The Impacts and Costs of Climate Change

Final Report
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***'Modelling support for Future Actions – Benefits and Cost of Climate Change Policies and Measures'.* ENV.C.2/2004/0088.**

Executive Summary

The effects of global climate change from greenhouse gas emissions (GHGs) are diverse and potentially very large, and probably constitute the most serious long-term environmental issue currently facing the world.

This paper is prepared as task 1 of the project '*Modelling support for Future Actions – Benefits and Cost of Climate Change Policies and Measures',* ENV.C.2/2004/0088, led by K.U.Leuven, Katholieke Universiteit Leuven. The paper provides a rapid review and analysis of the impacts and economic costs from climate change. The objective is to provide estimates of the benefits of climate change policy, i.e. from avoided impacts, for support to the Commission in considering the benefits and costs of mitigation efforts, and to support DG Environment in its report to the Spring Council 2005 and in future international negotiations on climate change.

Impacts of Climate Change (baseline)

The paper has reviewed the impacts of climate change, looking at potential impacts at a European and global level. The analysis has identified and prioritised the major effects from climate change. These are considered to be:

- Impacts of sea level rise, erosion, loss of land/coastal wetlands, and need for coastal protection;
- Effects on agriculture;
- Effects on energy use (including heating and cooling);
- Effects to human health from changes in cold related and heat related effects
- Effects to human health from the disease burden (and other secondary effects);
- Effects on water resources, water supply and water quality;
- Changes to tourism potential and destinations;
- Effects on ecosystems (loss of productivity and bio-diversity);
- Impacts from drought;
- Impacts from flooding;
- Impacts from storm damage and extreme weather (including costs to infrastructure);
- Socially contingent effects (arising from multiple stresses and leading to migration, famine, etc);
- Impacts from major events (e.g. loss of thermo-haline circulation, collapse of West-Antarctic ice sheet, methane hydrates).

Many of these areas are inter-related. In particular, the major events identified (the potentially catastrophic effects and major climate discontinuities) will have impacts across all categories. The risk of avoiding these major effects is highlighted as a specific benefit of future climate change policy, consistent with the precautionary principle.

Benefits of Different Stabilisation Targets

The review has assessed the potential effects of climate change associated with different stabilisation targets. These are consistent with specific analysis of CO_2 equivalent ppm concentrations, or temperature changes such as a maximum 2˚C rise above pre-industrial levels. It has been difficult to comprehensively assess the impacts associated with different targets, either at a European or global level. Some initial data highlights that the potential benefits of stabilisation targets could be very large, and there is increasing information emerging.

The IPCC Third Assessment Report confirms that risks of adverse impacts from climate change increase with the magnitude of climate change. It considered five causes for concern regarding climate change risks evolving in the period to 2100. Negative impacts on unique or threatened systems and risks from extreme climate events occur with a temperature change as small as 1˚C and these impacts and risks are projected to become significant and widespread for changes of 2 to 3˚C.

Above 2˚C temperature increase, the vast majority of market impacts are predicted to be negative and most regions will suffer adverse affects from climate change. Risks from large-scale discontinuities become significant above a 3˚C temperature change.

This information was updated in the recent 'Stabilisation 2005', an International Symposium on the Stabilisation of Greenhouse Gases, held in February 2005. The conference noted changes of up to 1˚C might be beneficial for a few regions and sectors such as agriculture in mid to high latitudes. A number of new impacts were identified. One example is the recent change in the acidity of the ocean, reducing its capacity as a carbon sink. The conference highlighted that a global temperature rise of about 1.5˚C may be a threshold that triggers melting of the Greenland ice-cap. The conference concluded that serious risk of large scale, irreversible system disruption, such as changes to the thermohaline circulation, reversal of the land carbon sink and possible destabilisation of the Antarctic ice sheets is more likely above 3^{o}C.

The findings of this review are summarised in the table below.

Summary of literature on climate impacts with different temperature stabilisation scenarios.

	Within 2˚C	**>2˚C to 2.5˚C**	**>3C**
Health	Estimated an average global temperature rise > 1.2°C will increase premature mortality by several hundred thousands excluding extreme events like heat waves.	A rise of 2.3^{o}C by 2080 puts up to 270 million at risk from malaria (IS92a S>1000).	A rise of 3.3^{o}C by 2080 would put up to 330 million at risk from malaria (IS92a unmit).
Ecosystems	Up to 1°C above pre-industrial levels up to 10% of ecosystem areas worldwide will shift.	A rise of 1–2°C above pre-industrial levels will shift up to 15–20% of ecosystem areas worldwide.	Rise of > 2°C above pre-industrial levels, global share of ecosystems shifting due to climate change likely above 20%, and much more in some regions. Global losses of coastal wetlands may exceed 10%.
Agriculture	The EU (and US) yields increases for up to 2°C temperature rise, but beyond this decline.	Heat stress likely to affect subtropics/tropics for 1.7°C temperature increase.	Higher average temperatures of 2.5°C in 2080 could result in 50 million additional people at risk of hunger. With a 3^{o}C rise a group of developing countries with a population of 2 billion will see the food deficit double.
Water	For many regions under water stress, global mean temperature increases above around 1.5^{o}C lead to decreases in water supply. Additional number of people in water shortage regions in the range 400-800 million for around a 1C warming.	Above 2 to 2.5°C global average temperature increase it is projected that additional 2.4 to 3.1 billion people will be at risk of water stress	Above 2.5^{o}C warming the level of risk begins to saturate in the range of 3.1- 3.5 billion additional persons at risk.
Major events	At 1.5^{o}C onset of complete melting of Greenland Ice: when complete 7m additional sea level rise.	Above 2˚C risk of major catastrophic events. Between 2^{o}C and 4.5^{o}C potential to trigger melting of the West Antarctic Ice Sheet eventually raising sea levels by a further 5-6m.	Above 3˚C risk of major catastrophic events very significant. Over 4^{o}C the probability of thermohaline shutdown up to 50% or above.

We highlight further work in this area, providing disaggregated impacts for different stabilisation targets, is one of the major research recommendations for the future.

Valuation of Climate Change (baseline)

The project has also reviewed the estimates of the monetary benefits of climate change. A number of approaches have been used to assess the total and the marginal global costs (social costs) of greenhouse gas emissions[1]. These estimates can be used to investigate the benefits of future climate change policy, and can be compared to the costs of greenhouse gas mitigation.

A recent review of the literature of the marginal social costs of climate change has found just under 30 studies[2]. If these are combined, this provides a mean value of around Euro 25/tCO_2, and a 95th percentile of Euro 96/tCO_2[3]. Some recent studies in the literature show a trend towards lower values than these, with some studies indicating marginal benefits that are lower than the marginal abatement costs of post-Kyoto (2020) scenarios, i.e. lower than Euro 20/tCO_2, and some probably lower than Euro 12/tCO_2[4]. However, these values must be viewed with caution. Recent work[5] has reviewed these literature estimates against the all potential climate change impacts – as represented by the matrix below showing all impacts and values. The work has concluded that the current literature values only represent a sub-set of all impacts. Most studies tend to be focused on the top left hand corner of the matrix (looking at market damages from predictable events). Very few cover non-market damages, and almost none include major events. The current literature values are therefore a sub-total of the full cost of climate change.

	Uncertainty in Valuation →			
Uncertainty in Predicting Climate Change ↓		**Market**	**Non Market**	**(Socially Contingent)**
	Projection (e,g, sea level Rise)	Coastal protection Loss of dryland Energy (heating/cooling)	Heat stress Loss of wetland	Regional costs Investment
	Bounded Risks (e.g. droughts, floods, storms)	Agriculture Water Variability (drought, flood, storms)	Ecosystem change Biodiversity Loss of life Secondary social effects	Comparative advantage & market structures
	System change & surprises (e.g. major events)	Above, plus Significant loss of land and resources Non- marginal effects	Higher order social effects Regional collapse Irreversible losses	Regional collapse

Source: Downing and Watkiss, 2003.

This work also undertook additional analysis with existing climate change valuation models, and concluded that a lower central bound might result in a value of 15 Euro/tCO_2, a central illustrative estimate of 20 - 25 Euro/tCO_2, and an upper central estimate of 80 Euro/tCO_2[6] (for current, year 2000 emissions – note these estimates do not include all the impacts in the risk matrix above). The full

[1] The marginal social cost is the damage from an additional tonne of CO_2 emitted. Specifically, it is the change in the net present value of the monetised impacts, normalised by the change in emissions. This should not be confused with the total impact of climate change or the average impact (the total divided by the total emissions of carbon).

[2] This review was undertaken bv Richard Tol. The values include the original authors' use of discount rate and equity weighting. Note from his analysis, Tol concluded that marginal damage costs of carbon dioxide emissions were unlikely to exceed $50/tC (14 Euro/t$CO_2$).

[3] We have converted from USD2000 to Euro2000 ($1 = €1.0) using purchasing power parity exchange rates from 2000.

[4] These are the marginal abatement costs from post-Kyoto policies in 2020, and for Kyoto in 2012, as estimated by the ECCP.

[5] Tom Downing, Cameron Hepburn, Chris Hope, and Paul Watkiss in work for the UK Department of Environment, Food and Rural Affairs, on the Social Cost of Carbon. http://socialcostofcarbon.aeat.com/; the project final report will be available in April 2005.

[6] The authors stress that there is no single value and that the range of uncertainty around any value depends on ethical as well as economic assumptions. These indicative values are based on a declining discount rate and include equity weighting.

statistical range around these numbers was found to be much larger, and the study also concluded that it was misleading to present the numbers as single estimates due to the uncertainty in the values. The study also undertook modelling analysis of emissions in future years, and found significant increases in the values for future emissions. The analysis showed rises of 2 to 3% per year – so for example the central illustrative estimate rose from 20 – 25/tCO_2 from emissions in the year 2000 to 34 Euro/tCO_2 by 2020 (in 2000 prices).

The values from such studies are dependant on a number of key assumptions, notably the discount rate used and the aggregation approach for impacts in different regions (whether distributional weights, i.e. equity weights[7]) are used. The choice of discount rate has a very large effect on any values, because most impacts of climate change occur in the future. Similarly most impacts occur in developing countries, and so the decision on whether to equity weight or not has a significantly bearing on the results[8].

Economic Benefits of different stabilisation targets

Emerging work is starting to assess the potential benefits of different stabilisation targets. One recent study[9] has undertaken an expert consultation on the social costs of specific climate change scenarios. The scenarios included three temperature scenarios (<2˚C, 2-4˚C, >4˚C), but also included variables with respect to major events, socially contingent effects, discount rates, equity weighting, etc. Most experts believed that under conditions of low temperature change (2˚C), the marginal social costs would be low, most probably below Euro 15/tCO_2. In contrast, for high temperature change (>4 °), the expert response was that costs would be high: probably greater than Euro 30/tCO_2 and plausibly as high as 140Euro/tCO_2.

The current study has also commissioned two new pieces of work from the FUND and PAGE models, to investigate the potential benefits of different stabilisation targets. The PAGE2002 model[10] has been used to examine a number of different stabilisation targets. The results show costs of

- Euro 74 trillion from climate change under the baseline business as usual scenario for an average discount rate of 2% pure rate of time preference and including equity weighting[11], falling to
- Euro 43 trillion under a 650 CO_2 equivalent ppm stabilisation scenario, and
- Euro 32 trillion under a 550 CO_2 equivalent ppm stabilisation scenario.

The analysis has also used the FUND model to assess the potential social costs under different CO2 stabilisation levels. This analysis above shows a strong decline in the marginal social cost of current emissions with lower CO_2 stabilisation concentrations.

7 By using equity weighting, it is possible to take into account how the costs and benefits accrue to different groups in society. Policies that deliver greater net benefit to individuals in lower income groups are rated more favourably than those that benefit higher. Equity weights can therefore be used to explicitly recognise distributional effects within a policy's net present value. In the case of climate change, we are trying to recognise that vulnerable societies are likely to see significant impacts, and therefore that climate change mitigation policy will have a dis-proportionately larger benefit to these groups.

8 Most models show that at small to moderate climate change, poorer countries (Africa, India, and Latin America) are net economic losers, whereas richer countries, especially mid – Northern latitudes may actually gain. Essentially, the more weight we put on the distribution of the impacts of climate change in developing countries, the more severe the aggregate impacts are.

9 Tom Downing at the Stockholm Environment Institute (Oxford office), as part of recent work for Defra (UK).

10 Run by Chris Hope at the Judge Institute at the University of Cambridge.

11 Values are in 2000 prices. Note a trillion is a million million. This is based on a time horizon of 2200 and discounted back to a net present value. The analysis for a business as usual run is based on the A2 scenario. The model has also assessed 550 ppm and 450 ppm CO_2 concentrations levels. The value of a 2% PRTP is broadly consistent with the current EC recommended discount rate of 4% social rate of time preference (assuming average GDP per capita growth of 2%). Note the use of lower discount rates, or declining discount rate schemes would give higher values than presented – the use of higher discount rates would give lower values. For equity weighting an elasticity of utility with respect to consumption of minus 1 has been used. Again the use of different assumptions on equity weighting would give different values.

Adaptation costs

The study has briefly considered adaptation. There is an emerging view that planning for climate change adaptation should begin as soon as possible because anticipatory and precautionary adaptation is more effective and less costly than forced, last minute, emergency adaptation or retrofitting (EEA 2004). The ability of human systems to adapt to and cope with climate change depends on such factors as wealth, technology, education, information, skills, infrastructure, access to resources and management capabilities (TAR 2001). Developing countries have less of these attributes and as a result have a lesser capacity to adapt and are more vulnerable to climate change impacts. Reviews of climate change adaptation work[12] have shown that climate change costing studies often pay little attention to adaptation costs and further research would increase the reliability of adaptation cost estimates.

Ancillary effects

There is growing recognition that mitigation policies or scenarios that are aimed at reducing greenhouse gas emissions may have important ancillary benefits. These potentially include:

- Reductions in air pollution;
- Reductions in other environmental burdens;
- Increased security of energy supply (and/or energy diversity), including reduced oil imports;
- Improved competitiveness;
- Increased employment;
- Innovation.

Whilst the full benefit of greenhouse gas reductions resulting from further climate action may only be experienced by future generations, the ancillary benefits of climate policy will accrue to the current generation. However, there have also been concerns that policies may lead to potential dis-benefits, with some literature referring to:

- Impacts on trade and competitiveness (note this is also mentioned as a potential benefit above);
- Decreases in employment (again, this is also mentioned as a potential benefits above);
- Lifestyle changes;
- Security and proliferation with specific technology options (nuclear).

The study has reviewed the available information on ancillary effects. From this, we conclude that the air quality benefits of GHG mitigation are likely to amount to a substantial benefit. A recent study (Defra, 2002) found 20 estimates of the monetary value of ancillary benefits in the literature. The estimates range from 1 Euro to 130 Euro/tCO_2 reduced, with an average from across the studies of 27 Euro/tCO_2.

It is also likely that many low carbon technologies will have ancillary benefits from reducing dependence on imports and increasing energy security. This is due to the likely increase in renewables, nuclear generation, coal generation with sequestration, as well as improvements in energy efficiency. The effects of policies on employment, trade and competitiveness remain the subject of much debate. These issues will be examined later in the study through the use of the GEM-E3 model.

Ancillary effects are important, and should be factored into the analysis of future climate change policies. However, to assess these impacts properly, the ancillary effects need to be assessed and reported separately, as they will vary with the exact policies and measures implemented.

[12] Climate Change Impacts and Adaptation: A Canadian Perspective, Natural Resources Canada 2004 http://adaptation.nrcan.gc.ca/perspective/profile_e.asp

Conclusions

The review has shown that the impacts of climate change and their economic costs are significant. Initial assessment of the benefits of stabilisation targets shows that many of the major effects of climate change could be avoided, and the benefits of post-Kyoto policies could be very significant in terms of reductions in impacts and social costs. There is also the major benefit of reducing the risk of major catastrophic events.

The review here has shown that the information on impacts and economic costs is increasing. However, there remain major information gaps and further research is needed to improve the information available to fully assess the benefits of policies. From the information available, we believe that monetary valuation of climate change policies is possible, and should be taken forward. However, we also believe that care must be taken in presenting and interpreting the monetary estimates, for example by avoiding the use of single simplistic estimates: given the uncertainty over future scenarios and impacts, monetary valuation, and ethical and moral issues, there is no 'single' estimate of the social costs of climate change. Further to this, we make a number of additional recommendations that would improve the analysis presented here.

- Firstly, we recommend that work is undertaken to present a more disaggregated analysis of the physical impacts of climate change, and the benefits of future policy.
- Secondly, we recommend that more disaggregated information is presented on the economic valuation of climate change, showing the balance of positive and negative economic effects (winners and losers) by impact category and region, rather than using single aggregated global values.
- Finally, we recommend that the analysis of future policies should consider full sensitivity and uncertainty analysis, along with the information of key impacts, to allow the comparison of benefits against the possible costs of future mitigation policies.

To progress these areas, we recommend a number of specific research conclusions:

First, some further work with the integrated assessment models:
- Additional model runs with PAGE and FUND would be useful to test different future policies (towards stabilisation targets for CO_2 equivalents of 400 ppm, 450 ppm, etc), with different assumptions relating to baselines, discount rates, equity weighting, and uncertainty analysis in relation to climate sensitivity. This should include analysis of long-term benefits, but also the specific benefits that would accrue from policies implemented between 2010 and 2025.
- It would also be extremely useful to run the models to look at the marginal social costs of climate change in different time periods, and for different pollutants (e.g. CO_2, CH_4, N_2O).

Secondly, to complement (and validate) the global assessments with detailed sectoral studies and regional integrations:
- To undertake some further analysis to progress a disaggregated analysis of the estimates by region (including Europe vs. international, and with the latter split by region). This would include disaggregating the model outputs (e.g. from FUND and PAGE), but also comparing these estimates to others in the literature from the regional studies.
- To undertake some further analysis to progress a disaggregated analysis of the estimates by impact category (e.g. health mortality cases, changes in agricultural production in tonnes, etc). This would include dis-aggregating the model outputs, but also comparing these estimates to others in the literature from the regional studies.
- There is a general need for the models to move towards more dynamic analysis of assessment, both for impact assessment (the dynamic processes of vulnerability and adaptation) and valuation.

Thirdly, to explore the main elements in the risk matrix (above) that are not well captured currently:
- To extend the analysis of bounded risks (e.g. in relation to floods, storm damage) and non-market valuation (e.g. health and ecosystems).

- To undertake scoping studies to assess the potential magnitude of major events, e.g. Greenland ice sheet, etc. Some preliminary work has been undertaken, but this is a major area for future studies to focus, both for the timing of events (and relationship with different stabilisation levels) and the impacts. These are likely to have a major impact on the values.
- Similarly, to progress the understanding of, and potential magnitude of socially contingent impacts, particularly looking at specific hot-spots such as Africa, Bangladesh, low lying islands.

Finally, a number of additional aspects:

- To further the analysis of adaptation costs. Both FUND and PAGE include adaptation, and it would be useful to separate out adaptation and damage costs. It would also be useful to undertake a wider review and analysis of the literature on adaptation costs.
- Finally, work to bring all the impact and valuation data together in a form useful for policy analysis (i.e. a multi-analysis framework). We believe that future policy considerations will need to balance impact analysis, monetary benefits, and work with significant uncertainty and sensitivity analysis to allow informed decisions. There is a need to develop a framework to maximise the usefulness of all the information for policy makers.

Contents

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Introduction

The effects of global climate change from greenhouse gas emissions (GHGs) are diverse and potentially very large.

The IPCC Third Assessment Report (IPCC, 2001) outlines the potential effects of climate change. It presents an increasing body of observations that give the picture of a warming world and changes in global and regional climate systems. Taking 1990 as the baseline, the current models project the following key climate change impacts by 2100.

- Global average temperature is predicted to rise by 1.4 to 5.8°C over the period to 2100 (temperatures rose by +0.6 °C in the 20th Century);
- Globally precipitation increases, but with regional increases and decreases of typically 5 to 20% in annual average rainfall;
- Sea levels rise by 0.09 to 0.88 m;
- Extreme events such as drought and severe storms are more likely;
- Beyond 2100 major changes in the climate system (e.g. alteration of North Atlantic Circulation, collapse of West Antarctic Ice Sheet) become more likely if climate change is not stabilised.

These changes will lead to major impacts on biodiversity and ecosystem services, on economic activities and on human health and welfare (including the loss of life and forced migration) with associated implications for international equity.

Traditionally the policy debate on climate change has focused on the costs of mitigation, i.e. how much it will cost to reduce greenhouse gas emissions in order to avoid climate change. This paper focuses on the impacts and economic costs to society from climate change actually occurring[13]. These costs represent the benefits of climate change policy and can be compared against the costs of greenhouse gas emission mitigation.

Policy Background

The EU is committed to providing leadership in the field of climate change and, as such, a key priority is contributing to global climate stabilisation efforts beyond 2012. As part of this priority, the EU needs to identify an emission reduction target up to 2030 and indicative targets beyond[14]. Different emission reduction strategies and/or different post-Kyoto targets will need to be evaluated in order to prepare for:

- The Commission Report to the Spring Council 2005;
- Negotiations on future commitments at international level.

In order to balance the climate policy debate, the Commission requires the benefits of climate change mitigation policies to be evaluated. Quantified benefits will ensure a more even judgement of policy impacts against the widely reported costs of implementing the policies. Monetised avoided impact benefits, estimated globally, but with a focus also on the European scale, will enable fully informed

[13] The economic costs to society of climate change are also known as the social cost of climate change (and sometime the social cost of carbon (the SCC)).

[14] '*Council believes that global average temperatures should not exceed 2 degrees above pre-industrial level and therefore concentrations lower than 550ppm CO_2 should guide global limitation and reduction effort*'. Council meeting, Luxembourg, 25 June 1996.

'*Council…acknowledges that to meet the ultimate objective of the UNFCC to prevent dangerous anthropogenic interference with the climate system, overall global temperature increase should not exceed 2˚C above pre-industrial levels'*. Spring Council meeting of 2004 policy making. This report summarises the available state of the knowledge on benefits, both in terms of impacts and economic effects, to provide support to the Commission. The paper is the output from task 1 of the project '*Modelling Support for Future Actions – Benefits and Cost of Climate Change Policies and measures'*, ENV.C.2/2004/0088, led by K.U.Leuven, Katholieke Universiteit Leuven.

The aim of the wider project is to provide consistent analytical materials and modelling capacity for an analysis of benefits and costs of mitigation efforts, in order to support DG Environment in its report to the Spring Council 2005 and in its future international negotiations on climate change. More specifically, the project will contribute to these aims through the following objectives:

- Providing a transparent review and assessment of the major damages from the impacts of climate change at European and global level;
- Quantifying the costs of individual damages in order to provide monetised benefits of avoided damages from action to mitigate climate change;
- Quantifying the ancillary benefits of further climate action;
- Providing policy simulations concerning future commitments at European and World level with the general equilibrium models GEM-E3-World and GEM-E3-Europe.

This report addresses the first three of these objectives, which make up task 1 of the project. It has undertaken a rapid review[15] of the literature to estimate the likely impacts of climate change and assesses the importance of each impact to determine a set of 'major damages'. It then reports on a rapid review of the information on the economic costs of climate change. Finally, it has undertaken a rapid review of the ancillary benefits of greenhouse gas mitigation policies.

[15] The work was undertaken during a short period during November 2004, as an input to the European Commission for it's Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions 'Winning the Battle Against Climate Change (SEC(2005)180. Published at *http://europa.eu.int/comm/environment/climat/pdf/staff_work_paper_sec_2005_180_3.pdf*

Review of the Impacts of Climate Change

The paper has undertaken a rapid review of the potential impacts of future climate change. The study has drawn on a number of key documents, notably the IPCC Third Assessment Report and recent work by the European Environment Agency, but has supplemented these with a wider review of other studies in the literature that focus on specific impacts or regions.

Impacts of Climate Change

The third assessment report sets out the potential impacts from climate change variability and events. The summary of effects is shown in the table below.

Table 1. Examples of climate variability and extreme climate events and examples of their impacts (IPCC 2001, Synthesis Report, WGII TAR SPM).

Projected changes during the 21st century in extreme climate phenomena and their likelihood	**Representative examples of projected impacts (all high confidence of occurrence in some areas)**
Higher maximum temperatures, more hot days and heat waves over nearly all land areas (*very likely*)	Increased incidence of death and serious illness in older age groups and urban poor. Increased heat stress in livestock and wildlife. Shift in tourist destinations. Increased risk of damage to a number of crops. Increased electric cooling demand / reduced energy supply reliability.
Higher (increasing) minimum temperatures, fewer cold days, frost days and cold waves over nearly all land areas (*very likely*)	Decreased cold-related human morbidity and mortality. Decreased risk of damage to a number of crops, and increased risk to others. Extended range and activity of some pest and disease vectors. Reduced heating energy demand.
More intense precipitation events (*very likely,* over many areas)	Increased flood, landslide, avalanche, and mudslide damage. Increased soil erosion. Increased flood runoff could increase recharge of some floodplain aquifers. Increased pressure on government and private flood insurance systems and disaster relief.
Increased summer drying over most mid altitude continental interiors and associated risk of drought (*likely*)	Decreased crop yields. Increased damage to building foundations caused by ground shrinkage. Decreased water resource quantity and quality. Increased risk of forest fire.
Increase in tropical cyclone peak wind intensities, mean and peak precipitation intensities (*likely,* over some areas)	Increased risks to human life, risk of infectious disease epidemics and many other risks. Increased coastal erosion and damage to coastal buildings and infrastructure. Increased damage to coastal ecosystems such as coral reefs and mangroves.
Intensified droughts and floods associated with El Niño events in many different regions (*likely*)	Decreased agricultural and rangeland productivity in drought- and flood-prone regions. Decreased hydro-power potential in drought-prone regions.
Increased Asian summer monsoon precipitation variability (*likely*)	Increase in flood and drought magnitude and damages in temperate and tropical Asia.
Increased intensity of mid-latitude storms (little agreement between current models)	Increased risks to human life and health. Increased property and infrastructure losses. Increased damage to coastal ecosystems.

In Europe, more recent work by the EEA has outlined the past trends and likely future effects ('Impacts of Europe's Changing Climate, An indicator-based assessment, EEA Report No 2/2004').

The tables below present past trends in Europe's climate, its current state and project possible future changes.

