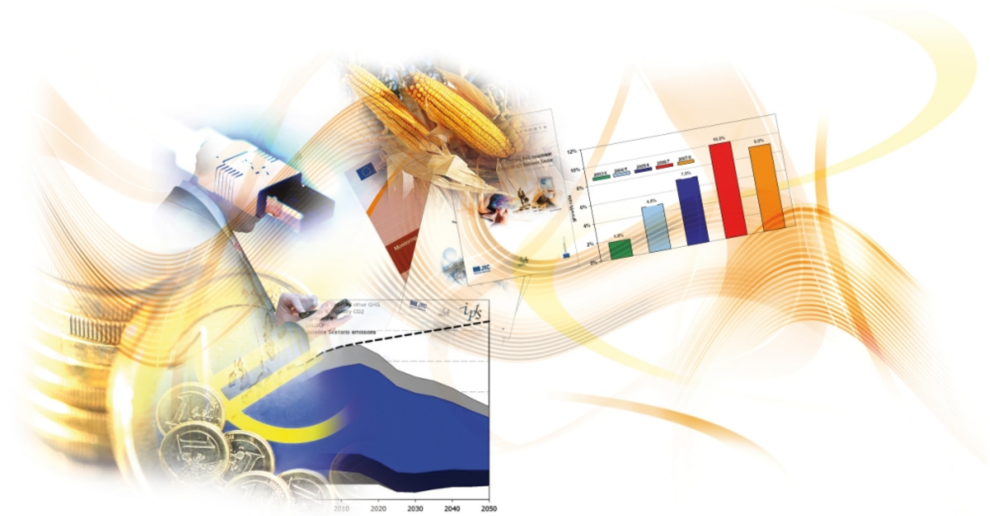
Climate change impacts in Europe

Final report of the PESETA research project

Juan-Carlos Ciscar (editor)



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Preface

The April 2009 EC White Paper on adaptation notes the need to better know the possible consequences of climate change in Europe. The main objective of the PESETA (Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis) project is to contribute to a better understanding of the possible physical and economic impacts induced by climate change in Europe over the 21st century in the following aspects: agriculture, river basin floods, coastal systems, tourism, and human health.

This research project has followed an innovative, integrated approach combining high resolution climate and sectoral impact models with comprehensive economic models, able to provide first estimates of the impacts for alternative climate futures. This approach has been implemented for the first time in Europe. The project has implied truly multidisciplinary work (including *e.g.* climate modelling, agronomic and civil engineering, health and economics), leading to conclusions that could not have been derived from the scientific disciplines in isolation.

This project illustrates well the Joint Research Centre (JRC)'s mission of supporting EU policymakers by developing science-based responses to policy challenges. The JRC has entirely financed the project and has played a key role in the conception and execution of the project. Two JRC institutes, the Institute for Prospective Technological Studies (IPTS) and the Institute for Environment and Sustainability (IES), contributed to this study. The JRC-IPTS coordinated the project and the JRC-IES made the river floods impact assessment. The integration of the market impacts under a common economic framework was made at JRC-IPTS using the GEM-E3 model.

Early results of the project have been used by DG Environment both as evidence of impacts concerning the justification of greenhouse gas mitigation policies (2007 Communication) and as first results on potential impacts, providing useful insights for the conception of adaptation policies at a pan-European scale, in the context of the Green Paper on Adaptation (July 2007) and the White Paper on Adaptation (April 2009).

The main purpose of this publication is to summarise the project methodology and present the main results, which can be relevant for the current debate on prioritising adaptation policies within Europe. A series of technical publications, including the various aspects of this integrated assessment, accompanies this summary report (please visit http://peseta.jrc.ec.europa.eu/).

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Executive Summary

Policy context

The international community is seeking agreement on post-2012 climate mitigation policies aimed at reducing global greenhouse gas (GHG) emissions. The European Union (EU) has proposed to limit the global temperature increase to 2°C above pre-industrial levels and has endorsed a commitment to cutting GHG emissions by at least 20% by 2020 compared to 1990 levels. The G8 have supported a GHG emission reduction goal for developed countries of at least 80% by 2050. Adaptation policies to minimise adverse impacts of climate change and to take advantage of existing opportunities will also be key in post-2012 climate policies.

The avoidance of environmental and economic damages and adverse effects on human health is the ultimate justification of more stringent climate policies. Yet little is known about the potential impacts of climate change on the European environment, human health and economy with respect to different sectors and geographical regions. Such information is necessary to design and prioritise adaptation strategies, as stressed by the European Commission (EC) White Paper on Adaptation.

Purpose and scope

The PESETA project makes the first regionally-focused multi-sectoral integrated assessment of the impacts of climate change in the European economy. The project also suggests an innovative modelling framework able to provide useful insights for adaptation policies on a pan-European scale, with the geographical resolution relevant to national stakeholders.

Five impact categories have been addressed: agriculture, river floods, coastal systems, tourism, and human health. These aspects are highly sensitive to changes in mean climate and climate extremes. The approach enables a comparison between the impact categories and therefore provides a notion of the relative severity of the damage inflicted. For the climate scenarios of the study, two time frames have been considered: the 2020s and the 2080s. The study evaluates the economic effects of future climate change on the current economy.

Other key impacts, such as effects on forestry, impacts in ecosystems and biodiversity and catastrophic events, have not yet been analysed. Therefore, the PESETA project underestimates the impacts of climate change in Europe to a large extent.

Methodology

Several research studies have estimated or employed climate damage functions as reduced-form formulations linking climate variables to economic impacts (usually average global temperature to gross domestic product, GDP). However, for assessing impacts and prioritising adaptation policies, such an approach has three disadvantages: (1) estimates are based on results from the literature coming from different, and possibly inconsistent, climate scenarios; (2) only average temperatures and precipitation are used, not considering other relevant climate variables and the required time-space resolution in climate data; (3) impact estimates lack the relevant resolution and sector-specific details.

PESETA has put forward an innovative methodology integrating (a) high time-space resolution climate data, (b) impact-specific models, which use common climate scenarios, and (c) a multi-sectoral computable general equilibrium (CGE) economic model, estimating the effects of climate change impacts on the overall economy.

Climate data, physical impact models and an economic model are integrated under a consistent methodological framework following three steps. In the first stage, daily and 50 x 50 km resolution (approximately the size of London) climate data are selected for a series of future climate scenarios. In the second step, these data serve as input to run the physical impact models for the five impact categories. The DSSAT crop models have been used to quantify the physical impacts on agriculture, in terms of yield changes of selected crops. Estimates of changes in the frequency and severity of river floods are based on simulations with the LISFLOOD model. Impacts of sea level rise (SLR) on coastal systems (*e.g.* sea floods) have been quantified with the DIVA model. The tourism study has modelled the changes in major international tourism flows within Europe assessing the relationship between bed nights and a climate-related index of human comfort. The human health assessment has been made using evidence about exposure-response functions, linking temperature to mortality. Heatwaves are not considered.

In the third stage, the market impact categories (those with market prices, *i.e.* agriculture, river floods, coastal systems and tourism) and their associated direct economic effects are introduced into a computable general equilibrium (CGE) model, the GEM-E3 Europe model, modelling individually most EU countries (Cyprus, Luxemburg and Malta are not included). This framework captures not only the direct effects of a climate impact on a particular region and sector but also the transmission of these effects to the rest of the economy. The CGE model ultimately translates the climate change scenarios into consumer welfare and GDP changes, compared to the baseline scenario without climate change.

The EU has been divided into five regions to simplify interpretation: Southern Europe (Portugal, Spain, Italy, Greece, and Bulgaria), Central Europe South (France, Austria, Czech Republic, Slovakia, Hungary, Romania, and Slovenia), Central Europe North (Belgium, The Netherlands, Germany, and Poland), British Isles (Ireland and UK), and Northern Europe (Sweden, Finland, Estonia, Latvia, and Lithuania). The main criteria for grouping countries are the geographical position and the economic size.

It should be noted that this project did not intend to produce forecasts of the impacts of climate change, but rather simulations under alternative future climate scenarios.

Scenarios

The 2020s are studied with one climate scenario. For the 2080s, four future climate scenarios have been considered to reflect the uncertainty associated with the driving forces of global emissions and the sensitivity of climate models to GHG concentration. Two global socio-economic scenarios are selected from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES): the high-emission A2 scenario and the lower-emission B2 scenario. For each socio-economic case, climate scenario output from two state-of-the-art regional climate models (RCMs), nested within a global circulation model (GCM), are used, from the EC-funded PRUDENCE project. The four 2080s scenarios are distinguished by the EU temperature increase: 2.5°C, 3.9°C, 4.1°C and 5.4°C. Compared to the preindustrial level, the global temperature increase of the PESETA scenarios are in a range between 2.6°C and 3.4°C.

For the scenarios considered, global SLR ranges from 48 to 58 cm by the end of the 21st century. The high range of SLR of the IPCC Third Assessment Report (TAR), an 88 cm SLR scenario, has also been studied in the coastal systems as a variant of the 5.4°C scenario. The current high range estimate of SLR is over 1 meter, although very uncertain.

Agriculture Findings

In the 2020s, most European regions would experience yield improvements, particularly in Northern Europe, with the exception of some areas in Central Europe South and Southern Europe. The EU overall yield gain would be around 15%.

In the 2080s the scenarios of lower warming would lead to small changes in yields for the EU, while the 5.4°C scenario could mean a fall in crop yields by 10%. All 2080s scenarios share a similar pattern in the spatial distribution of effects. Southern Europe would experience yield losses, which would become relatively high under the 5.4°C scenario – about 25%. Central Europe regions would have moderate yield changes. In all scenarios the Northern Europe region would benefit from positive yield changes, and to a lesser extent the British Isles for the 4.1°C and 5.4°C scenarios.

River Floods Findings

River flooding would affect 250,000 to 400,000 additional people per year in Europe by the 2080s, more than doubling the number with respect to the 1961–1990 period. In general terms, the higher the mean temperature increase, the higher the projected increase in people exposed by floods. An increase in people affected by river floods would occur mainly in the Central Europe regions and the British Isles.

The total additional damage from river floods in the 2080s ranges between 7.7 billion € and 15 billion €, more than doubling the annual average damages over the 1961–1990 period. The regional pattern of economic damages is similar to that of people affected. Thus, while Northern Europe would have fewer damages, the Central Europe area and the British Isles would undergo significant increases in expected damages.

Coastal Systems Findings

The number of people annually affected by sea floods in the reference year (1995) is estimated to be 36,000. Without adaptation, the number of people affected annually by flooding in the 2080s increases significantly in all scenarios, in the range of 775,000 to 5.5 million people. The British Isles, the Central Europe North and Southern Europe regions would be the areas potentially most affected by coastal floods. However, when adaptation is taken into account (dikes and beach nourishment) the number of people exposed to floods are significantly reduced.

The economic costs to people who might migrate due to land loss (through submergence and erosion) are also substantially increased under a high rate of sea-level rise, assuming no adaptation, and increase over time. When adaptation measures are implemented (building dikes), this displacement of people becomes a minor impact, showing the important benefit of adaptation to coastal populations under rising sea levels.

Tourism Findings

Concerning the 2020s, in the three main seasons (*i.e.* spring, summer and autumn) climate conditions for outdoor tourism improve in most areas of Europe. Changes are most significant in the Mediterranean region, where the area with very good to ideal conditions increases.

On the contrary, for the 2080s, the distribution of climatic conditions in Europe is projected to change significantly. For the spring season, all climate model results show a clear extension towards the North of the zone under good conditions. Excellent conditions in spring, which are mainly found in Spain in the baseline period, would spread across most of the Mediterranean coastal areas by the 2080s. Changes in autumn are more or less comparable to the ones in spring. In summer, the zone of good conditions also expands towards the North, but this time at the expense of the South, where climatic conditions would deteriorate.

The changes in bed nights due to changing climate conditions can be econometrically estimated, leading to changes in expenditure associated with bed nights. In all climate scenarios there would be additional expenditures, with a relatively small EU-wide positive impact. Southern Europe, which currently accounts for more than half of the total EU capacity of tourist accommodation, would be the only region with a decline in bed nights, estimated to be in a range between 1% and 4%, depending on the climate scenario. The rest of Europe is projected to have large increases in bed nights, in the range of 15% to 25% for the two warmest scenarios.

Human Health Findings

In the 2020s, without adaptation measures and acclimatisation, the estimated increases in heat-related mortality are projected to be lower than the estimated decrease in cold-related mortality. The potential increase in heat-related mortality in Europe could be over 25,000 extra deaths per year, with the rate of increase potentially higher in Central Europe South and Southern European regions. However, physiological and behavioural responses to the warmer climate would have a very significant effect in reducing this mortality (acclimatisation), potentially reducing the estimates by a factor of five to ten. It is also possible that there may be a decline in the sensitivity of mortality to cold, though this is more uncertain.

By the 2080s, the effect of heat- and cold-related mortality changes depends on the set of exposure-response and acclimatisation functions used. The range of estimates for the increase in mortality is between 60,000 and 165,000 (without acclimatisation), again decreasing by a factor of five or more if acclimatisation is included. The range of estimates for the decrease in cold-related mortality is between 60,000 and 250,000, though there may also be a decline in the sensitivity of mortality to cold.

Overall economic impacts in Europe

The consequences of climate change in the four market impact categories (*i.e.* agriculture, river floods, coastal systems and tourism) can be valued in monetary terms as they directly affect sectoral markets and – via the cross-sector linkages – the overall economy. They also influence the consumption behaviour of households and therefore their welfare.

The analysis of potential impacts of climate change, defined as impacts that might occur without considering public adaptation, can allow the identification of priorities in adaptation policies across impact categories and regional areas. If the climate of the 2080s occurred today, the annual damage of climate change to the EU economy in terms of GDP loss is estimated to be between 20 billion € for the 2.5°C scenario and 65 billion € for the 5.4°C scenario with high SLR.

Yet the damages in GDP terms underestimate the actual losses. For instance, the repairing of damages to buildings due to river floods increase production (GDP), but not consumer welfare. The aggregated impact on the four categories would lead to an EU annual welfare loss of between 0.2% for the 2.5°C scenario and 1% for the 5.4°C scenario, variant with a high SLR (88cm). The historic EU annual growth of welfare is around 2%. Thus climate change could reduce the annual welfare improvement rate to between 1.8% (for the scenario with a 0.2% welfare loss) and 1% (for the scenario with a 1% welfare loss).

EU-aggregated economic impact figures hide a high variation across regions, climate scenarios and impact categories. In all 2080s scenarios, most regions would undergo welfare losses, with the exception of Northern Europe, where gains are in a range of 0.5% to 0.8% per year, largely driven by the improvement in agricultural yields. Southern Europe could be severely affected by climate change, with annual welfare losses around 1.4% for the 5.4°C scenario.

