to scientific understanding and support decision-making by quantifying the relative importance of major processes and interactions in the society-biosphere-climate system. IMAGE provides: dynamic and long-term perspectives on the consequences of global change, insights into the impacts of global change, and a quantitative basis for analysing the relative effectiveness of various policy options to address global change. The framework has a general equilibrium economy model, and population model, which feed the

Box 4.1 The Stern Review: The Economic of Climate Change

This review was announced by the UK Chancellor of the Exchequer in July 2005, and reported in Autumn 2006. The review set out to provide a report to the UK Prime Minister and Chancellor assessing the economics of moving to a low carbon economy, focusing on a medium to long term, plus the potential of different approaches to adaptation and lessons for the United Kingdom, in the context of climate change goals. The findings of the review are summarised below.

The review concluded that the scientific evidence is now overwhelming: climate change is a serious global threat and demands an urgent global response.

From a review of the evidence, the report concludes that the benefits of strong and early action far outweigh the costs of not acting. Climate change will affect the basic elements of life for people globally — including in relation to access to water, food production, health and environment, potentially affecting hundreds of millions of people.

The investment that takes place in the next two decades will have a profound effect on the climate in the second half of this century (and beyond). Without action, the risks of major disruption to economic and social activity are potentially on a scale with the great wars and the economic depression in the first half of the 20th century, and it will be difficult or impossible to reverse these changes.

While all countries will be affected, the most vulnerable — the poorest countries and people — will suffer earliest and most. Climate change could have very serious impacts on growth and development. Prompt and strong action is clearly warranted. Because climate change is a global problem, the response must be international; with shared vision of long-term goals and agreement on frameworks that will accelerate over the next decade, and build on mutually reinforcing approaches at national, regional and international level.

Adaptation to climate change is essential. It is no longer possible to prevent the climate change that will take place over the next two to three decades, but it is still possible to protect societies and economies from its impacts to some extent. Adaptation will cost tens of billions of dollars each year in developing countries alone, and will put pressure on already scarce resources. Adaptation efforts, particular in developing counties, should be accelerated.

The review has been the subject of significant debate, particularly over the estimates of global costs and benefits presented, and over the choice of input assumptions on issues such as discount rate (note that many of the methodological assumptions that are involved are discussed in the previous chapter).

information on economic and demographic developments into three linked subsystems: the Energy-Industry System (EIS), the Terrestrial Environment System (TES), which computes land-use changes, and the Atmospheric Ocean System (AOS). The objective of IMAGE-2 is to explore the long-term dynamics of global change as the result of interacting demographic, technological, economic, social, cultural and political factors.

Other countries are progressing impact studies (e.g. there are studies in Germany and Belgium, as well as others) but to date these have had less focus on the economic assessment.

The work in the leading countries provides insights into the major challenges and opportunities for making progress in the economics of climate change. The diversity in the state of application across EEA member countries can be explained by the fact that countries are at widely varying stages in impacts and adaptation policy, but also because of the differing policy perspectives across European countries (e.g. the degree to which economic appraisal is adopted). It is also possible that some countries may consider themselves to be more vulnerable to the effects of climate change and thus more inclined to early action.

Given the current status, it would be beneficial for countries to exchange information, share experience and learn lessons from each other.

4.1.4 *Insurance sector studies*

Previous EEA reports (2004: 2005) have highlighted the considerable losses resulting from extreme weather events over recent years. These do provide useful information on the potential impacts and economic costs of Europe's society to projected climate change.

Following the recent rise in natural-hazard related claims, partly attributable to climate change, international insurance companies have produced a growing number of studies in this area. This section examines these studies.

The studies look at data on historic events, and employ sophisticated tools to estimate future costs of climate change, though it is highlighted that

Table 4.4 A comparison of damage costs of extreme weather events published by the insurance sector

Project	Organisation	Findings/policy relevance	Links to details
A Changing Climate for Insurance (2004) Financial Risks of Climate Change (2005)	Association of British Insurers (ABI) by Climate Risk Management in cooperation with Metroeconomica	Assessed major property insurance markets and the major weather perils affecting these markets: US hurricane, Japanese typhoon, and European windstorm. Found 2004 was the costliest year for typhoon damage in the last 100 years. By 2080 estimated • 65 % increase in world-wide costs of major storms • 75 % increase in costs of insured damage in a severe hurricane season in the USA • 65 % increase in costs of insured damage in a severe hurricane season in Japan • 5 % increase in wind-related insured losses from extreme European storms	www.abi.org.uk
Sigma study on natural catastrophes and man-made disasters. Opportunities and risks of climate change	Swiss Re Group	Found that in 2004: • 123bn USD total economic losses due to natural catastrophes and man-made disasters • 120bn USD economic losses due to natural hazards • 49bn USD insured losses	www.swissre.com
Annual Review: Natural Catastrophes 2004	Munich Re Group	Found that 2004 • Was most expensive natural catastrophe year in insurance history to date. • 145bn USD economic losses due to natural hazards • 95bn USD economic losses due to wind storms • 44bn USD insured losses	www.munichre.com
Climate Change and Insurance: An Agenda for Action in the United States	Allianz Group and WWF Allianz Group and WWF	Predicts climate change has the potential to significantly alter and intensify destructive weather patterns (US) with increased flooding, forest fires, and storm damage. These changes could make insurance unaffordable for customers in high-risk areas	www.allianz.com

the reports by the insurance sector reflect their individual perspectives and interests.

The results from a number of studies are summarised below. Since these studies were collated, the initial estimates for 2005 have been compiled, and also show high costs (in part due to hurricane Katrina, which alone accounted for a loss of USD 45 billion). Note whilst most losses relate to infrastructure, there is the potential for crop damage, losses to the tourism sector, or human health effects to also contribute to the totals.

4.2 Sectoral perspectives

This section summarises the information from literature, and puts a specific focus on the potential adverse economic impacts of projected climate change and sea level rise within the natural and socio-economic context of Europe. Regional variations in impacts are highlighted with a view to identifying priority areas (for measuring and monitoring of impacts, and where adaptation actions are most needed).

Consistent with previous EEA analysis (2005) the categorisation is split into discussion of 1) Europe's natural environment and associated services, and 2) other socio-economic sectors. The section also includes a summary and conclusion on regional variations across Europe and priority areas. Much of the literature on impacts in Europe has been summarised in the recent IPCC working group II (Alcamo *et al.*, 2007), so the sections below focus more on economic aspects. In addition, three case studies have been conducted on the costs of adaptation as examples to present in-depth information on the practical lessons:

- Room for the river. Case study on the costs of adaptation in the Netherlands;
- Sea level rise: the case of the Fondi plain. Case study on the costs of adaptation in Italy; and
- Agriculture and climate change. Case study on the costs of adaptation in Slovakia.

4.3 Nature and biodiversity

4.3.1 Natural environment and associated services

The functioning and ecosystem service provision from many natural and semi-natural ecosystems in Europe are known to be under threat from climate change and other pressures (Millennium Assessment, 2005). Such services include food and water supply, climate regulation, and species preservation. Ecosystem impacts from climate change across Europe have been studied by several projects already, including the concerted action ACACIA and the larger Integrated Project ATEAM (Schröter *et al.*, 2005)). There are some emerging estimates of potential ecosystems loss in Europe for coastal and terrestrial habitats, and there is compelling evidence that the extent and rate of climate change observed has affected species and ecosystems already (see EEA, 2004: EEA, 2005). The most recent report of the IPCC (Alcamo *et al.*, 2007) has pointed out that many areas are facing either increased flood risks (mainly in coastal wetlands) or drought (e.g., in the Mediterranean basin and Eastern Europe). Particularly sensitive areas include the Arctic region of Europe, mountain regions, and various coastal zones across Europe, especially in the Baltic and parts of the Mediterranean. These systems also have low adaptive capacity.

Studies of these risks, however, are scattered and do not yet consider a common methodological framework, nor a common scenario baseline, and very little of it considers valuation. There is some work that tries to assess valuation of ecosystem loss, reflecting ecosystem productivity and services, but also the wider use of ecosystems, increasingly using the Millennium Ecosystem Assessment framework. There is also a growing body of studies on ecosystem and biodiversity more generally, including greater numbers of primary valuation studies (e.g. Eftec, 2002), work studying where biodiversity loss has led to the loss/degradation of ecosystem services and consequently to economic costs (Kettunen and Brink, 2006). Nonetheless, while valuation knowledge is improving, it has far to go to cover the full range of ecosystem productivity and services, and the economic benefit to users and non-users. Overall, there remains a lack of quantitative data, and a major gap on quantitative economic analysis for ecosystem loss across Europe ([38]). Even in other areas where the scientific evidence on ecosystem damage is well studied and quantitative source receptor relationships identified (e.g. for air pollution and ecosystems), it has not been possible to quantify economic benefits for policy impact assessment (see the impact assessment of the EC Thematic Strategy on Air Pollution).
The economic costs and benefits of biodiversity in particular are highlighted as a research priority.