Table 2. Past climate change impacts at a European Level (Source: EEA 2004)

Change in state of environment	Examples of reported impacts	Quantified impact
Weather and climate extremes	• Catastrophic events: floods, storms, droughts, heatwaves	• In Europe 64% of catastrophic events since 1980 are directly attributable to weather and climate extremes.
Weather and climate extremes	• Catastrophic events: landslides and avalanches, caused by weather and climate	• In Europe, 25% of catastrophic events since 1980 attributable to landslides and avalanches.
Weather and climate extremes	• Economic losses from catastrophic events result from these weather and climate extremes (see 2 rows above).	• 79% of economic losses caused by catastrophic events result from weather/climate extremes
Weather and climate extremes	• Deaths from catastrophic events result from these weather and climate extremes.	• 82% of deaths caused by catastrophic events result from weather/climate extremes (Wirtz 2004)
Trends in weather and climate extremes	• Weather and climate related disastrous events	• Annual average frequency of events doubled in 1990s compared to 1980s (non climatic events, earthquakes etc, remained stable)
Past trends in weather and climate extremes	• Weather and climate related disastrous events causing economic losses	• In Europe economic losses from climate and weather related events increased in last 20 years from an annual average below USD 5 billion to USD 11 billion
Disastrous event - flooding	• Severe flooding in central Europe, August 2002	• AT, CZ, GE, SK, HU suffered economic losses of USD 17.3 billion & insured losses of USD 4.1 billion
European air temperature Europe warmed more than global average. 0.95 ^{o}C increase since 1990. Temperatures in winter increased more than those in summer. Greatest warming in northwest Russia and Iberian Peninsula.	• Increase in tick borne diseases from higher temperatures – TBE and Lyme disease (Lyme borreliosis)	• Increase in tick-borne encephalitis (TBE) in Baltic region and central Europe between 1980-1995. • 85,000 cases of Lyme borreliosis reported annually in Europe
European precipitation past trends Annual trends show northern Europe 10-40% wetter	• Increase in the number of very wet days in central and northern Europe.	• Annual precipitation increase in northern Europe by 10-40% during 1900-2000 leading to increased flooding and landslides.
European precipitation past trends Annual trends show southern Europe up to 20% drier. Precipitation decrease in summer of up to 5% per decade in southern Europe.	• Severe effects such as more frequent droughts, with considerable impact on agriculture and water resources.	• Droughts of 1999 caused losses of more than Euro 3 billion in Spain.
Past glacier retreat Glaciers in eight out of the nine European glacier regions are in retreat, which is consistent with the global trend. From 1850 to 1980, glaciers in the	• During the melting process, there is an increase in the number of hazardous incidents such as breaking glacier lakes, falling ice and landslides. • Incidents may also cause	• The hot dry summer of 2003 led to a loss of 10 % of the remaining glacier mass in the Alps.

Change in state of environment	Examples of reported impacts	Quantified impact
European Alps lost approximately one third of their area and one half of their mass. Since 1980, another 20–30 % of the remaining ice has been lost Current glacier retreat in the Alps is reaching levels exceeding those of the past 5 000 years.	infrastructure damage. • Glacier retreat affects tourism and winter sports in the mountains and reduces the attractiveness of mountain landscapes. • Changes in the water cycle are leading to a reduced supply of drinking water, weakening irrigation and curbing the generation of hydropower.	
Snow cover The northern hemisphere's annual snow cover extent has decreased by about 10 % since 1966. The snow cover period in the northern hemisphere land areas between 45 °N and 75 °N shortened by an average rate of 8.8 days per decade between 1971 and 1994.	• Altered river discharge • Impacts on vegetation (snow insulates) • Altered wildlife migration patterns • Adverse affect on snow sports and winter tourism • Adverse effect on hydro electric generation based on melt water • Benefits – reduced complications in road and rail maintenance, improved transport	• For every 1 °C increase in temperature, the snowline rises by about 150 metres.
Precipitation extremes The frequency of very wet days significantly decreased in recent decades in southern Europe, but increased in mid and northern Europe.	• Increased incidence of flooding. Number of flood events in Europe clearly increased during 1975-2001.	• Between 1975-2001, 238 flood events were recorded in Europe.
Temperature extremes Over last 100 years the number of cold and frost days has decreased in most of Europe.	• Decreased number of human deaths from cold. • Decreased number of bird deaths.	• Survival of some European bird species wintering in Europe increased between 2 % and 6 % per 1 °C rise in winter temperature
Temperature extremes Over the last 100 years the number of days over 25^{o}C (summer days) and of heatwaves has increased in most parts of Europe.	• Heatwaves are projected to become more frequent and more intense during the twenty first century and hence the number of excess deaths due to heat is projected to increase in the future.	• See 2003 Heatwave
Summer 2003 Heatwave	• Reduced crop yield	• During 2003 heatwave, many southern European countries suffered drops in crop yield of up to 30% (some of northern Europe profited from higher T and lower rainfall)
Summer 2003 Heatwave	• Deaths from heat.	• More than 20,000 excess deaths attributable to heat, particularly in aged population, in Western and Southern Europe

Table 3. Projected Climate Change Impacts at a European Level (Source: EEA 2004)

Change in state of environment	Examples of projected impacts	Quantified impact
Higher CO_2 concentrations Total rise of 170ppm CO_2-equiv since pre-industrial era (of which 61% CO_2). If no climate driven policies implemented an increase to 650 – 1215 ppm CO_2-equiv projected by 2100.	• Agriculture in most parts of Europe (esp. mid and northern Europe) is expected to potentially benefit from increasing CO_2 concentrations and rising temperatures • Cultivated area could be expanded northwards • Earlier sowing dates and increased crop yields (if sufficient water supply) • Any direct yield gain caused by increased CO_2 could be partly off-set by losses due to changes in the spatial distribution and intensity of pests and diseases (IPCC, 2001).	• Estimations show yield increases of 9 % to 35 % for wheat by 2050 (Hulme et al., 1999) • Largest increases in yield in southern Europe, particularly northern Spain, southern France, Italy and Greece. Also, large yield increases (3–4 t/ha) may occur in Scandinavia • In the rest of Europe, yields could be 1–3 t/ha greater than at present • Crop sowing date could be brought forward, e.g. 5 to 25 days earlier for wheat (Harrison et al., 2003).
Higher temperatures The rate of global warming in Europe of 0.1-0.2 ^{o}C has already been exceeded or will be exceeded within the next few decades (temperature in winter increases more than in summer). The EU target of limiting global temperature increase to 2^{o}C over pre-industrial levels is likely to be exceeded in ~2050.	• Survival rate of most bird species is likely to increase due to warmer winters • Average annual growing season will lengthen • Increased vegetation growth will be counteracted by water shortage • Likely to be reduced carbon sequestered in European terrestrial biosphere • Mountain species to be replaced by more competitive tree and shrub species, giving considerable loss of endemic species in mountain regions • In the long term, the area suitable for agriculture will shift northwards.	• Growing season lengthened by ~10 days between 1962-1995 and will increase further • Upwards species migration in the Alps (plant species richness increased in 21 out of 31 summits)…this will cause endemic mountain species to decline • For Scandinavia, it is projected that there will be a 40–60 % reduction of the current mountain vegetation area (Holten and Carey, 1992) • In Finland, the agricultural area could expand northwards by 100–150 km per 1 °C temperature rise (Carter and Saarikko, 1996)
European air temperature From 1990 to 2100 European average temp increase by 2 - 6.3^{o} C for Europe (without policy measures).	• Increase in tick borne diseases from higher temperatures – TBE and Lyme disease (Lyme borreliosis).	• Increase in tick-borne encephalitis (TBE) in Baltic region and central Europe. 85,000 cases of Lyme borreliosis currently reported annually in Europe.
Sea level rise Projected rate of sea level rise 1990-2100 is 2.2 to 4.4 times higher than the rate in the 20th century, sea level projected to rise for centuries. (Europe's rate of sea level rise in 20th century 0.8mm/year to 3mm/year) Under the range of the six SRES scenarios (IPCC, 2001a) and a calibrated global climate/ocean model, a sea level rise of 0.09–0.88 metres has been projected for 1990 to 2100, with a central value of 0.48m	• Sea level rise will cause flooding, coastal erosion and the loss of flat coastal regions. • Rising sea level increases the likelihood of storm surges, landward intrusion of salt water and endangers coastal ecosystems and wetlands. • Higher flood risk increases the threat of loss of life and property as well as of damage to protection measures and infrastructure, and might lead to an increasing loss of tourism, recreation and transportation functions.	• After 500 years, sea level rise from the thermal expansion of oceans may have reached only half its eventual level, glacier retreat will continue and ice sheets will continue to react to climate change. *Sea gradually rising around Europe; In the European Union, the coastline is about 89,000 km long and 68 million people could be affected by sea level changes.(EC 1997)*
Future trends in catastrophic events – storms, floods and droughts Increase in frequency, intensity and altered distribution of events due to climate change.	• Increased risk of high economic losses, increased vulnerability of insurance sector. • Property, casualty insurance and reinsurance face greater risks. • Smaller companies risk bankruptcy. • Flash floods will be more frequent and these have a high risk of fatality	• Annual average economic losses from weather and climate related events now at an annual average of ~USD 11 billion (risen from USD 5 billion 20 years ago due to increased wealth and more frequent events)

Change in state of environment	Examples of projected impacts	Quantified impact
Future Glacier retreat Very likely that the glacier retreat will continue.	• The ongoing retreat of glaciers will adversely affect summer skiing in glacier regions and therefore reduce tourism and its economic benefits in these regions (Bürki et al., 2003). • Furthermore, it might have adverse impacts on regional water resources.	• By 2050, about 75 % of the glaciers in the Swiss Alps are likely to have disappeared.
European precipitation future trends Average (land and ocean) precipitation is projected to increase by 2–7 % between 1990 and 2100 (IPCC, 2001a). Projections for Europe: • more annual precipitation for northern Europe (increase of 1–2 % per decade) • Winter - Europe is likely to become wetter (1–4 % per decade, exc Balkans &Turkey) • Summer – Northern Europe wetter (up to 2 % per decade)	• Amplified changes in annual river discharge – increase in all parts of northern and north Eastern Europe. • Decreased river discharge in southern and south Eastern Europe.	• By 2070, river discharge is expected to decrease by up to 50% in southern and SE Europe, and to increase by up to 50% or more in most parts of northern and NE Europe. • As a result, stress on water resources may continue to grow significantly in southern Europe.
European precipitation future trends Summer - Southern Europe up to 5 % drier per decade Decreasing trends in precipitation levels for southern Europe (max – 1 % per decade)	• Severe impacts on agriculture and water resources as moisture availability is already often limited in summer. • Amplified changes in annual river discharge – decline strongly in southern Europe	• Reduced crop yield in hotter and dryer areas.
Future trends in droughts It is likely that, by 2080, droughts as well as intense precipitation events will become more frequent.	• Bad harvests become more common	
Future trends in hot summers Cold winters are projected to disappear almost entirely by 2080 and hot summers are projected to become much more frequent.	• Heat waves will be more frequent and more intense in the number of excess deaths due to heat is projected to increase. Fewer cold spells will reduce winter deaths.	• Over 20,000 excess deaths from heat in W and S Europe summer 2003
Artic sea ice future trends Increase in global temperature.	• Decrease in the maximum ice thickness of about 0.06 metres per °C. • Increase in open water duration of about 7.5 days per °C (IPCC, 2001). • Sea ice extent by 2050 might be about 80 % less than in mid-twentieth century	• Sea ice may disappear in summer by the end of this century (Johannessen, 2002).
Snow – future trends Increase in temperature over Europe. European Alps and Pyrenees are likely to experience milder winters with more precipitation, and hotter, drier summers (Beniston et al., 1995).	• Regions currently receiving snowfall will increasingly receive precipitation in the form of rain. For every 1 °C increase in temperature, the snowline rises ~ 150 metres. There could be greater snow accumulation in regions above the freezing line due to increased snowfall (IPCC, 2001a). • Conditions are likely to reduce snow cover on low mountains. In temperate mountain regions, snow temperature is close to melting point and sensitive to changes in temperature.	• Snowfall in lower mountain areas will be increasingly unpredictable and unreliable over coming decades (Bürki et al., 2003). • Nearly half of all ski resorts in Switzerland, and even more in Germany, Austria and the Pyrenees, will face difficulties in attracting tourists and winter sport enthusiasts.

The main categories of impacts have been described below, and relevant key indicator data for Europe and also the world.

Sea level rise

By 2100, sea level rises of 0.09 to 0.88 metres, with a central value of 0.48m, is predicted to occur[16]. Sea level rise will cause flooding, coastal erosion and the loss of flat coastal regions. Coastal protection is possible, though this leads to additional costs. Rising sea levels increases the likelihood of storm surges, enforces landward intrusion of salt water and endangers coastal ecosystems and wetlands. Estimates in the European Union, where the coastline is about 89,000 km long, indicate some 68 million people could be affected by sea level changes (EC 1997).

At a global level, the effect is potentially more extreme. Populations that inhabit small islands and/or low-lying coastal areas (e.g. small island states such as the Maldives, the Bangladesh delta) are at particular risk of severe social and economic effects from sea-level rise and storm surges. The loss of these areas (e.g. for those living on small island states) will have potentially important secondary effects through migration and potential socially contingent effects.

Energy

Higher average temperatures are predicted in Europe, with both warmer summers and winters. There is also likely to be changes in seasonal temperature variability, with increased summer peaks (heat waves) (EEA 2004). The changes in average and peak temperatures will have positive and negative effects on energy use. There is likely to be a decrease in winter energy demand for heating, but this will be offset by an increase in summer energy use for cooling (air conditioning). The pattern of changes in energy use will vary across Europe, with northern latitudes likely to experience more benefits. Changes in energy use will also occur at a global level.

Health: thermal stress

More than 20 000 excess deaths attributable to heat, particularly among the aged population, occurred in western and southern Europe during the summer of 2003. Heat waves are projected to become more frequent and more intense during the twenty-first century and hence the number of excess deaths due to heat is projected to increase in the future[17]. However, rising temperatures will reduce winter excess deaths (and at present the cold leads to far more deaths than the heat). This will have particular benefits in northern latitudes of Europe. By 2080 in Europe, it is likely that cold winters will have almost entirely disappeared (EEA 2004).

Health: disease burden

In Europe tick-borne encephalitis cases increased in the Baltic region and central Europe between 1980 and 1995, and have remained high (EEA 2004). Ticks can transmit a variety of diseases, such as tick-borne encephalitis (TBE) and Lyme disease (in Europe called Lyme borreliosis). It is not clear how many of the 85 000 cases of Lyme borreliosis reported annually in Europe are due to the temperature increase over the past decades.

Recent work on climate change and human health risk and responses (McMichael et al, 2003) has looked at disease risk at a global level. They estimate:

- In 2030 the estimated risk of diarrhoea will be up to 10% higher in some regions than if no climate change occurred.
- Estimated effects on malnutrition will vary markedly among regions. By 2030, the relative risks for unmitigated emissions, relative to no climate change, vary from a significant increase in the South- East Asia region to a small decrease in the Western Pacific. Overall, although the estimates of changes in risk are somewhat unstable because of regional variation in rainfall, they refer to a major existing disease burden entailing large numbers of people.

[16] IPCC Third Assessment Report (2001).

[17] Impacts of Europe's changing climate An indicator-based assessment EEA Report No 2/2004

- The estimated proportional changes in the numbers of people killed or injured in coastal floods are large, although they refer to low absolute burdens. Impacts of inland floods are predicted to increase by a similar proportion, and would generally cause a greater acute rise in disease burden. These proportional changes are much higher in developing countries.

At a global level, the rising temperatures will put many additional people at risk of suffering from diseases like Malaria, dengue and schistosomiasis. For instance it is projected that a 2°C increase will result in 210 million people more at risk of malaria and an epidemic potential rise of 30-50% for dengue.

Climate variability is often a cause of health impacts and extreme weather events are likely to increase with carbon dioxide concentrations. Recent research indicates that much of the occurrence of climate related disease outbreak is caused by specific weather events, in combination with non-climate factors. More analysis is needed from the new climate models, though in some cases the relationship between climate and disease is clear e.g. diarrhea incidence in Peru increases by about 8% per degree C temperature rise (Stabilisation 2005).

Agriculture

Parts of Europe, particularly mid and northern Europe, are expected to have potential benefits to agriculture from increasing CO_2 concentrations and rising temperatures. The cultivated area could be expanded northwards, and growing seasons extended (EEA 2004). This will lead to increased crop yields (provided there is sufficient water supply). In southern parts of Europe, over the longer term, agriculture may be threatened by climate change due to increased water stress, with reduced yields in hotter and dryer areas. During the heat wave in 2003, many southern European countries suffered drops in yield of up to 30%, while some northern European countries profited from higher temperatures and lower rainfall. Bad harvests could become more common due to an increase in the frequency of extreme weather events (droughts, floods, storms, hail). There is also the possibility that any direct yield gain could be partly off-set by losses due to changes in the spatial distribution and intensity of pests and diseases.

Global projections[18] estimate EU (and US) yield increases for up to 2°C temperature rise, but beyond this yield declines. But in subtropics/tropics damages from increased heat stress are already projected for 1.7°C temperature increase. Higher average temperatures of 2.5°C in 2080 could result in 50 million additional people at risk of hunger.

The IIASA/FAO assessment of agriculture over the next century (Fischer *et al.* 2001) concluded that developing countries are net losers from the effects of global warming on agricultural production. Accounting for land suitability, population growth and other factors and a climate change scenario that brings around a 3°C warming in the 2080s, developing countries as a group suffer production losses. A large group of about 40 developing countries with a current population of 2 billion people, including around 450 million undernourished inhabitants, is projected to lose substantially, whilst about half of developing countries gain. Details of the projections for the group of developing countries experiencing malnourishment problems are found below. The 78 countries presently at some level of risk are divided into three groups, based on the proportion of undernourished people in each country.

[18] Sources: Parry 1999, Hare 2003, IPCC TAR

Table 4. Malnourished country group and climate change for approx 3°C warming in the 2080s (ECHAM4)

Group	Population	Proportion of population undernourished	Number of countries in group	Number of countries negatively affected	Impact
I 5-20% undernourished	2.1 billion	12%	28 Includes China	11	-10% decrease in cereal production. China gains
II 20-35% undernourished	1.5 billion	25%	27 Includes India with 60% of the undernourished	19 with over 80% of undernourished	Food deficit doubled
III More than 35% undernourished	440 million	50%	23 Most sub-Saharan African countries	10	Decrease in production 6 gain substantially

Source: Hare (2003). *Compiled from Fischer et al. (2001).*

Based on the future climate scenario of 3°C warming by the 2080s the majority of developed countries will experience negative impacts on cereal production. According to the ECHAM4 climate scenario, 3°C warming by the 2080s results in projected declines in cereal production, although at a world average level the volume of production is estimated to be sufficient to meet future needs. Developed countries as a whole are projected to experience a small loss in rain-fed cereal production. Within this group 17 developed countries gain, though only two countries, Russia and Canada, enjoy 90% of the gain. The majority of the group, encompassing 60% of the population of the developed country group, are projected to lose under this scenario of a 3°C temperature rise by the 2080s (Fischer *et al.* 2001). The effects are more severe for developing countries, as shown in the table below, where three climate models all predict that 3 billion or more people in developing countries will suffer significant reductions in cereal production. These badly affected countries will lose 5% or more of cereal production from the 3°C rise.

Sixty five developing countries are projected to experience agricultural production losses valued at US$56 billion in 1995 terms. These losses equate to 16% of the agricultural GDP of these countries (Fischer *et al.* 2001). Africa appears to be the biggest loser in these scenarios, with 29 countries projected to suffer production losses. Kenya and South Africa are, however, projected to gain substantially from climate change. In Asia, China gains substantially whilst India loses (Fischer *et al.* 2001). Overall Fischer *et al.* (2001) identify 40 "losing countries" with a total population close to 2 billion and an undernourished group of about 450 million. In these countries the gap between food production and supply is projected to double under climate change, "drastically" increasing the number suffering from under nourishment (Fischer *et al.* 2001).

Table 5. Developing country changes in rain fed cereal production potential 2080s for three climate models

Climate Model	Number of countries			Projected population 2080 (billions)			Change in cereal production potential (million tons)			
	G[a]	N	L	G	N	L	G	N	L	Total
ECHAM4	40	34	43	3.1	0.9	3.7	142	–2	–117	23
HADCM2	52	27	38	3.2	1.2	3.3	207	3	–273	–63
CGCM1	25	26	66	1.1	1.1	5.5	39	3	-268	–226

Source: Fischer *et al.* (2002). Notes: a. G = countries gaining +5% or more; N = small change of –5 to +5%; L = countries losing – 5% or more. This tables shows the number of developing countries projected to experience gains, no change or losses in cereal production potential on current cultivated land and potentially cultivatable and in the 2080s. ECHAM 4 refers to the AOGCM of the Max Planck Institute for Meteorology, HadCM2 to that for the Hadley Centre in the UK and CGCM1 to that of the Canadian Climate Modeling Centre.

Ecosystems
There are likely to be significant effects on ecosystems in Europe from climate change. For some species, there may be benefits from warmer winters from modest levels of climate change, for example with the survival rate of most bird species likely to increases, and potential benefits from increases in vegetation growth. However, there are also likely to be significant impacts, particularly for sensitive species such as alpine and mountain plant species and vegetation. There are also potential impacts from water shortages, especially if combined with high summer temperature peaks.

Significant impacts on ecosystems and water resources are likely with a temperature rise of between 1-2°C above pre-industrial levels, and the risks of net negative impacts on global food production occur with between 2-3°C global warming. Recent studies[19] indicate that a rise of up to 1°C above pre-industrial levels will cause up to 10% of ecosystem areas worldwide to shift. Some forest ecosystems will exhibit increased net primary productivity, increased fire frequency and pest outbreaks. Some hotspots with high biodiversity and protected areas of global importance will begin to suffer first from climate-change induced losses. Coral reefs will suffer increased bleaching. Range shifts of species and higher risks for some endangered species are likely. Most of these impacts can already be observed today.

A rise of 1–2°C above pre-industrial levels will shift up to 15–20% of ecosystem areas worldwide. Some protected areas of global importance and hotspots are likely to suffer severe losses of both area and species. Wildlife in arctic ecosystems will be harmed e.g. polar bear, walrus. Bleaching events are likely to be so frequent that coral reef recovery will be insufficient to prevent severe losses of biodiversity. For a rise of more than 2°C above pre-industrial levels, the global share of ecosystems shifting due to climate change is likely to be above 20%, and much more in some regions. Global losses of coastal wetlands may exceed 10%. At a global scale, reefs will undergo major disruptions and species loss, but will possibly not disappear completely. A large number of species will be endangered by range shifts. There is a risk that some protected areas of global importance will lose most of their area due to climate change.

There has been some work on the various ecosystem impacts under different temperature changes (Leemans and Eickhout, 2004). The key results are shown in the table below.

Table 6. Ecosystem impacts under different temperature change

Impact/ adapt	**1°C increase in global mean temperature**	**2°C**	**3°C**
% area of ecosystems affected	10.5	16	22
% total of nature reserves affected	10	19	30
% of strict nature reserves affected	9	18	26
% area of the affected ecosystems that can adapt	52	44	30
% total of affected nature reserves that can adapt	50	39	27
% of affected strict nature reserves that can adapt	49	38	24

Table constructed from Fig 4 from Leemans and Eickhout (2004) Impact and adaptations of all ecosystems, all nature reserves and structure nature reserves. For a global mean temperature increase of 1, 2 and 3 °C based on HADCM2. Numbers extracted visually from graph.

Leemans and Eickhout (2004) report some emerging benefits of climatic warming. Benefits from temperature increase are only realized when an ecosystem responds immediately by dispersing into

19 WBGU : Climate Protection Strategies for the 21st Century: Kyoto and beyond Special Report; Berlin 2003

new areas after a change in mean temperature. This is only the case for rapidly adapting ecosystems such as deserts and grasslands but is not true of forest ecosystems.

The study also reports that the adaptive capacity of forests rapidly declines at increasing global mean temperature increases. In ecosystems, many species, such as trees, have long lifetimes and limited dispersal capacities. For example, the maximum dispersal rate of common tree species is less than 100km per century.

At a rate of warming of 0.1^{O}C per decade (i.e. 1^{O}C GMTI in 2100), 50% of all impacted ecosystems are able to adapt within a century but only 36% of all impacted forests. Even when no additional increase in temperature is assumed, this percentage of ecosystems able to adapt increases only slowly when simulations continue beyond 2100. The adapted areas encompass immediate shifts along current ecosystem boundaries and ecosystems that can easily adapt, such as grasslands. Further spread of adapted ecosystems continues at an extremely slow pace (up to 100km per century).

Even small climate changes will have substantial consequences on temperature-limited ecosystems, such as tundra and it is suggested that the large-scale impacts will occur. All other ecosystems will, however, also be influenced but there are large regional differences depending on the original species, ecosystem and landscape, their sensitivity and exposure to regional changes in temperature and precipitation patterns. Not all impacts are negative. For example, tundra that is replaced by forests could potentially store more carbon and provide additional ecosystem services (e.g. wood). However, the decline of stressed species and ecosystems is generally a fast process (years to decades), often triggered by disturbances, while adaptation through migration and regrowth is a slow process (decades to centuries to millennia).

Forest ecosystems require the longest response times and have a low adaptive capacity, while most other ecosystems respond more rapidly. Large changes are projected in the boreal and temperate forests but they will probably not be realised during this century. There will be severe time lags in the response, which will lead to a sub-optimal functioning of these ecosystems and increase their sensitivity to pests and other disturbances, which are sources of additional stress. This highlights the vulnerability of ecosystems with increasing temperatures. The key conclusion from Leemans and Eickhout's paper is that even with a small global mean temperature increase, ecosystem impacts will be pronounced.

More recent research into ecosystem impacts indicates that impacts and vulnerability of ecosystems are likely to be underestimated. Leemans presented findings at the International Symposium on the Stabilisation of Greenhouse Gases, February 2005, concluding that ecosystems respond faster to changes in extreme weather than to average climate change. This helps to explain the more rapid appearance of ecological responses around the world, as a result of an increase in extreme weather events. In order to minimise ecosystem destruction, Leemans proposed that efforts be made to limit global warming to maximally 1.5^{o}C above pre-industrial levels and limit the rate of change to less than 0.05^{o}C per decade (Leemans 2005).

Water resources, water supply and water quality

There are likely to be significant changes in future European precipitation (rainfall), both in terms of average precipitation, seasonal variations, and the levels of heavy events. The projections for Europe show increases in precipitation, but there will be seasonal variations, and strong regional differences between northern and southern countries. Northern Europe is likely to see increases in rainfall, and increases in annual river discharges. Southern Europe is likely to see decreases in rainfall and river discharges, which may lead to further stress on water resources (EEA 2004). This may have important impacts on agriculture as moisture availability is already often limited in summer.

Water resources are sensitive to climatic variations in almost all regions of the world. In central Asia, melting glaciers and shorter winter seasons alter river flows. In mid-latitude regions increased temperatures lead to higher demand for water, particularly for irrigation. Decreased rainfall and more variable rainfall increase the risk of drought. The implications for water supply are an increase in potential regions of water stress and water poverty. Above 2 to 2.5°C global average temperature increase it is projected that an additional 2.4 to 3.1 billion people will be at risk of water stress[20]. The regional area subject to water stress under some scenarios is 10% of the Earth's land surface.[21]

Water quality is also sensitive to higher temperatures, lower river flows, saline intrusion with sea level rise and increased storminess. Low flows and higher temperatures are likely to decrease the dissolved oxygen in lakes and slow moving rivers, increasing stresses on fish. Low flows are already a problem in southern Europe, and this could be exacerbated by climate change. The many local controls on water quality have hindered a global assessment of potential climate change damages.