The sectoral and geographical decomposition of welfare changes under the 2.5°C scenario shows that aggregated European costs of climate change are highest for agriculture, river flooding and coastal systems, much larger than for tourism. The British Isles, Central Europe North and Southern Europe appear the most sensitive areas. Moreover, moving from a European climate future of 2.5°C to one of 3.9°C aggravates the three noted impacts in almost all European regions. In the Northern Europe area, these impacts are offset by the increasingly positive effects related to agriculture.

The 5.4°C scenario leads to an annual EU welfare loss of 0.7%, with more pronounced impacts in most sectors in all EU regions. The agricultural sector is the most important impact category in the EU average; the significant damages in Southern Europe and Central Europe South are not compensated for by the gains in Northern Europe. Impacts from river flooding are also more important in this case than in the other scenarios, with particular aggravation in the British Isles and in Central Europe. In the 5.4°C scenario variant with the high SLR (88 cm), which would lead to a 1% annual welfare loss in the EU, coastal systems would become the most important impact category, especially in the British Isles.

Further research

The proposed methodology is complex and subject to many caveats and uncertainties. Studying other sectors (such as transport and energy), non–market effects (*e.g.* loss in biodiversity), climate variability related damages, catastrophic damages, the cost-benefit analysis of adaptation, and considering land-use scenarios deserves additional research efforts, as well as broadening the set of climatic scenarios in order to better reflect climate modelling uncertainties.

1 OVERVIEW OF THE PESETA PROJECT

1.1 Project organisation

PESETA was coordinated by JRC/IPTS (Economics of Energy, Climate Change and Transport Unit) and involved ten research institutes (University of East Anglia, Danish Meteorological Institute, Polytechnic University of Madrid, JRC/IES, University of Southampton, FEEM, ICIS-Maastricht University, AEA Technology, Metroeconomica, and JRC/IPTS). The project also benefitted from the collaboration of the Rossby Center that kindly provided climate data of a transient climate scenario. The project has had a multi-disciplinary Advisory and Review Board, composed of renowned experts.

Notably, the PESETA project has largely benefitted from past DG Research projects that developed both high resolution climate scenarios for Europe and models to project impacts of climate change (*e.g.* the DIVA model). In particular, PESETA used climate data provided by the PRUDENCE project (Christensen *et al.*, 2007) and models and results from the following research projects: DINAS-COAST, NewExt, and cCASHh.

1.2 Motivation and objective of the study

The international community is looking for an agreement on post-2012 climate mitigation policies aimed at reducing global greenhouse gas (GHG) emissions. The European Union (EU) has pledged to limit the global temperature increase to 2°C above pre-industrial levels and has endorsed a commitment to cutting GHG emissions by at least 20% by 2020 compared to 1990 levels (Council of the European Union, 2005 and 2007). The leaders of the G8 have more recently (G8, 2009) supported the goal of developed countries to reduce GHG emissions by at least 80% by 2050. Adaptation policies to minimise adverse impacts of climate change and to take advantage of existing opportunities will also be key in post-2012 climate policies.

The avoidance of environmental and economic damages is the ultimate justification of more stringent climate policies. There are some studies addressing the impacts of climate change in Europe (*e.g.* Rotmans *et al.,* 1994; Parry, 2000; Schröter *et al.*, 2005; Alcamo *et al.,* 2007; EEA, 2008). However, little is known about the potential impacts of climate change on the European economy, in particular with respect to different economic sectors of interest and geographical regions of concern, necessary to design and prioritise adaptation strategies, as noted by the European Commission (EC) White Paper on Adaptation (European Commission, 2009a).

The main motivation of the PESETA project (Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis) has been to contribute to a better understanding of the possible physical and economic impacts induced by climate change in Europe over the 21st century, paying particular attention to the sectoral and geographical dimensions of impacts. This follows the recommendation of Stern and Taylor (2007) on following a disaggregated approach to study the consequences of climate change, concerning different dimensions, places and times.

The origin of the project dates back to the European Council request (Council of the European Union, 2004) of considering the potential cost of inaction in the field of climate change and, in more general terms, to enhance the analysis of the benefit aspects of European climate policies in terms of reduction of potential impacts.

Preliminary results of PESETA have been published in the Staff Working Paper accompanying the EC Communication on "Limiting Global Climate Change to 2 degrees Celsius. The way ahead for 2020 and beyond" (European Commission, 2007a). Moreover, early results on the impacts for the various sectors under one specific scenario have been published in the Green Paper "Adapting to climate change in Europe - options for EU action" (European Commission, 2007b), and in its Annex, as well as in the 2008 EEA report on impacts (EEA, 2008). The staff working document accompanying the 2009 White Paper on Adaptation (European Commission, 2009a) also contains early results of the project.

1.3 Scope of the assessment

The scope of the PESETA assessment concerning its time scale, scenarios, geographical coverage and impacts analysed is presented in what follows and, more in detail, in Chapter 2. Two time windows have been considered: the 2020s and the 2080s. The 2020s period refers to the middle decade of the 2011-2040 period, while the 2080s relates to the 2071-2100 period. The control period of the study is 1961-1990.

Regarding the 2020s only one climate scenario has been considered, as the climate then is mostly already determined by past GHG emissions. With respect to the 2080s, four alternative climate futures have been considered, covering an increase of temperature in Europe in a range of 2.5°C to 5.4°C.

PESETA focuses on the EU and results are presented according to the following breakdown to simplify interpretation (Section 2.2): Southern Europe (Portugal, Spain, Italy, Greece, and Bulgaria), Central Europe South (France, Austria, Czech Republic, Slovakia, Hungary, Romania, and Slovenia), Central Europe North (Belgium, The Netherlands, Germany, and Poland), British Isles (Ireland and UK), and Northern Europe (Sweden, Finland, Estonia, Latvia, and Lithuania).

In estimating the impacts of climate change five categories have been addressed. Four are market impact areas: agriculture, river basins, coastal systems, and tourism; and one is a non-market impact category: human health. This enables a certain comparison between them and therefore provides a notion of the relative severity of the damage inflicted. For each of these sectoral categories, a corresponding sectoral-based study is developed by the project partners.

The five aspects are highly sensitive to changes in mean climate and climate extremes. Agriculture is the main user of land and water, and still plays a dominant economic role in the rural areas of Europe. Previous studies (*e.g.* Alcamo *et al.*, 2007; EEA, 2008) show that the stress imposed by climate change on agriculture will intensify the regional disparities between European countries.

River floods are the most common natural disaster in Europe (EEA, 2004). Global warming is generally expected to increase the magnitude and frequency of extreme precipitation events (Christensen and Christensen, 2003; Frei *et al.*, 2006), which may lead to more intense and frequent river floods. Coastal regions are areas where wealth and population are concentrated and are undergoing rapid increases in population and urbanisation (McGranahan *et al.*, 2007). Sea level rise is a direct threat for productive infrastructures and for the residential and natural heritage zones.

Tourism is a major economic sector in Europe, with the current annual flow of tourists from Northern to Southern Europe accounting for one in every six tourist arrivals in the world (Mather *et al.*, 2005). Climate change has the potential to radically alter tourism patterns in Europe by inducing changes in destinations and seasonal demand structure (Scott *et al.*, 2008).

Human health will be affected by climate change, in direct and indirect ways (Costello *et al.*, 2009). Effects include changes in temperature-related mortality, food-borne diseases, water-borne diseases and vector-borne diseases.

This project does not pretend to be comprehensive as relevant impact categories are not included in the assessment. Market impact categories such as fisheries, forests and energy demand/supply changes have not yet been addressed. Other non-market impact categories like biodiversity and potentially catastrophic events are not considered in this study either.

1.4 The PESETA project methodology: innovative issues

There are two kinds of approaches to estimate impacts of climate change: top-down and bottom-up. Several research studies (*e.g.* Nordhaus, 1992; Nordhaus and Yang, 1996; Mastrandrea and Schneider 2004; Hitz and Smith, 2004; Stern, 2007) have estimated or employed climate damage functions as reduced-form formulations linking climate variables to economic impacts (usually average global temperature to gross domestic product, GDP). An illustration is the recent update of the estimate of the damage of climate change in the US of the Stern review (Ackerman *et al.*, 2009). These authors assume that economic and non-economic damages of climate change are a function of temperature:

$$D = a\ T^N$$

where D refers to damages, T is the temperature increase and a and N are parameters.

Indeed, this branch of the literature provided early estimates of the order of magnitude of the effects of climate change in the world and large regions, as a function of the global temperature change (*e.g.* Fankhauser, 1994, 1995; Hitz and Smith, 2004; Tol, 2009).

Yet, for assessing impacts and prioritising adaptation policies such top-down approach has some disadvantages. Firstly, estimates are based on results from the literature coming from different, and possibly inconsistent, climate scenarios. Secondly, only average temperature and precipitation are included, not considering other relevant climate variables and the required time-space resolution in climate data. Thirdly, and because of the previous point, impact estimates lack the geographical resolution for adaptation policies. Indeed, aggregate or top-down impact estimates might hide variability of interest in the regional and sectoral dimensions.

Another strand of the literature has followed a bottom-up approach. This bottom-up or sectoral approach has been implemented in PESETA, where the physical effects of climate change are estimated by running high-resolution impact-specific models, which use common selected high-resolution scenarios of the future climate.

PESETA builds upon examples of assessments made elsewhere, such as the California impact study (Hayhoe *et al.*, 2004), the US impact studies (*e.g.* Mendelsohn and Neumann, 1999; Jorgenson *et al.*, 2004; Ruth *et al.*, 2006; Karl et al., 2009), the Russian impact study (Roshydromet, 2005), global adaptation assessment (World Bank, 2009), and the FINADAPT study in Finland (Carter, 2007).

PESETA is indeed the first regionally-focused, quantitative, integrated assessment of the effects of climate change on vulnerable aspects of the European economy and its overall welfare. The PESETA project is characterized by a quantitative or model-based assessment of impacts of climate change.

The analysis is innovative because it integrates (a) high space-time resolution climate data, (b) detailed modelling tools specific for each impact category considered and (c) a multi-sectoral, multi-regional computable general equilibrium (CGE) economic model. The use of a CGE model to integrate all market impacts takes into account the indirect economic effects of climate change, in addition to the direct effects.

Moreover, a key feature of the methodological framework is consistency across the sectoral studies concerning the use of common socioeconomic and climate scenarios. All studies used the same datasets. Various approaches to adaptation have been considered, including the non-adaptation case (Section 2.4).

As noted by Rotmans and Dowlatabadi (1998), the distinctive feature of integrated assessment models, involving several scientific disciplines, such as that of the PESETA project, is that they can have added valued compared to a mono-disciplinary assessment.

However, it must be noted that quantifying the expected effects of climate change in a very long-term time horizon requires dealing with many sources of uncertainty, including *e.g.* future climate, demographic change, economic development, and technological change. There is poor understanding of processes (incomplete scientific methodologies) and large gaps in data. Consequently, the results of the project need to be interpreted with due care and, in particular, are to be considered as 'preliminary' given the exploratory nature of the PESETA research project.

Despite these limitations, the PESETA project provides a valuable indication of the economic costs of climate change in Europe based on state-of-the-art physical impact assessment and high-resolution climate scenarios (daily, 50x50 km grids).

1.5 Overview of this report

This report is divided into nine chapters, including this overview. Chapter 2 presents the main elements of the methodological framework of the project, including the main features of the climate scenarios. The following five chapters summarise the methodology of each sectoral assessment and its main physical and economic results. Chapter 3 deals with the agriculture assessment, chapter 4 with river floods, chapter 5 with coastal systems, chapter 6 with tourism and chapter 7 with human health.

Chapter 8 synthesises the whole PESETA project. The chapter presents the results of integrating the four economic impacts (agriculture, river floods, coastal systems and tourism) into the GEM-E3 computable general equilibrium model for Europe to explore possible adaptation priorities within the EU. The analysis assesses the welfare effects if the climate of the 2080s would occur today, therefore without considering the influence of socioeconomic change, *i.e.* economic growth and population dynamics. This implies that there is a certain underestimation of impacts. Higher future population and GDP would lead to higher impacts, *ceteris paribus*.

Moreover, the GEM-E3 assessment has been made assuming that there is no public adaptation (Levina and Tirpak, 2006). Therefore the 'potential' impacts of climate change have been studied. This evaluation of impacts allows to explore insights on where and which sectors to prioritize adaptation policies.

Chapter 9 summarises the main findings of the PESETA project, discusses its limitations and possible lines of further research. The tables in the Annex present for the EU as a whole and its regions the main climate indicators (in terms of temperature, precipitation and SLR), the physical effects and the economic impacts (welfare changes from the GEM-E3 PESETA model analysis).

2 METHODOLOGICAL FRAMEWORK

2.1 Introduction

While there have been independent sectoral studies on the effects of climate change in Europe (*e.g.* cCASHh for health, DINAS-COAST for coastal systems), few have followed a multi-sectoral approach (ATEAM is one exception; Schröter et al., 2005), which would make a pan-European assessment truly comparable across sectors, information necessary to prioritise adaptation resources. Moreover, most integrated assessment studies are based on climate data with coarse resolution, usually from output from Global Circulation Models (GCMs), with around 200 x 200 km grids, approximately the surface of the Netherlands.

PESETA has tried to bridge this information gap while benefiting from the emerging new climate data and methods. In that respect, a number of data and methodological improvements have occurred during the last few years, mainly from European Union funded DG Research projects. This notably includes the availability of data from several standardised high-resolution climate projections (PRUDENCE project), with 50 x 50 km resolution - the size of London - , and the development of bottom-up physical impact methodologies, such as for coastal systems model (from the DINAS-COAST project). The project has used five impact assessment models in an integrated manner to look at the following sectors: agriculture, river floods, coastal systems, tourism and human health.

Comparability of results across different sectors requires consistency in the methodology. Consistency has been the methodological backbone of the PESETA project. The consistency of all input data and economic valuation requirements has been explicitly addressed, while consistency in the physical impact methods, in particular relating to the interactions between impact categories, has been covered to a much lesser extent due to the formidable methodological challenges. All PESETA sectoral studies have used the same assumptions about economic growth and population dynamics.

The project has followed three sequential steps: firstly, selection of climate scenarios; secondly, assessment of physical impacts; thirdly, monetary evaluation of the physical impacts. This chapter explains the main issues of the PESETA project methodological framework, including the selected socioeconomic and climate scenarios, the treatment of adaptation and the economic assessment methodologies.