([38]) There have been recent ecosystem valuation reviews by the EEA and EC: though not in the context of climate change.

Similar issues exist for capturing the full economic effects of other natural systems and services, though some valuation is possible where market goods exist, e.g. for forests and fisheries.

4.3.2 *Forests and fisheries*

In a large part of Europe, forestry represents an important economic sector and there is potential for carbon sequestration ([39]). However, climate change will also affect forestry. Model simulations suggest that, temperature rise may lead to an increase in tree mortality in southern and central Europe, where forests are at the edge of their bio-geographical distribution (EEA, 2005). Limited moisture resulting from increasing temperature and possible reduced summer rainfall may lead to productivity declines in central and southern Europe, and summer temperature rise and reduction of precipitation may further increase fire risk (Lasch *et al.*, 2002). Such effects were evident in the summer 2003 heat-wave in France, which increased the costs of fighting forest fires(for the Ministry of the Interior) to 179 million euros, against 83 million euros in a normal year (Gillet, 2006). In contrast, under a warmer climate, it is expected that the northern range limits of most native tree species in Europe will expand (EEA, 2005). Recent work indicates potential benefits for Northern Europe, for example the FINADAPT project estimated that nationwide, total growth is estimated to increase by 44 % in Finland by 2100 (Carter *et al.*, 2007). The economic effects — positive and negative — of timber production can be captured using market prices. However, forests play a much greater role than timber alone, particularly in some EEA member countries, and there is a need to progress towards the total economic value of forestry including recreational uses for user and non-user values.

Studies of fisheries suggest a northward shift in the geographic distribution of some species, but also local extinction at the southern edge of the current range (for species such as salmon and cod). There is some work on the impacts and economic costs of climate change and fisheries, e.g. Link and Tol (2006) found a substantial weakening of the THC leads to impaired cod stock development, causing the associated fishery to become unprofitable in the long run. However, there are wider factors involved, including food chain effects, diseases, and for marine ecosystems, increased ocean acidity and the levels of catch (and sustainability) of commercial fisheries. Resource overexploitation is likely to be a more direct factor affecting fisheries, though this could increase the vulnerability of fisheries to projected climate changes.

4.3.3 *Coastal*

Coastal zones in Europe contain large human populations and significant socio-economic activities. They also support diverse ecosystems that provide important habitats and sources of food. One-third of the European Union population is estimated to live within 50 km of the coast, and some 140 000 km^2 of land is currently within 1 m of sea level. Significantly inhabited coastal areas in countries such as the Netherlands, England, Denmark, Germany and Italy are already below normal high-tide levels, and more extensive areas are prone to flooding from storm surges. Climate change is an additional pressure and is likely to have significant impacts on coastal zones, particularly via sea-level rise and changes in the frequency and/or intensity of extreme weather events, such as storms and associated surges. The most threatened coastal environments within Europe are deltas, low-lying coastal plains, islands and barrier islands, beaches, coastal wetlands, and estuaries. Direct impacts from sea-level rise include inundation and displacement of wetlands, lowlands, coastal erosion, increased storm flooding and damage, increased salinity in estuaries and coastal aquifers, and rising coastal water tables and impeded drainage. Potential indirect impacts include changes in the distribution of bottom sediments, changes in the functions of coastal ecosystems and impacts on human activities.

There are emerging estimates of the physical impacts and economic costs to coasts in Europe from sea level rise and flooding from storm events. Results using the DIVA database and model produced from the DINAS-COASTS DG research project ((DINAS-COAST Consortium, 2006; Hinkel and Klein, 2007; Nicholls *et al.*, 2007a; Vafeidis *et al.*, 2004; 2007) have been developed for Europe in the PESETA project (Richards and Nicholls, 2007). They show impacts increasing dramatically without adaptation: in the 2080s under the A2 SRES scenario some 19 000 km^2 of land in Europe could be permanently lost, potentially affecting some 1.4 million people in Europe experiencing flooding each year, and with estimated economic costs of 18 billion euro/year (current prices). Large areas of coastal wetlands are

([39]) EU-25 forestry sink potential amounted to nearly 279 million tonnes of CO_2-equivalent corresponding to the 5.75 % of total EU GHG emissions (Bosello *et al.*, 2007).

also threatened, with highest relative losses on the Mediterranean and Baltic Coasts.

However, adaptation has significant benefits. These strategies include (Nicholls *et al.*, 2007b): coastal defences (e.g. physical barriers to flooding and coastal erosion such as dikes and flood barriers); realignment of coastal defences landwards; abandonment (managed or unmanaged); measures to reduce the energy of near-shore waves and currents; coastal morphological management; and resilience-building strategies. Despite some difficulties in estimation, there is an extensive literature reporting the direct cost of adaptation to sea level rise and even estimating the optimal levels of protection (based on cost-benefit analysis ([40])) (e.g. Tol, 2004; Anthoff *et al.*, 2006; Richards and Nicholls, 2007). Under the same climate and sea level projection as above, with adaptation included (and optimised), DIVA suggests that the land loss falls to less than 1 000 km^2 (and the economic costs to around 1 billion EUR/year). There are costs of adaptation (coastal protection), estimated at some 1 billion EUR/year also — but these achieve significant reductions in the costs of inaction.

Notwithstanding uncertainties, a robust finding from the literature is that coastal protection appears to be able to reduce substantively the threat imposed by sea level rise at a relatively low cost ([41]). The studies show that adaptation is likely to be very extensive in Europe.

While it seems possible and indeed desirable to protect many areas of coasts through adaptation, this does not fully capture the full role of Europe's coastline. Under projected climate change and sea level rise, coastal ecosystems appear to be threatened, especially those in the Baltic, Mediterranean and Black Seas (see Figure 4.2 from the BRANCH project). These habitats could be severely reduced or disappear during the 21st century because of the low tidal range in these areas and the limited scope for onshore migration, which is due to the intense human use of the coastal zone (Nicholls and Klein, 2003a). Alcamo *et al.* (2007)

Table 4.5 Coastal studies with economic valuation

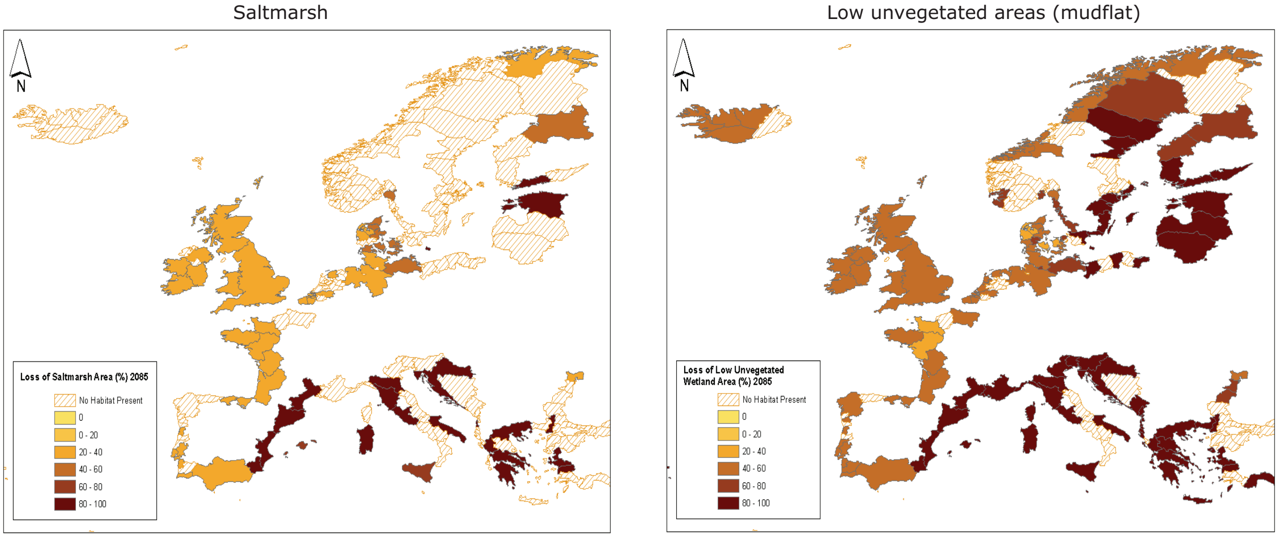
Study region	Sea level rise	Protection level	Billion USD/year
Tol (2002) [1]			
OECD-E	1 metre	86	1.7
Deke *et al.* (2002) [2]			
Western Europe	1 metre	Total	176 (0.02 % GDP)
Bosello *et al.* (2006) [3]			
EU	25 cm	Total	11.2 (0.02 % GDP)
Nicholls and Klein (2003) [4]			
Netherlands			12.3 (5.5 % GDP)
Germany	1 metre	Total	30 (2.2 % GDP)
Poland			4.8 (14.5 % GDP)
Nicholls *et al.* (2007)			
EU no adaptation	0.58		18
EU with adaptation	0.58		1.5

Note: [1] Including migration cost.
[2] Percentage of projected GDP in 2050. Undiscounted and expressed in 1997 USD.
[3] Percentage of 1990 GDP assumed to remain constant each year between 1990 and 2100. Values in 1990 USD.
[4] Total costs over a 100 years as percentage of 1990 GDP. Without protection the capital value loss would amount to the 69 % 30 % and 24 % of GDP respectively for the three countries.