The impacts of projected climate change on water resources appear to be significant. The IPCC's Third Assessment Report highlights that existing water stressed regions are likely to be more stressed in the future as a consequence of climate change. Water stress is a key impact projected to affect large numbers of people. The effects will be exacerbated by threshold behaviour caused by the interplay between climate change effects, socio-economic trends and limits to adaptation capacity (Arnell 2000; Jones 2000). For many regions under water stress, a global mean temperature increase above around 1.5°C would lead to a decrease in water supply. The table below from Arnell *et al*. (2002), summarizes the risks of water shortage with the associated increase in global mean temperature above 1861-1990 for three emission scenarios. The increase in water stress is presented for unmitigated emissions, and stabilization at 550 and 750 ppm CO_2 for the 2020s, 2050s and 2080s.

Table 7. Population with potential increase in water stress for three emission scenarios.

Year or period	**[a]No climate change (Millions)**	**Unmitigated Emissions (Additional Millions)**	**S750 (Additional Millions)**	**S550 (Additional Millions**
2020s	5022	338–623	242	175
2050s	5914	2209–3195	2108	1705
2080s	6405	2831–3436	2925	762

Sources: Arnell et al. (2002)
[a]Number of people in countries using more than 20% of their water resources. Increase in stress means a reduction in resource availability by more than 10%.

One of the main messages from this is that after the 2020s the number at risk rises rapidly with temperature and that reduction of the increase in temperature, at lower stabilization levels reduces the risk substantially (Hare 2003[22]).

There is a major increase in risk of water stress in the 2080s. The shape of the temperature response curves in the 2050s is quite different from that in the 2080s. Risk rises rapidly with any temperature increase in the 2050s, whilst in the 2080s, risk initially rises quite slowly. A 1°C increase in the 2050s is associated with an impact almost ten times larger than in the 2080s, whereas the level of risk is comparable in both periods for a 2°C or higher warming. As temperature increases in the 2080s period from around 1.0°C above 1861-1990 to around 2°C, the number at risk increases about five fold. One of the major reasons for this is the increased water scarcity problem for major mega-cities in Asia estimated for this time period (Hare 2003).

One of the major future risks identified in the Parry *et al.* (2001) and Arnell *et al.* (2002) work is that of increased water demand from megacities in India and China in the 2080s. It is not clear whether or

[20] Source: Parry et al, 2001
[21] Alcamo, J. and Henrichs, T. (2002) Critical regions: A model-based estimate of world water regions sensitive to global changes. Aquatic Science 64: 352-362.
[22] Source: Hare, W. (2003) Assessment of knowledge on impacts of climate change contribution to the specification of art. 2 of the UNFCCC: Impacts on ecosystems, food production, water and socio-economic systems (see http://www.wbgu.de/wbgu_sn2003_ex01.pdf)

to what extent additional water resource options would be available for these cities and hence, to what extent this finding is robust. This increased water demand from mega-cities may have implications for environmental flows of water in major rivers of China, India and Tibet if the mega-cities of India and China decide to seek large scale diversion and impoundments of flows in the region.

Hare's interpretation of the results on millions exposed to potential water stress can be summarized as:

- 1^{o}C of warming or below may still yield high levels of additional risk, particularly in the period to the 2020s and 2050s, with this risk decreasing due to the increased economic wealth and higher adaptive capacity projected for the coming century. For the 2020s, most of the current global climate models imply a level of risk of additional number of people in water shortage regions in the range 400-800 million for around a 1^{o}C warming.
- 1.5^{o}C of warming produces quite different but nevertheless substantial levels of risk in the different time periods under the Parry *et al.* (2001) analysis, with a peak in the 2050s at over 1,500 million, declining to around 500 million in the 2080s.
- A major threshold change in risk occurs in the Parry *et al.* (2001) analysis in moving from 1.5^{o}C to $2\text{-}2.5^{o}$C, with the numbers rising from close to 600 million to between 2.4-3.1 billion. As explained earlier, this is driven by the water demand of megacities in Indian and China in their model.
- 2^{o}C warming and above produces consistently very high levels of additional risk at all time periods under the HadCM2 scenarios. The range of risk for the current array of models in the 2050s is in the range 662 million to around 3 billion.
- Above 2.5^{o}C warming the level of risk begins to saturate in the range of 3.1- 3.5 billion additional persons at risk.

Above 2 to 2.5°C global average temperature increase it is projected that an additional 2.4 to 3.1 billion people will be at risk of water stress[23].

Drought

One of the most serious effects of climate change will be to increase the risk and possibly the duration of droughts.

Drought will have negative impacts in southern Europe where projections indicate up to 1 % per decade decrease in annual precipitation with decreases of 5 % per decade possible in summer (EEA 2004). This reduction in precipitation in southern Europe is expected to have severe effects, including more frequent droughts, with considerable impacts on agriculture and water resources. These negative effects can cause very heavy economic losses, for example droughts in 1999 caused losses of more than Euro 3 billion in Spain (EEA, 2004).

At a global level, higher temperatures and erratic rainfall are the primary causes, while a shift in circulation patterns, such as extended periods of El Niños, could see droughts lasting for years and possibly decades. Although the scenarios of future drought risk are as yet uncertain, the effects would be serious. The immediate consequences—water stress, food scarcity, reduced plant growth, disease burdens—can lead to economic, social and even political stresses. The most severe consequences, such as famine, forced migration and disease epidemics need not be direct consequences of a drought; however an increase in drought risk with climate change could push some sensitive ecosystems and economies beyond a threshold of sustainability. The global economic cost of drought has not been calculated. However, droughts in Africa have cost up to 8% of GDP, primarily due to loss of power production from hydroelectric plants.[24] Annual average losses in the United States due to drought are estimated at $6 to $8 billion.[25]

[23] Source: Parry et al, 2001

[24] Benson, C. and Edward J. Clay. 1998. 'The impact of drought on Sub-Saharan African economies: a preliminary examination.' *Technical Paper, 401.* Washington, D.C.: World Bank.

[25] 'Economic impacts of drought and the benefits of NOAA's drought forecasting services' National Oceanic ad Atmospheric Administration http://www.magazine.noaa.gov/stories/mag51.htm

The Third Assessment Report projects intensified droughts, associated with the likely increase in El Niño events in many different regions. The main impacts of drought will be decreased agricultural and rangeland productivity and decreased hydro-power potential in drought-prone regions.

Decreased agricultural productivity resulting from drought will contribute to the proportion of undernourished people, particularly in developing countries.

Although climate change scenarios indicate a further increase in the length of the growing season in Europe, the potential increase in productivity will be limited by drought stress. Drought stress increases when the water demand of the plants exceeds water availability.

Floods

Between 1975 and 2001, 238 flood events were recorded in Europe. Over this period the annual number of flood events clearly increased. The number of people affected by floods rose significantly, with adverse physical and psychological human health consequences[26]. With 2.0-6.4°C temperature increase the damage from riverine floods will be several times higher than in the no climate change case. With 1.4°C temperature increase coastal floods are projected to increase the number of people at risk by 10 million, 3.2°C will bring 80 million at risk.

Impacts from storm damage and extreme weather

Extreme weather events are also likely to increase, with heat waves, drought, floods, storms and tropical cyclones. Changes in both frequency and severity are possible, though these may not be linearly dependent on average climate.

In Europe, 64 % of all catastrophic events since 1980 are directly attributable to weather and climate extremes: floods, storms and droughts / heat waves. 79 % of economic losses caused by catastrophic events result from these weather and climate related events. Economic losses resulting from weather and climate related events have increased significantly in the last 20 years, from an annual average of less than USD 5 billion to about USD 11 billion. This is due to wealth increase and more frequent events. Four out of the five years with the largest economic losses in this period have occurred since 1997. The average number of annual disastrous weather and climate related events in Europe doubled over the 1990s compared with the previous decade, while non-climatic events such as earthquakes remained stable. Climate change projections show an increasing likelihood of extreme weather events. Thus, an escalation in damage caused is likely[27].

Socially contingent effects

There is an emerging consensus that widespread climate change may increase socially contingent effects[28], due to multiple stresses coming together. This is unlikely to affect Europeans directly, but may well have effects on Europe. The combination of stresses from climate change from the above effects may converge on a number of vulnerable areas, for example in Africa, leading to potential regional conflict, poverty or famine, migration, etc.

It is highlighted that the disproportionate impact of climate change occurs on developing countries because these countries are more vulnerable to climate change than developed countries: their economies rely more heavily on climate-sensitive activities; they are close to environmental tolerance limits; and they are poorly prepared to adapt to climate change. In contrast, richer societies tend to be better able to adapt and their economies are less dependent on climate. With the upper range of IPCC projections of climate change, the impacts are likely to adversely affect achievement of the

[26] Impacts of Europe's changing climate. An indicator-based assessment EEA Report No 2/2004
[27] Impacts of Europe's changing climate. An indicator-based assessment EEA Report No 2/2004
[28] We use classification of socially contingent damages to describe those large scale dynamics related to human values and equity that are poorly represented in damage estimates based on cost values, e.g. regional conflict, poverty.

Millennium Development Goals (as agreed at the World Summit of Sustainable Development (WSSD) at Johannesburg).

Overall, the IPCC (2001) concluded that ‘Projected climate change will have beneficial and adverse effects on both environmental and socio-economic systems, but the larger the changes and rate of change in climate, the more the adverse effects predominate’. Essentially, the severity of the adverse impacts will be larger for greater cumulative emissions and associated changes in climate.

Major catastrophic effects

Finally, there are a number of major effects - potentially catastrophic effects or major climate discontinuities. These would be classified as ‘significant’ changes in climate, and from a precautionary principle viewpoint, these would be the effects that we would want to avoid. They potentially include (Schellnhuber, 2004, Downing et al, 2004, Stabilisation 2005).):

- Loss of the West Antarctic ice sheet;
- Loss of the Greenland ice sheet;
- Methane outbursts, including runaway methane hydrates;
- Instability or collapse of the Amazon Forest;
- Reduced carbon sink capacity;
- Changes in the thermo-haline circulation (loss or reversal of the gulf stream, changes in Atlantic deep water formation, changes in southern ocean upwelling/circumpolar deep water formation);
- Indian Monsoon transformation;
- Change in stability of Saharan vegetation;
- Tibetan albedo change;
- ENSO triggering;
- Climate change induced ozone hole;
- Salinity valves;
- Rearrangement of biome distributions;
- A shift in mean climate towards an El Nino like state;
- Bodele dust supply change;

Many (but importantly not all) are thought to be longer-term events (i.e. that would occur at temperature changes >2˚C). The risk of these effects might warrant the consideration of a strong precautionary approach in policy setting, based around strong sustainability principles. This would support the setting of a precautionary threshold (e.g. such as the 2˚C level or another level that the scientific evidence indicated).

Recent research indicates that in many cases the risks from climate change impacts are greater than originally thought at the time of the Third Assessment Report 2001. The International Symposium on the Stabilisation of Greenhouse Gases, held in February 2005, identified new impacts. For example, the recent change in the acidity of the ocean is likely to reduce the capacity to remove CO_2 from the atmosphere and affect the entire marine food chain (Stabilisation 2005).

It has been highlighted that catastrophic effects from major changes in the climate system could overwhelm our response strategies.

Critical temperature thresholds were proposed at the International Symposium which would trigger major catastrophic effects. A global temperature increase of about 1.5^{o}C over present levels corresponds to an increase of 2.7^{o}C over Greenland. This temperature increase may be a threshold that triggers the melting of the Greenland ice-cap. If the Greenland ice sheet melted, global average sea levels would increase by around 7 metres – though this would take millennia (half the ice would melt in the first 1,000 years, with all melting after 3,000 years.). A smaller rise in global temperatures of around 1^{o}C is likely to cause extensive coral bleaching (Stabilisation 2005). With a temperature increase of 3^{o}C, the serious risk of large scale, irreversible disruption becomes more likely and impacts would include changes to the thermo-haline circulation, reversal of the land carbon sink and possible destabilisation of the Antartic ice sheets (with a temperature increase of >2°C, the melting of the West Antarctic Ice Sheet is considered a possibility, which could raise sea levels by a further 5-6 metres i.e. 0.6-1.2m per century.).

The time frame for major catastrophic events is not yet known, though it is apparent that 'tipping points' of temperature change could trigger these major events.

The Key Impacts of Climate Change
From the review undertaken here, we have concluded that the main impacts ('major effects' as defined in the project scope) are:

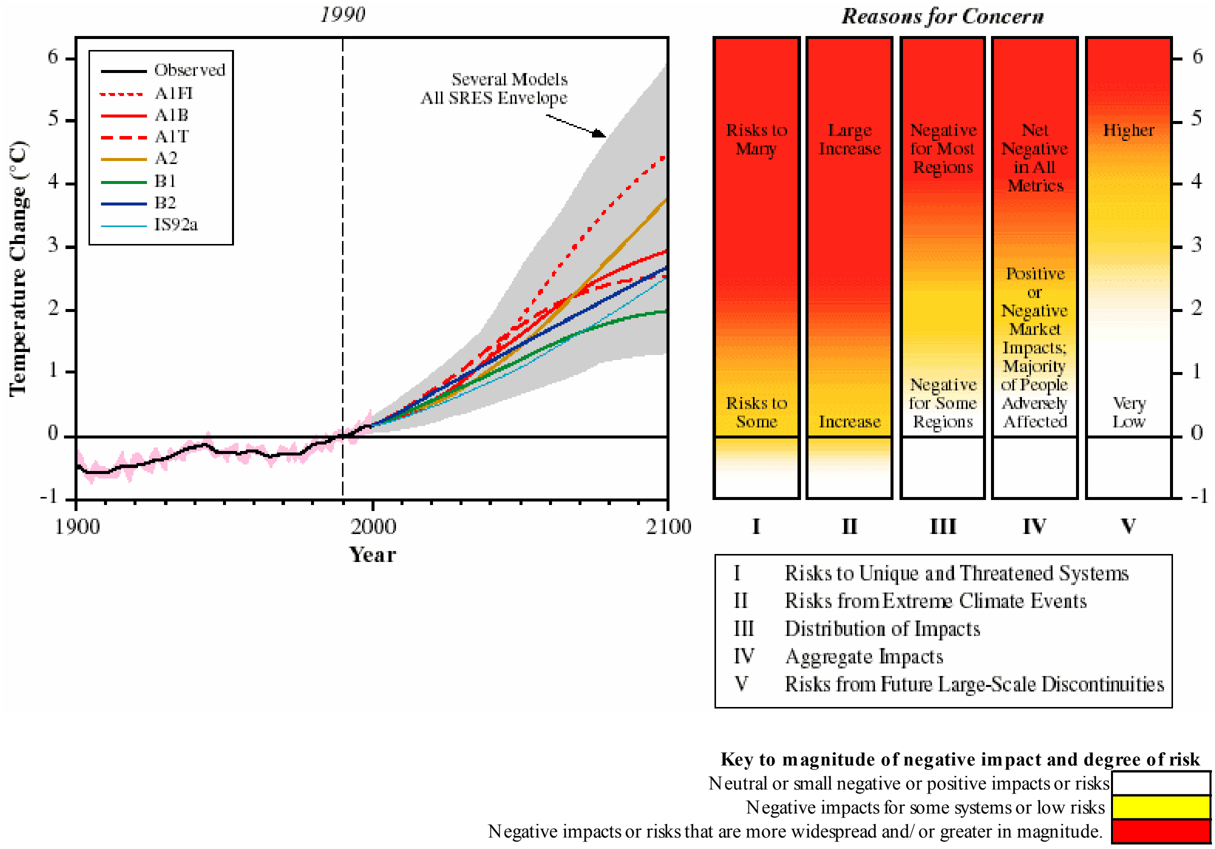
- Impacts of sea level rise, erosion, the loss of land and coastal wetlands, and need for coastal protection;
- Effects on agriculture;
- Effects on energy use (including heating and cooling);
- Effects to human health from changes in cold related and heat related effects
- Effects to human health from the disease burden (and other secondary effects);
- Effects on water resources, water supply and water quality;
- Changes to tourism potential and destinations;
- Effects on ecosystems (loss of productivity and bio-diversity);
- Impacts from drought;
- Impacts from flooding;
- Impacts from storm damage and extreme weather (including costs to infrastructure);
- Socially contingent effects (arising from multiple stresses and leading to migration, famine, etc);
- Impacts from major events (e.g. loss of thermo-haline circulation, collapse of West-Antarctic ice sheet, methane hydrates).

The Impacts associated with Different Stabilisation Targets

Most of the impacts literature is focused on the impacts of climate change. It is much more difficult to find the impacts at different concentration or temperature levels, especially at a global scale, and to combined this to provide a matrix of the benefits of different policy out-turns.

The Third Assessment Report confirms that risks of adverse impacts from climate change increase with the magnitude of climate change. This is shown in the figure below, which highlights the magnitude of the negative impact and the risk of this occurring in relation to increased temperature change. The left part of the figure displays the observed temperature increase (relative to 1990) and the range of projected temperature increase after 1990 as estimated by Working Group I of the IPCC from the Special Report on Emissions Scenarios (SRES). The right side displays five causes for concern regarding climate change risks evolving in the period to 2100. Risks from large-scale discontinuities only start to become significant above a 3˚C temperature change. Negative impacts on unique or threatened systems and risks from extreme climate events occur with a temperature change as small as 1˚C and these impacts and risks are projected to become significant and widespread for changes of 2 to 3˚C. Above 2˚C temperature increase, the vast majority of market impacts are predicted to be negative and most regions will suffer adverse affects from climate change.

Figure 1. The risks of adverse climate change impacts with the magnitude of climate change



Source: 'Climate Change 2001: Working Group II: Impacts, Adaptation and Vulnerability' IPCC, Summary for Policy Makers

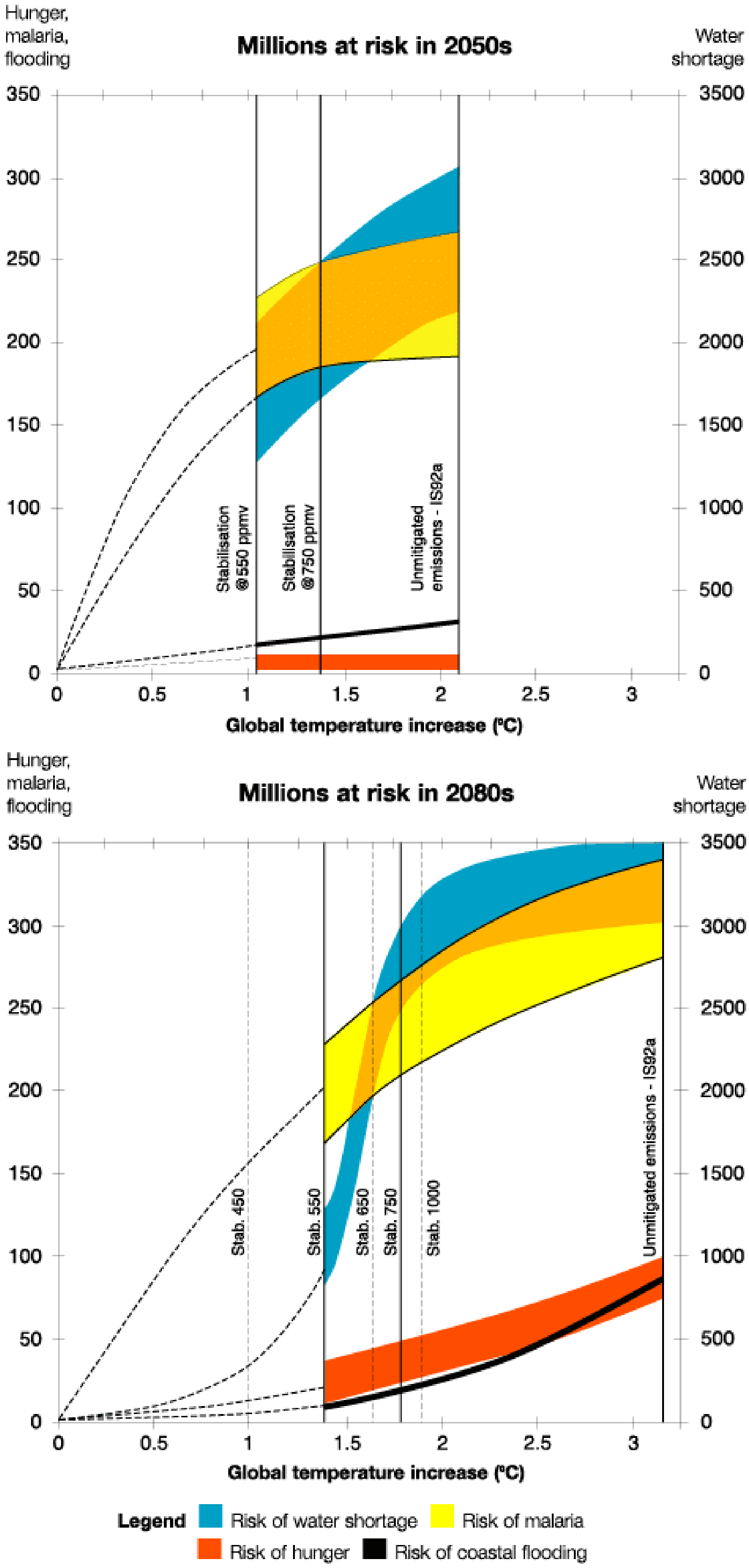
The IPCC reported that the assessment of impacts or risks takes into account only the magnitude of change and not the rate of change. Global mean annual temperature change is used in the figure as an approximation for the magnitude of climate change, but projected impacts will be a function of a number of factors including the magnitude and rate of global and regional changes in mean climate, extreme events and socio-economic conditions.

We have also reviewed the literature above and other studies to try and assess the potential impacts from different stabilisation levels.

Health

A paper by Parry and colleagues (Parry et al, 2001) has brought together results on the human impacts of hunger and malaria as well as water shortage and flooding. The study estimated effects, assuming that atmospheric concentrations of carbon dioxide are stabilized at 750 parts per million (ppmv) by 2250 and at 550 ppmv by 2150. The 750 ppmv target delays the damage but does not avoid it: by 2080, keeping to this target would halve the number at risk from hunger and flooding. The 750 ppmv target reduces the population at risk of malaria by about a third and water shortage by about a quarter. The authors estimate that to bring risk levels down from hundreds to tens of millions would require a stabilization target of about 550 ppmv. They also indicated on the graph below (taken from the study), the approximate locations of 450, 650 and 1000 ppmv stabilization pathways and their effects. Although analyses have not yet been conducted for these stabilization levels, it appears that the 450 ppmv pathway would achieve very great reductions in millions at risk, although very high costs of mitigation would be incurred.

Figure 2. Additional millions of people at risk from hunger, malaria, flooding and water shortage with increasing global temperature, relative to 1961-90 mean. (Parry et al, 2001)



There is also an update (McMichael 2003), on some of the risks, shown below.

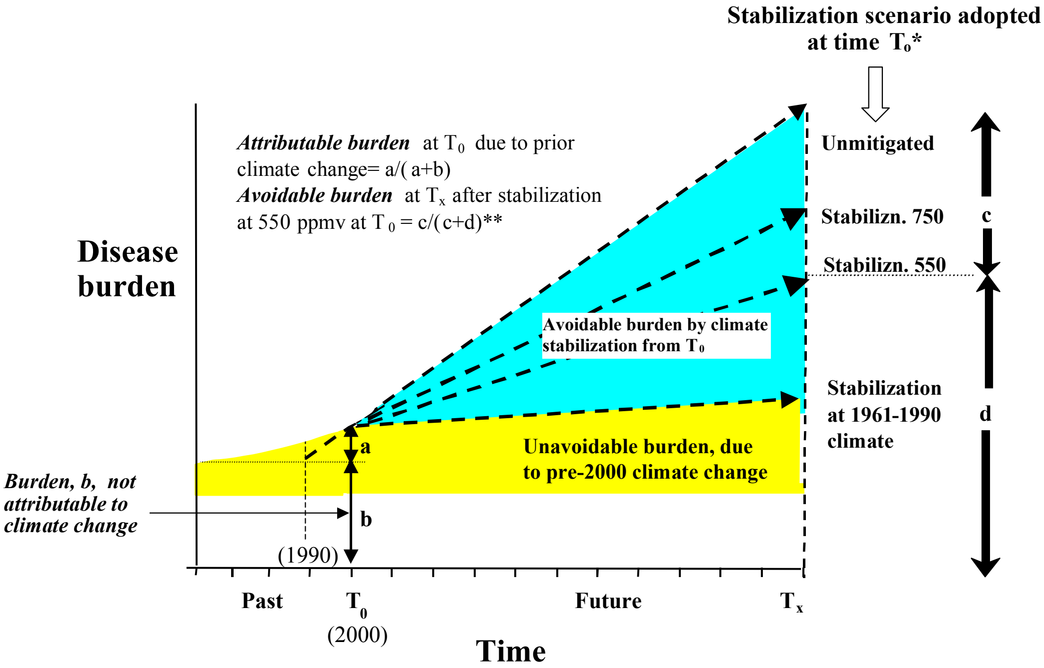
McMichael presents a climate change risk assessment of the burden of disease with increasing carbon dioxide concentration levels. The table above shows a risk assessment for the increase in malaria in 2030: for the Africa region, stabilisation at 550ppmv would see an increase in malaria of up to 9% whereas the increase would be up to 17% if emissions were not abated in the period to 2030. The direct effect of heat or cold deaths due to cardio-vascular disease, and risk of diarrhoea and other direct climate effects (malnutrition and flood deaths) on human health are describe in similar risk tables in McMicheal *et al*. (2003b).

Figure 3. Estimates for relative risks of malaria attributable to climate change

GBD: malaria Estimates for relative risks of malaria attributable to climate change in 2030, under alternative exposure scenarios. (For each entry, the lower value, 1.00, indicates no change. Upper figure indicates that, e.g., malaria in African region, under unmitigated emissions, would increase by up to 17% .)

Region	Range of relative risks, for each of the 3 emissions scenarios		
	Unmitigated Emissions	Stab 750	Stab 550
African region	(1.00 - 1.17)	(1.00 - 1.11)	(1.00 - 1.09)
Eastern Mediterranean region	(1.00 - 1.43)	(1.00 - 1.27)	(1.00 - 1.09)
Latin American, Caribbean region	(1.00 - 1.28)	(1.00 - 1.18)	(1.00 - 1.15)
South-East Asian region	(1.00 - 1.02)	(1.00 - 1.01)	(1.00 - 1.01)
Western Pacific region*	(1.00 - 1.83)	(1.00 - 1.53)	(1.00 - 1.43)
Developed countries#	(1.00 - 1.27)	(1.00 - 1.33)	(1.00 - 1.52)

* without developed countries # and Cuba



Source: Figures taken from a presentation given by Tony McMichael 'Estimating the Climate Attributable Burden of Disease' NCEPH 2nd October 2003

A review of the impacts of temperature change on human systems formed an important outcome from the International Symposium on the Stabilisation of Greenhouse Gases, held in February 2005. Appendix 1 of this report presents literature review tables of human system impacts and the tables were published as an outcome of the Stabilisation 2005 event. The impacts have been grouped according to the degree of temperature change relative to pre-industrial levels and some key examples are highlighted below. The magnitude of the impact depends on the population scenario used for each model output and the temperature change, thus the examples below illustrate the severity of the impact but are sometimes not directly comparable.