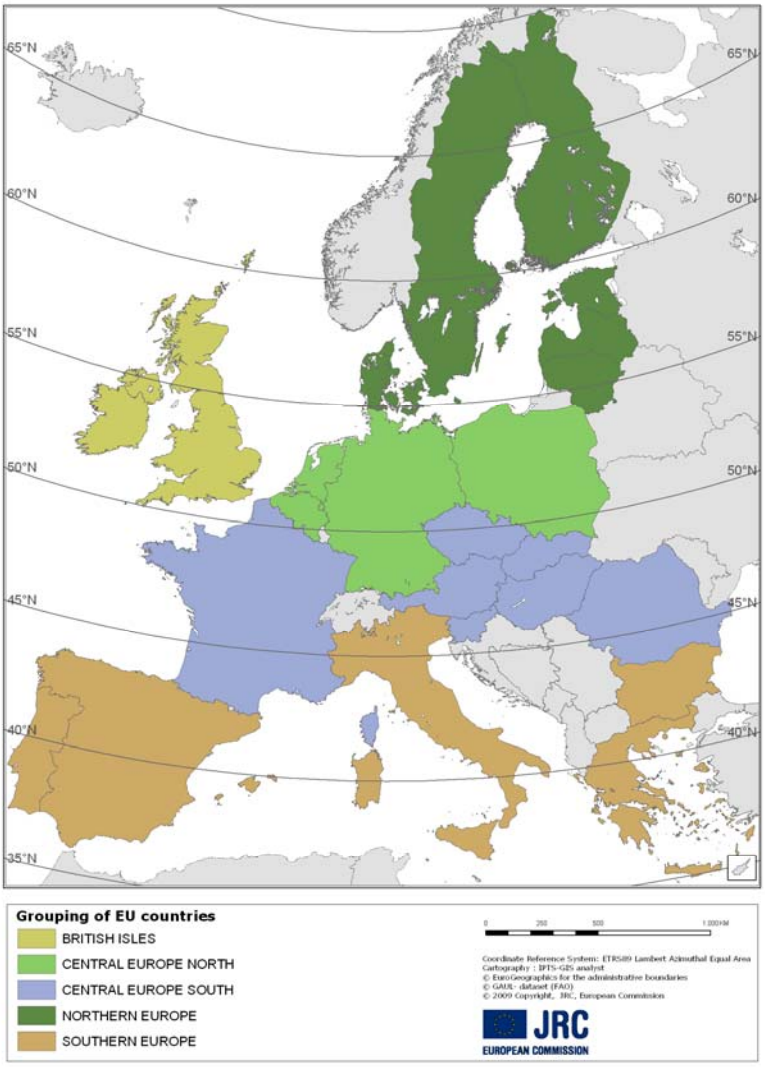
2.2 Grouping of countries

The assessment covers all EU countries, with the exception of Luxemburg, Malta and Cyprus. In order to present the results, EU countries have been grouped into five regions: Southern Europe (Portugal, Spain, Italy, Greece, and Bulgaria), Central Europe South (France, Austria, Czech Republic, Slovakia, Hungary, Romania, and Slovenia), Central Europe North (Belgium, The Netherlands, Germany, and

Poland), British Isles (Ireland and UK), and Northern Europe (Sweden, Finland, Estonia, Latvia, and Lithuania). Given that the main driver of the projected impacts is climate change and that there are some coherent spatial patterns of climate change, the main criterion for grouping countries has been the geographical position.

However, the grouping of countries has also tried to ensure that each region is of comparable economic size, as defined by the share in 2000 EU GDP. With the exception of the Northern Europe region, which only accounts for 6% of the EU GDP, the other regions have a size in the range of 18% to 32%. The difference in the economic scale of the regions has to be considered when interpreting the results. Figure 1 shows the EU countries by assigned region.

Figure 1. Grouping of EU countries in the study



2.3 Scenarios

The climate scenarios were selected to be useful for impact assessment modellers (*e.g.* Mearns *et al.*, 2003). Several criteria were considered: be based on state-of-the-art climate models and be scientifically credible; be readily available; meet the data needs of the sectoral impact models; reflect part of the range of the IPCC SRES emissions scenarios; and provide European-wide information at high resolution for two future time periods: 2011-2040 and 2071-2100.

2.3.1 Socioeconomic scenarios

Underlying all climate scenarios are emissions and concentration scenarios, *i.e.* projections of atmospheric concentrations of greenhouse gases and aerosols. The most widely-used scenarios come from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (Nakicenovic and Swart, 2000). According to SRES and IPCC (2001; 2007a), none of the six possible future storylines or the associated marker scenarios can be considered more likely than another. However, it was not considered feasible within the constraints of the PESETA project to consider more than two emissions scenarios. Thus two had to be chosen that were representative of the full range, but also for which appropriate climate model output was available. For these reasons, it was agreed to focus on the ‘high’ A2 scenario (which reaches a carbon dioxide concentration of 709 ppm at 2100) together with the ‘low’ B2 scenario (which has a concentration of 560 ppm at 2100). Given that the emissions are higher under the A2 scenario than in the B2 scenario, the consequences of the A2 scenario could be interpreted as 'the cost of inaction'. However, as there are not explicit mitigation policies in either scenario, that interpretation does not seem appropriate.

An overview of the main driving forces of the A2 and B2 scenarios is provided in Table 1. Global population growth is much higher under the national enterprise A2 scenario, with population reaching more than 15 billion by the end of the century, compared with 10.4 billion for the global stewardship B2 scenario. This is obviously one of the main determinants of the lower emissions path of B2. GDP expands in a similar way under the two scenarios. Moreover, the economic convergence of developing countries is slower in A2. While the ratio of GDP per capita of developed to developing countries at the end of the 21st century is four in the A2 scenario, it is only three under the B2 scenario.

Table 1. Overview of the main driving forces

Scenario group	1990	A2		B2	
		2050	2100	2050	2100
Population	5.3	11.3	15.1	9.3	10.4
World GDP (trillion 1990US$)	21	82	243	110	235
Per capita income ratio: developed countries and economies in transition (Annex-I) to developing countries (non-Annex-I)	16.1	6.6	4.2	4	3

2.3.2 Climate scenarios

Two time windows have been considered in this study: 2011-2040 (2020s) and 2071-2100 (2080s) (Table 2). The 2020s scenario is the A2 socioeconomic SRES scenario with the RCA3 regional model and boundary conditions from the ECHAM4 global model; this dataset comes from the Rossby Centre (SMHI).

Table 2. The PESETA climate scenarios

SRES scenario	Global model	Regional model	Scenario period	Temperature increase
B2	HadAM3H/HadCM3	HIRHAM	2071-2100	2.5°C
A2	HadAM3H/HadCM3	HIRHAM	2071-2100	3.9°C
B2	ECHAM4/OPYC3	RCAO	2071-2100	4.1°C
A2	ECHAM4/OPYC3	RCAO	2071-2100	5.4°C
A2	ECHAM4/OPYC3	RCA3	2011-2040	-

Four climate futures for the 2080s have been considered in order to reflect the uncertainty associated with the driving forces of global emissions and the sensitivity of climate models to GHG concentration. For each SRES scenario, climate output from two state-of-the-art regional climate models (RCMs), nested within a global circulation model (GCM), have been selected from the PRUDENCE project (Christensen *et al.*, 2007): HIRHAM driven by HadAM3h and RCAO driven by ECHAM4. Daily RCM output at 50 km resolution has been used to drive the physical impact models. The average temperature increase in the EU ranges from 2.5°C to 5.4°C, depending on the greenhouse gas emission scenario and climate model used. Hereafter, the climate futures are called scenarios and are distinguished by the EU temperature increase, thus 2.5°C (B2 HadAM3h-HIRHAM), 3.9°C (A2 HadAM3h-HIRHAM), 4.1°C (B2 ECHAM4-RCAO) and 5.4°C (A2 ECHAM4-RCAO).

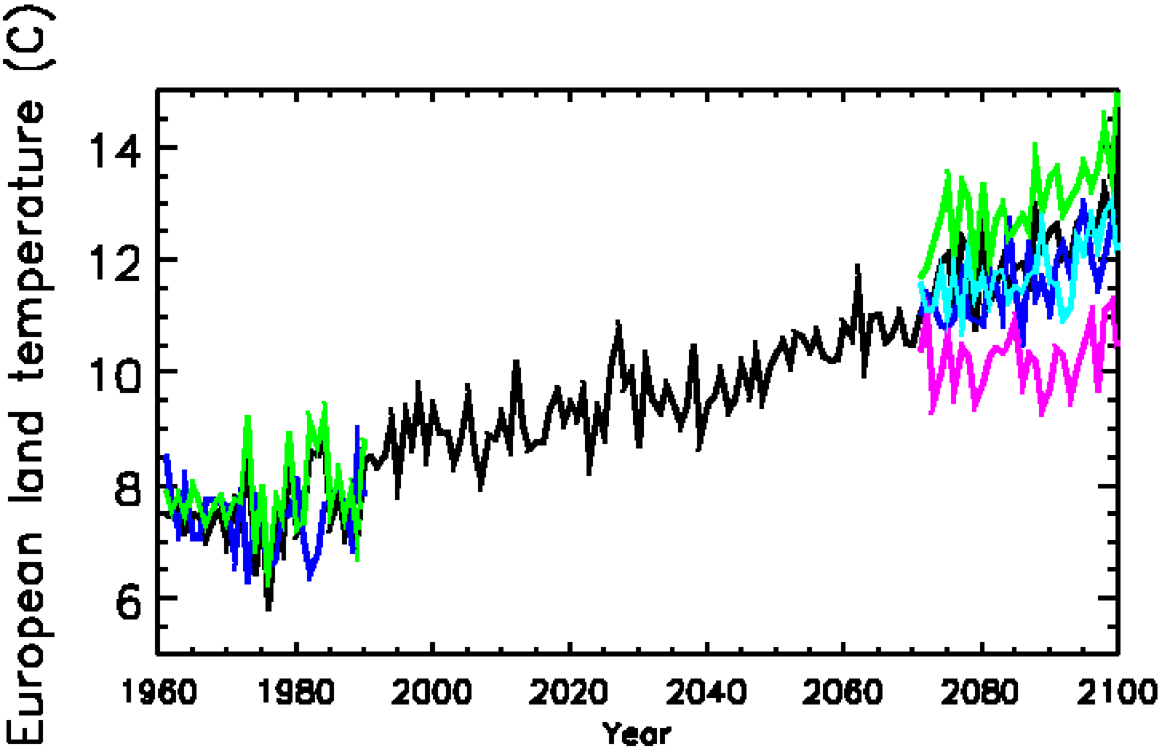
It should be noted that for the 2071-2100 period the EU warming is higher than that of the globe (Table 3). Compared to the preindustrial level, the global temperature increase of the PESETA scenarios are in a range between 2.6°C and 3.4°C.

Table 3. Global and EU temperature increase (2071-2100, compared to 1961-1990)

Climate scenario	Global	EU
B2 HadAM3h-HIRHAM	2.4°C	2.5°C
A2 HadAM3h-HIRHAM	3.1°C	3.9°C
B2 ECHAM4-RCAO	2.3°C	4.1°C
A2 ECHAM4-RCAO	3.1°C	5.4°C

Figure 2 shows the simulated European land temperature for the transient scenario from the Rossby Center (covering the 1961-2100 period), and the 2080s scenarios, including also the simulation in the respective control periods (1961-1990).

Figure 2. European land temperature (°C)



Note: Black line: RCA3/ECHAM4 transient; green lines: 5.4°C scenario time lines; blue lines: 3.9°C scenario time lines; cyan line: 4.1°C scenario; to be compared with the green line for 1961-1990; purple line: 2.5°C scenario; to be compared with the blue line for 1961-1990.

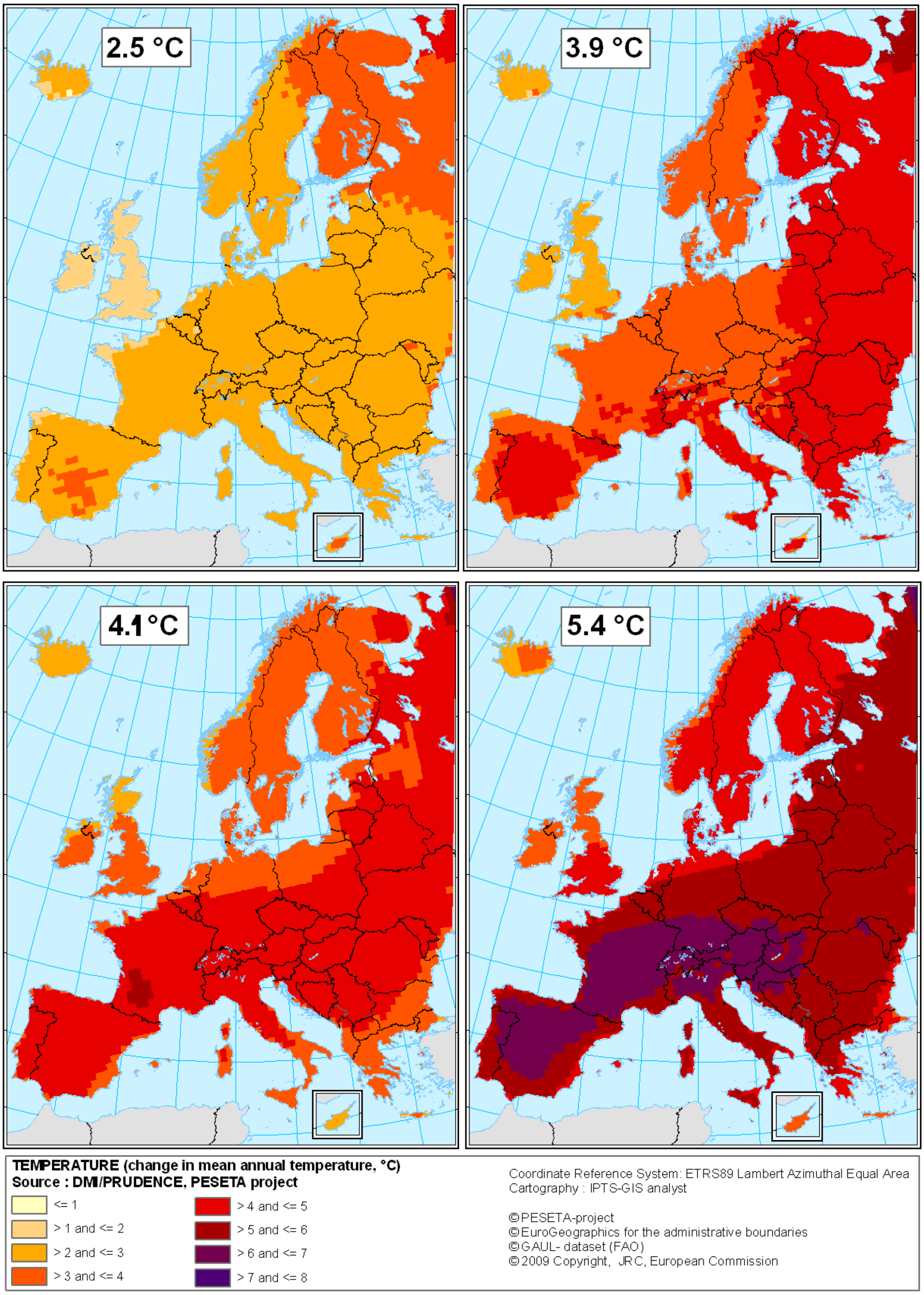
As already noted, in this study the EU has been divided into five regions to simplify interpretation: Northern Europe, British Isles, Central Europe North, Central Europe South, and Southern Europe. Northern Europe is the area with the highest temperature increase, compared to the 1961-1990 period (Table 4, Figure 3), in the 2.5°C and 3.9°C scenarios, whereas in the 4.1°C and 5.4°C scenarios Central Europe South and Southern Europe experience the largest temperature increases. The more oceanic British Isles have the lowest temperature increase throughout all scenarios. The regional precipitation pattern is similar in all scenarios (Figure 4). The Central Europe South and Southern Europe regions experience annual decreases compared to the 1961-1990 control period, while most other EU regions have positive precipitation changes in all scenarios, but with large seasonal differences.