([40]) Extrapolation from local to European or global scale, as it is commonly undertaken for climate-change induced sea-level rise, imposes simplifying assumptions and generalisations that can undermine reliability. Issues of social-economic vulnerability are particularly complex. Difficulty increases when costs of coastal protection (adaptation), are compared to benefits in order to identify an appropriate level of intervention.

([41]) However, costs which are a tiny percentage of GDP in large regional aggregations such as Europe, often become much more relevant simply moving to the national dimension. Note also that the socio-economic responses triggered by planned coastal protection policies need to be carefully taken into account.

Figure 4.2 Relative loss of area by the 2080s (relative to 2000) assuming a 1-m sea-level rise scenario by 2080s



Source: BRANCH Project: Biodiversity Requires Adaptation in Northwest Europe under a CHanging climate, using the DIVA model. Richards, J. and Nicholls, R. J., 2007.

report that sea-level rise is likely to cause an inland migration of beaches and the loss of up to 20 % of coastal wetlands. Adaptation, especially engineered systems used for human settlements, has less potential ([42]).

4.4 Economic sectors

4.4.1 Agriculture

Agriculture accounts for only a small part of gross domestic production (GDP) in Europe, and it is considered that the overall vulnerability of the European economy to changes that affect agriculture is low (EEA, 2005). However, effects may still be substantial at a European level, not least due to distribution of changes. Climate affects crop productivity and crop range in a number of ways. Temperature and climate affect yield and growing season, and there is also a direct (positive) CO_2 fertilisation effect. However, there are a number of complex interactions with other factors, e.g. extreme events (summer heat, winter rain, storms), pests and diseases, and complex interactions with other key sectors, e.g. with water availability for irrigation. There is also a need to consider the wider multi-functionality of agriculture in relation to landscape, rural economies/society, etc. Climate model studies (e.g. EEA, 2005) indicate greater stresses will become apparent in southern European (Mediterranean) and southerly eastern European countries with a changing climate, due to the larger climate signals that these areas receive (with higher than average increases in temperature for Europe), and also greater reductions in summer water availability (and perhaps increases in drought), leading to lower yields. Agriculture is a more significant sector for these countries in terms of employment and GDP, which could compound these effects ([43]). In contrast, the agricultural systems in Western Europe are considered to have lower sensitivity to climate change, and the modelling predictions show likely opportunities (yield increases and wider agricultural crops) for Northern Europe. The recent IPCC 4th assessment report (2007b) concludes that in Northern Europe, climate change is initially projected to bring mixed effects, including some benefits such as increased crop yields and increased forest growth. However, as climate change continues, its negative impacts are likely to outweigh its benefits.

([42]) Though there are some potential through managed retreat, the concept of leaving room for water (similarly for rivers) is being considered as one way to partially offset some of the potential effects on coastal ecosystems, though it is unlikely to fully preserve the current balance of coastal wetlands and ecosystems in Europe.

([43]) However, there will be socio-economic development at the same time as Europe's climate changes. While agriculture is currently a higher share of GDP for these countries, with development, it is almost certain to fall. This highlights the need to consider a changing climate alongside future projections of socio-economic development. Moreover, agricultural efficiency and productivity are likely to increase with technological development.

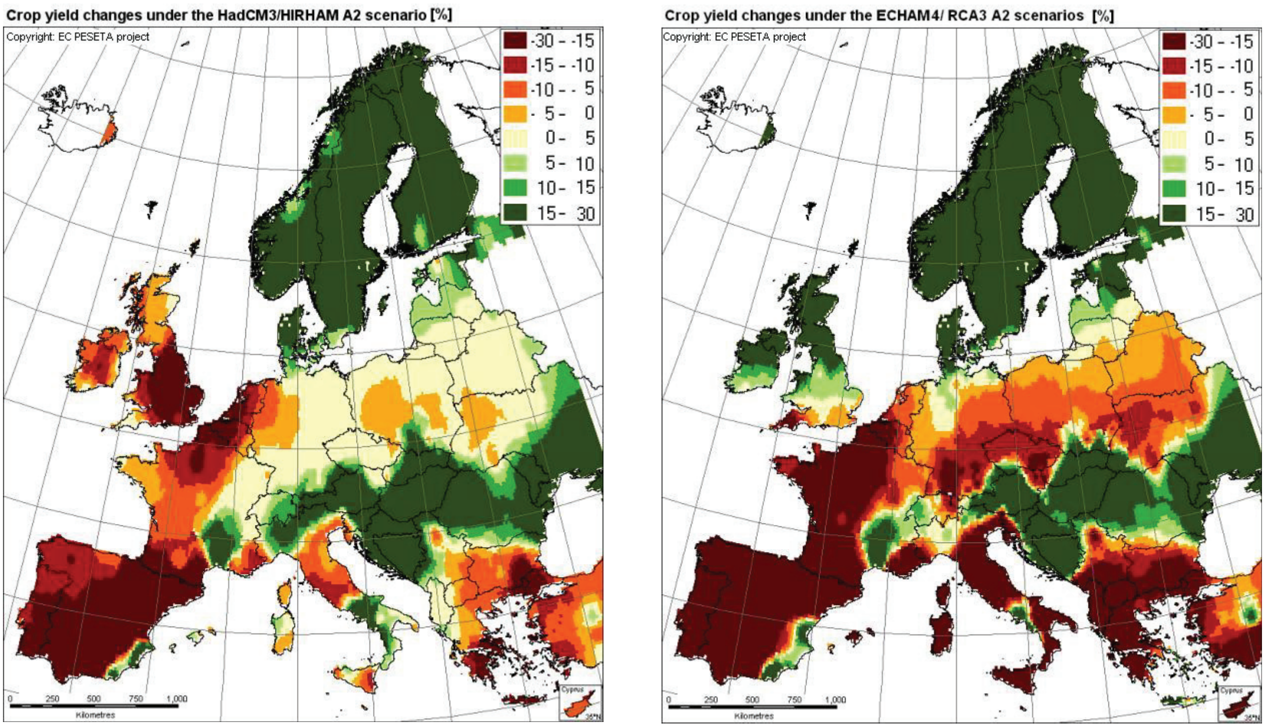
There is an extensive literature on the impacts of climate on agriculture. Most of these analyses now build in (autonomous) adaptation, reflecting a likely trend of producers altering practices and even crop types by region as climate changes. Several studies show the likely spatial patterns outlined above, with a strong distribution of yield changes across Europe, as found in the recent PESETA project below. The maps give indications of the general spatial pattern of changes in agriculture yields across Europe using two different models. The maps show that southern and western Europe could experience a decrease of yields of 10 % or more, though there is an equivalent improvement of yields in Nordic countries. The model used for the right hand map gives a greater climate signal and so greater predicted changes.

These changes in yield can be valued in economic terms, using crop prices. Most studies also consider these changes in relation to wider changes in global agricultural production and prices, i.e. from the likely changes in supply and demand of agricultural products and prices, and relationships with land price, using partial or general equilibrium models. The global studies on the costs of inaction (e.g. from the IAMs discussed in an earlier section) show that agriculture is one of the dominant sectors in current estimates of economic costs (see Downing *et al.*, 2005).

Recent valuation studies in the United Kingdom predict increases in yield and also revenue in the 2020s, but with these declining by the 2050s and with revenue changes becoming negative in nearly all regions by the 2080s with expected economic losses up to GBP 24 million/year (Hamilton *et al.*, 2006) particularly in more southern areas where water becomes increasingly limited. The study also indicated that similar agricultural losses could occur as a result of flooding (without adaptation).