Impacts on human systems from 1^{o}C temperature increase relative to pre-industrial levels:
- Globally 615-1660 millions at risk from water stress for scenario A2 (Parry 2004)
- Arnell predicts 240 millions at risk from water stress for scenario IS92a S750 (Arnell 2002)

Impacts on human systems between 1^{o}C and 2^{o}C temperature increase relative to pre-industrial levels:
- Risk of death due to flooding increased 4.64 fold in Central and South America for S550 (McMichael et al 2004)
- Globally 1620-1973 millions at risk from water stress for scenario A2 (Parry 04)

Impacts between 2 and 3^{o}C temperature increase relative to pre-industrial levels:
- Food production threatened in Southern Africa, S Asia and parts of Russia (ECF 2004)
- Globally 2.3-3.0 billions at risk from water stress for scenario IS92a S750 (Parry 2001)

Impacts at or above 3^{o}C temperature increase relative to pre-industrial levels:
- Globally 3.1-3.5 billions at risk from water stress for scenario IS92a, unmitigated emissions (Parry 2001)
- Entire regions out of production, 80-125 millions at risk from hunger (Hare 2003, Parry 2001)
- Wheat yield decline of up to 34% in Indian subcontinent (ECF 2004)

Ecosystems
A literature review of the impacts of temperature change on ecosystems was a key conference outcome from the recent International Symposium on the Stabilisation of Greenhouse Gases (Stabilisation 2005). A summary table on ecosystem impacts, published on the web-site of this Defra sponsored event, is provided in Appendix 2 of this report. In this section the ecosystem impact has been grouped according to the scale temperature change for an increase of 1^{o}C through to 3^{o}C or above.

Some of the significant potential impacts of temperature change of 1^{o}C relative to pre-industrial levels are listed below:
- 82% of global coral reefs are likely to be bleached (Hoegh-Guldberg 1999)
- 10% global ecosystems transformed (Leemans and Eickhout 2003)
- Only 53% of wooded tundra remains stable and ecosystems variously lose between 2 to 47% of their extent (Leemans and Eickhout 2003)
- Increased ecosystem disturbance by pests and disease

Impacts between 1 and 2^{o}C temperature increase relative to pre-industrial levels:
- 97% of global coral reefs are likely to be bleached (Hoegh-Guldberg 1999) and reefs become extinct in the Indian ocean (Sheppard 2003)
- Total loss of artic summer ice and whole ecosystem stressed (ACIA 2004)
- 16% global ecosystems transformed (Leemans and Eickhout 2003)
- 50% loss of salmonid fish in USA (Keleher & Rahel 1996)

Impacts between 2 and 3^{o}C temperature increase relative to pre-industrial levels:
- 15-37% of species extinct globally for 2.5^{o}C increase (Thomas 2004)
- Large impacts on the Tibetan plateau (Ni 2000)

Impacts at or above 3°C temperature increase relative to pre-industrial levels:

- 22% of global ecosystems transformed: ecosystems lose between 7 and 74% of their extent (Leemans and Eickhout 2003)
- Alpine species near extinction in Europe (Bugmann 1997)
- 60% loss of tundra ecosystem globally (Hare 2003/Malcolm et al 2002)

A recent publication has assessed the potential impacts on ecosystems (Thomas et al, 2004.). Using projections of species' distributions for future climate scenarios, they assess extinction risks for sample regions that cover some 20% of the Earth's terrestrial surface. Exploring three approaches they predict, on the basis of mid-range climate-warming scenarios for 2050, that 15–37% of species in a sample of regions and taxa will be 'committed to extinction'. When the average of the different methods and dispersal scenarios is taken, minimal climate-warming scenarios produce lower projections of species committed to extinction (18%) than mid-range (24%) and maximum change (35%) scenarios. The table below shows the proportion of species extinction by area. It can be seen that a step change in the number of species extinct occurs between the minimum and mid-range climate change and also between the mid and maximum expected climate change for the majority of sample regions.

Table 8. Projected percentage extinctions for different taxa and regions (simplified from Thomas et al, 2004)

Taxon	Region	Number of species directly assessed	With dispersal			No dispersal		
			Minimum expected climate change	Mid-range climate change	Maximum expected climate change	Minimum expected climate change	Mid-range climate change	Maximum expected climate change
Mammals	Mexico	96	5	8		24	26	
	Queensland	11	16		77			
	South Africa	5	0	0			69	
Birds	Mexico	186	4	5	-	9	8	-
	Europe	34	-	-	7			48
	Queensland	13	12		85			
	South Africa	5	-	0	-	-	51	-
Frogs	Queensland	23	13		68			
Reptiles	Queensland	18	9		76			
	South Africa			0			50	
Butterflies	Mexico	41	7	7		13	19	
	South Africa	4		0			78	
	Australia	24	7	23	33	16	35	54
Other invertebrates	South Africa	10		0			85	
Plants	Amzonia	9						
	Europe	192	6	7	8	18	22	29
	Cerrado	163				66	75	
	South Africa Proteaceae	243		38			52	
All species			11	19	33	34	45	58

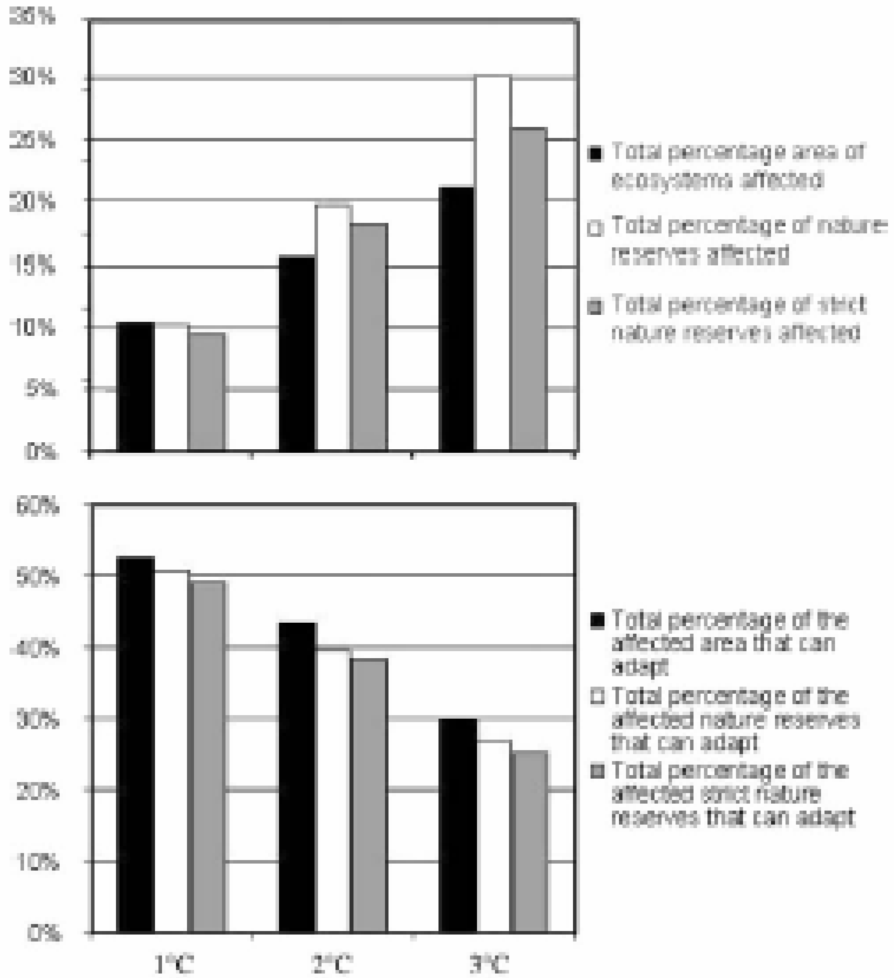


Fig. 4. Impact (top) and adaptation levels *(bottom) of all ecosystems, all nature reserves and strict nature reserves. Notes: For a global mean temperature increase of 1°C, 2°C and 3°C based on the HADCM2 GCM.

Source: Thomas et al, 2004.

Major Catastrophic Effects
Between 2000 and 2005, more literature has been published on the major impacts of climate change in relation to temperature rise. A literature review of major catastrophic effects was conducted as part of the International Symposium on Stabilisation of Greenhouse Gases, 2005. The table below summarises the predicted effect on the Earth's systems of various temperature increases above pre-industrial levels.

Table 9. Major catastrophic effects of climate change on the Earth's Systems (Stabilisation 2005)

Temp rise above pre-industrial (^oC)	CO_2 conc^n (ppm)	Impacts to the earth system	Region affected	Source
1.5		Onset of complete melting of Greenland Ice: when complete 7m additional sea level rise	All coastal regions, many cities inundated	Gregory 2004
2-3?	~CO_2 doubling	Collapse of Amazon rainforest. Replaced by Savannah: huge consequences for biodiversity and human livelihoods	S America, globe	Cox et al 2000, Betts 2005
2-3?	~550ppm	Conversion of terrestrial carbon sink to carbon source due to temperature enhanced soil and plant respiration overcoming CO_2 enhanced photosynthesis. Desertification of many world regions.	Global	Cox et al 2000, Cox 2005, ECF 2004
Any		Release of C to atmosphere due to deterioration of ecosystems at rapid rates of temperature change.	Global	Neilsen 1993
	Double	Net primary production increases by 10%	Globe	Betts 2005
	Double	Runoff increases by 12%	Globe	Betts 2005
Base case (to be clarified)	2100	Collapse of thermohaline circulation: maximum likelihood of shutdown of 4 in 10 for climate sensitivity 3C (climate sensitivity could lie between 1.5 – 11C)	Globe: cooling NW Europe, warming Alaska & Antarctic, lower rainfall in S America	Schlesinger 2005
1-3		Collapse of thermohaline circulation affecting fisheries, ecosystems, agriculture (expert opinion: probability 'a few percent')	Northern and Western Europe	Ramsdorf in ECF 2004
2-4.5		Potential to trigger melting of the West Antarctic Ice Sheet raising sea levels by a further 5-6m i.e.0.6-1.2m per century	Globe	ECF 2004
4-5		Expert opinion: probability of thermohaline shutdown up to 50% or above.	Northern and Western Europe	Ramsdorf in ECF 2004
		THC collapse, Greenland Ice Sheet melt and West Antarctic Ice Sheets may interact in ways that we have not begun to understand		Discussed at Symposium
		Potential release of methane from melting tundra and clathrates from shallow seas	Globe: feedback accelerated warming	IPCC 2001
		By 2100 acidification of the oceans pH falls by 0.4 and may disrupt ecosystem functioning	World oceans	IPCC 2001; Blackford 2005
		By 2250 acidification pH falls by 0.77	World oceans	IPCC 2001; Blackford 2005
		Increased variability in summer monsoons exacerbating flood/drought damage	Asia, Australia	IPCC 2001, Steffen 2005, Lal 2003
	16 x CO2	Permanent El Nino	Globe	Navarra 2005

Source: Avoiding Dangerous Climate Change, International symposium on stabilisation of greenhouse gases, 1-3 Feb 2005, Met Office UK

Summary of climate impacts in relation to temperature increase

The material above on the impacts associated with different temperature increase scenarios is summarized in the table below.

Table 10. Summary of literature review on climate impacts with different temperature stabilisation scenarios, compiled for this report.

		Temperature change	
	Within EC target <(2˚C)	>2˚C to 2.5˚C	>3C
Health	Globally it is estimated that an average temperature rise above 1.2°C will cause an increase in premature mortality by several hundred thousands without accounting for extreme event like heat waves.	A rise of 2.3^{o}C by 2080 puts up to 270 million at risk from malaria (IS92a S>1000).	A rise of 3.3^{o}C by 2080 would put up to 330 million at risk from malaria (IS92a unmit).
Ecosystems	Up to 1°C above pre-industrial levels up to 10% of ecosystem areas worldwide will shift.	A rise of 1–2°C above pre-industrial levels will shift up to 15–20% of ecosystem areas worldwide.	For a rise of more than 2°C above pre-industrial levels, the global share of ecosystems shifting due to climate change will likely be above 20%, and much more in some regions. Global losses of coastal wetlands may exceed 10%.
Agriculture	The EU (and US) yields increases for up to 2°C temperature rise, but beyond this decline.	Heat stress likely to affect subtropics/tropics for 1.7°C temperature increase.	Higher average temperatures of 2.5°C in 2080 could result in 50 million additional people at risk of hunger. With a 3^{o}C rise a group of developing countries with a population of 2 billion will see the food deficit double.
Water	For many regions under water stress, global mean temperature increases above around 1.5^{o}C lead to decreases in water supply. Additional number of people in water shortage regions in the range 400-800 million for around a 1C warming.	Above 2 to 2.5°C global average temperature increase it is projected that additional 2.4 to 3.1 billion people will be at risk of water stress	Above 2.5^{o}C warming the level of risk begins to saturate in the range of 3.1-3.5 billion additional persons at risk.
Major events	At 1.5^{o}C onset of complete melting of Greenland Ice: when complete 7m additional sea level rise.	Above 2˚C risk of major catastrophic events. Between 2^{o}C and 4.5^{o}C potential to trigger melting of the West Antarctic Ice Sheet eventually raising sea levels by a further 5-6m.	Above 3˚C risk of major catastrophic events very significant. Over 4^{o}C the probability of thermohaline shutdown up to 50% or above.

We stress that within the time-scale of this project, it has not been possible to undertake a thorough review of the impacts in aggregation, and especially to collate material for different stabilisation targets. We highlight this as a key priority for future research.

Review of Valuation of Climate Change

Impact studies begin with an inventory of the effects on multiple criteria - typically lives lost, the burden of disease on humans, species lost, etc. Negotiating global climate change targets has tended to recognise such multiple effects, in effect corresponding to an informal multi-criteria approach[29].

However, a common metric is desirable, if possible, for consistency in policy evaluation on climate change mitigation. The most common metric is monetary. A monetary metric is particularly well suited to measure market impacts. For example: the costs of sea level rise could be expressed as the capital cost of protection and the economic value of land and structures lost in the absence of protection; agricultural impact can be expressed as costs or benefits to producers and consumers; and changes in water runoff might be expressed in new flood damage estimates.. Using a monetary metric to express non-market impacts, such as effects on ecosystems or human health, is more difficult, though it is possible. There is a broad and established literature on valuation theory and its application, including studies on the monetary value of lower mortality risk, ecosystems, quality of life, etc. However, economic valuation, especially in the area of climate change, is often particularly controversial, because of ecosystem and socially contingent effects, the potential magnitude of major impacts (include irreversible climate shifts), and because of issues with intergenerational and international equity. There is also an incomplete understanding of climate change itself. Nonetheless, there has been considerable research in to this area, and numerous studies have estimated the costs of climate change. We have summarised the key areas that these studies focus on, along with comments on valuation, in the box below.

The Social Costs of Climate Change: Key Areas of Assessment in the Literature and the Models

Sea level rise leads to costs of additional protection, or otherwise loss of dry land and wetland loss. The balance will depend upon future decisions about what protection is justified. Costs of protection are relatively well known and included in nearly all models, but other costs (rising sea levels increases the likelihood of storm surges, enforces landward intrusion of salt water and endangers coastal ecosystems and wetlands) are more uncertain and often excluded (or only partially captured in terms of valuation). Populations that inhabit small islands and/or low-lying coastal areas are at particular risk of severe social and economic effects from sea-level rise and storm surges. This raises the issue of migration (e.g. for those living on small island states), the costs of which depend on diverse social and political factors (so called socially contingent effects) but these are not captured in the current valuation models.

Energy use impacts will depend on average temperatures and range, but there will be a combination of increases and decreases in demand for heating (both in terms of overall energy supplied, and to meet peak demands). Benefits from increased winter temperatures that reduce heating needs may be offset by increases in demand for summer air conditioning, as average summer temperatures increase. The models capture these effects, although the reference scenario is difficult to project.

Agricultural impacts depend upon regional changes in temperature and rainfall, as well as atmospheric carbon dioxide levels (and fertilisation). The key impacts will be to crops and changes in the cultivated area and yields. These effects depend on many factors and in some areas, the area suitable for cultivation and potential yields will increase. Climate variability, as well as mean climate change, is an important consideration. Adaptive responses will be important - choice of crop, development of new cultivars and other technical changes, especially irrigation (see also water supply below). Most valuation studies capture the direct impacts, but it is important to note these do not fully determine damages - these will also depend on changes in demand and trade patterns driven by socio-economic factors – but also complex responses to climate variability, pests and diseases, etc.

[29] Multi-criteria analysis (MCA) is a structured approach used to determine overall preferences among alternative options, where options accomplish several objectives.

Water supply impacts depend on changes in rates of precipitation and evapo-transpiration and demand changes – including those driven by climate change. The water demand of biological systems is affected by various climatic factors, including temperature and humidity. Water supply systems are usually optimised to meet (currently) extreme supply/demand conditions and the costs of shortage can be very high. Climatic variability is therefore important in determining damages. Climate change will exacerbate water shortages in many water-scarce areas of the world. There is the potential for water scarcity and severe socially contingent damages, which are not quantified at present. Water supply is included in some models, though coverage is often partial.

Health impacts include both an increase in (summer) heat stress and a reduction in (winter) cold stress, though as these are in opposite directions the net mortality impact (global) of direct temperature changes may be quite small. Direct health impacts from temperature changes are included and valued in many studies. The area amenable to parasitic and vector borne diseases, such as malaria, will expand and impacts could be large. The inclusion of disease burdens has been advanced through specific studies, and some models include partial coverage of such effects. Socially contingent damages to health (via other impacts such as food production, water resources and sea level rise) in vulnerable communities are difficult to estimate but could be very large, and these are not included in any of the valuation modelling frameworks. Overall, climate change is projected to increase threats to human health, particularly in lower income populations, predominantly within tropical/subtropical countries.

Ecosystems and biodiversity impacts are amongst the most complex and difficult to evaluate. Ecological productivity and biodiversity will be altered by climate change and sea-level rise, with an increased risk of extinction of some vulnerable species. Most of the major ecosystem types are likely to be affected, at least in parts of their range. Some isolated systems are particularly at risk, including unique and valuable systems (e.g. coral reefs). Recent evidence has also identified acidification of the oceans, which is an observable consequence of rising CO_2 levels in the atmosphere, with potentially large impacts on marine ecosystems and fluxes of greenhouse gases between the ocean and the atmosphere. The analysis of ecosystems effects is one of the most problematic areas, in terms of a comprehensive or reliable assessment of the impacts of climate change on ecosystems, and on valuations of ecosystems. Most studies do not capture ecosystems effects fully – with valuations relying on *ad hoc* estimates of species loss and contentious valuation studies. The value of ecosystem function may also be important, but has received even less attention, and is not included in valuation modelling.

Extreme weather events are also likely to increase, with heat waves, drought, floods, and potentially storms, tropical cyclones and even super-typhoons. However, the frequency and severity of extreme events may not be linearly dependent on average climate. Climate variability will also be important and there is no consensus on how this will change. Impacts and damages will also depend on the location and timing of the hazard and adaptive responses. For example, cyclone damage to property will tend to rise with wealth, but mortality effects may fall considerably. Extreme events are excluded from all but a few studies in relation to valuation.

Major Events, i.e. the risk of major effects - potentially catastrophic effects or major climate discontinuities are the most uncertain category. They include (Schellnhuber, 2004: Pachuari 2005) such potential events as loss of the West Antarctic ice sheet; loss of the Greenland ice sheet; methane outbursts (including runaway methane hydrates); instability or collapse of the Amazon Forest; changes in the thermo-haline circulation (loss or reversal of the gulf stream, changes in Atlantic deep water formation, changes in southern ocean upwelling/circumpolar deep water formation); Indian monsoon transformation; Change in stability of Saharan vegetation; Tibetan albedo change; ENSO triggering; reduced carbon sink capacity, and other events. Many have previously been thought to be longer-term events (i.e. that would occur at temperature changes >2˚C), though recent evidence (presented at The International Symposium on the Stabilisation of Greenhouse Gases, held in February – Stabilisation 2005) indicates that in many cases the risks from major climate change impacts are greater than originally thought at the time of the Third Assessment Report 2001, and may actually occur at lower temperature thresholds. Major events are not captured in the models.

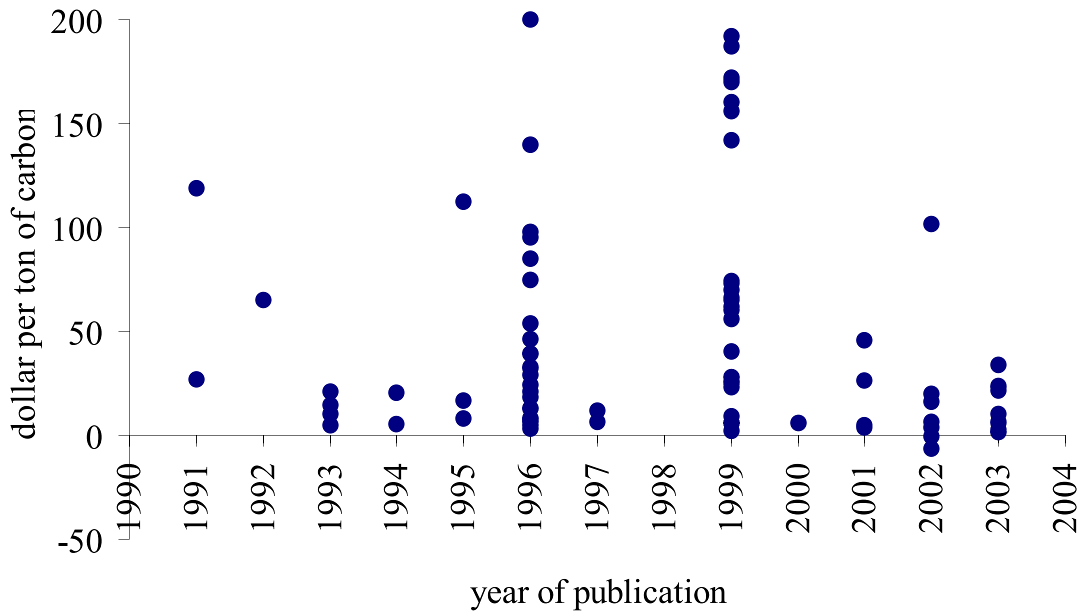
The project has undertaken a rapid review of the estimates of the monetary impacts of climate change. A number of approaches have been used to assess the total and the marginal global costs (social costs) of greenhouse gas emissions[30]. These estimates can be used to investigate the benefits of future climate change policy, and can be compared to the costs of greenhouse gas mitigation. The study has also commissioned a number of specific runs with some of the climate change valuation models[31], to derive estimates of marginal and total costs from future climate change scenarios.

Literature Review

The marginal damages caused by carbon dioxide emissions were estimated in the IPCC Second Assessment Report at US$5 – 125/tC (broadly equivalent to Euro 1 to 34/tCO_2). More recent work has arrived at essentially the same range of numbers, though with most estimates towards the lower end of the range.

A number of recent reviews have presented the literature on the costs of climate change, e.g. Watkiss et al, 2002; Downing and Watkiss, 2003; Tol 2004. The latter is the most recent comprehensive, and has assessed the marginal social cost of greenhouse gas emissions from 28 studies in the literature[32] (including peer reviewed studies and the grey literature). These studies provide 103 estimates (when the best estimate and range is taken into account). The range of values is presented below.

Figure 5. Marginal social cost of greenhouse gas emissions from 28 studies



Source: Tol (2004). Note, one study from the early 1990s is excluded which has very high values (1800$/tC)

[30] The marginal social cost is the damage from an additional tonne of CO_2 emitted. Specifically, it is the change in the net present value of the monetised impacts, normalised by the change in emissions. This should not be confused with the total impact of climate change or the average impact (the total divided by the total emissions of carbon).

[31] The models have been used to estimate marginal costs for increased emissions (run with and without additional pulses of emissions), for comparison with marginal cost estimates for mitigation.

[32] This work was undertaken by Richard Tol, and updated his meta-analysis of published studies. The Marginal Damage Costs Of Carbon Dioxide Emissions: An Assessment Of The Uncertainties. *Richard S.J. Tol. April 2004.* Published in Energy Policy.

The probability characteristics of the marginal costs of carbon dioxide emissions

$/tC ($1995)	Mode	Mean	5%	10%	Median	90%	95%
Base	1.5	93	-10	-2	14	165	350
Author-weights	1.5	129	-11	-2	16	220	635
Peer-reviewed only	5.0	50	-9	-2	14	125	245
No equity weights	1.5	90	-8	-2	10	119	300
Equity weights	-0.5	101	-20	-2	54	250	395
PRTP=3% only	1.5	16	-6	-2	7	35	62
PRTP=1% only	4.7	51	-14	-2	33	125	165
PRTP≤ 0% only	6.9	261	-24	-2	39	755	1610

The analysis combined the studies to form a probability density function. This has shown that uncertainty is strongly right-skewed. If all studies are combined, the median $14/tC (1995 values), the mean $93/tC, and the 95 percentile $350/tC. This is approximately equal to a median of Euro 4/tCO_2, a mean of Euro 25/tCO_2, and a 95 percentile of Euro 96/tCO_2. For this review, we consider the mean is the appropriate estimator of central tendency; given the right-skewed distribution the mode and the median will both be biased towards low valuations. Using the weights favoured by authors, the mean is $129/tC and the 95 percentile $635/tC[33] . Studies with a lower discount rate had higher estimates and much greater range. Similarly, studies that use equity weighting have higher estimates and a larger range. Studies that are peer-reviewed have lower estimates and smaller uncertainty ranges. The highest estimates are in the grey literature. In his paper, Tol concluded that the marginal damage costs of carbon dioxide emissions are unlikely to exceed $50/tC (14 Euro/t$CO_2$), and are probably much smaller.

The trend in the data is towards lower values over time, as shown in the figure above. The reason for the drop in the estimated values over the past decade is because of more recent 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 (which allows economic costs to be off-set in anticipation of climate change). Based on this newer literature, some commentators conclude that the social costs of climate change are low: with typical assumptions about discounting and aggregation, the central estimate of the marginal damage cost of carbon dioxide emissions may be lower than the marginal abatement costs for post-Kyoto scenarios (Euro 20/tCO_2) and possibly below the estimated marginal abatement cost to Europe of meeting Kyoto (Euro 12/tCO_2[34]). However, it should be noted that such trends may change in future analysis. Two emerging findings are that climate sensitivity and likelihood of severe impacts increases at lower temperature thresholds maybe higher than previously expected[35].

Moreover, the studies do not cover all the impact categories described above, and most researchers (and indeed the IPCC) consider the possibility of negative surprises are more likely than positive ones. We have therefore assessed the coverage of the valuation studies to investigate the extent to which they may under-estimate the "full" impacts of climate change.

[33] The explanation of this increase is that some studies (Azar and Sterner, 1996; Tol, 1999) deliberately reproduce the low estimates of Nordhaus (1994) and then argue that his assumptions are biased downwards.

[34] The costs considered are from the European Climate Change Programme (ECCP 2001), which identified 42 possible measures, which could lead to some 664-765 MtCO_2 equivalent emissions reductions that could be achieved at a cost lower than 20€/tonne CO_2eq. This is about double the emissions reduction required for the EU in the first commitment period of the Kyoto Protocol. They provide approximate costs for Kyoto and post Kyoto (e.g. 2020) scenarios of €12/tCO2 in 2010, €16/tCO2 in 2015 and €20/tCO2 in 2020.