Table 4. Summary of socio-economic and climate scenarios

	Scenarios			
	2.5°C	3.9°C	4.1°C	5.4°C
World population in 2100 (10^{12})	10.4	15.1	10.4	15.1
World GDP in 2100 (10^{12}, 1990US$)	235	243	235	243
CO_2 Concentration (ppm)	561	709	561	709
Δ Temperature (ºC)*				
World	2.4	3.1	2.3	3.1
EU‡	2.5	3.9	4.3	5.4
Northern Europe	2.9	4.1	3.6	4.7
British Isles	1.6	2.5	3.2	3.9
Central Europe North	2.3	3.7	4.0	5.5
Central Europe South	2.4	3.9	4.4	6.0
Southern Europe	2.6	4.1	4.3	5.6
Δ Precipitation (%)*				
EU‡	1	-2	2	-6
Northern Europe	10	10	19	24
British Isles	-5	-2	10	5
Central Europe North	3	1	6	-1
Central Europe South	2	-2	-4	-16
Southern Europe	-7	-15	-13	-28
Sea Level Rise (high climate sensitivity) (cm)	49	56	51	59

*Increase in the period 2071–2100 compared to 1961–1990. ‡European regions: Southern Europe (Portugal, Spain, Italy, Greece, and Bulgaria), Central Europe South (France, Austria, Czech Republic, Slovakia, Hungary, Romania, and Slovenia), Central Europe North (Belgium, The Netherlands, Germany, and Poland), British Isles (Ireland and UK), and Northern Europe (Sweden, Finland, Estonia, Latvia, and Lithuania).

Figure 3. Projected 2080s changes in mean annual temperature



Source : DMI/PRUDENCE, PESETA project

Coordinate Reference System: ETRS89 Lambert Azimuthal Equal Area
Cartography : IPTS-GIS analyst

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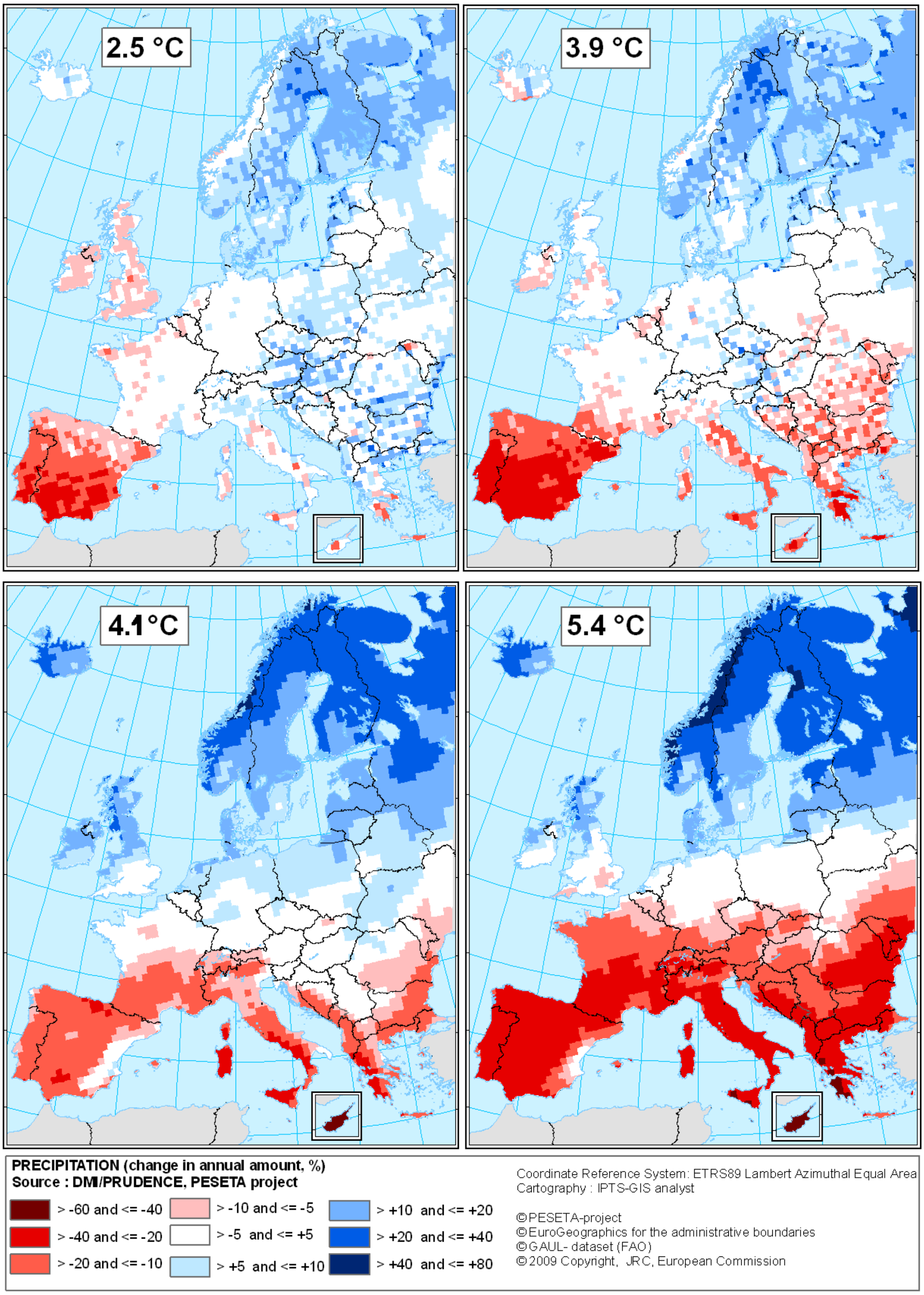
Figure 4. Projected 2080s changes in annual precipitation



PRECIPITATION (change in annual amount, %)
Source : DMI/PRUDENCE, PESETA project

Coordinate Reference System: ETRS89 Lambert Azimuthal Equal Area
Cartography : IPTS-GIS analyst

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Table 5 shows the sea level rise (SLR) scenarios considered in the coastal systems assessment of PESETA. They are consistent with the outputs of the GCMs used in the project. For each of the climate scenarios a low, medium and high SLR case has been considered, in order to account for the uncertainty in future SLR. They are also compared to the low and high IPCC sea-level rise figures (Church *et al.*, 2001). Moreover, the IPCC Third Assessment Report (TAR) high and low scenarios have been studied because they encompass the full range of uncertainty in sea-level rise projections (IPCC, 2001), excluding uncertainties due to ice sheet instability and melting in Antarctica.

Table 5. Global sea-level rise scenarios at 2100

Global Circulation Model		**ECHAM4**		**HADCM3**		**IPCC TAR**
Socio-Economic Scenario		**A2**	**B2**	**A2**	**B2**	**A2/B2**
SLR (cm)	**Low**	29.2	22.6	25.3	19.4	9
	Medium	43.8	36.7	40.8	34.1	-
	High	58.5	50.8	56.4	48.8	88

Given recent evidence on accelerated SLR (Rahmstorf *et al.*, 2007) only the high climate sensitivity case has been taken into account in the integration of the market sectors into the GEM-E3 model (Chapter 8). For the scenarios considered, this leads to a global sea level rise in the range of 48 to 58 cm by the end of the century (Table 5). The high range of SLR of the IPCC Third Assessment Report (TAR), 88 cm, has also been studied for the coastal system impact as a variant of the 5.4°C scenario.

2.3.3 Climate data needs of the sectoral assessments

A key criterion for the final selection of scenarios was the specific climate data needs of the various physical impact methods (Table 6). It can be seen that these needs differ from sector to sector, particularly with respect to the variables requested, but also with respect to the preferred temporal and spatial resolution. The river floods model was the most demanding in terms of resolution, requiring daily data at 50 km spatial resolution, and for some specific scenarios at 12 km resolution.

Table 6. PESETA climate data needs by sector

Sector	Variables requested	Time resolution	Spatial resolution
Agriculture	Max/min temperature Precipitation CO_2-equivalent concentration	monthly monthly annual	50 x 50 km
River Floods	Temperature Precipitation Net (or downward) shortwave (solar) radiation Net (or downward) longwave (thermal) radiation Humidity Wind speed For comparison purposes: evaporation, snow and runoff.	daily	12x12 km and 50 x 50 km
Coastal Systems	Regional surfaces of sea level rise	annual	-
Tourism	Max/average temperature Hours of sun or cloud cover Wind speed Relative humidity or vapour pressure	monthly	50 x 50 km
Human Health	Max/min/average temperature Relative humidity or vapour pressure	daily	50 x 50 km

2.3.4 Overview of scenarios in each impact category

The impacts of climate change in a specific sector depend both on the socio-economic and the climate signals. The climate change signal was considered in all sectoral impact studies (Table 7). The coastal systems and human health assessments have also taken into account the influence of the change in the socio-economic scenario from the present to the future, *i.e.* economic growth and population dynamics.

Table 7. Socio-economic and climate signals across impact studies

Impact Category	Socio-economic signal	Climate signal	Socio-economic and climate signals
Agriculture	-	X	-
River Floods	-	X	-
Coastal Systems	X	X	X
Tourism	-	X	-
Human Health	X	X	X

Table 8 shows the number of cases analysed in each impact study. The five sectoral impact assessments have considered the four 2080s scenarios. The agriculture, coastal systems and human health studies have also assessed the 2020s scenario. In some sectors a number of additional cases have also been considered. As previously noted, in coastal systems for each climate scenario three sea level rise (SLR) cases have been taken into account: low, medium and high. In addition, the lower and higher range of the IPCC TAR SLR scenarios have been studied, as well as a case with no SLR. For each of the SLR cases, both a non-adaptation and an optimal adaptation case have been analysed with the DIVA coast model (section 5.1). Concerning tourism, three cases of impacts have been considered, depending on how tourism demand reacts to changing climate (section 6.1). In the human health study, two different exposure-response functions have been used (section 7.1).

Table 8. Cases analysed per sector

Impact Category	Climate Scenarios		Variants	Total number of cases analysed
	2020s	2080s		
Agriculture	1	4	-	5
River Floods	-	4	-	4
Coastal Systems	1	4	No SLR Low/medium/high SLR IPCC low/high SLR Non adaptation/optimal adaptation	72
Tourism	-	4	Alternative demand assumptions	12
Human Health	1	4	Two exposure-response functions	8

2.4 Adaptation

Adaptation assumptions are relevant for the overall results by impact category. In the PESETA project an effort has been made to have a realistic and credible approach to adaptation. In the various models applied in this analysis private adaptation actions (Levina and Tirpak, 2007) have been taken into account: farm level adaptation in agriculture, change in tourism flows in the tourism assessment, acclimatisation in the human health study, and migration to safer areas in coastal systems.

In addition, the coastal systems assessment has explicitly considered public adaptation measures, using a simplified cost-benefit framework. The optimal protection level is determined by the equalisation of marginal costs and benefits (Tol, 2005). Two hard, engineering adaptation measures are considered. First of all, dikes are built to protect the coast. The costs of dikes are compared to the benefits in terms of lower sea flood damages, river flood damages, salinisation costs and migration costs. The second measure is beach nourishment, which is decided by comparing the nourishment costs (basically a function of cubic metre of sand) with its benefits. The benefits depend on agriculture land value if there are not tourists, and where there are tourists, the benefits depend on the number of tourists and their expenditure.

2.5 Economic assessment

2.5.1 Discounting

The simulated economic effects of climate change refer to the 2020s and 2080s. Yet those effects cannot be directly compared to the size of the economy as of today. Economic effects are usually discounted in order to account both for the growth in per capita income of the economy (the same Euro has a higher value today than for the richer future society) and the fact that there is a preference for current consumption versus future consumption (as reflected in the positive interest rate *e.g.* of public bonds).

However the choice of the discount rate is a very controversial issue (Stern and Taylor, 2007; Nordhaus, 2007) because it requires value judgements, *e.g.* the valuation of future generations' welfare by today's generation.

In order to make the economic assessment of PESETA transparent it was decided to report undiscounted monetary effects in the economic estimates for the 2080s. Concerning the integration of market impacts into the GEM-E3 model (Chapter 8), as the evaluation is made concerning the impacts of future climate on today's economy, so discounting monetary impacts is not required.

2.5.2 Valuation methods: direct economic effects

The sectoral studies produced estimates of the "direct" economic effect. Those effects are limited to the sector under consideration and do not take into account the consequences in the rest of the economy. This is known in the economic literature as partial equilibrium analysis.

The river flood, coastal systems, tourism and human health studies have made a direct economic effect analysis. In particular, the river flood assessment considers the direct damages due to river floods, mainly affecting residential buildings and economic activities (Section 4.3). The costal systems study considers the impacts in terms of land losses, migration costs and sea flood costs (Section 5.3). The tourism study measures the effect in tourism expenditure from assumptions on expenditure per bed night (Section 6.3). Finally, the human health study values mortality effects using standard economic methods: value of statistical life and value of life years lost (Section 7.3).