However, while these models generally consider the effects of projected changes in temperature and CO_2 fertilisation, they do not fully consider issues of water availability, and rarely consider extreme events. The latter could be important for Europe in relation to heat extremes and floods. As an example, the droughts of 1999 caused losses of more than EUR 3 billion in Spain (EEA, 2004) and the hot summer of 2003 in Europe is estimated to

Figure 4.3 Simulated crop yield changes by 2080s relative to the period 1961–1990 according to a high emission scenario (IPCC A2) and two different climate models: (left) HadCM3/HIRHAM, (right) ECHAM4/RCA3



Source: PESETA project. http://peseta.jrc.es/docs/Agriculture.html. A. Iglesias/L. Garrote.

have led to USD 15 billion in economic losses to farming, livestock and forestry from the combined effects of drought, heat stress and fire (Munich Re, 2004) ([44]).

Finally, the role of autonomous and planned adaptation is extremely important for agriculture — and has been studied more intensively for this sector than any other (with the possible exception of coastal defences). While most analysis considers short-term autonomous adaptation (to optimise production), as outlined above, there are also potential long-term adaptations in the form of major structural changes to overcome adversity caused by climate change ([45]). These are usually the result of a planned strategy. There are a number of studies that show the benefits of adaptation to farmers in reducing negative impacts by at least 20 %, and even turning losses into gains (though it is highlighted that such studies rarely provide an explicit cost for adaptation).

Overall, it is likely that there will be a different pattern of potential effects across Europe. In higher latitudes, such as Northern Europe, rising temperatures may initially increase production of some crops. In contrast, in lower latitudes, increasing water shortages and high temperatures may lead to substantial declines in crop yields. It is highlighted that the modelling of the CO_2 fertilisation effect ([46]), the effects of extreme events, and of human adaptation options, especially the costs of adaptation, are still surrounded by large uncertainties.

4.4.2 Tourism

With growing income and increasing leisure time, the tourism industry in Europe is expected to continue to grow. At present, predominant tourist flows are from north to south (to the coastal zone — the primary tourist resource of Europe), which helps to transfer capital. But under changing climate, if summer heat-waves increase in frequency or if prolonged droughts result in water supply problems and forest fires, existing tourist flows to the Mediterranean might be reduced, and there is almost certain to be a redistribution of seasonal flows.

Temperature rise is likely to change summer destination preferences: outdoor activities in northern Europe may become more attractive, while summer temperatures and heat waves in the Mediterranean may lead to a seasonal shift in tourism from summer to spring and autumn. These flows have been assessed in a number of recent studies. An example of the change in summer tourism attractiveness, from PESETA, shown below using an analysis of Tourism Climate Index (TCI), comprising the climate features temperature, humidity, sunshine, rain and wind. The index shows the climatic suitability for general summer tourism purposes (June–August). The maps represent the summertime TCI scores in the baseline period on the left (1961–1990) and towards the end of the century (2071–2100) in the IPCC A2 scenario.

The maps show the direction of tourism shifts. The maps indicate significant shifts in the climatic suitabilities for tourism, with the belt of excellent summer conditions moving from the Mediterranean towards northern Europe. However, the reduction in attractiveness of current summer resorts are likely to be at least partially offset by increased opportunities for tourism in northern Europe. In the shoulder seasons (Spring and Autumn, not shown here), TCI scores are generally projected to increase throughout Europe (which could compensate for some losses experienced in summer).

Other recent work (Hamilton and Tol, 2006) shows some of the tourism flows in Europe with climate change. For all of the countries and scenarios, the number of inbound tourists increases. Population growth and economic growth in the rest of the world cause the shift in the balance. The impact of climate change is either to increase the rate of growth — for example, the United Kingdom or for Sweden — or to decrease the rate of growth — for example, Spain and Italy. The analysis also shows changes in country specific patterns. For example in the United Kingdom, climate change amplifies the shift towards more inbound tourists relative to outbound ([47]). By the 2050s, for all of the climate change scenarios, there are more tourists arriving from abroad than there are tourists leaving the United Kingdom.

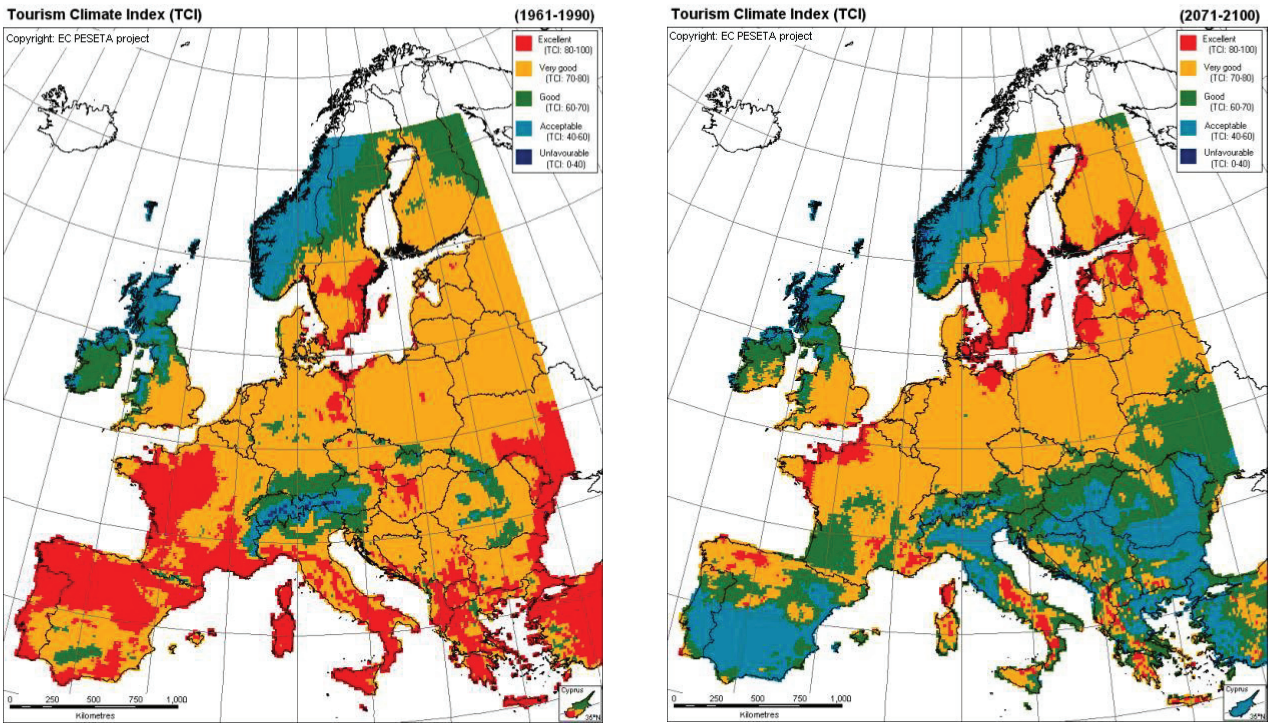
([44]) Though overall positive effects on the UK agricultural, fruit and viticulture industries are also estimated to have occurred (Metroeconomica, 2005), with estimated economic benefits of GBP 64 million, though this included a mix of positive and negative effects — though the authors note that it is not possible to conclude with any confidence that these gains/losses are wholly attributable to the weather conditions that prevailed in the summer of 2003.

([45]) Adaptation can also be undertaken at different scales i.e. farm level, regional level and national level. Note that there are differences between models in the way that adaptation is included, e.g. between a spatial/Ricardian, or a structural approach.

([46]) More recent work has indicated that the CO_2 fertilisation effect may be lower, either due to other limiting factors (climate or precipitation), e.g. see Stern, 2006 from Warren, 2006b, for a discussion.

([47]) This is because the UK becomes more attractive for the UK citizens and so holidays abroad are replaced by domestic holidays and secondly, it is because the United Kingdom becomes more attractive for tourists from abroad.

Figure 4.4 Simulated conditions for summer tourism in Europe for 1961–1990 (left) and 2071–2100 (right) according to a High-Emissions Scenario (IPCC A2)



Source: PESETA project. http://peseta.jrc.es/docs/Tourism.html. P. Martens/B. Amelung/A. Moreno.

Water shortages due to extended droughts are also likely to affect tourism flows, especially in southeast Mediterranean where the maximum demand coincides with the minimum availability of water resources (note the linkages with water availability, but also health). The analysis above do not take water availability into account.