[35] See the Report of the Steering Committee from the International Symposium on the Stabilisation of Greenhouse Gases, Hadley Centre, Met Office, Exeter UK, Feb 2005.

Assessing the Coverage of the Literature Values

As outlined in the main impact text, climate change affects different categories of impacts. Valuation studies do not include the full list of all impacts. It is important to take account of these differences in reviewing the values above, to ensure we are comparing like with like, and to assess the coverage of the modelling estimates against all likely impacts of climate change. We have reviewed the studies against a risk matrix[36]. This matrix separates climate change impacts, and valuation of those impacts, into nine individual categories, described below:

Categories of impacts

The IPCC TAR shows three main categories of climate change, with different confidence levels, which are:

- ***Projections***. For example, with respect to (relatively) predictable trends such as sea level rise or average global temperature rises.
- ***Bounded risks***. Other elements are less clear, but which generally fall within a range that can be assigned approximate probabilities, for example, the change in the probability of summer drought.
- ***System change and surprises***. For example, the impacts related to large scale dynamics and regional feedbacks that are currently beyond our ability to predict with much confidence, such as alterations of North Atlantic Circulation, collapse of the West Antarctic Ice Sheet, or release of methane hydrates.

Valuation of impacts

There is a similar range of confidence in our ability to provide robust estimates of economic damages. The categories can be split into:

- ***Market damages,*** where we have high confidence, for example with respect to traded goods such as for agriculture;
- ***Non-market damage,*** *which is further split into*
    - ***Non-market goods where valuation is undertaken***, for example with valuation of health or ecosystems; and
    - ***Socially contingent effects***, such as regional conflict or poverty, where we are trying to capture large-scale dynamics related to human values and equity that are poorly represented in valuation estimates.

A risk-based approach combines both of these aspects, i.e. the nature of uncertainty in climate change with the elements of economic valuation. Such a risk matrix shown provides some structure to the search for more robust estimates of the costs of climate change, and helps inform what is covered in the current economic values, and what is not. It provides a holistic approach for addressing categories not covered by integrated assessment models and not likely to be covered in the foreseeable future.

[36] Downing, T., and Watkiss, P. (2003). The Marginal Social Costs of Carbon in Policy Making: Applications, Uncertainty and a Possible Risk Based Approach. Paper presented at the DEFRA International Seminar on the Social Costs of Carbon.

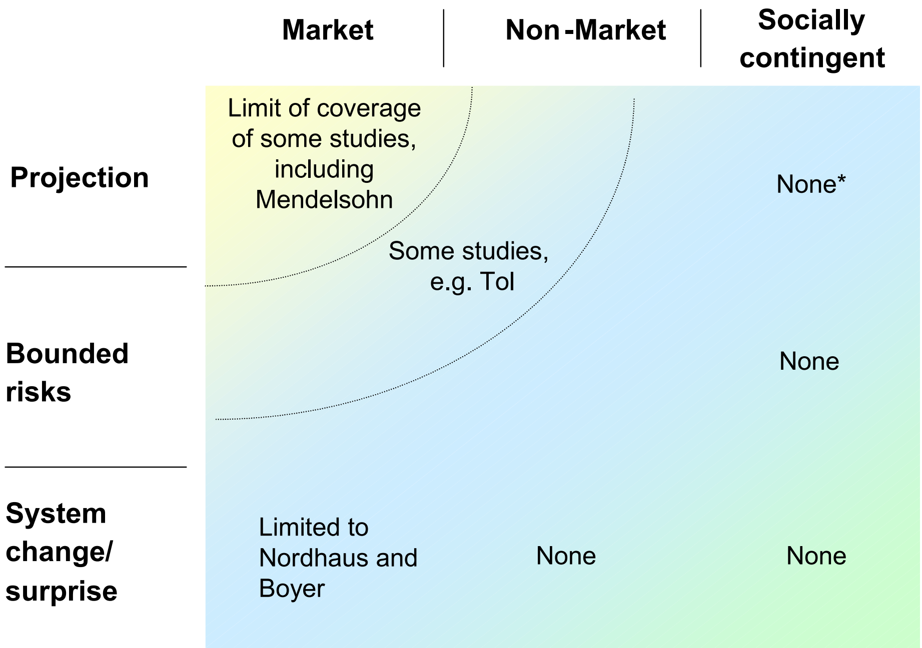
Figure 6. Risk Matrix for Categorising the Impacts of Climate Change covered in the benefits models and the economic values.

Uncertainty in Predicting Climate Change ↓ / Uncertainty in Valuation →	Market	Non Market	(Socially Contingent)
Projection (e,g, sea level Rise)	Coastal protection Loss of dryland Energy (heating/cooling)	Heat stress Loss of wetland	Regional costs Investment
Bounded Risks (e.g. droughts, floods, storms)	Agriculture Water Variability (drought, flood, storms)	Ecosystem change Biodiversity Loss of life Secondary social effects	Comparative advantage & market structures
System change & surprises (e.g. major events)	Above, plus Significant loss of land and resources Non- marginal effects	Higher order social effects Regional collapse Irreversible losses	Regional collapse

Source: Downing and Watkiss, 2003.

The 28 projects which have estimated the costs of climate change have been mapped against the matrix, and the coverage is shown below.

Figure 7. Coverage of Existing Studies Against the Matrix



Source: Watkiss et al, 2004.
* Some sectoral and/or regional studies exist for socially contingent effects for 'projections' (and limited analysis of 'bounded risk'), but they are limited to impacts, and do not extend to economic costs.

Very few studies extend beyond the top left hand corner of the matrix and none even have a full coverage of the four boxes that represent market and non-market impacts for the projected and bounded risks of climate change. There are only limited studies that have considered any socially contingent effects, or the potential for longer-term effects.

This leads us to the conclusion that the uncertainty in the value concerns the 'true' value of impacts covered by the models and also the uncertainty from impacts that cannot yet be quantified and valued. **Perhaps more importantly, it shows that the values in the literature are almost certainly a sub-total of the full cost of climate change.**

Recent work[37] has reviewed the literature values against all possible impacts of climate change, and has concluded that the recent literature values are almost certainly a sub-total of the full cost of climate change. When all possible impacts are considered, the authors conclude that a lower indicative estimate for the marginal damage costs for the full risk matrix might result in a minimum value of 15 Euro/tCO_2, a central illustrative estimate of some 25 Euro/tCO_2, and an upper indicative estimate of at least 80 Euro/tCO_2 and possibly much higher[38] (for current, year 2000 emissions).

However, in practice there is no single value – the value varies according to time-scale, scenarios, ethical choices, as well as the underlying scientific and economic analysis. To illustrate, the estimates above reflect the costs from a year 2000 marginal emission pulse. Emissions in later years (towards 2030 and beyond to 2050) will have greater impacts, when expressed as damage cost per tonne CO_2. The full profile of marginal social costs of climate change over time is therefore needed in policy analysis. This is discussed in a later section.

[37] Tom Downing, Cameron Hepburn, and Paul Watkiss in work for the UK Department of Environment, Food and Rural Affairs, on the Social Cost of Carbon. http://socialcostofcarbon.aeat.com/; the project final report will be available in late 2005.

[38] The authors stress that there is no single value and that the range of uncertainty around any value depends on ethical as well as economic assumptions. These indicative values are based on a declining discount rate and include equity weighting.

Key Choices in Determining the Values (Benefits)

There is another key element to the estimates of the costs of climate change. This lies in the choice of a number of key assumptions. Indeed, much of the variation in estimates arise from a few key parameters in the choice of decision perspectives, most importantly:

- Discount rate used;
- Approach to weighting impacts in different regions (equity weighting);
- The time period of emissions;
- Study time-horizon;
- Strong or weak sustainability approach;
- Ancillary benefits.

These parameters are discussed below.

Discount Rate

As impacts of climate change take place in the future, the discount rate used is of major importance. The discount rate[39] (see box) used can have an extremely large impact on the social cost of carbon. Many of the earlier studies are based on studies that use a 1% or 3% discount rate[40]. The difference between these two discount rates has a dramatic impact on the value; for example, using the original ExternE result, a switch from a 3% discount rate to 1% rate increases the central value from Euro 20/tCO_2 (3% d.r.) to 44/tCO_2 (1% d.r.)[41].

Most impact assessment modelling studies present results in terms of the pure rate of time preference (PRTP), as this is the fundamental parameter. The social rate of time preference is given by the pure rate of time preference plus the per capita GDP growth rate multiplied by the negative of the elasticity of utility with respect to consumption, which is a parameter used to determine the equity weights. This also allows the use of different growth rates in different regions, an important aspect for non-OECD analysis. When studies use a PRTP of 0%, they are still discounting but only to account for the extra wealth that future generations will enjoy.

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[39] '*Discounting is a technique used to compare costs and benefits that occur in different time periods. It is a separate concept from inflation, and is based on the principle that, generally, people prefer to receive goods and services now rather than later….. **The discount rate is used to convert all costs and benefits to 'present values', so that they can be compared.***'. Source: UK HMTreasury Green Book.

[40] The discount rate here refers to the use of the social time preference rate (STPR).

[41] The ExternE values are reported by Eyre et al. (1999)

Social rate of time preference (SRTP) / Pure Rate of Time Preference (PRTP)

Social Time Preference is defined as the value society attaches to present, as opposed to future, consumption. The Social Rate of Time Preference (SRTP) is a rate used for discounting future benefits and costs, and is based on comparisons of utility across different points in time or different generations. The UK HM Treasury Green Book guidance recommends that the SRTP be used as the standard real discount rate.

The STPR has two main 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). The Green Book suggests a PRTP value of around 1.5 per cent a year for the near future.
- An additional element, if per capita consumption is expected to grow over time, reflecting the fact that these circumstances imply 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 Green Book indicates the annual rate of g is 2 per cent per year, and the elasticity of the marginal utility of consumption (μ) is around 1.

SRTP is the sum of these two components

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

With a pure time preference rate of 1.5%, and values of 2% of g and 1 for μ, the resulting recommended discount rate is 3.5%. A similar value is used in European policy appraisal, with a SRTP of 4%.

Source: *Green Book. HM Treasury.*

There has also been a recent shift in the literature towards declining discount rates. For example, the UK HMT Green Book recommends a discount rate of 3.5% for projects up to 30 years with a declining schedule thereafter.

Period of years	0–30	31–75	76–125	126–200	201–300	301+
Discount rate	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%

Source: *Green Book. HM Treasury.*

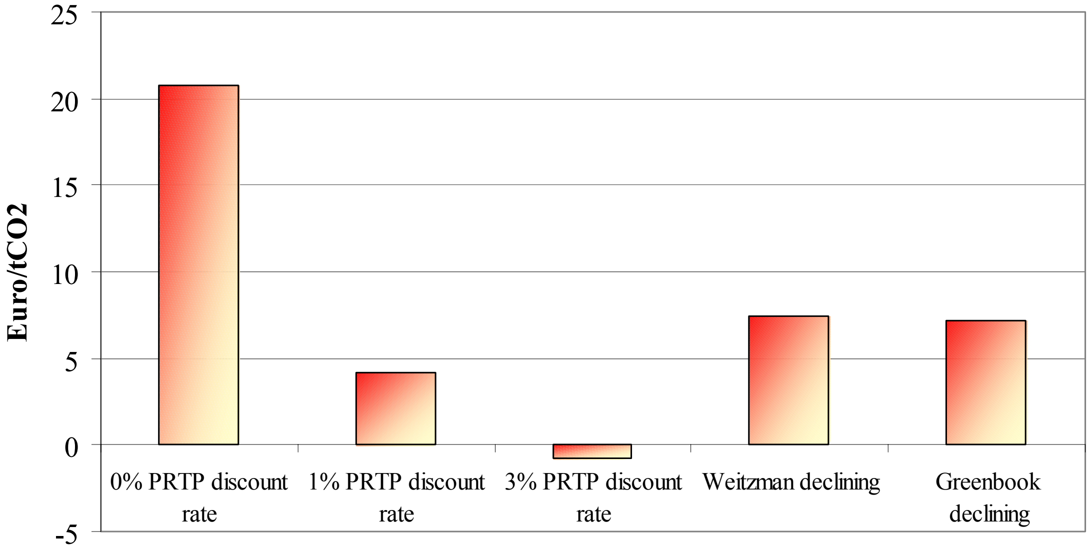
The main rationale for declining long-term discount rates results from uncertainty about the future. A declining discount rate increases the values for the costs of climate change, because it reduces the short-term benefits, and attaches greater weight to long-term impacts.

An example of the effect of discounting is shown below using the FUND model (see later section for model description), with a sensitivity analysis looking at different PRTP rates and declining discount schemes, with no equity weighting adjustment (see later section). Note there is no consideration of all bounded risks, any socially contingent effects or any major events in the model, and we stress that the figure is simply a sensitivity analysis and carries no implication about values that should be used in practice.

The figure shows very large variation in the impacts arises from this PRTP parameter alone (all other aspects of the model being constant). With a higher PRTP rate, the aggregate values can be positive.

Discount Scheme	0% PRTP	1% PRTP	3% PRTP	Greenbook declining	Weitzman declining
Euro/tCO_2	20.8	4.2	-0.7	7.4	7.2

Figure 8. Modelled Costs of Climate Change with Different Pure Rate of Time Preference and declining discount rate schemes (no equity weighting)

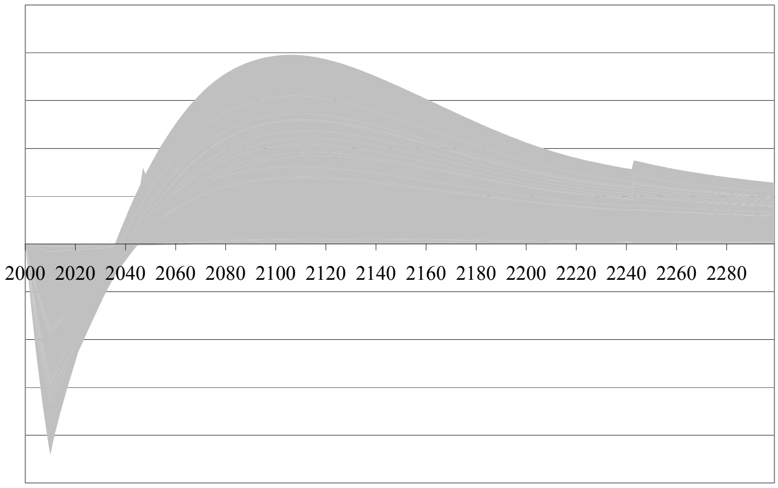


Source: FUND. Version 2.8. Pure rate of time preference. Time horizon 2300.
There is no equity adjustment, it is assumed that costs and benefits can be traded off, coverage of market and non-market impacts is partial, and socially contingent effects and climate system major events are. They are presented only as an illustration of the effects of discount rate. Including these other effects would have a large effect on the above values. The model parameter shown is the 'Best Guess' estimate. This is the model author's 'best guess' for all parameters. The best guess for climate sensitivity is 2.5 degrees Celsius equilibrium warming for a doubling of the atmospheric concentration of CO_2. Recent evidence suggests that the probability of higher climate sensitivity may have increased – see Report of the Steering Committee, International Symposium on Stabilisation of Greenhouse Gases, Hadley Centre, Met Office, 2-5 Feb 2005.

The reason why this switch occurs with the PRTP rate can be shown with the pattern of the impacts over time from FUND – shown below at 0% pure rate of time preference. It can be seen that in the short-term, to 2040, the model finds there are net benefits at an aggregate level. The use of a higher discount rate therefore puts greater importance to these short-term effects, relative to the economic dis-benefits in later years. The results refer only to the subset of impacts quantified (including the omission of socially contingent and major events). They do not include any equity weighting, and the model assumes full trade-offs between categories and regions[42], although the coverage of impacts is by no means complete

[42] This is consistent with the general assumptions in cost-benefit analysis. A different perspective, i.e. one based on strong sustainability, would not consider this assumption valid.

Figure 9. The Modelled Profile of Economic Costs over Time (0% prtp)



Source: FUND. Version 2.8. Pure rate of time preference. Time horizon 2300.
There is no equity adjustment, it is assumed that costs and benefits can be traded off, coverage of market and non-market impacts is partial, and socially contingent effects and climate system major events are. They are presented only as an illustration of the effects of discount rate.

Weighting of Effects (Distributional or Equity Weighting)

Many models show that at small to moderate climate change, poorer countries (Africa, India, and Latin America) are net economic losers, whereas richer countries, especially mid – northern latitudes, show smaller losses or may gain from moderate warming, at least in the short-term. The IPCC (in it's summary for policy makers) recognises that 'the impacts of climate change will fall disproportionately upon developing countries and the poor persons within all countries, and thereby exacerbate inequities in health status and access to adequate food, clean water, and other resources.'

The disproportionate impacts of climate change on developing countries occurs because:

- These countries are exposed to significant climatic threats;
- Their economies rely more heavily on climate-sensitive activities;
- They are close to environmental tolerance limits; and they are poorly prepared to adapt to climate change.

In contrast, richer societies tend to be better able to adapt, their economies are less dependent on climatic resources, and climatic hazards are less disruptive to economic growth. There are issues in applying CBA for climate change, where impacts are spread across countries with very different income levels. An aggregate estimate of the impacts of climate change inevitably implies combining benefits and disbenefits across winners and losers.

There are different ways of aggregating economic effects in different countries or regions, and this influences the global values. This has been a major source of contention in the climate change valuation discussion. For example, studies which have adjusted willingness to pay (WTP) estimates for income differentials across regions using local values have led to major debate[43]. As a result, there has been a shift towards the aggregation of monetised impacts using so-called equity weights (distributional weights). By using equity weighting, we are able to take into account how the costs and benefits accrue to different groups in society. Generally policies that deliver greater net benefit to individuals in lower income groups are rated more favourably than those that benefit higher. Equity

[43] When aggregated, this implies lower monetary valuation for a life lost in Bangladesh for example, than in the for example in Europe This approach has led to criticism in international policy discussions, and raises the issue of how to be consistent in policy development between domestic and international expenditure.

weights can therefore be used to explicitly recognise distributional effects within a policy's net present value. In the case of climate change, we are trying to recognise that vulnerable societies are likely to see significant impacts, and therefore that climate change mitigation policy will have a dis-proportionately larger benefit to these groups. The equity weighting scheme adopted makes a very large difference to the overall values, for example, the approach used on how to aggregate between the winners (e.g., agriculture in Finland) and the losers (e.g. sea-level rise in the Maldives or Bangladesh) can alter the estimates by almost an order of magnitude (i.e. by ten times).

Essentially, the more weight we put on the distribution of the impacts from climate change, the more severe the aggregate impacts are estimated to be. As a result, the global picture depends on how we aggregate. If we count in numbers of Euros, under some types of aggregation scheme the world as a whole may appear to lose a little. If we count in terms of numbers of people and associated physical damages, the losses become apparent.

There is no consensus on equity weighting approaches for climate change. There may be different theoretically correct approaches depending on the policy perspective and application. A different approach might be warranted from an individual member state policy perspective, as distinct from the perspective of a global policy maker. A more detailed summary of this issue is presented below[44].

In a pure utilitarian framework, equity weighting is based upon the *diminishing marginal utility of consumption*. Evidence on the appropriate value of the elasticity of marginal utility (ε), can be found from a variety of sources. However, no definitive guidance exists on the correct value, which can be regarded as an ethical parameter.

A value of $\varepsilon = 1$ is commonly employed in the literature. Some commentators have highlighted that this is not consistent with the current rate of spending on foreign aid in individual member states (e.g. Pearce, 2003). Given current rates of foreign aid, a value of ε closer to zero, if not negative, would emerge. However, this does not necessarily mean such values are appropriate for (international) climate change policy.

The appropriate course of action depends strongly on the perspective of the decision maker.

- If we take the perspective of a global decision maker, equity weighting at $\varepsilon \leq 1$ may be appropriate for damages.
- If we employ a strict member state perspective consistent with MS spending in other policy areas, particularly foreign aid, then equity weighting is difficult to justify.

There are three possible reasons why climate change and standard domestic (or European) policies may differ in their approach to equity weighting. These are: (1) Climate change is intergenerational and there is no reliable mechanism of intergenerational transfers; (2) It is non-marginal, so applying the Kaldor-Hicks rule may not be wise; and (3) It is international, and there is no international taxation system. Any policy that satisfies one of these three issues could be argued to have a claim to equity weighting. This would include foreign aid but arguably other domestic and international policies with international or intergenerational consequences (e.g. agricultural subsidies or biodiversity policies)[45].

[44] Based on a short note commissioned for the study. 'Equity weighting of climate change damages: Where do we stand?' Cameron Hepburn. St Hugh's College, Oxford University.

[45] This argument does not justify climate change using equity weighting when aid decisions do not, but it presents a case for using equity weights in both instances.

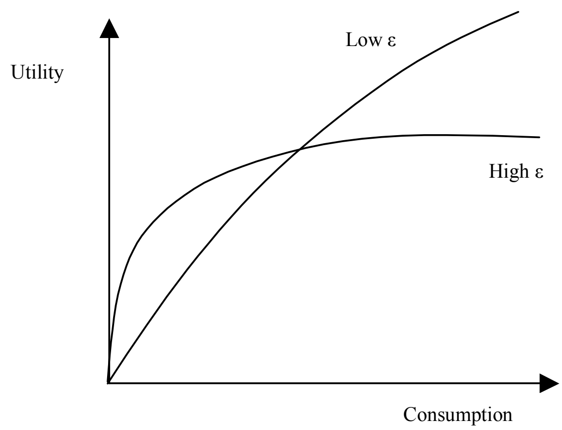
Equity Weighting

With a utilitarian social welfare function, each person's utility counts equally. It is generally accepted that each additional unit of consumption provides diminishing marginal utility.

That is, giving 1 Euro to a rich person produces less utility (*welfare* or *happiness* may substitute as rough equivalents) than giving 1 Euro to a poor person. So, utility increases with consumption, but at a decreasing rate. A common way to represent this is when utility, u, of consumption, c, is represented by an isoelastic utility function: $u(c) = c^{(1-\varepsilon)}/(1-\varepsilon)$, where ε denotes the elasticity of marginal utility.

In this function, the higher ε, the more rapidly marginal utility falls with additional wealth. In other words, a high ε implies that there is little additional utility gained from additional consumption by people who are already rich. A higher ε therefore implies a higher aversion to inequality.

Utility functions for different ε



The impact of different choices for ε can be shown by considering two countries, one rich (R) and one poor (P). Suppose country R has an income ten times that of country P. The table below, adapted from Pearce (2003), shows the value of a marginal Euro to R relative to a marginal Euro to P. For ε = 0 (no equity weighting), a Euro to R is worth the same as a Euro to P. For ε = 1.0 (commonly employed in the literature), giving 10 cents to P achieves the same utility increase as giving 1 Euro to R: marginal income to P is valued ten times more highly than to R.

Impact of equity weighting when $Y_R = 10Y_P$

ε	0.0	0.5	0.8	1.0	1.2	1..5	2.0	4.0
Loss to R as a fraction of gain to P	1.0	0.31	0.16	0.10	0.06	0.03	0.01	~0

Hence even though a pure utilitarian would not weight *utility*, a utilitarian would weight *consumption flows* because of the diminishing marginal utility of consumption. These weights on consumption flows are termed *equity weights* and the appropriate equity weight for consumption going to country R is $(Y_N/Y_R)^\varepsilon$, where Y_N is a benchmark (or numeraire) income level. The equity weight for consumption going to P is equivalently $(Y_N/Y_P)^\varepsilon$. The numeraire level is important and is discussed further below.

Evidence on the *correct* value of ε could come from: (a) lab experiments on individual behaviour; (b) revealed preferences of individuals; (c) revealed social preferences by government spending on programs designed to reduce inequality in the member states; (d) Member state or European government spending on programs designed to assist other countries.

Based on evidence of individual behaviour in categories (a) and (b), Cowell and Gardiner (1999) suggest that values between 0.5 and 4 are plausible. After examining social programs in category (c), Pearce (2003) argues that values above ε = 2 are unreasonable because they imply an unrealistically high level of aversion to inequality. Pearce (1999) concludes that values between 0.5 and 1.2 seem reasonable. Finally, cursory inspection of foreign aid spending in category (d) would suggest that even ε = 1 is extremely high – for example member state governments spend more on its relatively rich citizens than on aid to relatively poor people in other countries. However, this finding simply reflects the inapplicability of the global utilitarian ethic to the interests of individual nation-states.

There is another aspect to equity weighting which should also be considered. In standard economic models, the elasticity ε used in equity weighting is the same parameter as appears in the Social Rate of Time Preference:

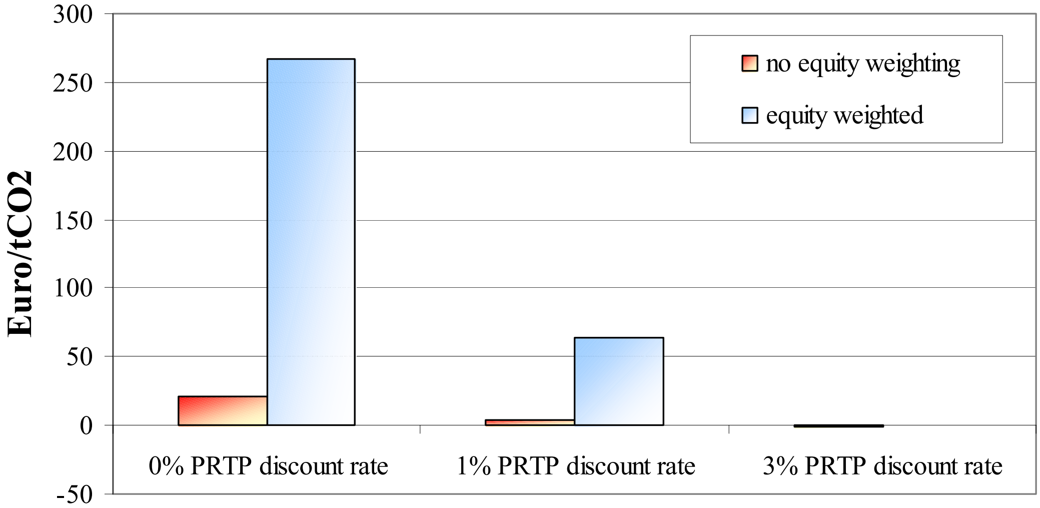
$$SRTP = PRTP + \varepsilon * g$$

where PRTP is the Pure Rate of Time Preference, ε is the negative of the marginal elasticity of utility with respect to consumption, and g is the per capita GDP growth rate. From this perspective, a more consistent approach is to specify the PRTP and elasticity that we wish to use, and derive consistent equity weights and SRTP values.

The effect of equity weighting can dramatically increase the values. This is shown below, again using the FUND model. Note there is no consideration of socially contingent effects or surprises in the model, and we stress that the figure is simply a sensitivity analysis and carries no implication about values that should be used in practice.