Nevertheless, the direct effects provide only part of the overall economic consequences of climate change because they will also affect the rest of the economy (*e.g.* Darwin and Tol, 2001). This is the case for instance of river floods. The impact assessment provides the damages due to land uses in the flooded area. But those damages also will induce additional effects in other sectors and aspects of the economy. Thus the damages to the commercial sector will lead to lower income for the business owners, which will lead to lower expenditure by them, additionally depressing economic activity in other sectors of the economy. A similar case occurs with agriculture. In countries facing drops in yields, other industries will undergo lower production levels, such as the agroindustry sector. The study of the overall economic consequences, considering the indirect effects in addition to the direct effects, can be made with computable general equilibrium (CGE) models (Shoven and Whalley, 1992).

2.5.3 Valuation methods: overall economic (general equilibrium) effects

Two sectoral studies have applied the CGE methodology. The agriculture and coastal system assessments have both used the GTAP general equilibrium model to value the overall effects on the economy. They have assessed the impact of future climate on the future economy. Both the climate signal and socioeconomic change have been taken into account.

Moreover, in the last stage of the project the four impact categories that can be considered as 'market' impacts (agriculture, river floods, coastal systems and tourism) have been integrated in the GEM-E3 CGE model (Chapter 8). There, to ensure consistency, only the impact due to climate change is considered, which was studied in all sectors (Table 7).

3 AGRICULTURE IMPACT ASSESSMENT

Agriculture is the main user of land, and water, and it still defines society in the rural areas of Europe. European agriculture accounts for one half of the global trade of food products and it is directly influenced by European and global policy. Climatic conditions directly affect agriculture and the water resources needed to maintain a stable production in many areas of Europe (Iglesias *et al.*, 2007; 2009a; Olesen and Bindi, 2002) and the provision of essential ecosystem services (Metzger *et al.*, 2006). It is likely that the stress imposed by climate change on agriculture and water intensifies the regional disparities in rural areas and the overall economy of European countries (Alcamo *et al.*, 2007; EEA, 2008; Stern, 2007). Understanding the impact of climate change is complicated because changes in physical and social variables are often derived by using different assumptions and inconsistency of inputs across geographical and time scales. As a result, some of the most profound impacts of climate change may be more difficult to project than the future climate itself.

This chapter summarises the methodology and the main results of the agriculture impact assessment. Detailed information can be found in the accompanying PESETA technical report of Iglesias *et al.* (2009b).

3.1 Agriculture integrated methodology

3.1.1 The modelling approach

European scenarios of agricultural change for the years 2020s and 2080s are developed based on global scenarios of changes in environmental and socio-economic variables and the understanding of the sensitivity of each agricultural region to these changes. The most important determinants of changes in agricultural production are: changes in agroclimatic regions, crop productivity, and crop management (deliberate adjustments of the crop calendar, nitrogen fertiliser, and amount of irrigation water in order to optimise productivity in each scenario); livestock production is not considered, except for the possible inference of crop productivity. Then, the expected change in future crop productivity is calculated across Europe. Finally, monetary estimates of the projected changes are derived. It is assumed that (i) farmers follow an adjusted crop management in response to climate; (ii) irrigated areas do not increase significantly; and (iii) fiscal policies remain unchanged. Because of the nature of these assumptions, it is considered that the results represent an agricultural policy scenario that does not impose major additional environmental restrictions beyond the ones currently implemented, neither include pollution taxes (for example for nitrogen emissions to mitigate climate change).

The assessment links biophysical and statistical models in a rigorous and testable methodology, based on current understanding of processes of crop growth and development, to quantify crop responses to changing climate conditions. Dynamic process-based crop growth models are specified and validated for sites in the major agro-climatic regions of Europe. The validated site crop models are useful for simulating the range of conditions under which crops are grown, and provide the means to estimate production functions when experimental field data are not available. Variables explaining a significant proportion of simulated yield variance are crop water (sum of precipitation and irrigation) and temperature over the growing season. Crop production functions are derived from the process based model results. The functional forms for each region represent the realistic water limited and potential conditions for the mix of crops, management alternatives, and potential endogenous adaptation to climate assumed in each area.

In particular, nine agro-climatic regions are defined based on K-mean cluster analysis of temperature and precipitation data from 247 meteorological stations, district crop yield data, and irrigation data. The yield functions derived from the validated crop model, the DSSAT model (Rosenzweig and Iglesias, 2008; Rosenzweig and Iglesias, 2002; Iglesias *et al.*, 2006; Rosenzweig and Iglesias, 1994), are then used with the spatial agro-climatic database to conduct a European wide spatial analysis of crop production vulnerability to climate change.

Adaptation is explicitly considered and incorporated into the results by assessing country or regional potential for reaching optimal crop yield. Optimal yield is the potential yield given non-limiting water applications, fertilizer inputs, and management constraints. Adapted yields are calculated in each country or region as a fraction of the potential yield. That fraction is determined by the ratio of current yields to current yield potential.

The methodology incorporates a number of strengths: it is based on an interdisciplinary, consistent bottom-up methodology that uses a range of emission scenarios to provide insights into the effects of climate change policy. The physical approach expands process-based crop model results over large areas and therefore overcomes the limitation of data requirements for the crop models; it includes conditions that are beyond the range of historical observations of crop yield data; and includes simulation of optimal management and thus estimate agricultural responses to changes in regional climate.

3.1.2 Limitations and uncertainties

There is a large uncertainty surrounding future emissions and their underlying dynamic driving forces. This uncertainty is increased in going from emission values to climate change, from climate change to possible impacts and finally from these driving forces to formulating adaptation and mitigation policies (Gupta *et al.*, 2003). The study considers changes in agroclimatic regions but not on the evolution of land use to the 2080s. Determining how farmers will adapt to climate change is a very complex dynamic process which is difficult to quantify. The study considers that farmers optimise management under climate change scenarios but cannot implement changes that require policy intervention. How agriculture policies might react to a changing climate is another critical factor which cannot be incorporated in the simulations.

The uncertainty of the climate scenario is characterised by selecting two emission scenarios (A2 and B2), two global climate models (HadCM3 and ECHAM) downscaled across Europe, and two time frames. In all regions, uncertainties with respect to the magnitude of the expected climate changes result in uncertainties of the agricultural evaluations. For example, in some regions projections of rainfall, a key variable for crop production may be positive or negative depending on the climate scenario used and variable in each season. In general, the assessment shows that the estimated yield changes vary more among different climate models, while the GDP projections show more discrepancy across socio-economic scenarios. Nevertheless, the time horizon is the main determinant of the physical and economic projections.

3.2 Physical impacts

The results show that agroclimatic regions will have substantial modifications as a result of climate change, in agreement to previous analyses. These changes in agroclimatic regions have important implications for the evaluation of impacts on future crop productivity. Here, the production functions are implemented in future agroclimatic regions - that is, the farmers in each location in the future have knowledge of how and what to produce. That is, the crop productivity changes include the changes in crop distribution in the scenario due to modified crop suitability under the warmer climate and farmers' adaptation (non-policy driven). European crop yield changes include the direct positive effects of CO_2 on the crops, the rain-fed and irrigated simulations in each district. It is very important to notice that the simulations considered no restrictions in water availability for irrigation due to changes in policy. In all cases, the simulations did not include restrictions in the application of nitrogen fertilizer. Therefore the results should be considered optimistic from the production point and pessimistic from the environmental point of view.

There are large differences among European regions in the impacts of global change in crop productivity. Figure 5 to Figure 8 shows modelled European crop yield changes for all the 2080s scenarios, and Figure 9 for the 2020s scenario. The estimates for each European region appear in Table 9. The crop productivity changes include the changes in crop distribution in the scenario due to modified crop suitability under the warmer climate and farmers' adaptation. The 2080s less warming scenarios would lead to small changes in yields for the EU, while the 5.4°C scenario could mean a fall in crop yields of 10%. All 2080s scenarios share a similar pattern in the spatial distribution of effects. High yield improvements in Northern Europe are caused by lengthened growing season, which decreases cold effects on growth and extends the frost-free period. Crop productivity decreases in Southern Europe are caused by a shortening of the growing period, with subsequent negative effects on grain filling. The British Isles would have yield losses for the two less warming scenarios (2.5°C and 3.9°C), which would become gains under the other two warmer scenarios. Regarding Central Europe, the country projections of yield changes depend on the particular scenarios.

Concerning the 2020s, all European regions would experience yield improvements, particularly in Northern Europe, with the exception of some areas in central Europe South and Southern Europe. The EU overall yield gain would be 17%.

Figure 5. Agriculture: crop yield changes of the 2.5°C scenario (2080s)

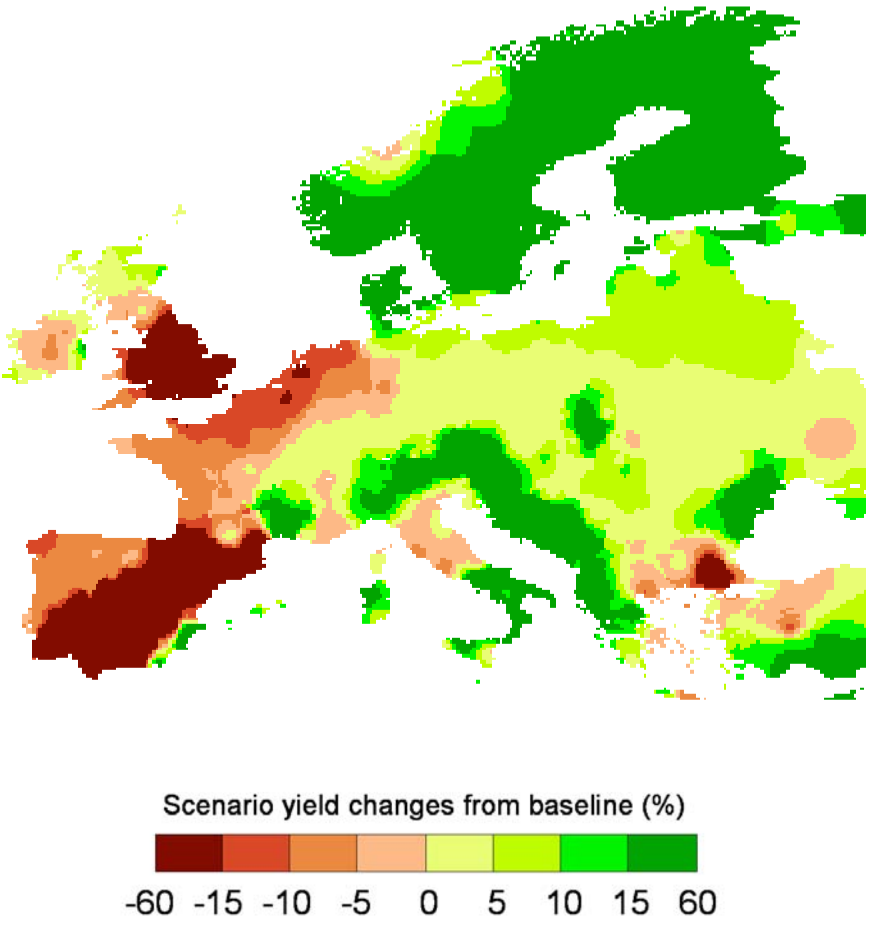


Table 9. Agriculture: crop yield changes (%), compared to the 1961-1990 period

	B2 HadAM3h 2.5°C	A2 HadAM3h 3.9°C	B2 ECHAM4 4.1°C	A2 ECHAM4 5.4°C	2025
Northern Europe	37	39	36	52	62
British Isles	-9	-11	15	19	20
Central Europe North	-1	-3	2	-8	16
Central Europe South	5	5	3	-3	7
Southern Europe	0	-12	-4	-27	15
EU	3	-2	3	-10	17

Figure 6. Agriculture: crop yield changes of the 3.9°C scenario (2080s)

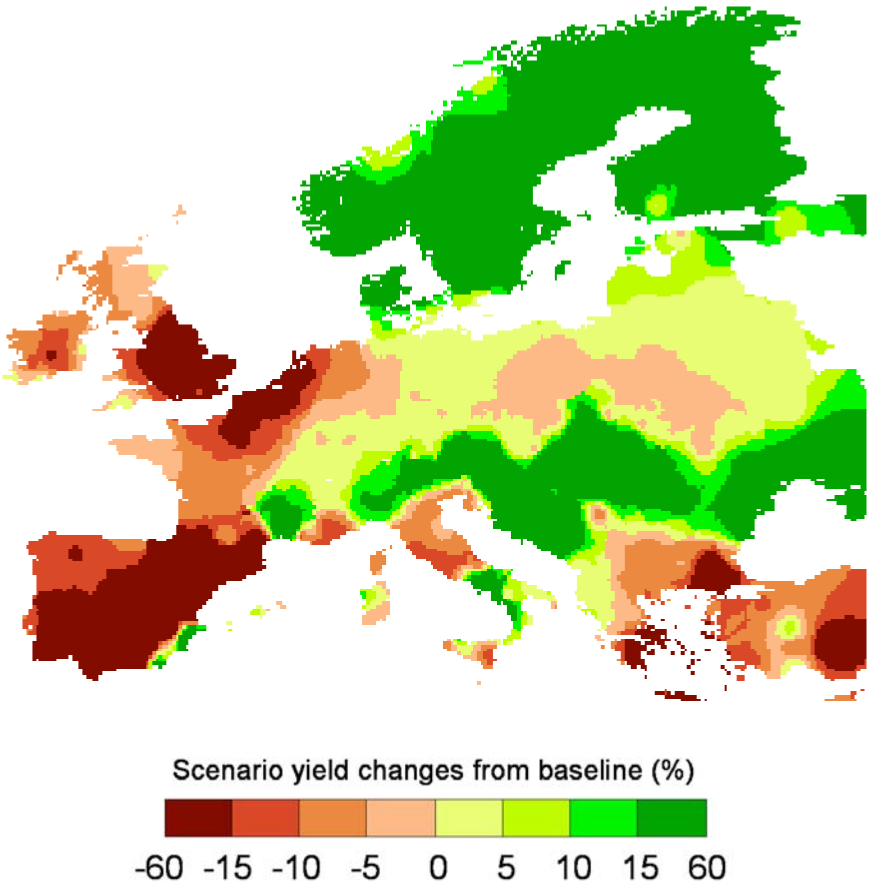


Figure 7. Agriculture: crop yield changes of the 4.1°C scenario (2080s)