There is also an issue of cultural heritage and the potential threat of climate change (which includes,

Table 4.6 The number of inbound tourists to a selection of European countries for the High scenarios both with and without climate change for the time slices 2020s, 2050s and 2080s

Inbound tourists	With climate change			Without climate change			Difference		
	2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s
Czech Republic	46.2	126	213.6	50.7	124.6	194	– 4.5	1.3	19.5
Denmark	2.2	3.3	4.7	2.4	3.3	4.4	– 0.2	0	0.4
France	77.3	109.4	152.5	89	122.5	167	– 11.7	– 13.1	– 14.5
Germany	20	32	47.5	22.5	32.2	43.5	– 2.5	– 0.2	4
Greece	13.2	18.3	24	15.9	23.2	32	– 2.7	– 4.9	– 8
Ireland	6	8.4	12.1	6.9	9.2	12.4	– 0.9	– 0.8	– 0.4
Italy	39.8	55.7	75.7	47.3	67.3	92.8	– 7.4	– 11.6	– 17.1
Netherlands	8.5	12.1	17.3	9.7	13.1	17.7	– 1.2	– 1	– 0.4
Spain	48.4	66.6	91.4	57.9	81	113	– 9.5	– 14.4	– 21.5
Sweden	3.5	6.2	10.3	3.5	4.8	6.3	0.1	1.4	4
United Kingdom	42	87.9	175.9	45.6	88.5	162.8	– 3.6	– 0.6	13.1

Source: Hamilton and Tol, 2006.

but is wider than tourism alone). This is an emerging area, though it is clearly important for many major cities. As an example, there has been economic analysis of the potential impacts of climate change in Venice, with emerging valuation studies (Breil *et al.*, 2005).

Rising temperature may also undermine the financial viability of the winter sports industry in Europe. Studies show that there is a statistically significant trend in snow-cover reduction in the Alps over recent years. Recent work (OECD, 2007) has quantified the impacts on European Alpine winter tourism, in terms of number of sky resorts at risk (though without assessment of economic losses). It found that the numbers of Alpine ski areas in Austria, France, Germany, Italy, and Switzerland that can be considered as naturally snow-reliable is likely to fall from approximately 600 now, to 500 under 1 °C, and approximately 400 under 2 °C (though with a strong pattern on sensitivity by country). There are some adaptation measures (snow making). Use of such measures has increased in recent years (for example, in France almost half a billion euros were spent between 1990 and 2004 on artificial snow-making installations, while in Austria, approximately EUR 800 million were spent between 1995 and 2003 — though not all of this is necessarily in response to changes in climate. These measures are cost-effective, but have limits and costs are likely to increase non-linearly as temperatures increases (and beyond certain limits it is simply not viable).

4.4.3 Energy

Energy industries are the single most important source for greenhouse gas emissions in Europe. However, the energy sector will also be affected by climate change. Studies have demonstrated that energy demand is linked to climatic conditions, with changing demand for winter heating and summer cooling. The changing climate in Europe is likely to lead to a decrease in the demand of winter heating, but an increase in summer cooling (which can be described as either an impact or an adaptation).

The potential importance of energy demand is one of the strongest drivers in the global costs of inaction estimates (and often the dominant value, see Downing *et al.*, 2005). However, the economic costs for Europe (at a net level) are predicted to be modest in the short-medium term, though they do have a strong distributional pattern across Europe — with rising cooling (electricity) demand in summer in Southern Europe, but reduced heating (energy) demand in winter in Northern Europe (see Alcamo *et al.*, 2007) ([48]). These changes will affect peak demand for electricity in different countries across Europe, which may be more important (in economic terms) than aggregate energy use ([49]). These may be exacerbated by extreme events (e.g. heat waves) and the peak daily requirements through air conditioning. There may also be an emerging issue of energy use rising for water supply (pumping, desalination, recycling, water transfers). Adaptation has a role to play here — particularly through alternatives to mechanical air conditioning, e.g. through passive ventilation, building design, planning, etc.

A changing climate also has potential effects on other aspects of the electricity sector, for example with respect to hydro-electric flow (in summer, and from snow melt), from wind resources, and from water abstraction for large generation plant (for example, in 2003, there were restrictions on abstraction for cooling water).

4.5 Human interests

4.5.1 Human health

Climate change is likely to affect human health, either directly related to the physiological effects of heat and cold, or indirectly, for example, through the increased transmission of food-borne or vector-borne pathogens, or through the flooding. An increase in some of these impacts has already been observed over the recent decades in Europe (e.g. the summer heat waves in 2003 alone claimed more than 35 000 excess deaths: (EEA 2004).

([48]) As an example, Giannakopoulous (2006) estimates a 30 % increase in energy demand in Athens by 2080 during July due to air conditioning by the 21st century (but a decrease in demand during the milder and shorter winter period), whilst Livermore, estimates increases of up to 50 % in Italy and Spain by the 2080s. At the same time, decreases in net overall energy demand are predicted in more northerly countries, due to reduction in winter energy demand, e.g. for the United Kingdom (Metroeconomica, 2006).

([49]) Note that these changes also need to be seen in the context of wider demand changes. Electricity usage and demand in Europe have been rising steadily since the mid-1990s and this trend is expected to continue (EEA, 2004a) but the demand changes from climate are potentially important economically. Overall, at low levels of temperature change the increased spending on cooling should be more than off-set by saving from reduced heating expenditure, but the situation reverses at some point of future change. Note also that air conditioning is strongly correlated with income — even if we had the same climate in future years the demand pattern between heating and cooling would change because of income changes. Finally, there are issues of technological innovation and efficiency gains in heating and cooling.

There is some uncertainty over the net effects (the sum of heat and cold effects) for Europe under a changing climate, and especially the distribution of benefits across Europe. There are literature estimates of effects (e.g. WHO global burden of disease (McMichael, 2004), and the recent PESETA project (AEA, 2007)): the latter has estimated the economic effects of these events in Europe and found large economic costs (billion/year) from summer mortality by the 2080s, though these will be offset by potentially larger economic benefits from the reduction in winter mortality. Populations will partly acclimatise to future temperatures, and there is also the potential for adaptation beyond this, for example with the current heat alert systems across many EEA member countries for extremes (as implemented in France post 2003, and also in other member states). It is also highlighted, however, that heat related health concerns themselves are likely to drive interactions with energy use and air conditioning.

Climate-sensitive infectious diseases, such as salmonella, have the potential to increase under a changing climate. Some emerging work (AEA, 2007, based on Kovats, 2003) shows that the disease burden in Europe could be significant, and have a potentially high cost (potentially several billion euro a year by the period 2070–2100 through medical costs, lost time at work, willingness to pay to avoid pain and suffering, and through the small number of cases of food poisoning that are fatal), though adaptation offers a low cost means to reduce these.

The increasing intensity of heavy rainfall is likely to make extreme floods more frequent in some areas of Europe (see below). While the number of deaths and injuries from floods are relatively low in Europe, flood events do have important wider effects, notably in wider well being (mental health, stress and depression). There is some emerging quantification and valuation of the latter well-being impacts (AEA, 2007, based on impact studies such as Reacher *et al.,* 2004), which shows that without adaptation, baseline costs could be significant (billions per year). However, coastal and river flooding adaptation should reduce these very significantly.

Globally climate-induced changes in the potential distribution of malaria are projected mainly in poor and vulnerable regions. In Europe localised outbreaks are possible in areas where the disease has been eradicated, but vectors are still present (Reiter *et al.*, 2004), though strengthening of effective surveillance and prevention programmes (adaptation) should ensure that these are minimised. There is emerging work assessing climate change impacts on the distribution of vector-borne diseases in Europe (malaria, leishmaniasis, West Nile virus) from the EDEN project.

Finally, there are a number of emerging health issues from climate change in Europe, where quantification and valuation have not been explored. A warmer climate may have important effects on air quality in Europe (for ozone formation). The seasonality of allergic disorders may change with implications of direct costs in terms of over-the-counter medication for allergic rhinitis, and wider economic costs to individuals.

Data on the costs of surveillance and outbreak control (adaptation costs) are starting to emerge and there are adaptation strategies that can be implemented by health sectors (e.g. see the cCASHh project), most of which are likely to build on well-established public health approaches, though further work is needed to fully assess the costs of adaptation. Most adaptation measures appear to be low-cost (e.g. provision of information), but there is the potential for some to involve potentially costly large-scale vaccination or other prevention programmes against vector-borne disease ([50]). Some recent studies have considered the potential direct and indirect costs of health care (e.g. Bosello *et al.*, 2006) and show that these are likely to be relatively small for Europe in terms of GDP. They also highlight that there are likely to be strong distributional implications for climate change and health, with poorer countries being either more exposed or more vulnerable.