	Euro/tCO_2		
Scheme	**0% PRTP**	**1% PRTP**	**3% PRTP**
No equity weighing	21	4	-0.7
Equity weighted	267	64	-0.3

Figure 10. The effect of equity weighting (FUND 2.8).



Source: FUND. Version 2.8. Pure rate of time preference. Time horizon 2300. The values above do not include all impacts of climate change, i.e. they are a sub-total of the 'full' value. They are presented only as an illustration of the effects of discount rate. Including these other effects would have a large effect on the above values.

The Time Period of Emissions

Recent work has assessed the potential change in emissions over time (under a business as usual scenario). This shows that emissions in future years will have a greater total impact than emissions now.

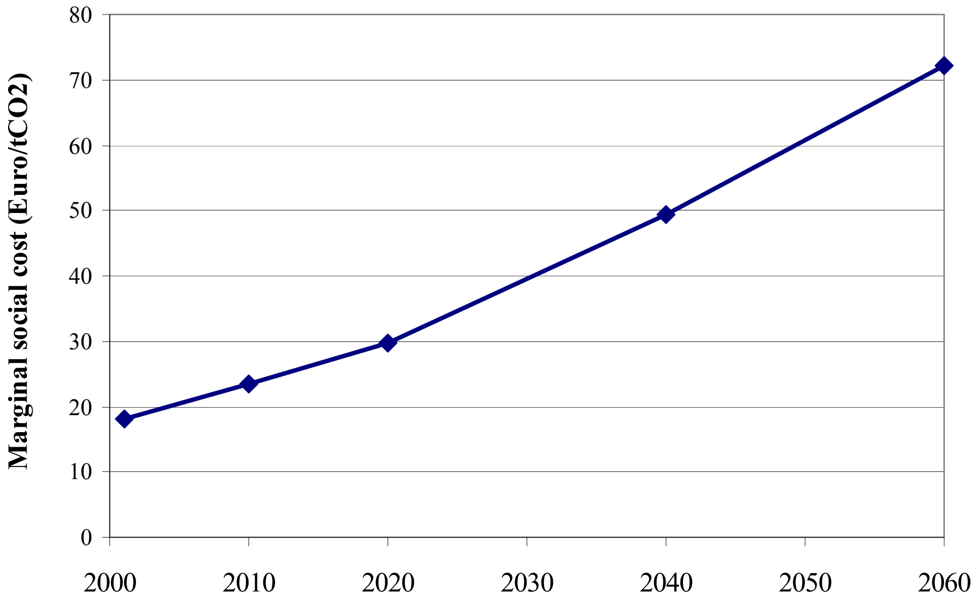
Analysis from the PAGE model (see later section) has been used to assess how the marginal social cost of emissions will change in future decades, under a scenario of no further action. The best fit to the mean values is a 2.4% increase in the marginal social cost of emissions each year. The central values for marginal social costs therefore needed to be increased in line with this to compare to the future projections of marginal abatement costs.

Marginal social costs of climate change from GHG emissions in year of emission

Year of emissions	**2001**	**2010**	**2020**	**2040**	**2060**
Euro/tCO_2	18	23	30	49	72

Source: PAGE. Based on the A2 scenarios, with PPP exchange rates, Green book SRTP, an equity weight parameter of 1. This leads to a higher value in 2000 than using the usual PAGE output above, as the standard PAGE analysis is equivalent to a mean 2% prtp.

Figure 11. The increase in marginal costs of emissions in future years without post-Kyoto action.



Values are presented as the value in the year of emissions in 2000 prices. They are not discounted back to the year 2000.

The rate of increase for the FUND model also shows rises in future years (albeit at slightly lower levels than the PAGE model above).

Model Time-Horizon

Aggregate models suggest that aggregate impacts of climate change may be positive in the short term when climate change is still relatively modest, but turn negative for more severe climate change. Uncertainties also increase rapidly in the longer-term, including the chance of large-scale discontinuities (thermohaline circulation, West-Antarctic Ice Sheet, loss of biomass carbon from increased incidence of forest fires or soil drying, greater methane release from boreal ecosystems). Many of the existing models (at least their best estimates of the social costs) have a time horizon of 2100, thereby excluding these major effects. The impact and costs of climate change are sensitive to the time horizon chosen, i.e. essentially whether the hazards of the remote future are considered or not, though these effects are dampened by discounting (especially at higher discount rates).

Some models have now started to look at the effects of time-scale. A longer modelling time-scale clearly increases the uncertainty, partly because of the uncertainty about the scenarios and partly because parameter uncertainties accumulate over time. Many models are therefore extending the lifetime to 2200 or even 2300. What is clear is that the effects of extending the time horizon, even with discounting, can substantially increase the estimated marginal cost of emissions in the period 2000-2100. The impact from extending the time horizons is increased with a low discount rate, and with equity weighting.

Reporting of Statistical Data

Both the mean and the median have been used as a measure of central tendency for the social costs of climate change. Since for skewed distributions they give substantially different results *even with the same underlying data* it is important to consider which is appropriate, so that at least consistent comparisons can be made.

Defining a central value in a data set in the presence of outliers is difficult. The usual measure, the arithmetic mean or average, is an unbiased measure of the expected value if the data form a homogeneous population with few real outliers. However, the data may not be drawn from a single population and the mean is sensitive to the tails of the distribution.

This is important for the estimation of climate change impacts as the models show that the distribution is right skewed, i.e. the mean is higher than the median value[46] and there are often outliers. The median is less sensitive to outliers, and has been regularly quoted in literature studies, but is biased towards lower values when the probability distribution has a long, high-value tail (as with climate change impacts – note this may have led to bias in some of the values published.).

Strong and Weak Sustainability

In looking at any social cost of climate change value, it is extremely important to realise what is, and is not, included in the value. It is also important to understand the 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, consistent with a cost-benefit analysis, assume full substitutability, i.e. between very different impact categories. This may mean that the aggregated economic cost is the net of the losses from for example to damages to natural ecosystems, against the positives, for example from reduced energy for heating.

It is clear that different stakeholders will have different views on whether such substitution will be acceptable. In order to help examine these issues, we propose that some detailed analysis is undertaken, showing the balance of positive and negative effects, by region (rather than single global values).

Marginal Effects

For policy appraisal (cost-benefit analysis) we are interested in the marginal social costs of climate change[47]. The marginal damage cost is the damage from an additional tonne of CO_2 emitted. Specifically, it is the change in the net present value of the monetised impacts, normalised by the change in emissions. The models used in the analysis have been used to estimate the marginal social costs, i.e. the models are run with and without additional pulses of emissions to assess the marginal costs. However, the underlying analysis within the models, such as for loss of land, may not adequately reflect scarcity, i.e. the models may be underestimating the true marginal costs[48]. There have also been concerns that some of the potential changes from climate change are clearly non-marginal (e.g. the risk of major changes to ocean currents, major sea level rise – note these are also non-linear)[49]. Some commentators have responded to this by arguing it still possible to look at marginal changes around policy decisions in regard to climate change policy, whilst recognising that non-marginal impacts are not fully represented.

[46] Measures based on a cumulative probability function include the quartiles and median. The distribution of the data is captured in the median and quartiles: The minimum, maximum, and three quartiles (lower 25%, median or 50% and upper 25%) are derived from the ordered data set. The median is the value for which 50% of the data are larger.

[47] Rather than the total costs of future climate change out-turns, or the average costs associated with for example a doubling of CO_2 concentrations.

[48] In practice, the SCC estimates from models such as FUND are 'average' marginal damage costs.

[49] Threshold effects present particular challenges, both in estimating the physical impacts of climate change and in determining appropriate WTP/WTAC values for these impacts.

Economic Benefits of Different Stabilisation Targets

The section above summarises the effects of climate change without further action. It is important to also assess the benefits of potential stabilisation targets[50], expressed either in relation to CO_2 concentrations (e.g. 450, 550, and 650 CO_2 equivalent ppm concentrations) or to temperature change such as a limit of a 2˚C rise above pre-industrial level. This provides the analysis of the potential benefits of future mitigation policy. The study has used a number of models to investigate the potential social costs associated with different stabilisation targets, compared to a business as usual run. In comparing different analysis, it is important to be specific about the targets considered (see box below).

Specifying Stabilisation Targets

In assessing the benefits of potential targets, it is important to specify a number of assumptions. For example, whether a target relates to a CO_2 concentration in the atmosphere (e.g. 550 CO_2 ppmv) or an equivalent CO_2 concentration including all greenhouse gases (e.g. 550 CO_{2equiv} ppmv). Likewise, when considering a climate target that should not exceed 2˚C above pre-industrial levels, it is important to note if this is based on a specific climate sensitivity (e.g. 2.5˚C for a doubling of pre-industrial levels). For this analysis, we have used recent conversion factors for converting temperature targets into greenhouse gas concentration/radiative forcing targets as CO_2 equivalent concentrations (note these are different from GWP).

Conversion table Stabilisation Target for >2100

CO_2 (ppmv)	CO_2 (ppmv)
350 + other	400
390 + other	450
470 + other	550
550 + other	650

Source: Detlef van Vuuren. Options and Challenges for Post-Kyoto Regimes. Presented at the EC workshop on Climate Policy Post 2012. 9th November, 2004. Brussels. Based on Meinshausen, 2004.

Knowledge Elicitation of Experts

Recent work[51], has undertaken an expert consultation on the importance of main factors driving climate change valuation and responses to specific scenarios. The scenarios assessed included:

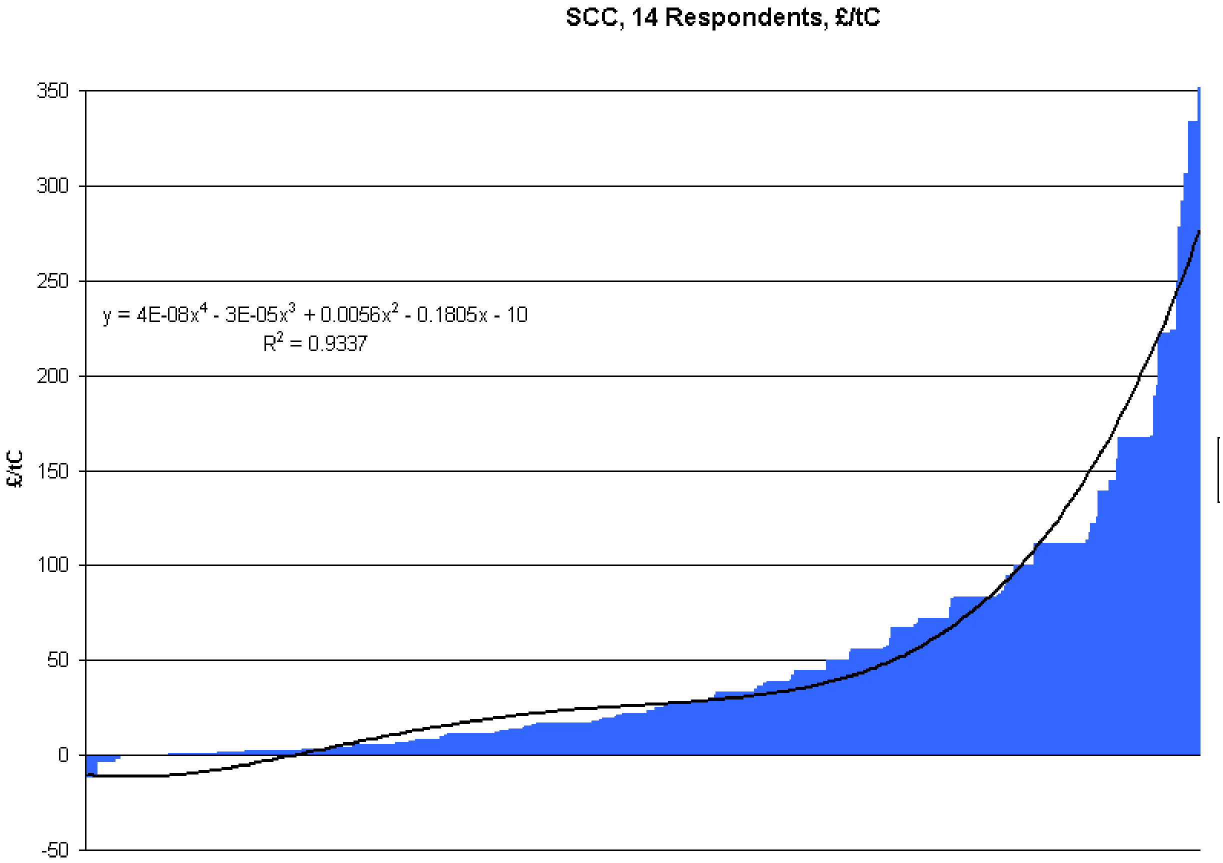
- Three temperature scenarios, including scenarios of surprises;
- Market and non-market damages, and inclusion of socially contingent effects, with and without adaptation;
- Different discount rates and equity schemes.

The analysis was undertaken with 14 experts. The range of responses to the various scenarios, expressed as a social cost of carbon in £/tC is shown below

[50] Note given historical and current emissions, we are already committed to some level of warming and climate change.

[51] Tom Downing, at the Stockholm Environment Institute (Oxford office), as part of recent work for Defra in the UK on the social costs of carbon

Figure 12. Social Cost of Climate Change Consultation based 14 respondents

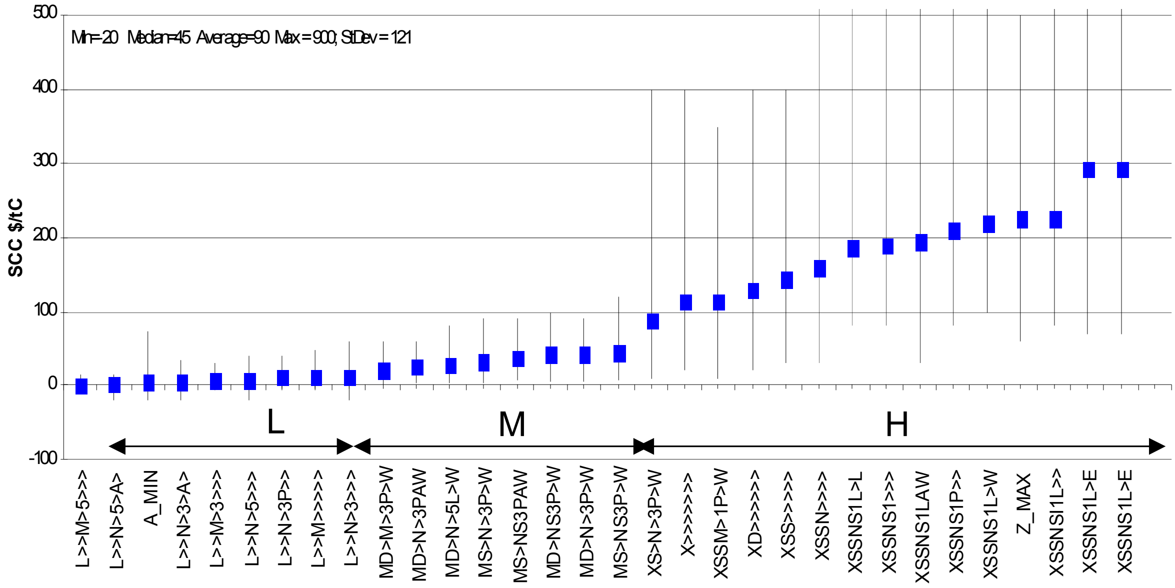


The range of estimates from the scenarios, from all experts, ranged from -4 to 140 Euro/tCO_2 (-$15 to 525/tC). Most experts believed that under conditions of low temperature change (2˚C), the costs would be low, most probably below Euro 15/tCO_2 (~$50/tC). In contrast, for high temperature change (>4 °), the expert response of high costs, likely to be above > Euro 30/tCO_2 (~$100/tC), and plausibly with an upper bound of 140Euro/tCO_2 ($525/tC). The responses, grouped into the three categories (low, medium and high temperature change) are shown below.

A number of observations were made from the analysis:

- All experts thought minimum estimate might be close to zero/ a benefit, reflecting a view low or moderate climate change has net benefits for some years;
- All increased their initial 'high' estimate as they went through the process, and were questioned on issues such as the possibility of surprises or socially contingent effects;
- All felt the confidence in the numbers was very low;
- No single factor dominates uncertainty for larger estimates. Several combinations of factors could lead to the impacts being over Euro 60/tCO_2 ($200/tC)

Figure 13. Social Cost of Climate Change responses grouped as low, medium & high temperature change



Model Analysis with the PAGE Model

The PAGE model, run by Chris Hope at the Judge Institute at the University of Cambridge has been used to examine a number of different stabilisation targets, as part of work commissioned for this study.

PAGE2002 is an updated version of the PAGE95 integrated assessment model (Plambeck, Hope and Anderson, 1997, Plambeck and Hope, 1995 and Plambeck and Hope, 1996). The main structural changes in PAGE2002 are the introduction of a third greenhouse gas and the incorporation of possible future large-scale discontinuities into the impact calculations of the model (IPCC, 2001a, p5). Default parameter values have also been updated to reflect changes since the IPCC Second Assessment Report in 1995. The full set of equations and default parameter values in PAGE2002 are given in Hope, 2004. Most parameter values are taken directly from the IPCC Third Assessment Report (IPCC, 2001b). Rather than only give single estimates, PAGE builds up probability distributions of results by representing 31 key inputs to the marginal impact calculations by probability distributions.

The basic assumptions that go into the model, such as that the economic and non-economic impacts in the EU before adaptation, are given in the following table

	Mean	Min	Mode	Max
Econ impact in EU(%GDP for 2.5 degC)	0.5	-0.1	0.6	1
Non-econ imp EU (%GDP for 2.5 degC)	0.73	0	0.7	1.5
Impact function exponent	1.76	1	1.3	3

And the following climate sensitivity/range:

	Mean	Min	Mode	Max
Equilibrium warming for 2xCO2 (degC)	3	1.5	2.5	5

In relation to adaptation, a 2˚C rise in temperature can be tolerated before economic impacts in developed regions occur, and adaptation can reduce these by 90% after 10 years. For economic impacts in developing regions there is no tolerable temperature rise, but adaptation can decrease the impacts by 50% after 10 years. Finally, for non-economic impacts in both regions there is no tolerable temperature rise and adaptation can reduce them by 25%.

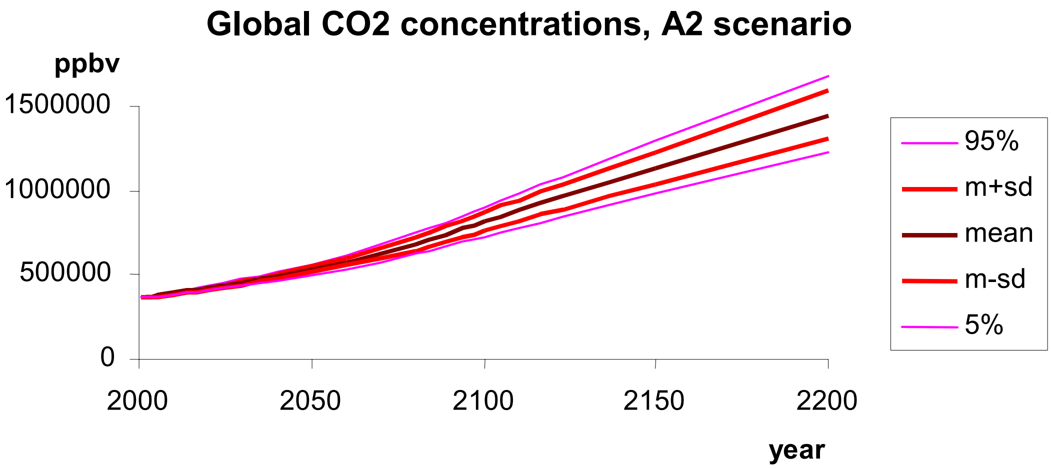
The model has been used to assess the total impacts, discounted back to a net present value, and the marginal social cost of carbon under different stabilisation targets. The total damage values presented are based on all global damages over a time horizon of 2200 and discounted back to a net present value. The analysis for a business as usual run is based on the A2 scenario. The model has also assessed 550 ppm and 450 ppm CO_2 concentrations levels. These are broadly equivalent to 550 ppm and 650 ppm CO_2 equivalence (though PAGE includes stimulation of natural CO_2 using IPCC estimates of lower effective uptake of CO_2 by oceans as the temperature increases, so the model actually predicts higher increases). The PAGE model uses a range of parameters, including discount rate and equity weighting. For these runs, the mean values are for a mean discount rate of 2% pure rate of time preference (PRTP) and an elasticity of utility with respect to consumption of minus 1 (i.e. an equity weighted scenario). The value of a 2% PRTP) is broadly consistent with the current EC recommended discount rate of 4% social rate of time preference (assuming average GDP per capita growth of 2%). Note the use of lower discount rates, or declining discount rate schemes would give higher values than presented here.

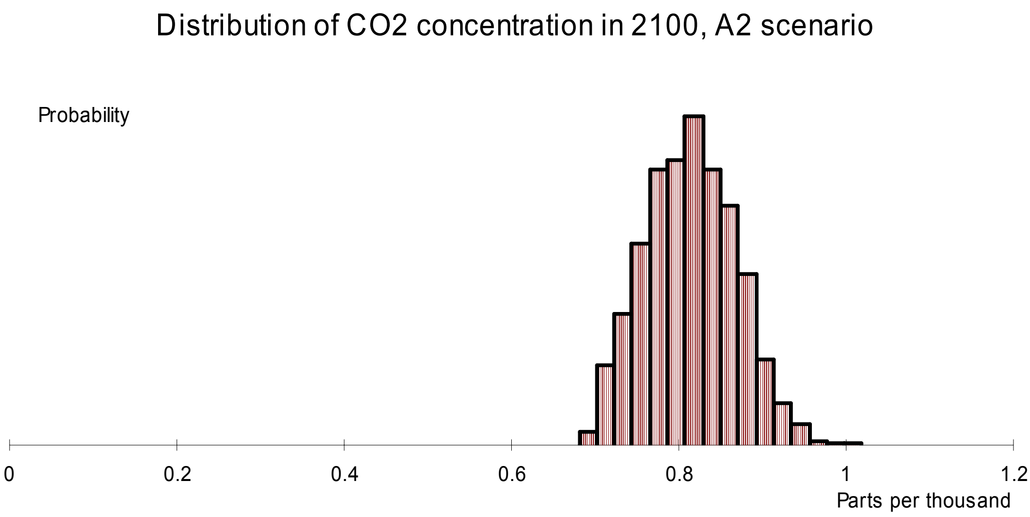
Most impact assessment modelling studies present results in terms of the pure rate of time preference (PRTP), as this is the fundamental parameter. The social rate of time preference is given by the pure rate of time preference plus the per capita GDP growth rate multiplied by the negative of the elasticity of utility with respect to consumption, which is a parameter used to determine the equity weights. This also allows the use of different growth rates in different regions, an important aspect for non-OECD analysis. When studies use a PRTP of 0%, they are still discounting but only to account for the extra wealth that future generations will enjoy.

The results are shown below by scenario.

Baseline A2
Under this scenario, the mean CO_2 concentration is about 815ppm by 2100 (1140ppm by 2150, 1450ppm by 2200). The figures below show concentration over time and the probability distribution for 2100.

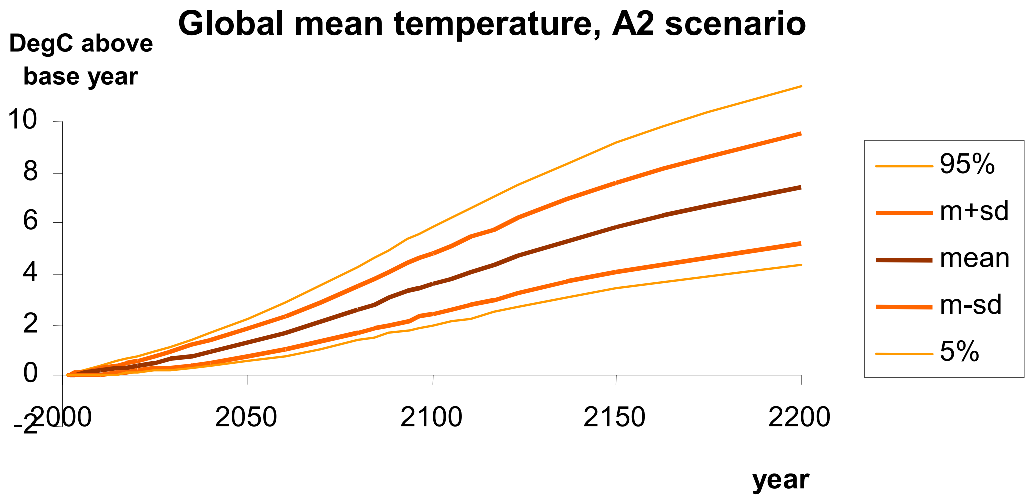
Figure 14. A2 Scenario (i) Carbon dioxide concentration over time and (ii) probability distribution for 2100





The mean temperature is 4.1°C above pre-industrial by 2100. The figure below shows the global mean temperature over time over time compared to the base year of 2000; add 0.5°C to get global mean temperature compared to pre-industrial.

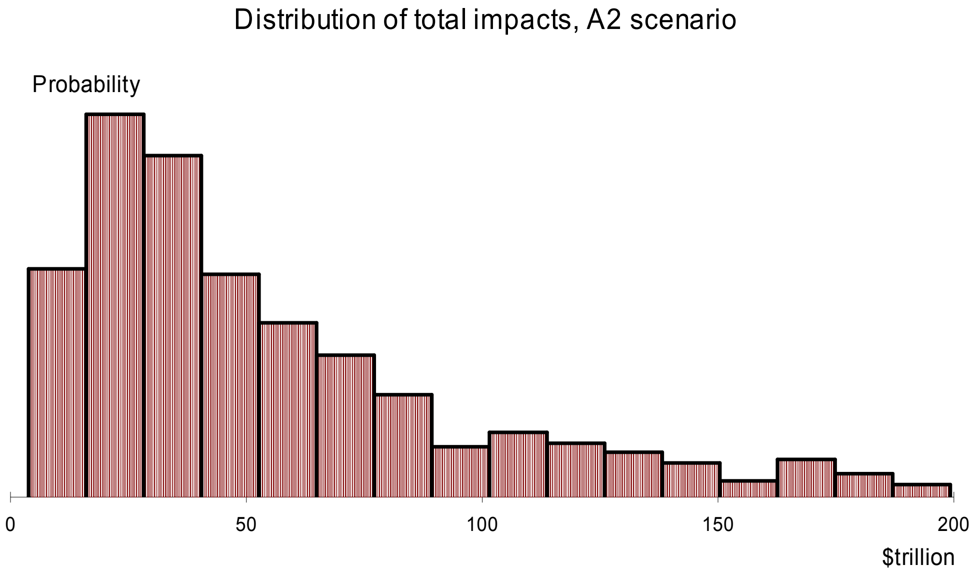
Figure 15. Global mean temperature over time for the A2 Scenario



Under the A2 scenario, the mean impacts of climate change are $73 trillion (US$ 2000 prices) – equivalent to Euro 74 trillion in 2000 prices (note a trillion is a million million[52]). This is based on a time horizon of 2200 and discounted back to a net present value. The PAGE model uses a range of parameters, including discount rate and equity weighting[53]. The range of results is shown below (a small number of runs that gave impacts above $200 trillion are not shown on the graph, but are included in the mean impacts of $73 trillion).