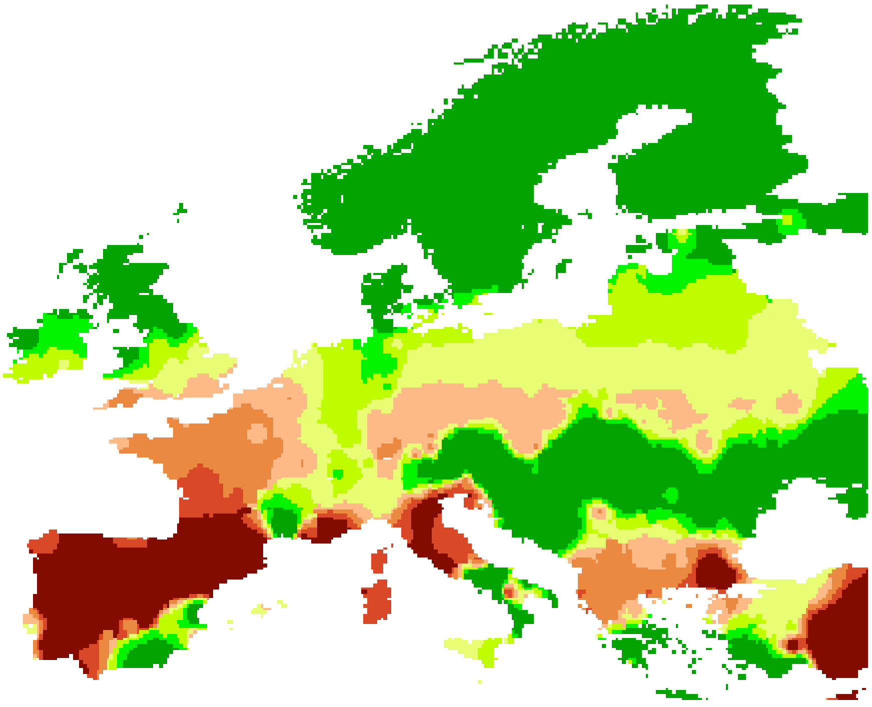


Figure 8. Agriculture: crop yield changes of the 5.4°C scenario (2080s)

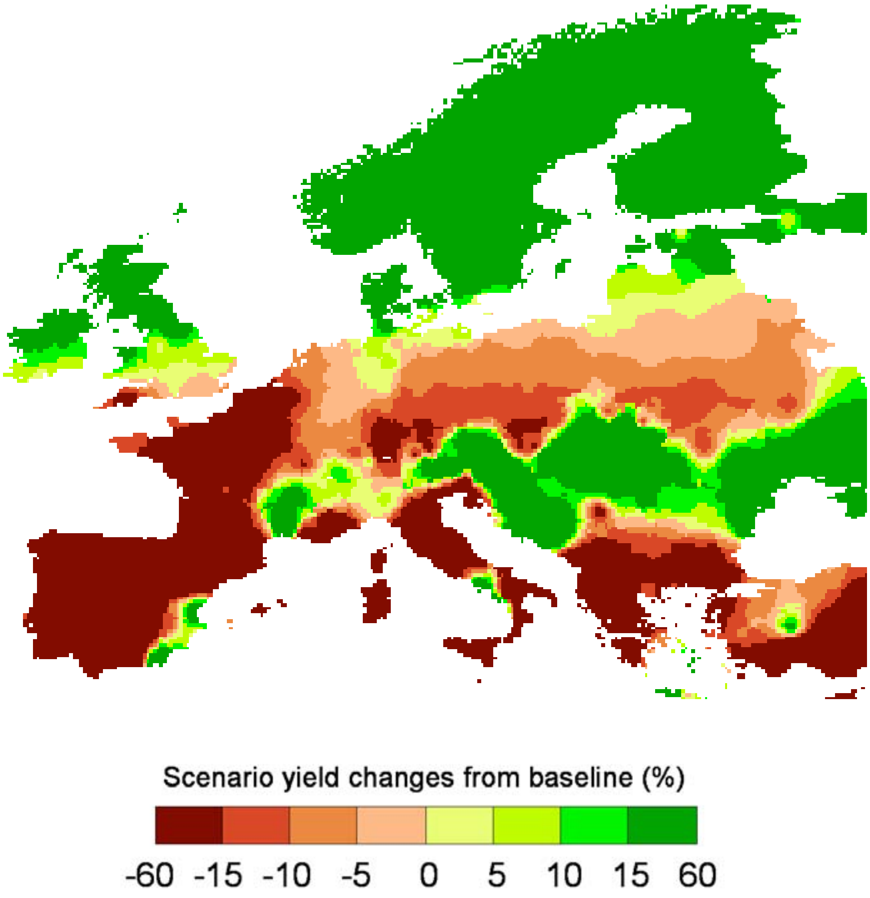
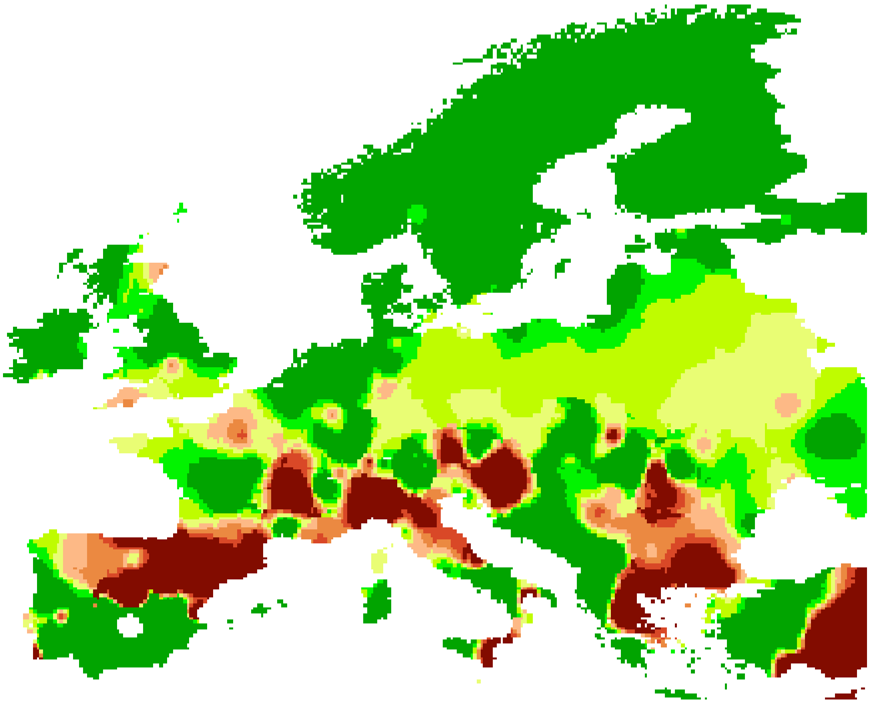


Figure 9. Agriculture: crop yield changes of the 2020s scenario



3.3 Economic impacts

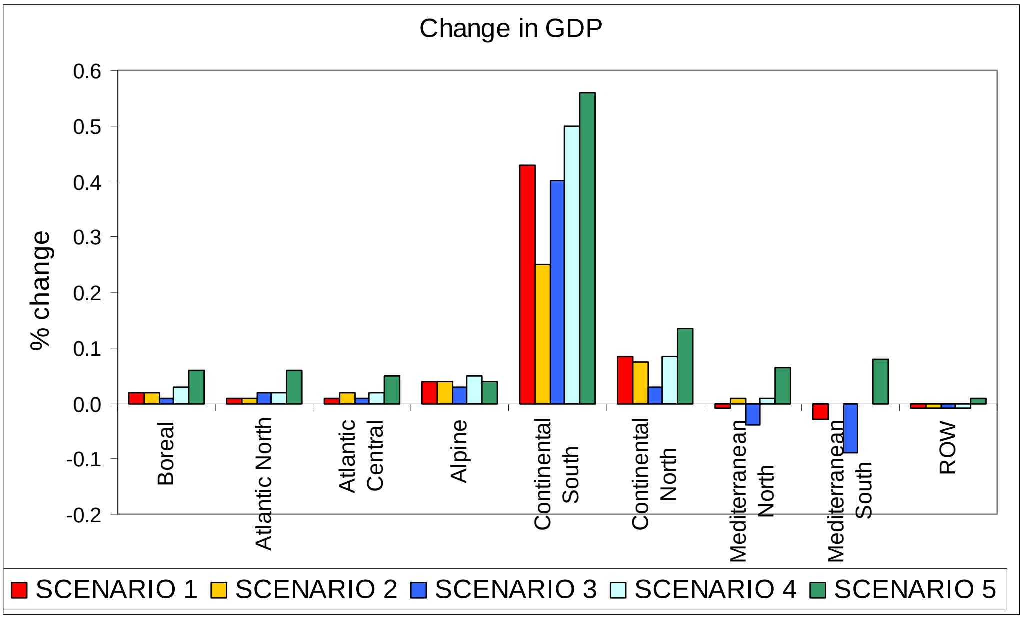
The global GTAP general equilibrium model (Hertel, 1997), calibrated to the year 2001, has been used to evaluate the economic impacts of climate change in agriculture. The productivity shock has been introduced in GTAP as land-productivity-augmenting technical change over crop sector in each region. The increase in population projected for each scenario has been considered. For consistency the rest of the world region could also experience a change in productivity. The average crop yield changes for the world are based on Parry *et al.* (2004) for the HadCM3 and A2 and B2 scenarios. Table 10 details the regional aggregation implemented in the GTAP model.

Table 10. Agriculture: regional aggregation

Agricultural region	**Countries included**
Boreal	Finland, Sweden
Atlantic North	Ireland, United Kingdom
Atlantic Central	Belgium, Denmark, Germany, Luxembourg, The Netherlands
Alpine	Austria
Continental North	Check Republic, Estonia, Latvia, Lithuania, Poland, Slovakia
Continental South	Bulgaria, Croatia, Hungary, Romania, Slovenia
Mediterranean North	France, Portugal
Mediterranean South	Cyprus, Greece, Italy, Malta, Spain

The estimated changes in GDP per region (Figure 10) confirm the significant regional differences between Northern and Southern European countries. The effects on GDP are smaller than the productivity increases, as usually is the case in general equilibrium simulations, due to the ability of the economy to factors substitution to accommodate the changes. However, the patterns are consistent with the physical impacts that are all positive except in the Mediterranean countries. The most important increases seem to concern the continental region, where the productivity increases enlarge GDP more intensively due to the increasing importance of the agricultural sector in the region. Water restrictions and socio-economic variables that modify the outcome may also be considered in further studies. The monetary estimates show that in all cases uncertainty derived from socio-economic scenarios (*i.e.* A2 versus B2) has a larger effect than uncertainty derived from climate scenarios.

Figure 10. Agriculture: GDP changes under the climate change scenarios



Note: Scenarios 1 to 4 refer to the 2080s climate, compared to the 1961-1990 period: scenario 1 is A2 HadAM3h (3.9°C), scenario 2 is B2 HadAM3h (2.5°C), scenario 3 is A2 ECHAM4 (5.4 C), and scenario 4 is B2 ECHAM4 (4.1°C). Scenario 5 is the 2020s.

4 RIVER FLOODS ASSESSMENT

River floods are the most common natural disaster in Europe (EEA, 2004). Global warming is generally expected to increase the magnitude and frequency of extreme precipitation events (Christensen and Christensen, 2003; Frei *et al.*, 2006), which may lead to more intense and frequent river floods.

This chapter summarises the methodology and the main results of the river flood impact assessment. Detailed information on the methodology can be found in Feyen *et al.* (2006).

4.1 Modelling floods in river basins

4.1.1 The modelling approach

Estimates of changes in the frequency and severity of river floods are based on simulations with the LISFLOOD model followed by extreme value analysis (Dankers and Feyen, 2008). The LISFLOOD model, which transfers the climate forcing data (temperature, precipitation, radiation, wind-speed, humidity) into river runoff estimates, is a spatially distributed, mixed conceptual-physically based hydrological model developed for flood forecasting and impact assessment studies at the European scale (van der Knijff *et al.*, 2008). Using a planar approximation approach, the simulated discharges with return periods of 2, 5, 10, 20, 50, 100, 250 and 500 years have been converted into flood inundation extents and depths. The latter have been translated into direct monetary damage from contact with floodwaters using country specific flood depth-damage functions (Huizinga, 2007) and land use information (EEA, 2000). Population exposure has been assessed by overlaying the flood inundation information with data on population density (Gallego and Peedell, 2001). By linearly interpolating damages and population exposed between the different return periods, damage and population exposure probability functions have been constructed under present and future climate. From the latter, the expected annual damage and expected annual population exposed have been calculated.

Static, country-specific protective capacities for floods have been considered by truncating the damage and population exposure probability functions at certain return periods. Various flood protection levels were imposed depending on country GDP per capita (protection to 100-year, 75-year and 50-year return periods).

It is assumed that the population and the economic structure are as of today's. Therefore, the additional damage that would occur because of population growth and economic development has not been considered in this assessment. In this respect, the figures below underestimate the projected damages by the end of the century.

4.1.2 Limitations and uncertainties

The different steps in the chain "emissions → climate → extreme flow → flood inundation → damage" are subject to uncertainty. When applying the framework outlined above for macro-scale flood damage assessment it was necessary to adopt a series of assumptions, which should be kept in mind when interpreting the results. First of all, the climate scenarios used only capture a part of the uncertainty range attributable to emissions of greenhouse gasses (with the A2 and B2 scenarios only two out of six SRES storylines are considered) and neglect uncertainty due to inter-GCM and inter-RCM variability. Secondly, no downscaling or bias correction was applied to the climate data because at present no high-quality, high-resolution meteorological dataset exists at European scale that would allow a proper downscaling of the climate data used. This may locally lead to underestimation of flood frequencies due to the inability of the RCM to explicitly represent fine-scale climatic structures, especially for the coarse resolution run (B2, 50 km). Thirdly, hydrological uncertainty is not accounted for. Several studies (*e.g.*, Wilby, 2005) showed, however, that this layer of uncertainty is generally much lower than the uncertainty of the climate input to the hydrological model. Fourthly, flood return levels are estimated using extreme value analysis based on simulated time series of 30 years, which may result in large extrapolation errors for high return periods. Moreover, changes in land use and land cover are not incorporated in the climate runs or in the economic impact evaluation due to the absence of reasonable macro-scale land use change scenarios for the SRES storylines. This may result in an underestimation of future flood risk.

The approach used is based on direct estimated potential flood damage caused by water depths on land use typologies. Other factors that might contribute to the increase of losses, such as flood velocity, building characteristics, content of sediment in water, as well as indirect economic losses, are not included in this study.

The above list of assumptions implies that monetary estimates of flood damage are inherently uncertain. It should be noted, however, that the goal of this study was to evaluate changes in flood damage due to climate change, rather than to estimate absolute values of flood damage. Given that most of the assumptions apply to both the control and scenario period it can be expected that estimates of changes in flood damage are relatively less affected by the assumptions compared to the absolute flood damage estimates.