4.5.2 Water

Europe has a very diverse hydrological pattern. In the south, there is significant seasonal variation in river flow due to long and dry summers. To the west, there is less extreme variation, and in catchments underlain by absorbent aquifers river flows remain reasonably constant throughout the year (EEA, 2005). In the north and east, much precipitation falls as snow. As a result, significant

([50]) It is difficult to estimate the costs and benefits of measures because: first, there is a general lack of information concerning the potential costs of many interventions; second, it is often extremely hard to assess the reduction in physical health impacts that these measures will achieve; third, it is very difficult to disentangle the costs of adaptation to changes in health status induced by climate change from those related to change in health status per se. Note also that it can be argued that changes in health care expenditure are an impact of climate change rather than an adaptation to it.

river flow occurs during the snow melting period in spring.

The EEA report on climate change and water adaptation issues (EEA, 2007b) highlights that in recent decades more intense rainfall events have occurred and parts of Europe have experienced extreme weather events in the form of severe floods, droughts and heat waves. Analyses from climate change models project an exacerbation in the frequency and intensity of these events. Changes in precipitation, combined with rising temperatures and reduced snow cover, will have impacts on water quality and quantity, requiring water managers to incorporate climate change in their planning and investment decisions.

Water is a critical core sector so that impacts here have a cascade effect reflecting the wide variety of water use. Changes in water demand strongly depend on economic growth and societal development, as well as patterns of demand change from other sectors. Economic sectors which are projected to be most affected are (EEA, 2007b): agriculture (increased demand for irrigation), energy (reduced hydropower potential and cooling water availability), health (worsened water quality), recreation (water-linked tourism), fisheries and navigation, as potentially serious impacts on biodiversity. The dominant impacts are flooding in central Europe, hydropower, health and ecosystem concerns in the northern countries, and water scarcity in the southern countries.

There are now good studies of the potential economic costs of floods in Europe. There are many studies which have estimated the economic costs of recent extreme flood events in Europe, for example the severe flooding in central Europe of August 2002 (in Austria, Czech Republic, Germany, Slovakia and Hungary) led to economic losses of USD 17.3 billion and insured losses of USD 4.1 billion (EEA, 2004). The observed upward trend in flood damage can be attributed to socio-economic factors, such as the increase in population and wealth in flood-prone areas, to changes in the terrestrial system, such as urbanisation, deforestation and loss of natural floodplain storage, as well as to changes in climate.

Emerging studies are now looking at the projected future impacts. Recent climate modelling projections suggest that in the coming decades global warming will intensify the hydrological cycle and increase the magnitude and frequency of intense precipitation events in most parts of Europe, especially in the central and northern parts (Christensen and Christensen, 2003; Semmler and Jacob, 2004). This will likely contribute to an increase in flood hazard triggered by intense rain, particularly the occurrence of flash floods (IPCC, 2007b). Flood hazard may also rise during wetter and warmer winters, with increasingly more frequent rain and less frequent snow. On the other hand, ice-jam and early spring snowmelt floods are likely to reduce because of warming (Kundzewicz *et al.*, 2006).

Some preliminary estimates (ABI, 2005) indicate that annual flood losses in Europe could rise to EUR 100–120 billion (tenfold) by the end of the century (though flood management could reduce this). Besides the projected growth in direct damage to settlements and infrastructure, an increase in the number and severity of flood events will affect large parts of European industry and power generation that are located in flood prone areas. This may create competitiveness concerns due to increased risks of business interruption. As a result, economic losses of flooding could increase 10 to 20 times by the 2080s under high emission and economic growth scenarios (e.g. Hall *et al.*, 2005).

More detailed disaggregated work under the PESETA project (Feyen *et al.*, 2007) has modelled changes in river flows in a changing climate in Europe, studying two river catchments (Danube and Meuse) in detail.

- For the Upper Danube the estimated total damage of a 100-year flood is projected to rise by around 40 % of the current damage estimate (an increase of EUR 18.5 billion) for the high emission scenario (A2) and around 19 % for the low emission scenario (B2) by 2100.
- The number of people affected in the Upper Danube is projected to increase by 242 000 (around 11 %) for the A2, and 135 000 (around 6 %) for the B2 scenario.
- While these do not include adaptation responses, they show that the potential effects are significant, especially when extrapolated to a European scale. However, adaptation can reduce these significantly (see the Dutch case study below).

There is also the issue of water scarcity. Alcamo *et al.* (2007) (IPCC, WGII) predict that the percentage area under high water stress in Europe is likely to increase from 19 % today to 35 % by the 2070s, and the additional number of people affected by the 2070s is expected to be between 16 million and 44 million. There are only a few studies of the impacts and economic costs of these changes. Work in the United Kingdom has estimated the economic losses to households of foregone water use due to the anticipated water deficit by 2100 in south-east England (Wade *et al.*, 2006) at between GBP 41 and 388 million a year (depending on scenario), but that the costs of largely (but not entirely) eliminating these deficits would be only GBP 6 to 39 million/year (effectively the costs of adaptation).

Nonetheless, there remains only partial coverage of the full cross-sectoral effects of water, and the potential cascade effects to all sectors. Further work on capturing these effects, and looking at cumulative pressures is highlighted as a priority.

4.5.3 Built environment and infrastructure

The final section considered captures the man-made environment, i.e. the built environment including infrastructure.

The main potential vulnerability of the built environment is to extreme events (floods and storm events), though also including heat-waves and drought. The first two capture the potential for damage, whilst the latter are potentially important in relation to subsidence.

The recent impacts and costs to the built environment from the current climate extremes were considered in an earlier section from the insurance sector studies, and the risks of coastal and river floods were outlined in the sections above.

Storms are currently the costliest weather catastrophes in the developed world and they are likely to become more powerful in the future as the oceans warm and provide more energy to fuel storms (Stern, 2006). This effect will be magnified for the costs of extreme storms, which are expected to increase disproportionately more than the costs of an average storm.

ABI estimated that wind-related insured losses from extreme European storms will increase by at least 5 % to EUR 25–30 billion. Swiss Re recently estimated that in Europe the costs of a 100-year storm event could double by the 2080s with climate change (USD 50/EUR 40 billion in the future compared with USD 25/EUR 20 billion today), while average storm losses were estimated to increase by only 16–68 % over the same period (Heck *et al.*, 2006). Some estimates indicate that the cumulative contribution of changing climate risk and socio-economic development are likely to double worldwide economic losses due to natural disasters every ten years.

Looking at other events, the total loss of the hot summer 2003 in France (including from power generation, stress on the transport system, stress on forests and other ecosystems including fires, reduced wine production and decreased agricultural productivity) has been estimated at 0.1–0.2 % of GDP equivalent to 15–30 billion euros (Gillet, 2006). The 2003 summer was also estimated to have increased building subsidence claims by 20 % in the United Kingdom, with estimated impacts of GBP 30 to 120 million (Metroeconomica, 2006) and damage to transport infrastructure (rail buckling and road subsidence) of GBP 40 million (Watkiss and Horrocks, 2006). These studies also predict the likely future trends in the United Kingdom and show potentially strong increases in future economic costs.

Predicting the future effects from extreme events is difficult. Firstly, there is less confidence in the climate model predictions for such events. Second exposure is likely to increase due to changes in economic development, which increases the value and density of human and physical capital. Adaptation will be able reduce the costs and disruption caused by extreme weather events such as storms, floods and heat-waves, though note at higher temperatures, the costs of adaptation will rise sharply and the residual damages remain large. The additional costs of making new infrastructure and buildings more resilient to climate change in OECD countries could range from USD 15–150 billion each year (0.05–0.5 % of GDP), with higher costs possible with the prospect of higher temperatures in the future (Stern, 2006) ([51]).

It is also highlighted that likely increased claims against losses induced by more frequent and intense climate change events or their more difficult predictability, will probably translate into increases in risk premiums, and/or increases in the levels of uninsured assets.

4.5.4 Case studies

As part of the study on the costs of adaptation, three case studies were considered (summarised in Box 4.2). The key lessons from the case studies are:

([51]) Infrastructure is particularly vulnerable to heavier floods and storms, in part because OECD economies invest around 20 % of GDP or roughly USD 5.5 trillion in fixed capital each year, of which just over one-quarter typically goes into construction. This preliminary cost calculation assumes that adaptation requires extra investment of 1–10 % to limit future damages from climate change. Stern, 2006.

Box 4.2 Costs of adaptation: case studies

As part of the work, the study has undertaken a number of case studies on the costs of adaptation.

Room for the river. Case study on the costs of adaptation to climate change in the Netherlands.