[52] We use the definitions of a billion = one thousand million, and a trillion = a thousand billion (million million).
[53] The mean values are a PRTP of 2%, and an elasticity of utility with respect to consumption of minus 1.

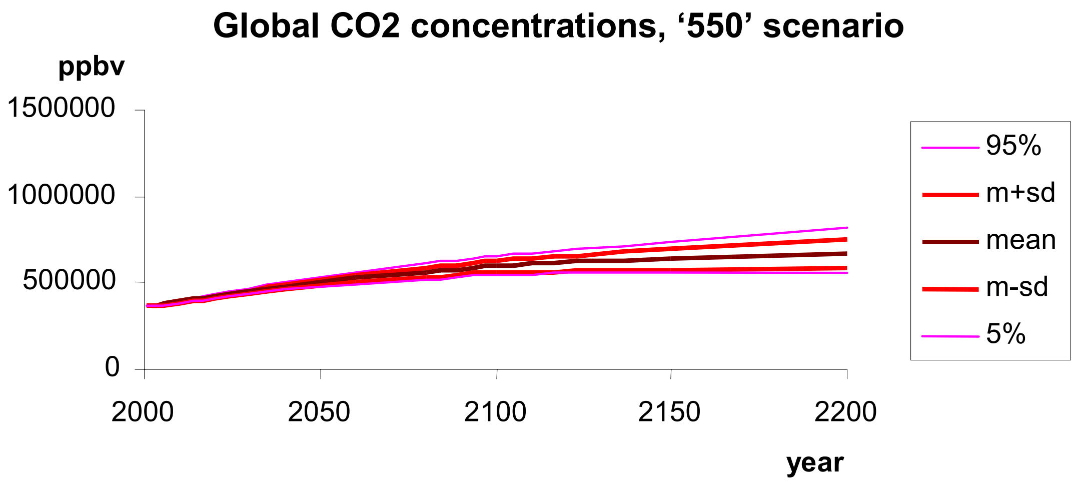
Figure 16. Distribution of total impacts based on the A2 Scenario using the PAGE model



Scenario 550 CO_2 ppm (650 ppm CO_2 equivalent)

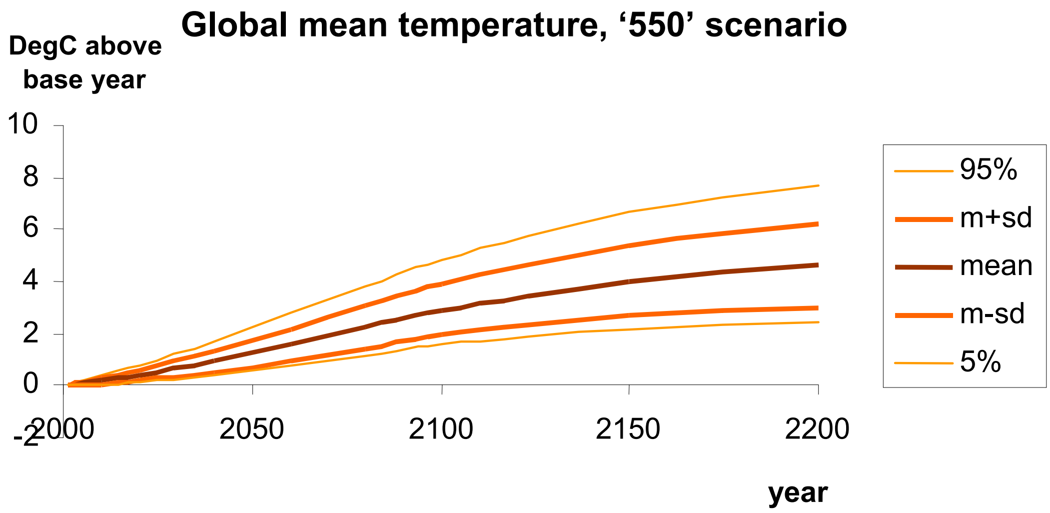
Because of the stimulation of natural CO_2 that is included in the PAGE model the scenario does not actually stabilise at 550ppm. Mean CO_2 concentration is about 594ppm by 2100 (635ppm by 2150, 670ppm by 2200). The figure below shows concentration over time.

Figure 17. Carbon dioxide concentration over time for the 550 ppm scenario



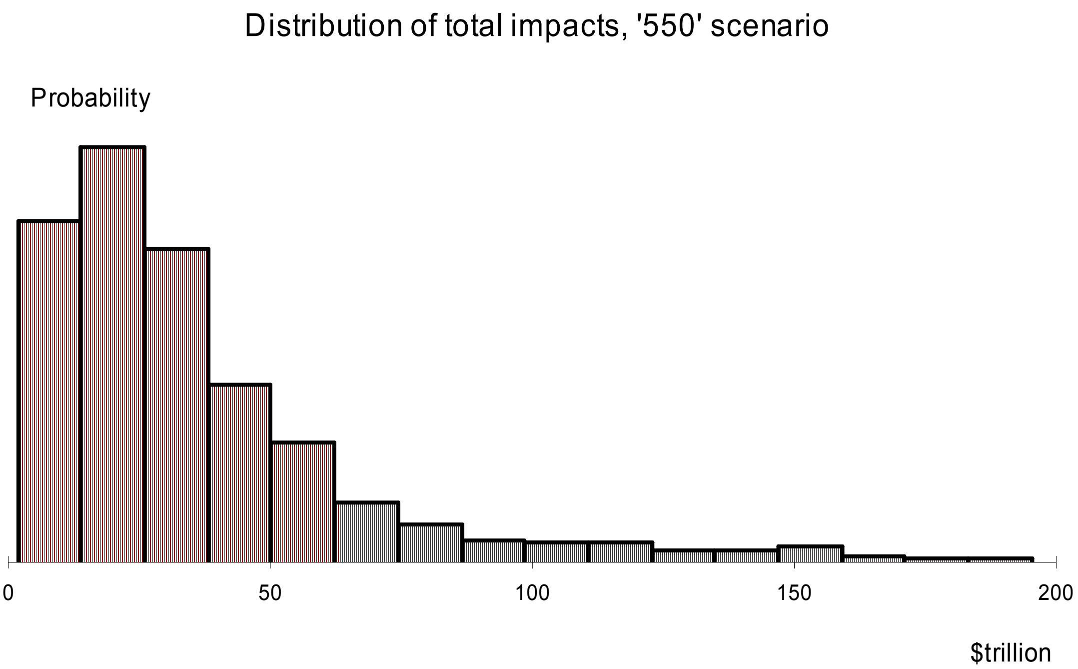
The mean temperature is 3.4°C above pre-industrial by 2100. The figure below shows the global mean temperature over time over time compared to the base year of 2000; add 0.5°C to get global mean temperature compared to pre-industrial.

Figure 18. Global mean temperature over time for the 550 ppm scenario



This leads to a mean net present value of Euro 42 trillion (2000 prices, estimated from $42 trillion), down from Euro 74 trillion in the A2 scenario, mainly because of the big difference in temperature after 2100).

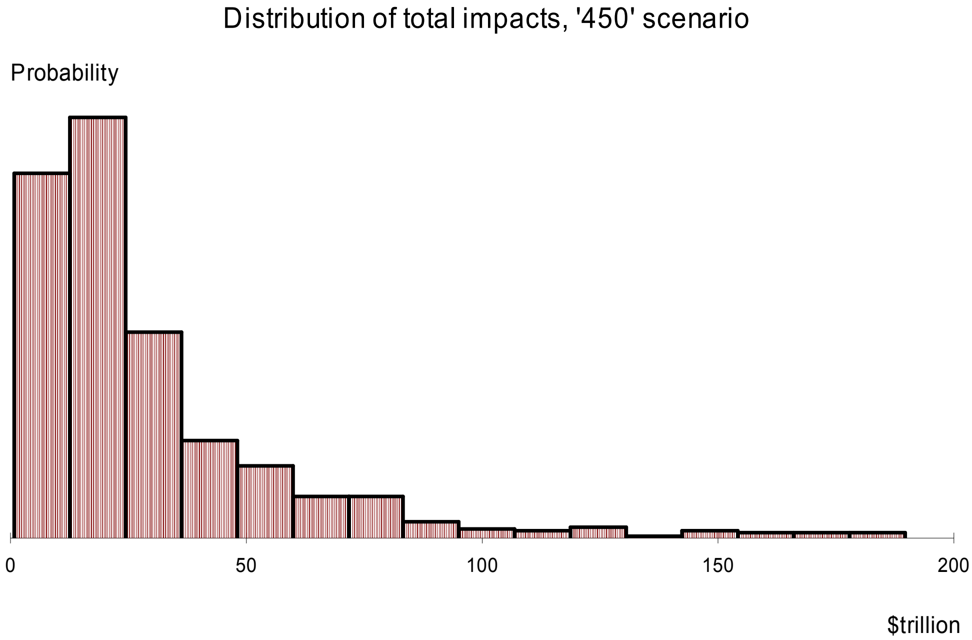
Figure 19. Distribution of total impacts based on the 550 ppm Scenario using the PAGE model



Scenario 450 CO_2 ppm (~550 ppm CO_2 equivalent)

Because of the stimulation of natural CO_2 that is included in the PAGE model the scenario does not actually stabilise at 450ppm. Mean CO_2 concentration is about 512ppm by 2100 (550ppm by 2150, 590ppm by 2200). Under this scenario, mean damage is reduced to a net present value of Euro 32 trillion (2000 value: estimated from $32 trillion).

Figure 20. Distribution of total impacts based on the 450 ppm Scenario using the PAGE model



Marginal Social Costs

Interestingly, the analysis did not show a large drop in the social cost of carbon under the three scenarios. The results were $43/tC (43 Euro) under both the baseline and 550 ppm scenario, $40/tC (40 Euro) under the 450 ppm scenario, reflecting several non-linearities in the effects). The reason why this is true is not straightforward. It is caused by the interplay between the logarithmic relationship between forcing and concentration (which will tend to make one extra tonne under the 550 ppm scenario cause more damage), the non-linear relationship of damage to temperature (which will tend to make one extra tonne under the A2 scenario cause more damage), and discounting (which will tend to make early damage more costly than late damage).

FUND analysis

The FUND model, run by Richard Tol at the University of Hamburg has also been used to assess damages as part of work commissioned for this study. In summary, The Climate Framework for Uncertainty, Negotiation, and Distribution model, version 2.8, (FUND2.8) is an integrated assessment model, coupling demographics, economy, technology, carbon cycle, climate, and climate change impacts. FUND2.8 includes sea level rise, energy consumption, agriculture, forestry, water resources, cardiovascular and respiratory diseases, malaria, dengue fever, schistosomiasis, diarrhoea and ecosystems. Other impacts are unknown.

The model includes reduced forms of more complex models. It values impacts using standard monetary valuation methods, particularly benefit transfer. It has a time period through to 2300, and has 16 world regions.

The model has been used to explore the impact of discount rate and equity schemes on the marginal social cost of carbon[54]. This was outlined in a previous section.

[54] The Benefits Of Greenhouse Gas Emission Reduction: An Application Of Fund. Richard S.J. Tol. March 2005.

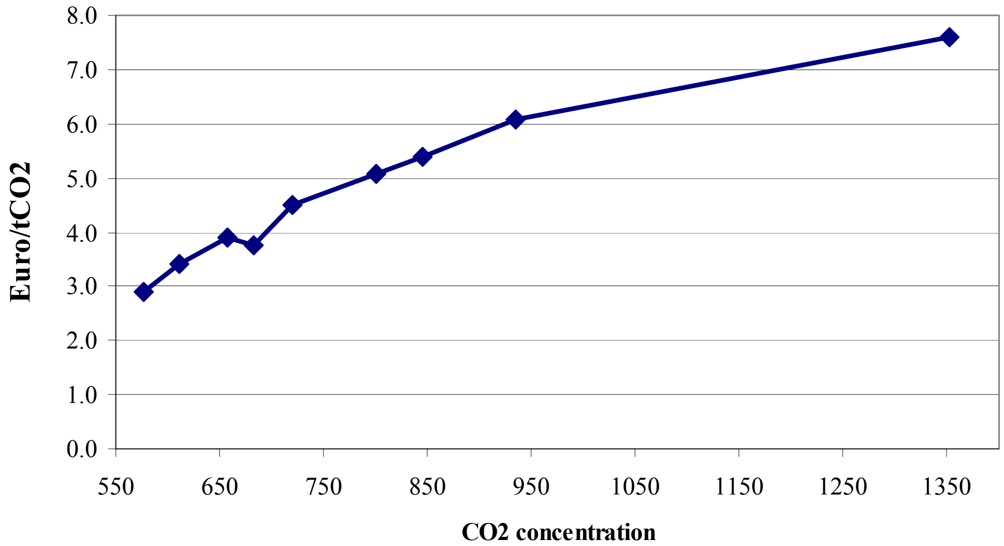
The study has assessed the possible marginal social cost values from FUND under different future scenarios, consistent with different emissions paths and global post-Kyoto policies. The results are shown below and show the marginal damage costs of carbon dioxide emissions in the period 2000-2009, for the business as usual scenario and various policy scenarios. The scenarios are ranked according to the their maximum CO_2 concentration in the atmosphere.

This analysis has only been undertaken using the FUND best estimate for current emissions – it has not been completed for future time periods, or with the full monte carlo analysis (to generate median and mean values), as this would require detailed additional modelling work. This analysis is highlighted as a priority for future work.

	Euro 2000/tCO_2					
MaxCO2	**0%**	**1%**	**3%**	**Weitzman**	**Gollier**	**Greenbook**
1352	22	4.4	-0.8	7.9	605	7.6
934	18	3.1	-1.1	6.2	588	6.1
846	17	2.7	-1.2	5.7	576	5.4
800	16	2.4	-1.2	5.4	566	5.1
720	15	2.0	-1.3	4.8	541	4.5
682	14	1.5	-1.5	4.4	527	3.8
658	13	1.5	-1.4	4.1	514	3.9
611	12	1.1	-1.5	3.6	485	3.4
577	11	0.7	-1.5	3.0	455	2.9

Source: FUND. Version 2.8. Pure rate of time preference. No equity weighting. Time horizon 2300. The values above do not include all impacts of climate change, i.e. they are a sub-total of the 'full' value. They are presented only as an illustration of the effects of discount rate. Including these other effects would have a large effect on the above values.

Figure 21. Marginal social costs under different policy scenarios (CO_2 concentrations) from FUND, current emissions, no equity weighting. Best Guess. Declining Greenbook discount rates.



Note values are presented without equity weighting.
Note, the time profile excludes climate system 'surprises' and socially contingent effects

The analysis above shows a strong decline in the values with lower CO_2 stabilisation concentrations. The proposed stabilisation targets are on the far left of the graph (in fact off the scale to the left). The strong decline in the FUND values under lower stabilisation targets is consistent with the concept that progress stabilisation (and lower temperature changes) would prevent much of the major potential damages of climate change, leading to lower marginal values. It also appears that deeper emission cuts avoid more damage, but the additionally avoided damage gets progressively smaller[55].

However, FUND does not include any of these major events, any socially contingent effects, excludes many bounded risks, and the numbers above do not include equity weights, all of which would significantly increase the values above. Note the graph above only relates to current emissions, other work with FUND has shown that the marginal social costs rise for emissions in future years (i.e. 2010 and subsequent decades). Therefore some care must be taken in drawing too many conclusions from the analysis.

Adaptation costs

Both the FUND and the PAGE models include adaptation, and it would be useful to separate out adaptation and damage costs. It would also be useful to undertake a wider review and analysis of the literature on adaptation costs. The modelling of adaptation remains a major issue that justifies further work; key adaptation issues and areas for further work are discussed below.

Adaptation to climate change is needed to prevent or limit severe damage to the environment, society and economies and to help ensure sustainable development in the face of climate change. Adaptation is necessarily cross-cutting as it involves promoting an understanding of how the changing climate will affect all sectors in different ways in each country. However, adaptation will also incur costs and will not prevent all damages.

Planning for climate change adaptation should begin as soon as possible because anticipatory and precautionary adaptation is more effective and less costly than forced, last minute, emergency adaptation or retrofitting (EEA 2004). The ability of human systems to adapt to and cope with climate change depends on such factors as wealth, technology, education, information, skills, infrastructure, access to resources and management capabilities (TAR 2001). Developing countries have less of these attributes and as a result have a lesser capacity to adapt and are more vulnerable to climate change impacts.

Reviews of climate change adaptation work[56] have shown that climate change costing studies often pay little attention to adaptation costs and more work needs to be completed in this area. Areas for improvements in costing studies include:

- more realistic estimates of the costs of implementing adaptation measures
- distinguish between autonomous and anticipatory adaptation: there are generally economic advantages to anticipatory adaptation
- more research into the distribution of adaptation costs and benefits

Further research in these areas would increase the reliability of adaptation cost estimates.

[55] The analysis has also revealed some potentially interesting trends – with deep cuts, emission reduction may become so costly that economic growth is slowed down, and vulnerability to climate change increases.
[56] Climate Change Impacts and Adaptation: A Canadian Perspective, Natural Resources Canada 2004 http://adaptation.nrcan.gc.ca/perspective/profile_e.asp

Ancillary Effects

There is growing recognition that mitigation policies or scenarios that are aimed at reducing greenhouse gas emissions may have important ancillary benefits. These potentially include:

- Reductions in air pollution;
- Reductions in other environmental burdens;
- Increased security of energy supply (and/or energy diversity), including reduced oil imports;
- Improved competitiveness;
- Increase employment;
- Innovation.

However, there have also been concerns that policies may lead to potential dis-benefits, including

- Impacts on trade and competitiveness (note this is also mentioned as a potential benefit above);
- Decreases in employment (again, this is also mentioned as a potential benefits above);
- Lifestyle changes;
- Security and proliferation with specific technology options (nuclear).

This section reviews review the potential ancillary benefit for each of these categories. In each case, we have considered:

- The potential effects of the benefit;
- The possible approach to quantification and valuation of benefits;
- Where possible, the likely magnitude of the benefits (impacts and economic benefits).

Air Quality

Numerous studies have shown that air quality ancillary benefits of GHG mitigation may be a significant benefit, offsetting a substantial proportion of mitigation costs. Whilst the full benefit of greenhouse gas reductions resulting from further climate action may only be experienced by future generations, the ancillary benefits of climate policy will accrue to the current generation.

The effects of air quality ancillary benefits will be quantified in the general equilibrium modelling, GEME3, later in the study. A brief review has been made here.

A number of recent and emerging studies have assessed the potential ancillary effects of green house gas mitigation policies (see Defra, 2002). The study found 20 estimates of the monetary value of ancillary benefits from the literature. The table summarises location, pollutants and impacts that are analysed by each study.

The estimates range from 1 to 13 Euro per tonne of CO_2 reduced. The average ancillary benefit, calculated from all studies presented in the table is approximately 27 Euro/tCO_2 (Defra 2002). Some care must be taken in comparing studies, due to the differences in methodology, analysis techniques and damages included. Thirteen out twenty estimates of ancillary benefits from the literature are below 20 Euro/tCO_2 and studies concentrating purely on health impacts from a limited selection of pollutants tend to report the lowest estimates. Studies considering a wider range of pollutants and additional impacts such as materials damage, visibility and vegetation damage generally report higher ancillary benefits.

Table 11 Available monetary estimates of ancillary benefits* (Defra 2002)

Study	Country	Average Ancillary benefit (EURO**/ tCO_2abated)	Coverage of Study
HAIKU/TAF (1999)	USA	1	Health effects from NOx, incl PM, excl O3
ICF/PREMIERE/Holmes et al	USA	1	Health effects from NOx, incl PM, excl O3
PREMIERE/ Dowlatabadi et al (1995)	USA	1	Health effects from NOx, incl PM, excl O3
Burtraw et al (1999)	USA	1	Health effects from SO2 & NOx
Coal/PREMIERE (1997)	USA	2	Health effects from NOx, incl PM, excl O3
Coal/ PREMIERE/ RIA (1996)	USA	7	Health effects from NOx, incl PM, excl O3
EXMOD (1995)	USA	7	Health, visibility, environmental effects from NOx, SO2, incl PM excl O3
Goulder/ Scherage & Leary (1993)	USA	8	Health effects from SO2, NO2, CO, Pb
Abt Assocs. & Pechan-Avantil Grp (1999)	USA	10	Health, visibility and materials damage from SO2, NO2, O3,CO,PM,Pb
Boyd et al (1995)	USA	10	Health & visibility effects from SO2, NO2, O3, CO, PM,Pb
Scheraga & Leary (1993)	USA	11	Health effects from TSP, PM, SOx, NOx, CO & VOC
Garbaccio et al (2000)	China	13	Health effects from SO2 & PM
Cifuentes et al (2000)	Chile	16	Health effects from SO2, NOx, CO, HC, PM & dust
Viscusi et al (1994)	USA	22	Health and visibility effects from SO2, NO2, CO, HC, PPM, dust
Barker & Rosendahl (2000)	W.Europe	39	Humand & animal health, materials damage, vegetation effects from SO2, NOx, PM
Brendemoen & Vennemo (1994)	Norway	63	Health & environmental effects from SO2, NOx, CO, PM, CO2, VOC, CH4, NO2, traffic noise, road maintenance, congestion, accidents
Dessus & O'Conner (1999)	Chile	66	Health effects from 7 air pollutants (not specified)
Ekins (1996)	Not specified	70	Not specified
Lutter & Shogren (1999)	USA	77	Not specified
Aunan et al (2000) Kanudia & Loulou (1998)	Hungary	130	Health, materials damage, vegetation. Damage from TSP, SO2, NOx, CO, VOC, CO2, CH4, NO2

This table was published by Defra in 'Ancillary Effects of Greenhouse Gas Mitigation Policies' October 2002. Defra adapted the information from OECD (2001), IPCC (2001) & Burtraw & Toman (2000)
** Conversion based on UK Financial Times Exchange Rate 11/11/04 1 EURO = £0.70

Another recent study[57] concludes that about 50% of the costs of the Kyoto target can be re-gained in terms of reduced costs of air pollution control.

Other Environmental Improvements

In addition to the air pollution benefits above, there may be other environmental benefits from low carbon policies. For example:

[57] Exploring the ancillary benefits of the Kyoto Protocol for air pollution in Europe - Energy Policy; D.P. van Vuuren et al. (in press)

- In the agricultural sector, policies to reduce methane and nitrogen dioxide emissions from agriculture result in ancillary benefits to ecosystems, reduction in the use of nitrogen fertilisers lead to reduced eutrophication and acidification of ecosystems. Benefits from agricultural GHG policies include ecosystem and biodiversity benefits and improved water quality from ammonia emission reduction.
- Forests planted as carbon sinks could lead to ancillary benefits in improved biodiversity, wildlife habitats, landscape, timber supply and recreational opportunities, depending on the land type and forest management.

Energy Security and Oil imports

Recent energy projections show an increasing trend towards energy imports in Europe, especially for oil and gas, as well as a concentration of energy in imported gas. This raises a number of issues, including:

- Energy security (security of supply including disruptions, fuel price shocks);
- Energy diversity;
- Macroeconomic effects from imports;

It is generally assumed that low carbon technologies will have ancillary benefits from reducing dependence on imports and so increasing energy security. This is due to the likely increase in renewables, nuclear generation, coal generation with sequestration, as well as improvements in energy efficiency. However, recent low carbon modelling in the UK has shown that under a 550ppm target, there is rapid uptake of natural gas with carbon sequestration. This would mitigate against some of the potential benefits of low carbon policies.

These effects will be assessed later in the project, through the use of the GEM-E3 model.

Employment Effects, Trade and Competitiveness

The effects of environmental legislation on employment, trade and competitiveness remain the subject of debate. A number of studies (Watkiss et al 2004, OECD 2004) have shown that effects from existing environmental legislation are low, and far less important than labour markets. However, there have been concerns that such effects might be more important for climate policy, given the large structural changes that would be required.

The potential effects on employment from the policies and their effects on competitiveness and terms of trade will be assessed with GEM-E3 later in the project.

Innovation

This will be investigated later in the study.

Lifestyle Changes

The move towards a low carbon society could possibly lead to changes in lifestyle. For example, it is possible that future constraints over aviation could emerge (or at least price changes in the costs of aviation), unless alternative fuels could be found.

Technology Specific (Nuclear)

Much of the low carbon modelling has shown relative increases in the use of nuclear power. The widespread adoption of this option, particularly in new countries, might raise concerns over waste disposal, safety and (potentially) proliferation.

Summary of Ancillary Effects

From the review, we conclude that the air quality benefits of GHG mitigation may amount to a substantial benefit. It is also likely that many low carbon technologies will have ancillary benefits from reducing dependence on imports and increasing energy security. This is due to the likely increase in renewables, nuclear generation, coal generation with sequestration, as well as improvements in energy efficiency. The effects of policies on employment, trade and competitiveness remain the subject of much debate. These issues will be examined later in the study through the use of the GEM-E3 model.

Ancillary effects are important, and should be factored into the analysis of future climate change policies. However, to assess these impacts properly, the ancillary effects need to be assessed and reported separately, as they will vary with the exact policies and measures implemented.

Conclusions and Future Research

The review has shown that the impacts of climate change and their economic costs are significant.

Initial assessment of the benefits of stabilisation targets shows that many of the major effects of climate change could be avoided, and the benefits of post-Kyoto policies could be very significant in terms of reductions in impacts and social costs. There is also the major benefit of reducing the risk of major catastrophic events.

The review here has shown that the information on impacts and economic costs is increasing. However, there remain major information gaps and further research is needed to improve the information available to fully assess the benefits of policies. From the information available, we believe that monetary valuation of climate change policies is possible, and should be taken forward. However, we also believe that care must be taken in presenting and interpreting the monetary estimates, for example by avoiding the use of single simplistic estimates: given the uncertainty over future scenarios and impacts, monetary valuation, and ethical and moral issues, there is no 'single' estimate of the social costs of climate change. Further to this, we make a number of additional recommendations that would improve the analysis presented here.

- Firstly, we recommend that work is undertaken to present a more disaggregated analysis of the physical impacts of climate change, and the benefits of future policy.
- Secondly, we recommend that more disaggregated information is presented on the economic valuation of climate change, showing the balance of positive and negative economic effects (winners and losers) by impact category and region, rather than using single aggregated global values.
- Finally, we recommend that the analysis of future policies should consider full sensitivity and uncertainty analysis, along with the information of key impacts, to allow the comparison of benefits against the possible costs of future mitigation policies.

To progress these areas, we recommend a number of specific research conclusions:

First, some further work with the integrated assessment models:
- Additional model runs with PAGE and FUND would be useful to test different future policies (towards stabilisation targets for CO_2 equivalents of 400 ppm, 450 ppm, etc), with different assumptions relating to baselines, discount rates, equity weighting, and uncertainty analysis in relation to climate sensitivity. This should include analysis of long-term benefits, but also the specific benefits that would accrue from policies implemented between 2010 and 2025.
- It would also be extremely useful to run the models to look at the marginal social costs of climate change in different time periods, and for different pollutants (e.g. CO_2, CH_4, N_2O).