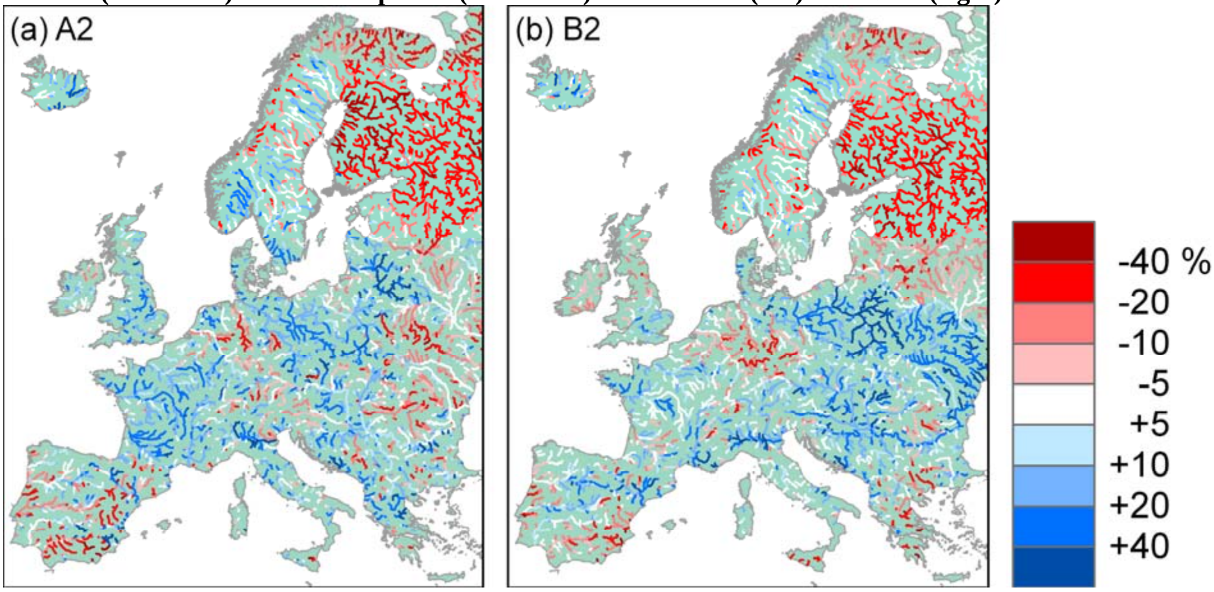
4.2 Physical impacts

Figure 11 shows the change in the 100-year return level of river discharge between the scenario and control run for the 3.9°C and 2.5°C scenarios. Note that an increase or decrease in the 100-year return discharge translates as an increase or decrease in the probability of occurrence of a current 100-year flood level. Under both scenarios, the 100-year return discharge levels are projected to increase in many parts of Europe (blue lines in the maps).

A notable exception to this can be seen in the northeast, where warmer winters and a shorter snow season will reduce the magnitude of the spring snowmelt peak. In some other rivers in central and southern Europe a decrease in extreme river flows is projected as well (red lines in the maps). In many parts of Europe though, especially in the west, as well as in parts of Eastern Europe, the simulations suggest that present-day 100-year floods will be more intense and frequent by the end of this century.

The largest difference between the two scenarios can be found in parts of Eastern Europe, where the 2.5°C scenario shows a strong increase in extreme river flows whereas the 3.9°C scenario results in little change or even a decrease. This implies that with respect to changes in discharge extremes, the lower-emissions 2.5°C scenario should not necessarily be regarded as less extreme (as is the case for temperature). Let note again, however, that the estimation of discharge levels with high return periods from a 30-year long time series is subject to large uncertainties due to extrapolation. Also, as noted before, differences between the A2 and B2 scenario may in part be due to the discrepancy in horizontal resolution of the regional climate data.

Figure 11. River floods: relative change in 100-year return level of river discharge between scenario (2071-2100) and control period (1961-1990) for the 3.9ºC (left) and 2.5ºC (right) scenarios



Note: Shown here are only rivers with an upstream area of 1000 km^2 or more.

The four first columns of Table 11 detail the projected annual number of people affected by river floods under the various climate futures, additional to those of the 1960-1990 period. The fifth column of the table presents the simulated people affected on average over the 1961-1990 period. River flooding would affect 250,000 to 400,000 additional people per year in Europe by the 2080s, more than doubling the number with respect to the 1961–1990 period. The Northern Europe region would have less people exposed to flooding in most scenarios. The Southern Europe region would also have less people affected by floods under the 5.4°C scenario.

An increase in people exposed to floods would occur mainly in the Central Europe regions and the British Isles. In general terms, the higher the mean temperature increase, the higher the projected increase in people affected by floods.

Table 11. River floods: additional expected population affected (1000s/year)

	B2 HadAM3h 2.5°C	A2 HadAM3h 3.9°C	B2 ECHAM4 4.1°C	A2 ECHAM4 5.4°C	simulated 1961-1990
Northern Europe	-2	9	-4	-3	7
British Isles	12	48	43	79	13
Central Europe North	103	110	119	198	73
Central Europe South	117	101	84	125	65
Southern Europe	46	49	9	-4	36
EU	276	318	251	396	194

4.3 Economic impacts

The four first columns of Table 12 present the projected expected annual economic damages in the 2080s, additional to those simulated in the control period (1961-1990). The fifth column of the table represents the simulated damages of the 1961-1990 period. The total additional damage ranges from 7.7 to 15 billion €, more than doubling the annual average damages over the 1961-1990 period. The regional pattern of economic damages is similar to that of people affected. Thus, while Northern Europe would have lower damages, the Central Europe area and British Isles would undergo significant increases in expected damages.

Table 12. River floods: additional expected economic damage (million €/year)

	B2 HadAM3h 2.5°C	A2 HadAM3h 3.9°C	B2 ECHAM4 4.1°C	A2 ECHAM4 5.4°C	simulated 1961-1990
Northern Europe	-325	20	-100	-95	578
British Isles	755	2,854	2,778	4,966	806
Central Europe North	1,497	2,201	3,006	5,327	1,555
Central Europe South	3,495	4,272	2,876	4,928	2,238
Southern Europe	2,306	2,122	291	-95	1,224
EU	7,728	11,469	8,852	15,032	6,402

Figure 12 and Figure 13 show the expected annual damage at regional resolution (aggregated over administrative level NUTS 2) for the two lowest warming scenarios, 2.5°C and 3.9°C scenarios, respectively. The regional patterns in flood damage changes in Europe reflect largely those observed in the changes in flood hazard (Figure 11), but regional differences can be noted especially in the magnitude of change. Under both scenarios flood damages are projected to rise across much of western, central and Eastern Europe, as well as in Italy and northern parts of Spain. The strongest decrease in flood damage is projected for the North-Eastern parts of Europe. Most notable differences between the two emission scenarios are observed in Ireland, northern and western parts of the UK, southern Baltic regions, northern parts of Greece, Belgium, the Netherlands, western and central parts of Germany, and northern parts of the Czech Republic. For these regions damages are projected to decrease under the 2.5°C scenario, whereas an increase is projected under the 3.9°C scenario. For Romania the opposite is observed.

Figure 12. River floods: relative change in expected annual direct damage (averaged over administrative level NUTS2) between scenario (2071-2100) and control period (1961-1990) for the 2.5°C scenario.

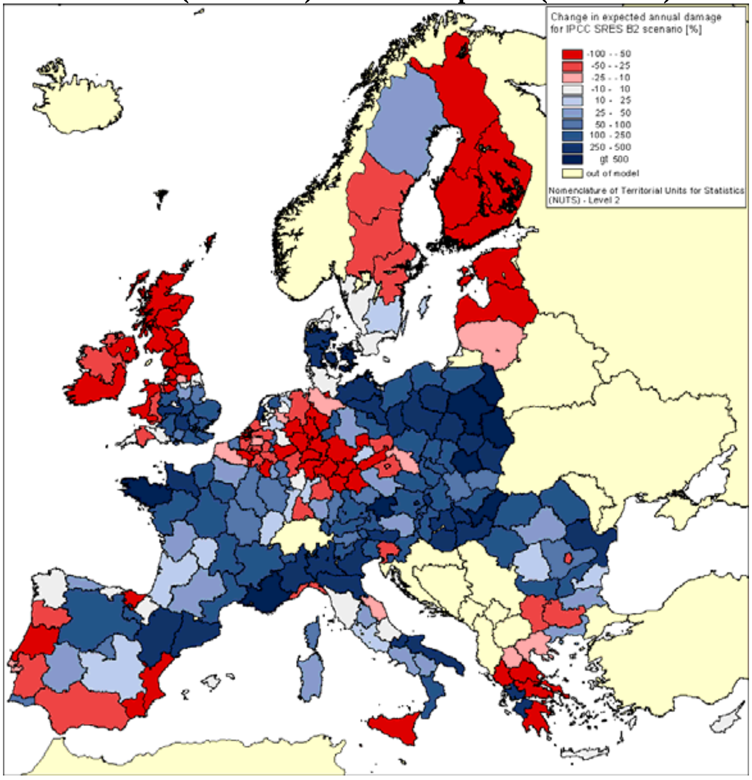
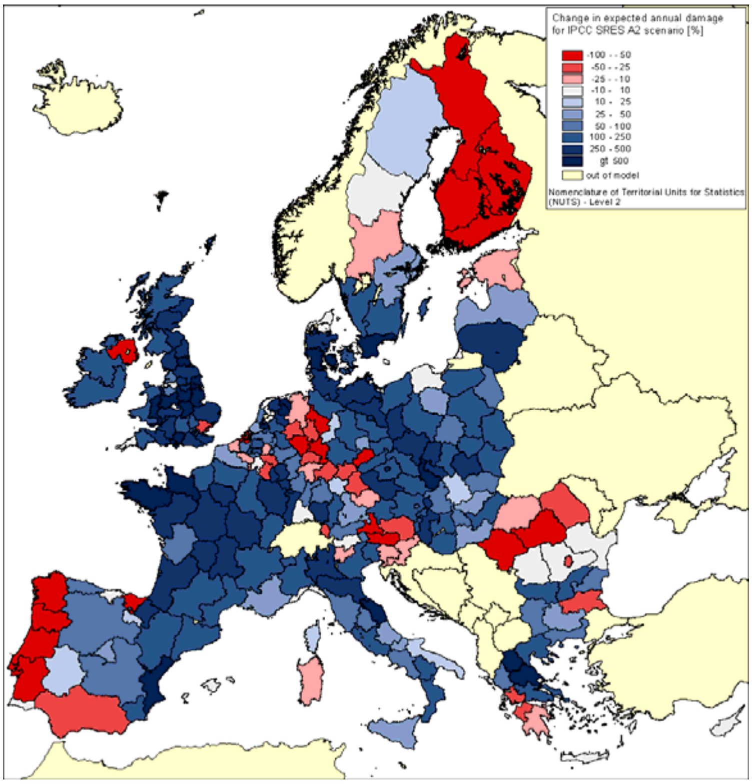


Figure 13. River floods: relative change in expected annual direct damage (averaged over administrative level NUTS2) between scenario (2071-2100) and control period (1961-1990) for the 3.9°C scenario



5 COASTAL SYSTEMS ASSESSMENT

Coastal regions are areas where wealth and population are concentrated and are undergoing rapid increases in population and urbanisation (McGranahan *et al.*, 2007). Sea level rise is a direct threat for productive infrastructures and for the residential and natural heritage zones.

This chapter summarises the methodology and the main results of the coastal systems impact and adaptation assessment. Detailed information can be found in the accompanying PESETA technical report Richards and Nicholls (2009).

5.1 Modelling approach in coastal systems

5.1.1 Coastal system model

Sea level rise (SLR) will have major direct impacts in Europe. Impacts of sea level rise in coastal systems have been quantified with the DIVA model (Hinkel and Klein, 2006; McFadden, *et al.*, 2007; Nicholls and Klein, 2005; Nicholls *et al.*, 2006; Nicholls *et al.*, 2007; Vafeidis *et al.*, 2004). DIVA operates at the level of the individual linear coastal segments, which are independently considered. The model database contains over 80 parameters for each variable-length segment that are utilized to fully describe the physical characteristics of the coastline. The model calculates the impacts of sea-level rise on each of these coastline segments, including direct coastal erosion, coastal flood impacts, changes in wetlands, flood effects in river mouths, sea water intrusion and salinisation. The economic costs due to land and wetland loss (related to erosion and flooding) and the number of people flooded are computed in the economic module of DIVA.

DIVA has an adaptation module that controls a range of possible adaptation responses. This allows giving more realistic estimates of impacts, costs and adaptation for a range of SLR scenarios (Nicholls *et al.*, 2007b). In this analysis, adaptation costs include (1) dike building and (2) beach nourishment (to counter beach erosion), with the decisions on adaptation being based on cost-benefit analysis. The results of the assessment show that in Europe adaptation is widespread, reflecting the large economic values located in many coastal zones.

Table 13 shows the SLR for all scenarios considered. For each of the climate scenarios a low, medium and high SLR case has been considered (Gordon *et al*,. 2000; Roeckener *et al.*, 1996), in order to account for the uncertainty in the future SLR. In addition, impacts are computed for the low and high IPCC sea-level rise figures (Church *et al.*, 2001). The IPCC Third Assessment Report (TAR) high and low scenarios encompass the full range of uncertainty in sea-level rise projections (IPCC, 2001), excluding uncertainties due to ice sheet instability and melting in Antarctica.