The Netherlands has a long history in adapting to changing flood risks. Recently, flood management has broadened its focus from safety issues to a more integrated policy approach including issues of landscape, nature, recreation and cultural heritage. Flood management has also shifted its focus from technical measures (especially dike strengthening) to spatial solutions that aim to create 'Room for the River'. The new policy approach tries to take account of long-term developments and risks, such as those presented by climate change. Climate change is expected to have a significant effect on peak discharges of the main rivers Rhine and Meuse. There are also other natural and socio-economic developments in the longer run that may require adjustments to the flood defence system. An approximate assessment of the cost of adaptation to climate change for flood defence along the river Rhine was made, on the basis of a study of the Netherlands Bureau of Economic Policy Analysis and some simplifying assumptions. The most important conclusions were that adaptation could mitigate most of the climate change induced increases in river flooding risks at relatively modest costs. Specifically, 'optimal' flood defence investments would reduce climate-induced flood damage from EUR 39.9 billion to 1.1 billion over the 21th century at a relatively modest cost of around EUR 1.5 billion. This cost figure is relatively modest in comparison to the damages avoided as well as in comparison to flood defence investments that were made in the 20th and early 21st century.

Sea level rise: the case of the Fondi plain. Case study on the costs of adaptation to climate change in Italy

The Fondi plain case study, focused on adaptation, identifies the most efficient option of adaptation to an expected sea-level rise in the coastal area of the Fondi plain, providing a methodological framework for the socio-economic evaluation of local interventions of adaptation through the application of cost-benefit analysis. The economic value of the areas at risk of flooding in the Fondi Plane is calculated, to represent the 'no intervention' option, and compared with the costs of two alternative measures of land protection, i.e. the improvement of the existing inland water drainage system and the reconstruction of a pre-existing dune along the coast. Case specific results suggest the efficiency of the improvement of the drainage system: due to an already developed and well working drainage system, the incremental costs linked to the expected sea level rise, ranging between 50 and 100 million euros are much lower compared to the potential damage implied by a 'do nothing' strategy, ranging between 130 and 270 million euros. The analysis of this case strongly suggests the need to complement the economic analysis not only with a technical feasibility study, but primarily with a social and political analysis of the local context. In particular, the study highlights how the social costs of other kinds of local interventions, that technically could seem cheaper (e.g. re-storing pre existing dunes and waterproofing with demolition of houses on vulnerable land) can be very high and that the social acceptability of the adaptation options must be taken into account and become crucial to the process of evaluation.

Agriculture and climate change. Case study on the costs of adaptation to climate change in Slovakia

Successfully addressing adaptation needs in the transition countries requires a number of steps including long-term planning, scientific investigation, policy implementation and capacity building. Current levels of knowledge about impacts of climate change on agriculture are not sufficiently addressed in transition countries and if such data is available they are not sufficiently backed up with information about current farming practices and the feasibility of the identified adaptation options. This requires the recognition of farmers' reception of climate change data presented in climate variability, pest exposure, or lack of precipitation leading to drought. As identified in the study, farmers seek an extension agency that will provide translation of climate scenarios and their impacts to vulnerability of agricultural systems. The agency will also outline measures to tackle these vulnerabilities. To minimize the sensitivity to climate change of agricultural systems, the farmers reported that in particular new information and technologies were the most feasible. Addressing these opportunities the institutional structures need to be developed, or the capacities need to be enhanced in the exiting ones in order to provide this information. Consequently, this also requires the strong collaboration between different institutions including scientific institutes and universities. There is a need to increase the potential for an optimal 'fit' between information supply and the local institutional structures. The major constrain to proceeding with certain adaptation option was the lack of financial resources. This lack among the agricultural producers has created the focus on short-term planning often operating on year-to-year basis. Promotion of long-term planned adaptation options requires a specific support-scheme that could help the producers to overcome the lack of financial resources in larger investments such as infrastructure development, diversification of production, or insurance. Providing a source of financial support is important, because many of the outlined options that foster adaptation reflect serious problems of lack of investment in agriculture and in the long run, agricultural growth will suffer if such investments are ignored during transition.

- Undertaking detailed studies of adaptation (cost and benefits) is complex and time-consuming. It relies on significant data availability and to be undertaken properly, needs local stakeholder input and consideration of the specific local social and economic conditions. Local consideration can significantly increase the costs of adaptation.
- There remain significantly methodological challenges in undertaking these detailed adaptation studies at a local level. There are issues with uncertainty, especially in applying theoretical adaptation proposals into a specific local context.

4.6 Conclusions

The following conclusions can be drawn in relation to the key impacts for Europe's natural environment and its society:

- Europe's natural environment and associated services, its production systems (agriculture, fisheries, forestry, terrestrial ecosystems) and other key socio-economic sectors (tourism, energy, human health care, built environment) are under pressure from environmental change and socioeconomic development. Climate change is an additional pressure and impacts of changing climate on the environment and society are observed across the region. This is already leading to some economic impacts in Europe, particularly through recent extreme weather events.
- Projected changes in climate (including extremes and sea level rise), compounded by other environmental changes and ongoing socio-economic development, are expected to have wide ranging impacts and economic effects on natural and human systems in Europe. The overall net effects across Europe are unclear, not least due to the limits on quantification and valuation, but are potentially significant. Some of these fall on systems that are under pressure from other environmental change and development processes. Further work is needed to provide quantification and valuation across all areas, and all sectors, for the range of climate risks from temperature rise, through to extreme events and potentially major events.
- For most sectors, there is a strong geographical (spatial) distribution of effects, including economic effects, across Europe. Whilst there is a range of positive and negative economic effects across sectors and regions, there appears to be a significant trend towards more impacts (negatives) in South-eastern Europe and the Mediterranean (e.g. in relation to energy demand, agricultural productivity, water availability, health effects, summer tourism, ecosystems, etc.). Future trends in economic, social, institutional, and technological development in these regions also need to be taken into account.
- Adaptation has an extremely important role in reducing economic costs across Europe. While adaptation has a cost, the information available shows it significantly reduces the residual costs of climate change (the costs of inaction), and in many cases has benefits that dramatically outweigh costs. However, there is very little quantified information on the costs of adaptation, and further work is urgently needed to progress the evidence base and provide the information needed to allow informed, cost-effective and proportionate adaptation in Europe.
- The relationship between mitigation and adaptation is still highly unexplored, in particular strong and reliable quantitative evidence is missing. This knowledge gap needs to be bridged as soon as possible to design an effective, efficient and equitable climate change policy.

5 Conclusions and research gaps

5.1 Conclusions

This review has provided a synthesis of the economic costs of climate change impacts, and the costs of adaptation, and a classification of most recent studies and methodological variables. It has identified important gaps, criteria for 'good practice', and recommendations for future work.

Despite increasing efforts being devoted to research on various aspects of the economics of climate change in Europe, there is limited confidence in the magnitude and rate of estimates. Knowledge on the potential impacts of the economic changes on natural and human systems is not yet detailed enough and there are important evidence gaps. Much of this relates to the quantification of impacts and costs, but it is also strongly affected by methodological issues.

5.2 Challenges

Important evidence gaps remain and there is considerable scope for advancing economic assessment of impacts and adaptation. There are a number of challenges which should be addressed to make progress on these aspects. These are summarised below.

5.2.1 Challenges: economic costs

The report has compared the methodological issues in the sections (Chapter 3) against the existing studies on the costs in action. While individual studies do cover most methodological aspects, no studies extend beyond a few areas. This highlights the need for wider methodological analysis to properly address the full costs of climate change.

A major difficulty in impact assessment and valuation is still the incomplete understanding of climate change itself, in particular the regional details of climate change, but also the coverage across the range of climate change effects (including extreme events).

Non-market damages, indirect effects, horizontal inter-linkages, and the socio-political implications of change are also still poorly understood. There is a particular gap on methodological issues for the economic costs and benefits of biodiversity. Uncertainty, transient effects (the impact of a changing rather than a changed and static climate), and the influence of change in climate variability are other factors deserving more attention. Related to this, there is a general need for the analysis and models to move towards more dynamic analysis of assessment, both for impact assessment (the dynamic processes of vulnerability and adaptation) and valuation.

Current climate change scenarios and current climate change impact studies use crude spatial and temporal resolutions, often too crude to capture a number of essential details that determine the impacts. Knowledge gaps continue at the level of impact analysis.

The basis of global impact assessments tend to be case studies with a more limited scope, often undertaken in the United States, which are then extrapolated to other regions. Such extrapolation is difficult and can be successful only if regional circumstances are carefully taken into account, including differences in geography, level of development, value systems and adaptive capacity. While there are a growing number of country-level case studies, the current knowledge of local impacts is still too uneven and incomplete for a careful, detailed comparison across regions. At present differences in assumptions often make it difficult to compare case studies across countries.