Secondly, to complement (and validate) the global assessments with detailed sectoral studies and regional integrations:
- To undertake some further analysis to progress a disaggregated analysis of the estimates by region (including Europe vs. international, and with the latter split by region). This would include disaggregating the model outputs (e.g. from FUND and PAGE), but also comparing these estimates to others in the literature from the regional studies.
- To undertake some further analysis to progress a disaggregated analysis of the estimates by impact category (e.g. health mortality cases, changes in agricultural production in tonnes, etc). This would include dis-aggregating the model outputs, but also comparing these estimates to others in the literature from the regional studies.
- There is a general need for the models to move towards more dynamic analysis of assessment, both for impact assessment (the dynamic processes of vulnerability and adaptation) and valuation.

Thirdly, to explore the main elements in the risk matrix (above) that are not well captured currently:

- To extend the analysis of bounded risks (e.g. in relation to floods, storm damage) and non-market valuation (e.g. health and ecosystems).
- To undertake scoping studies to assess the potential magnitude of major events, e.g. Greenland ice sheet, etc. Some preliminary work has been undertaken, but this is a major area for future studies to focus, both for the timing of events (and relationship with different stabilisation levels) and the impacts. These are likely to have a major impact on the values.
- Similarly, to progress the understanding of, and potential magnitude of socially contingent impacts, particularly looking at specific hot-spots such as Africa, Bangladesh, low lying islands.

There are perhaps ten significant developments which are ongoing or contemplated in the integrated assessment community. Reducing uncertainty in the geophysical drivers of climate change include (i) improving the scale of assessment and understanding aggregation issues, (ii) linking damage functions to probabilistic scenarios of climate change; (iii) understanding cross-sectoral and multi-stressor effects and (iv) refining estimates of potentially catastrophic impacts. Reducing uncertainty in economic valuation includes: (1) adding new sectors to the damage functions; (2) broadening the range of economic techniques (such as the premium attached to risk aversion); (3) including additional metrics that policy maker may wish to take into account; (4) bounding exercises to provide a first-order estimate of the range of potential damages; (5) understanding the dynamic aspects of vulnerability and adaptive capacity and their relationship to damages over time; and (6) exploring the effects of alternative value systems, particularly in the loss of non-market resources and non-marginal, socially contingent effects. Of course, these developments are contingent upon improvements in climate and impacts science, which we note below. These developments can be charted in the risk matrix. It is apparent that improving estimates related to the larger uncertainties—the lower and right-hand cells—requires several improvements, and these may be the more difficult developments, constrained by the lack of data, the choice of analytical tools and the framing of climate policy decisions.

Finally, a number of additional aspects:

- To further the analysis of adaptation costs. Both FUND and PAGE include adaptation, and it would be useful to separate out adaptation and damage costs. It would also be useful to undertake a wider review and analysis of the literature on adaptation costs.
- Finally, work to bring all the impact and valuation data together in a form useful for policy analysis (i.e. a multi-analysis framework). We believe that future policy considerations will need to balance impact analysis, monetary benefits, and work with significant uncertainty and sensitivity analysis to allow informed decisions. There is a need to develop a framework to maximise the usefulness of all the information for policy makers.

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Appendix 1 Human System Impacts

Table A1. Impacts of temperature increase above pre-industrial levels on human systems
Source: Conference Outcomes Table 2a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

Temp-erature rise above Pre-ind -ustrial	Year in whic h this occur s	Population scenario	Impact to human systems m.a.r. = additional millions of people at risk than would be the case in absence of climate change	Region affected	Source
			OBSERVED IMPACTS		
0.6	2004		Extreme weather is causing substantial and increasing damage partly due to climatic factors (not attributed)		IPCC 2001
0.6	2004		Increase in severity and frequency of extreme events in tropical small island states (not attributed)		Krishna et al 2000; Trotz 2002; Hay et al 2003
0.6	2000	-	Climate change has been MODELLED (not observed) to have caused the loss of 150,000 lives and 5.5 million DALY/yr since 1970	Globe	McMichael et al 2004
0.6	2004		Changes in streamflows, flood and drought observed (e.g. earlier peak runoff) (not attributed)	Europe, Russia, N America, Sahel, Peru, Brazil, Colombia	
0.6	2004	-	High temperatures of 2004 summer in Europe attributed to anthropogenic cause with greater than … confidence	Europe	Stott 2004
0.6	204		Heatwave associated		**WHO**

Table A1. Impacts of temperature increase above pre-industrial levels on human systems (contd)
Source: Conference Outcomes Table 2a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

		with unusual 2004 summer caused 14802 deaths in France, and approximately 25000 in Europe		
<= 0.6	1967 onwards	Abrupt change in regional rainfall pattern causing food insecurity, water stress (not attributed)	Sahel	**Dore 2005**
0.6	2000	Since 1970, number people affected by drought increased from 0 to 35 million (not attributed)	Southern Africa	ECF 2004
0.6		Increased frequency and intensity of drought (not attributed)	Africa, Asia, SW Australia	IPCC 2001, ECF 2004
0.6		Increased cloud amount, annual precipitation, and heavy precipitation events (not attributed)	Mid- and high-latitudes N henisphere	IPCC 2001, **Dore 2005**
0.6		Lake and river ice duration reduced by 2 weeks (not attributed)	Mid and high latitudes N hemisphere	**Dore 2005**
0.6	2004	Water stress increase associated with drying & warming (not attributed)	Australia	ECF 2004
0.6		Rainfall decline in W hemisphere, subtropics, E equatorial region observed, consistent with more frequent El Nino-like conditions	S hemisphere, especially 5 Andean countries	ECF 2004
		PREDICTED IMPACTS		
Observed and predicted to worsen		Rainfall decline, loss of glaciers predicted; serious drinking water, energy generation and agriculture problems,	Peru	ECF 2004

Table A1. Impacts of temperature increase above pre-industrial levels on human systems (contd)
Source: Conference Outcomes Table 2a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

	adaptation may not be economically feasible. In 20 years glaciers below 5500m will have disappeared causing hydropower problems		
From 0.6 C upward. rising with T	Very likely more heatwaves, causing elevated mortality rates in elderly/urban poor, risk crop damage, stress to livestock, increased cooling demand	All land areas	IPCC 2001
From 0.6C upward rising with T	Decreased cold days in twentieth century. Higher minimum temperatures, reducing cold-related mortality. Increased risk to some crops, decreased to others, reduced heating demand. Extended range of some pests and disease vectors.	Almost all land areas	IPCC 2001
From 0.6C upward rising with T	Increased summer drying over continents likely, decreasing crop yields, damaging buildings, decreasing water resources and increasing forest fire	Continental interiors	IPCC 2001
From 0.6C upward rising with T	Increase in magnitude/frequency of precipitation events, very likely: causing floods, landslides, avalanche, increased soil erosion (not attributed)		IPCC 2001
From 0.6C upward rising with T	More intense El Nino, increasing strength of associated droughts/floods likely,	S America, Australia	IPCC 2001

Table A1. Impacts of temperature increase above pre-industrial levels on human systems (contd)
Source: Conference Outcomes Table 2a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

		decreasing agricultural productivity and hydro-power potential, causing water stress		
From 0.6C upward rising with T	2025	Water quality degraded	??	IPCC 2001
From 0.6C upward rising with T		Melting permafrost disrupts built infrastructure and destabilises slopes causing landslides	Arctic	ACIA 2004
From 0.6C upward rising with T	2025	Increased energy demand for summer cooling demand and decreased winter heating demand very likely		IPCC 2001
From 0.6C upward rising with T	2025	Market sector losses likely in many developing countries, mixture of gains and losses in developed countries		IPCC 2001
From 0.6C upward rising with T		Large scale damage to infrastructure and threat to human lives	Caribbean & tropical small island states due to increased magnitude and frequency of extreme weather events	ECF 2004
From 0.6C upward rising with T		As above	Himalayas: glacier lake outbursts	ECF 2004
From 0.6C upward rising with T		As above	Andes: rainfall decline/ma	ECF 2004

Table A1. Impacts of temperature increase above pre-industrial levels on human systems (contd)
Source: Conference Outcomes Table 2a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

				ssive glacier melt eliminating hydropowe r and water supplies; outburst floods	
0.8	2020	B1	400 mar from water stress	Globe	Parry 04
0.8	2030	S550	Malarial risk increased by factor 1.27, dengue by 1.3	N America	McMichael et al 2004
0.8	2030	S550	Risk of death due to flooding increased by 1.44	W Africa	McMichael et al 2004
0.8	2030	S550	Risk of death due to flooding increased by 3.58	C/S America	McMichael et al 2004
0.9	2020	A2	615-1660 mar from water stress	Globe	Parry 04
0.9	2020	B2	508-592 mar from water stress	Globe	Parry 04
1	2020	IS92a, S750	240 mar from water stress	Globe	Arnell 02
1	2020	A1F1	829 mar from water stress	Globe	Parry 04
1			10% decrease barley yield	Uruguay	IPCC 2001
1			6-10% decrease rice yield	S Asia	ECF 2004
1	2020	-	Disbenefit to agriculture	Less developed	Several authors
1	2020	-	Benefit to agriculture	Developed	Several authors
1.2	2020	IS92a, unmit	330-620 mar from water stress	Globe	Arnell 02
1.3	-	-	Food price rise begins	Globe	Hare 03
1.3	2050	IS92a, S550	1300 – 2300 mar from water stress	Globe	Parry 01

Table A1. Impacts of temperature increase above pre-industrial levels on human systems (contd)
Source: Conference Outcomes Table 2a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

1.3	2050	S550	Risk of death due to flooding increased by 1.48	W Africa	McMichael et al 2004
1.3	2050	S550	Risk of death due to flooding increased by 3.76	C/S America	McMichael et al 2004
1.3	2030	S750	Malarial risk increased by factor 1.33, dengue by 1.33	N America	McMichael et al 2004
1.3	2050	IS92a S550	160-220 mar from malaria	Globe	Parry 01
1.3	2050	IS92a, S550	5 mar from hunger	Less developed	Parry 01/Hare 03
1.3	2080	IS92a, S450	400 mar from water stress	Globe	Parry 01
1.3	2080	IS92a S450	150 mar from malaria	Globe	Parry 01
1.4	2050		Shorelines behind bleached coral reefs now vulnerable to storm damage; damage and tourism loss could lead to 140-420million$ loss in Caribbean alone.	Caribbean, Indian Ocean, small island states	ECF 2004
1.45	2050	B1	988 mar from water stress	Globe	Parry 04
1.5	2080	IS92a >S450	165 mar from malaria	Globe	Parry 01/Hare 03
1.5-2C	-	-	Poor farmers' income declines in this range	Less developed	Hare 03
1.6	2050	B2	1020-1057 mar from water sress	Globe	Parry 04
1.6	2030	unmit	Malarial risk increased by factor 1.51	N America	McMichael et al 2004
1.6	2030	S550	Risk of death due to flooding increased by 1.64	W Africa	McMichael et al 2004
Any	Any		River flood hazard increase	Europe	IPCC 2001
			Increase in magnitude of cyclones likely, increasing risks to	Tropical & sub-tropical	IPCC 2001

Table A1. Impacts of temperature increase above pre-industrial levels on human systems (contd)
Source: Conference Outcomes Table 2a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

			human life, infectious disease epidemics, coastal erosion and damaging coastal infrastructure, coral reefs and mangroves	regions	
1.6	2030	S550	Risk of death due to flooding increased by 4.64	C/S America	McMichael et al 2004
1.8	1200	S550	International tourism flows negatively impacted	S Europe, Caribbean, SE Asia	**Viner 2005,** IPCC 2001
0.8-2.6	2050		Higher market impact likely in developing countries, more losses and fewer gains in developed countries	Globe	IPCC 2001
0.8-2.6	2050		Increased insurance prices and reduced availability of insurance very likely	Globe	IPCC 2001
1.7	2050	IS92a, S750	1600-2600 mar from water stress	Globe	Parry 01
1.7	2080	IS92a, S550	760 mar from water stress	Globe	Parry 01
1.9	2050	A2	1620-1973 from water stress	Globe	Parry 04
2	-	-	Threshold above which agricultural yields fall	EU, Canada, USA, Australia	Hare 03
2			Double/triple frequency of bad harvests leading to inter-regional political tension	Russia	ECF 2004
2			Destruction of Inuit hunting culture	Arctic	ECF 2004
2			Wheat yield decrease	S Asia	ECF 2004
2			Maize yield 15% decrease	Uruguay	IPCC 2001
2	2050	IS92a, unmit	26 mar from coastal flood	Globe especially	Parry 2001, IPCC 2001

Table A1. Impacts of temperature increase above pre-industrial levels on human systems (contd)
Source: Conference Outcomes Table 2a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

				S & SE Asia	
1.8-.2.6	2050s		40% rainfall decline from 1961-1990 average (in all models)	Africa Mahgreb	ECF 2004
2.1	2080	IS92a, S750	2.3-3.0 bar from water stress	Globe	Parry 01
2.1	2080	B1	2-3 mar from coastal flood	Globe	Parry 04
2.1	2080	B1	10-20 mar from hunger		Parry 04
2.2	2050	IS92a, unmit	2900 mar from water stress	Many regions	Arnell 02
2.26	2050	A1F1	1136 mar from water stress	Globe	Parry 04
2.3	2050	IS92a Unmit	180-230 mar from malaria	Globe	Parry 01
2.3	2100		30-70% loss snowpack losing 13-30% water supply	California	**Hayhoe 2005**
2 – 2.5			Food production threatened	Southern Africa, S Asia, parts of Russia	ECF 2004
??		2050-2100	Dry season water security loss & complete loss glaciers	W China	ECF 2004
2.5 - 3			Rice yields reduced 10-20% (no CO2 fertilisation) (or change by -10% to 20% assuming total CO2 fertilisation)	China	ECF 2004
2.3			13-30% loss water supply due to snowpack loss	California	Hayhoe 2004
2.3	2050	IS92a, unmit	7 mar of hunger	Less developed	Parry 01/Hare 03
Any	Any		Sea level rise and cyclones displace several million people from coasts	Tropical Asia	

Table A1. Impacts of temperature increase above pre-industrial levels on human systems (contd)
Source: Conference Outcomes Table 2a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

Any	Any		Runoff increase in N but decrease in arid areas; however in N may not be in useful season	Asia	IPCC 2001; Arnell 2004
Any	Any		Vector borne disease expands poleward	Latin America and Asia	IPCC 2001
2.3	2080	IS92a >S1000	230-270 mar from malaria	Globe	Parry 01
2.3	2080	IS92a, >S1000	33 mar from hunger	Less developed	Parry 01/Hare 03
2.1/2.4	2080	B1/B2	5% fall in cereal production yield		Parry 04
2.4	2080	B2	16-27 mar from coastal flood	Globe	Parry 04
		A1B: 2050-2100	Increase in magnitude/frequency of precipitation: causing high flood damage	Japan	**Emori 2005**
2.4	2080	B2	150 to (-12) mar from hunger (range due to CO2 fertilisation inclusion or not)		Parry 04
1.8 – 2.6 combined with rainfall decrease up to 40%	2050		Large scale displacement of people (climate refugees from low food security, poverty and water stress)	Mahgreb (N Africa) and Sahel	ECF 2004
2.6 and -20% precip			5 to 30% loss rice/wheat yields putting food security at risk	Indian subcontine nt	ECF 2004
2.6	2100	-	30-70% snowpack loss ie 13-30% water supply lost	California	ECF
2.8	2080	IS92a, >S1000	50 mar from hunger	Globe	Parry 01/Hare
2 – 2.5			Fisheries impacted	NW Africa, E African lakes	ECF 2004
2 – 2.5			Fishery damage removes primary protein	Malawi	ECF 2004

Table A1. Impacts of temperature increase above pre-industrial levels on human systems (contd)
Source: Conference Outcomes Table 2a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

			source for 50% of population		
2 – 2.5			Combined effects of precipitation changes, floods, droughts, reducing crop yields leading to significant risk commercial & subsistence of up to 80% crop failure	Southern Africa	ECF 2004
Not specified			Deglaciation of Himalayan region affects hydrology of Indian region, disrupting agriculture	Nepal, India	ECF 2004
2.6	-	-	Rapid increase in flooding damaging agriculture and endangering life	Bangladesh	ECF 2004
2.5 to 4	-	-	Crop failure rise from 50 to 75%	S Africa	ECF
1.4-5.8	2100		High market impacts likely in developing countries, net losses in developed countries		IPCC 2001
3	-	-	65 countries lose 16% agricultural GDP	Less developed	Fischer 2001
3 with -25% less rain			Wheat and grape yields fall	Norte Chico, Chile	Downing 92
3 with 25% less rain			Maize and potato yields increase	Chile	Downing 92
3.2	2080	A2	29-50 mar from coastal flood	Globe, especially S/SE Asia, Africa, Mediterranean	Parry 04
3.2	2080	A2	600 mar from hunger (-30 CO2 ff)		Parry 04
3.3	2080	IS92a	80 mar from coastal flooding	Globe	Parry 01

Table A1. Impacts of temperature increase above pre-industrial levels on human systems (contd)
Source: Conference Outcomes Table 2a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

3.3	2080	IS92a unmit	280-330 mar from malaria	Globe	Parry 01
3.3	2080	-	560-1350 thousand at risk from coastal flooding	Caribbean	Parry 99
3.5	2080	IS92a, unmit	3.1-3.5 bar from water stress	Globe	Parry 01
4.0/3.2	2080	A1/A2	10% fall in cereal production		Parry 04
3.5	2080	IS92a unmit	65-75 mar from hunger	Globe	Parry 01
3 – 4			Loss in farm income between 9 and 25%	Indian subcontine nt	ECF 2004
3 – 4			Wheat yield decline of up to 34%	Indian subcontine nt	ECF 2004
3.3-6.3			5-12% drop in country's production;14-41% in agricultural regions	Russia	ECF 2004
4	2080	A1F1	7-10 mar from coastal flood	Globe	Parry 04
4.0	2080	A1F1	300 mar from hunger (30 CO2 ff)		Parry 04
4.2	-	-	Entire regions out of production 80-125 mar from hunger		Hare 03/Parry 01
4.3	2080	IS92a unmit	Coastal flooding several times worse than in 1990	Globe	Arnell 02
Not known			Loss of sovereignty of small island states and countries with large low lying deltaic regions		ECF 2004
Not known			Regional conflict over water supplies or food supplies	Nile, parts of Russia	ECF 2004

Appendix 2 Ecosystem Impacts

Table A1. Impacts of temperature increase above pre-industrial levels on ecosystems
Source: Conference Outcomes Table 1a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

Temp-erature rise above prein-dustrial	Year in which this occurs	Population scenario	Impacts to unique and threatened ecosystems	Region affected	Source
			OBSERVED CHANGE		
0.6	2004		143 studies of 1473 species showed that of the 587 species which showed changes in phenology (e.g. timing of leaf bud), distribution, abundance, morphology, or genetic frequencies, the change in 82% of these is in direction consistent with response to climate change	All regions	Parmesan and Yohe 2003
0.6	1965-2004		Loss grassland & acacia, loss flora/fauna, shifting sands (not attributed)	Sahel	ECF 2004
0.6	2004		Northward migration plants; disappearance of species from S Europe	Europe	EEA 2004
0.6	2004		Spring phenology advanced by 5 days	All regions	Root et al 2003
0.6	2004		Growing season lengthened 11 days	Europe	IPCC 2001
0.6	2004		3 to 4C winter temperature rise	Alaska/Canada	ACIA 2004
0.6	2004		Major reorganisation of plankton ecosystems: Change in plankton distribution; increasing phytoplankton biomass; extension of the seasonal growth period; N shift of	North Sea	EEA 2004; Richardson and Schoeman 2004

Table A1. Impacts of temperature increase above pre-industrial levels on ecosystems (continued)
Source: Conference Outcomes Table 1a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

		zooplankton		
0.6	2004	Likely to have caused severe decrease in sandeel abundance	North Sea	Arnott and Ruxton 2002
0.6	2004	Likely to have caused large scale breeding failure of seabirds	UK	**Lanchberry 2005**
0.6	2004	Dramatic change in community composition of UK marine fish	English & Bristol Channels	**Hawkins 2005**
0.6	2004	Decreased alpine flora, migration to higher altitudes	Japan, Europe	**Harasawa 2005**, EEA 2004
0.6	2004	Altered distribution of trees, butterflies, birds, insects	Japan	**Harasawa 2005**
		PREDICTED CHANGE		
0.7	2015	Africa's last tropical glacier Kilimanjaro lost (not attributed)	Africa	Thompson et al 2002
< 1		Coral reefs at high risk		Hoegh-Guldberg 1999
< 1		High risk to Australia's most biodiverse region, the Queensland rainforest	Australia	Williams et al 2003
< 1		High risk to richest floral area in world	S Africa	Rutherford et al 1999
< 1		Risk extinction of vulnerable species	SW Australia	Pouliquen-Young & Newman 1999
< 1		Range losses for animal species in S Africa, and Golden Bowerbird in Australia	S Africa, Australia	Rutherford et al 1999; Hilbert et al 2003
1		Coral reefs 82% bleach	Globe	Hoegh-Guldberg 1999
1		10% Global Ecosystems transformed; only 53% wooded tundra remains	Globe	Leemans & Eickhout 2003

Table A1. Impacts of temperature increase above pre-industrial levels on ecosystems (continued)
Source: Conference Outcomes Table 1a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

			stable, loss cool conifer forest. Ecosystems variously lose between 2 to 47% of their extent.		
1			Increased ecosystem disturbance by pest/disease, especially in Boreal forest, Australia, California	Globe	IPCC 2001, Hare 2003, ECF 2004
1.4			Extinction of coral reefs	Indian Ocean	Sheppard 2003
1.5	2050	B1	18% all species extinct	Globe	Thomas 04
1 - 2			Severe damage to Karoo	S Africa	Rutherford et al 1999
1-2			Risk extinction frogs/mammals (40% loss rainforest area)	Australia's most biodiverse region (Queensland wet tropics)	Williams et al 2003
1 – 2			Many eucalypts out of range	Australia	Hughes et al 1996
1 – 2			Large/severe impacts to salmonid fish	N America	Keleher and Rahel 1996
1 -2			Risk some animal extinctions	Mexico, S Africa	Peterson et al 2002
1 – 2			50% rainforest loss	Australia	Hilbert et al 2001
1 – 2			Great loss Alpine zone	Australia	Busby 1988
1 -2			High stress Alpine zone	Europe	Hare 03
1 -2			Severe damage to Arctic ecosystem	Arctic	ACIA 2004
2			Coral reefs 97% bleached	Globe	Hoegh-Guldberg 1999
2 or 2-3			Amazon collapse	S America, globe	Cox et al 2004
2	2100		Total loss Arctic summer ice, high risk extinction of polar bears, seals, whole ecosystem stressed	Arctic	ACIA 2004
2			16% global ecosystems		Leemans &

Table A1. Impacts of temperature increase above pre-industrial levels on ecosystems (continued)
Source: Conference Outcomes Table 1a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

		transformed : ecosystems variously lose between 5 and 66% of their extent		Eickhout 2003
2		Further ecosystem disturbance by fire & pests	Globe	IPCC 2001
2		50% loss of Kakadu and Sundarbans wetlands	Australia, Bangladesh	Gitay et al 2001, Qureshi & Hobbie, 1994, Smith et al 1998
2		42% loss of Arctic tundra	Arctic	**Folkestad 2005**
2		Millions of the world's shorebirds nest in Arctic, from the endangered Spoon-billed Sandpiper and very common Dunlin and would lose up to 45% of breeding area	Globe	**Folkestad 2005**
2		Millions of Geese eg Whitefront and endangered Red-breasted Goose lose up to 50% breeding area	N hemisphere	**Folkestad 2005**
?		Snow leopards at risk	Russia	ECF 2004
2		Severe damage to boreal forest	China	Ni 2001
2		50% loss lemming	Arctic	Kerr & Packer 1998
2		50% loss salmonid fish	USA	Keleher & Rahel 1996
2		Large range loss animals	Mexico	Peterson et al 2002
2		Transformation of ecosystems and species loss	N Europe	ECF 2004
2		Fire/pests attack scrub	Mediterranean	Mouillot et al 2002
2.2	A1F1	15-37% species extinct	Globe	Thomas 04
2.5		Total loss Kakadu	Australia	Gitay et al

Table A1. Impacts of temperature increase above pre-industrial levels on ecosystems (continued)
Source: Conference Outcomes Table 1a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

2.5		Extinction of Karoo's 2800 plants	S Africa	Rutherford et al 1999, Hannah et al 2002
2.5		Extinctions in Fynbos	S Africa	Midgley et al 2002
2.5		Extinctions of forest mammals	Australia (Queensland)	Williams et al 2003
2.5		Extinctions of endemics such as Hawaiian honeycreeper birds	Hawaii	Benning et al 2002
2.5		Extinction of Golden Bower bird	Australia	Hilbert et al 2003
2 – 3		Large impacts	Tibetan plateau	Ni, 2000
2 -3		Extinctions of alpine flora	New Zealand	Halloy & Mark 2003
2.6		20-70% loss of key bird habitat at 4 major sites	USA	Galbraith et al 2002
2.6		Cold temperate forest e.g. maple at risk	USA	Hare 03
3		50% all nature reserves cannot fulfil their conservation objectives	Globe	Leemans & Eickhout 2003
3	2100	Risk of loss of 60% species	Europe	ECF 2004; Bakkenes et al 2002
3		More pronounced ecosystem disturbance by fire/pests	Globe	IPCC 2001
3		Complete loss of Chinese boreal forest ecosystem	China	Ni 2001
3		Complete loss alpine zone	Australia	Pouliquen-Young & Newman 1999
3 (due to slr)		Large loss migratory bird habitat	Baltic, USA, Mediterranean	Nicholls et al 1999, Najiar et al 2000, Galbraith et al 2002
3		50% loss prairie pothole breeding habitat of	USA	Sorenson et al 1988

Table A1. Impacts of temperature increase above pre-industrial levels on ecosystems (continued)
Source: Conference Outcomes Table 1a 'Avoiding Dangerous Climate Change, A Scientific Symposium on Stabilisation of Greenhouse Gases', 1-3 February 2005, Met Office, UK

	waterfowl		
3	22% global ecosystems transformed: ecosystems variously lose between 7 and 74% of their extent	Globe	Leemans & Eickhout 2003
3	Alpine species near extinction	Europe	Bugmann 1997
3	66% animals lost from Kruger	S Africa	Erasmus et al 2002
3	50% loss eucalypts	Australia	Hughes et al 1996
3	80% range loss butterflies	Australia	Beaumont & Hughes 2002
3	60% species loss	Mediterranean	Hare 03
3	Large biome shifts	Europe	Malcolm et al 2002
3.4 (due to slr)	22% loss coastal wetlands	Globe	Nicholls et al 1999
3.4	77% loss low tundra	Canada	Hare 03 based on Malcolm et al 2002
3.8	60% loss tundra ecosystem	Globe	Hare 03 based on Malcolm et al 2002
3.8	44% loss taiga ecosystem	Globe	Hare 03 based on Nelson et al 1997