There is a need to complement the global studies with bottom up, more disaggreagated studies that look at the potential costs of climate change (though these also have uncertainty attached to them). To ensure consistency these must be based on a coherent and harmonised analysis, with a uniform set of assumptions on climate, socio-economics, etc. The need for more detailed and consistent European studies is a key priority.

At the global level the range of cost estimates of climate change impacts are large, and cannot be expressed in single representative values. There therefore needs to be recognition of this range (which also exists for mitigation costs for example) and policies should be designed to consider and respond to the uncertainty. Importantly, there is a need to communicate this uncertainty (and avoid single values) for translating the scientific and economic evidence to policy makers. One interpretation of assessing the 'costs of inaction' is to be able to say that not undertaking significant emissions reductions now will result in greater costs in the future. Other views suggest that it is better to wait until we have a better idea of the benefits of mitigation. However from the overview of the literature and methodology there remain significant knowledge gaps. The case for early action must rest in large part on the precautionary principle, i.e. delaying action may cause significant irreversible damage.

The adoption of alternative temporal and spatial aggregation criteria and the influence on the estimated impacts and on the net benefits of adaptation vs. mitigation should be pursued and assessed, stressing in particular its equity dimension. Cost assessments by world/regions and over different time horizons should be carried out and compared adopting alternative weights. Both economic and ethical considerations should be accounted for in the evaluation process and should guide policy actions in climate change control.

At the same time research needs to make progress in improving our understanding of the uncertainty in the scientific and policy debate, possibly incorporating a statistical measure of uncertainty in the analysis of costs of climate change impacts. So far only a few studies have moved in this direction. Alongside this, there is a need to improve and expand the coverage (completeness) of studies, making sure that additional sectors, and additional types of climate change are included. In particular, both dimensions of impacts — uncertainty in predicting climate change (impacts) and uncertainty in the valuation of these impacts — should be covered more comprehensively. The current focus of impact assessments should be extended to include not only market damages from predictable events but also non-market damages and the impacts of major catastrophic events and surprises.

5.2.2 *Challenges: costs of adaptation*

The survey of the literature shows that a lot of work has been carried out in the field of vulnerability and adaptation. However the linkage between costs of adaptation versus residual damage and costs of mitigation is very weak. There is little information in fact that shows (a) how adaptation costs compare to the potential damages of not adapting and (b) how the adaptation costs would change if there were more mitigation. These many linkages and trade-offs are crucial to estimate the cost on inaction in the field of climate change.

Major advances are needed in the economic analysis of adaptation. Adaptation will entail complex behavioural, technological and institutional adjustments at all levels of society, and not all population groups will be equally adept at adapting. The analysis is further complicated by the strong link between adaptation and other socio-economic trends. The world will substantially change in the future, and this will affect vulnerability to climate change, as well as adaptation responses ([52]). Even without explicit adaptation, impact assessments therefore vary depending on the 'type' of socio-economic development expected in the future.

The types of adaptation that are being assessed differ across sectors. It is suggested that a way forward in this area would be to identify feasible adaptation options at the local (national or sub-national) level and to aggregate the findings to larger regional aggregates, such as Europe.

There is a fundamental 'gap' between the assessments of adaptation strategies at the local level and at the national or even global level. A 'best practice' European assessment of adaptation costs would report on European-wide adaptation costs, but would also highlight local bottlenecks with potentially very high costs of adaptation, such as, for example, the protection of London and Rotterdam against rising waters.

Most studies that assess adaptation options do not differentiate between different rates and speeds of climate change. Moreover, most studies use a comparative static framework for assessment (a comparison between two equilibrium states) and not a dynamic, transient framework.

There is as yet little research into 'realistic' adaptation options by different stakeholders in different socio-economic, cultural and political settings. There is also little to no research into (antagonistic or synergistic) interactions between

([52]) As an example, the growing pressure on natural resources from unsustainable economic development is likely to exacerbate the impacts of climate change. However, if this pressure leads to improved management (e.g. water markets), vulnerability might decrease.

adaptation actions at different regional or temporal scales. Uncertainty about the rate of adaptation compounds to the uncertainty about the type of adaptation that will be pursued (see above). This compounded uncertainty affects the reliability of the assessment of adaptation costs. Uncertainty about the rate and speed of adaptation can possibly be reduced (but not completely avoided) by examining decision-making processes in local, sector-specific case studies.

Most studies assess direct costs or expenditures (on coastal defence, health care, energy bills). Very few studies assess higher-order costs and total welfare costs. Those that do assess 'equilibrium' costs, while no study explicitly assesses transition costs. The studies that have examined equilibrium effects of adaptation measures generally conclude that these effects may be important, if not for the total magnitude of the costs than at least for the distribution of the costs among different economic actors and even countries (through international trade effects). A complete review and analysis of the importance of equilibrium effects might be very useful at the European level. One way to study the importance of equilibrium effects in the area of adaptation would be to examine ex post assessments of the macroeconomic effects of investments to reduce vulnerability to current climate variability, such as, for example, coastal defences. One example would be a study of ex post macroeconomic assessments of the Dutch Delta Plan.

There is little explicit attention to any possible co-benefits of adaptation, including the potential beneficial effect of adaptation measures on damages due to current climate variability. While this is conceptually a difficult issue, more attention should be paid to the distribution of benefits to actors that are currently vulnerable to climatic variability and actors that may become (more) vulnerable to a future change in variability. Among others, this issue seems to be important in coastal defence, river management, and health care.

Uncertainty is a key characteristic of climate change and hence also of adaptation to climate change. There are several types of uncertainty. One type of uncertainty is the inherent 'randomness' of climate variability. Even if the change in probability distribution of climate impacts is known with certainty, it remains uncertain who will be impacted at what date. The insurance industry plays a vital role in pooling such risks. Another type of uncertainty regards the incidence and rate of climate change itself. Another important role of the insurance industry is to 'signal' increased expected climate risks through the terms of its policies. In this way, the insurance industry may help society to adapt to future climate change by way of clear market incentives. If the expectation of climate change of the insurance industry is relatively accurate (or at least unbiased), this may also reduce the danger of maladaptation by private and public economic actors.

There are few studies that explicitly focus on distributional aspects of adaptation. There are many studies that point to the need for enhancing adaptive capacity in developing countries, but few studies that analyze actual private and public adaptive behaviour in these countries. There is limited research into the relationships between adaptation and income distribution within or between countries and regions.

Finally, adaptation needs to be consistently harmonised with other strategies, primarily mitigation, in order to design the most efficient effective and socially acceptable climate change policy. Accordingly, further work is needed to progress the analysis of the costs of adaptation, and the residual costs of climate change. There is also a need to progress the issue of maladaptation.

5.2.3 Challenges: policy

Alongside these scientific and technical challenges above, there is a need to progress the policy aspects (and the policy process) in relation to the costs of inaction, and also the costs and benefits of adaptation. This includes developing new policy frameworks for these areas at the European scale, and beyond this down to Member State and regional level.

As a final note, despite the challenges across all areas above, sufficient information is available to start with action (i.e. the research gaps do not mean that economic impacts should not be considered, nor that adaptation should not be progressed). Further efforts and research will help strengthen the scientific, technical and economic capacity for assessing impacts and adaptation, and to bring these together within common methodological approaches and consistent policy frameworks that consider the economic perspective. As improved information appears, this will further improve policy analysis and decision making.

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Annex I IPCC Scenarios: information from Summary for policy-makers from Working Group 1

Table SPM-2 Projected globally averaged surface warming and sea level rise at the end of the 21st century for different model cases. The sea level projections do not include uncertainties in carbon-cycle feedbacks, because a basis in published literature is lacking. {10.5, 10.6, Table 10.7}

	Temperature change (°C at 2090–2099 relative to 1980–1999) [a]		**Sea level rise (m at 2090–2099 relative to 1980–1999)**
Case	Best estimate	Likely range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations [c]	0.6	0.3–0.9	NA
B1 scenario	1.8	1.1–2.9	0.18–0.38
A1T scenario	2.4	1.4–3.8	0.20–0.45
B2 scenario	2.4	1.4–3.8	0.20–0.43
A1B scenario	2.8	1.7–4.4	0.21–0.48
A2 scenario	3.4	2.0–5.4	0.23–0.51
A1FI scenario	4	2.4–6.4	0.26–0.59

Note: a These estimates are assessed from a hierarchy of models that encompass a simple climate model, several EMICs, and a large number of AOGCMs.

c Year 2000 constant composition is derived from AOGCMs only.

The emission scenarios of the IPCC special report on emission scenarios (SRES)

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies.

Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

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

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

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

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

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

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