Table 13. Global sea-level rise scenarios

	Global Circulation Model	ECHAM4		HADCM3		IPCC TAR
	Socio-Economic Scenario	**A2**	**B2**	**A2**	**B2**	**A2/B2**
SLR (cm)	**Low**	29.2	22.6	25.3	19.4	9
	Medium	43.8	36.7	40.8	34.1	-
	High	58.5	50.8	56.4	48.8	88

5.1.2 Limitations and uncertainties

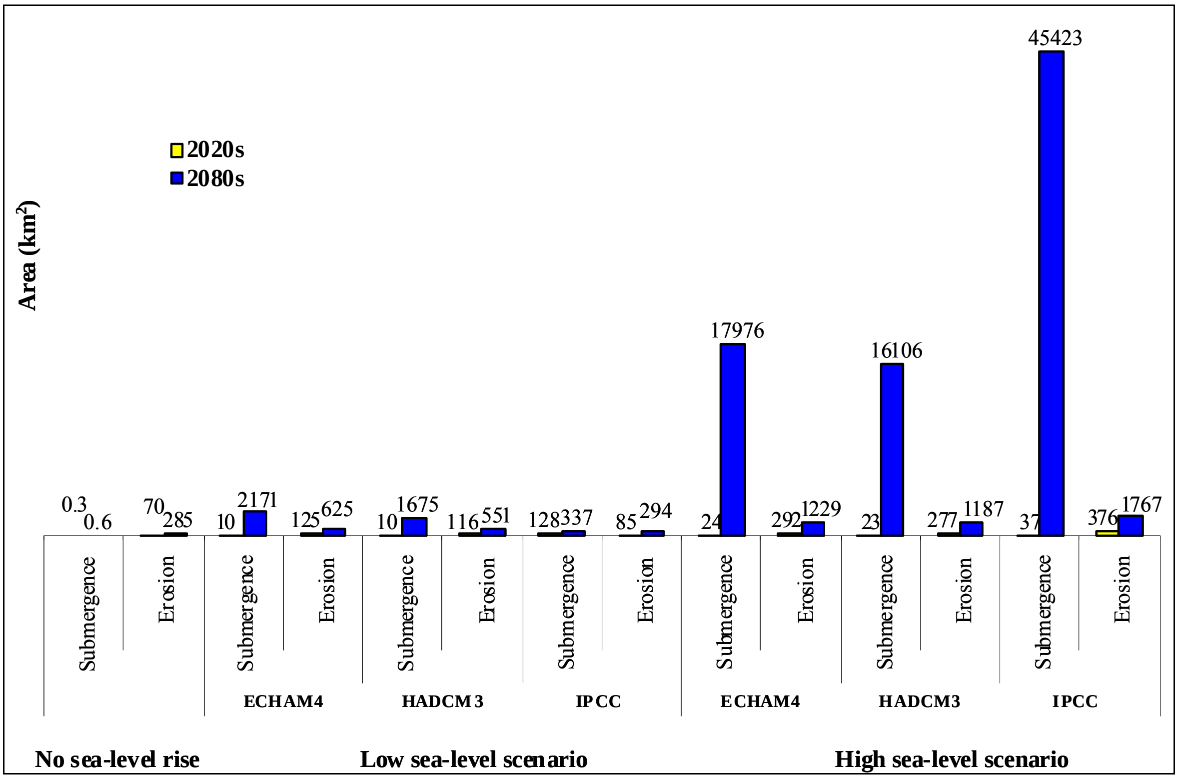
There are many sources of uncertainty that should be considered when interpreting the results. Firstly, while DIVA has greatly improved spatial resolution compared to earlier analyses, coastal data at the European scale still presents problems and hence introduces uncertainties. Secondly, the single adaptation options are a caricature of what adaptation could be as a much wider variety of measures are potentially available. However, they are well understood options and hence they provide a meaningful sense of how adaptation could reduce impacts and the costs. Thirdly, how land use will evolve to the year 2085 is not considered in the coastal study (it is assumed that the current coastal land use pattern is maintained with new coastal residents and infrastructure inflating the current pattern). Finally, the impacts will highly depend on the magnitude of sea-level rise, which on its turn will depend on many factors.

5.2 Physical impacts

Each of the sea-level rise scenarios in Table 13 were investigated for each SRES storyline. Detailed results of the coastal systems physical impact assessment appear in Richards and Nicholls (2009). The physical impacts discussed here are land loss due to submergence and erosion, and number of people actually flooded each year (Figure 14 and Figure 15, respectively).

Without adaptation, land loss increases over time and is higher for an increased rate of sea-level rise. These losses are substantially reduced with cost-benefit adaptation with annual land loss due to submergence potentially being reduced by two or three orders of magnitude (2085, high sea-level rise, both A2 and B2).

Figure 14. Coastal systems: comparison of DIVA outputs for land loss in the EU under the A2 storyline without adaptation



The number of people actually exposed to coastal flooding also increases over time and with increasing sea level if no adaptation is undertaken (Figure 15). It is clear that adaptation has a significant impact of the results for each parameter under investigation. Impacts are generally higher for the A2 storyline for all models. This is due to both the higher rates of sea-level rise and the larger increase in population used within this storyline.

Figure 15. Coastal systems: comparison of DIVA estimates of the number of people flooded in the EU with and without adaptation by 2085

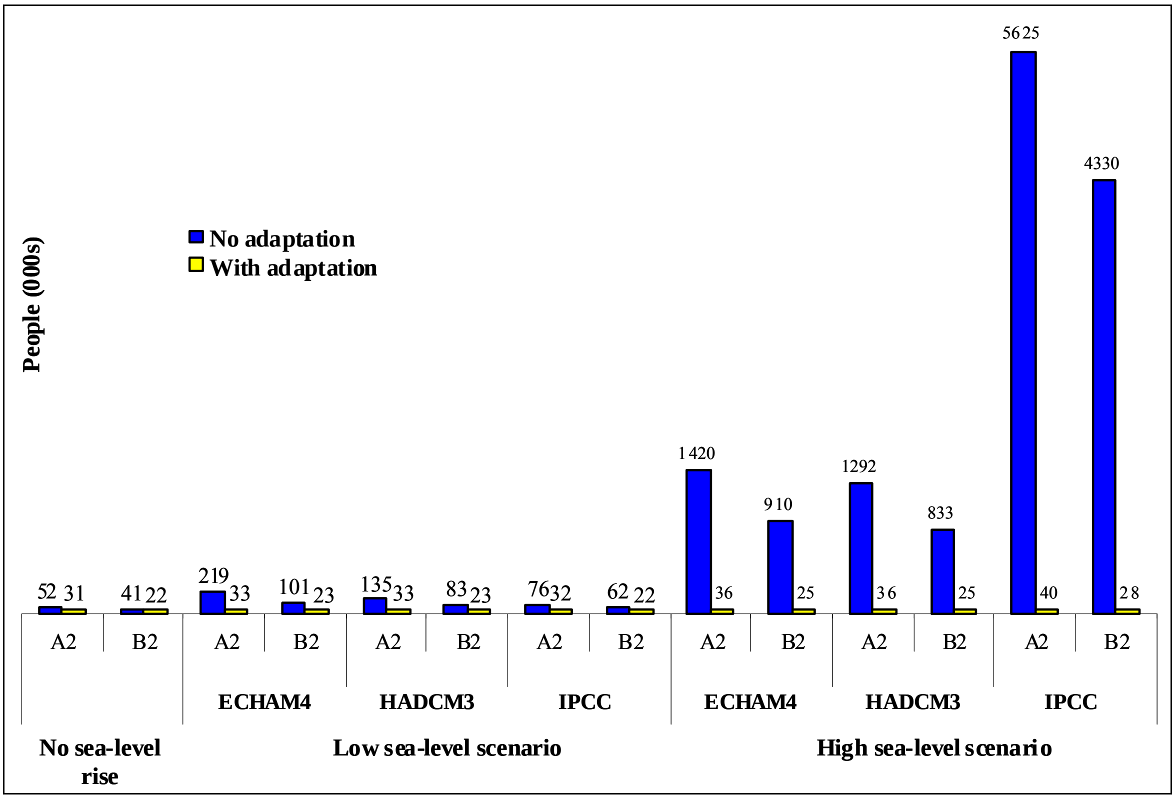


Table 14 presents the number of people flooded, additional to the model base year (1995), for the EU regions in the 2085 scenarios common to all sectoral studies, with high climate sensitivity (high SLR) and without adaptation. The table also includes in its last column the results for the highest SLR of IPCC (88 cm). These five scenarios are studied in the integration of the four market sectors of section 8. The number of people annually flooded in the EU in the reference year is estimated to be 36,000. Without adaptation, people annually flooded increases significantly in all scenarios, in the range of 775,000 to 5.5 million people. The British Isles, the Central Europe North and Southern Europe regions would the European areas potentially more affected by coastal floods.

Table 14. Coastal systems: people flooded (1000s/year) in main scenarios with high climate sensitivity, without adaptation

	B2 HadAM3h 2.5°C	A2 HadAM3h 3.9°C	B2 ECHAM4 4.1°C	A2 ECHAM4 5.4°C	A2 ECHAM4 high SLR
Northern Europe	20	40	20	56	272
British Isles	70	136	86	207	1,279
Central Europe North	345	450	347	459	2,398
Central Europe South	82	144	85	158	512
Southern Europe	258	456	313	474	1,091
EU	775	1,225	851	1,353	5,552

However, when adaptation is taken into account, the numbers of people flooded are significantly reduced and are relatively consistent across the sea-level scenarios (Figure 15). Under the A2 scenario with adaptation, the number of people actually flooded remains relatively stable over time as increased protection is offset by increasing coastal population (*i.e.* exposure). Under a B2 scenario including adaptation, the number of people flooded falls as the population is similar for the 2020s and 2080s, having peaked in the 2050s and subsequently fallen (Arnell *et al.*, 2004).

The DIVA model also produces results at more resolution than country level, NUTS2. Figure 16 shows the spatial distribution of people flooded in the base year of the model, while Figure 17 refers to the B2 scenario and Figure 18 to the A2 scenario. Regions in red indicate where coastal floods could affect more people. Under the A2 scenario (Figure 18) increases in the numbers of people flooded per year can be seen for large areas of Greece and Latvia when compared to the B2 scenario (Figure 17).

Figure 16. Coastal systems: baseline results for people actually flooded (1000s/year) across Europe

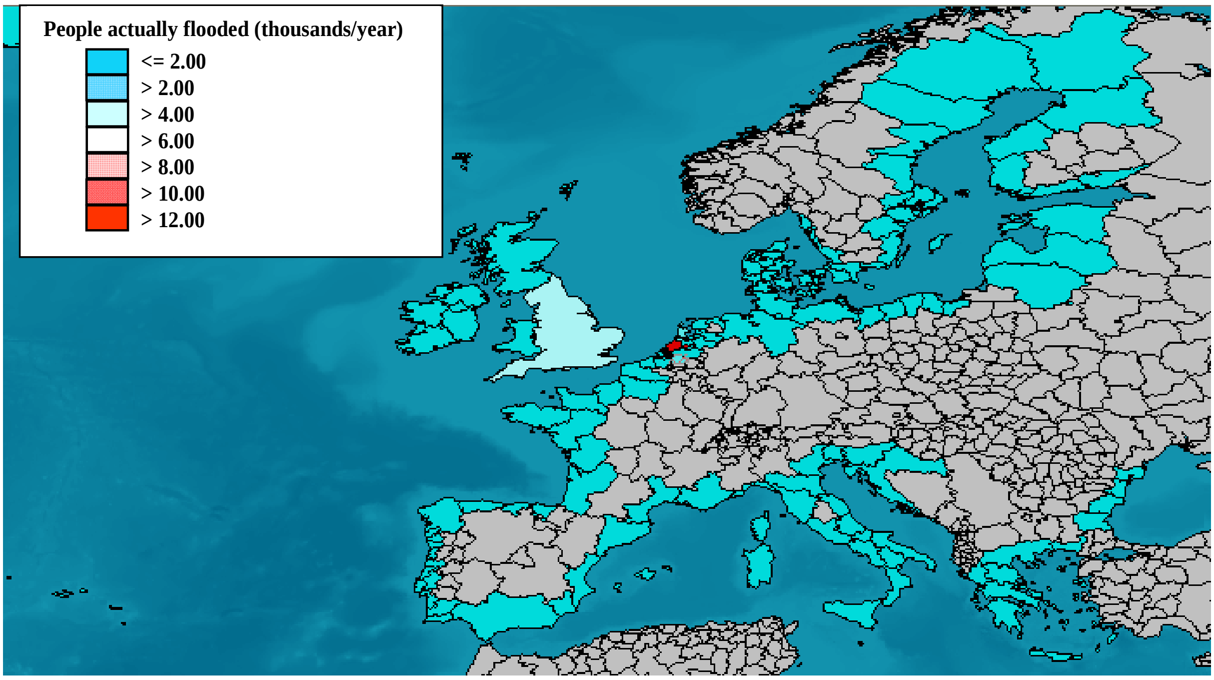


Figure 17. Coastal systems: people actually flooded (1000s/year) across Europe, for the B2 scenario, 2085 (ECHAM4; 4.1°C), without adaptation

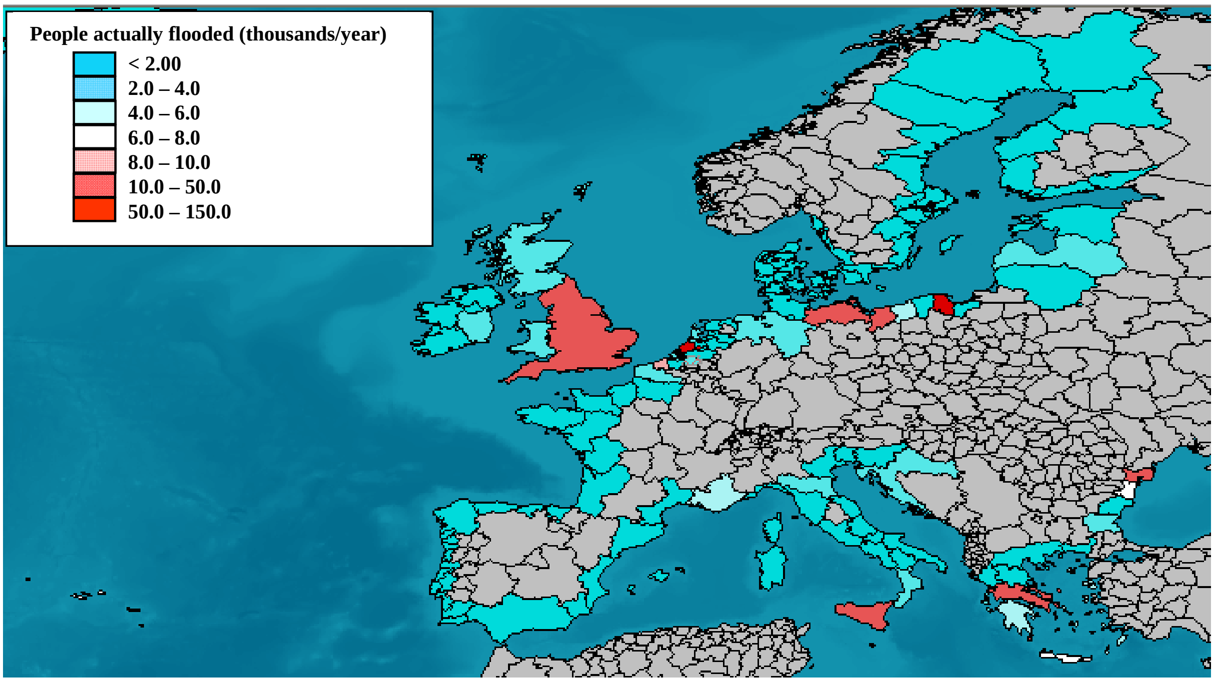
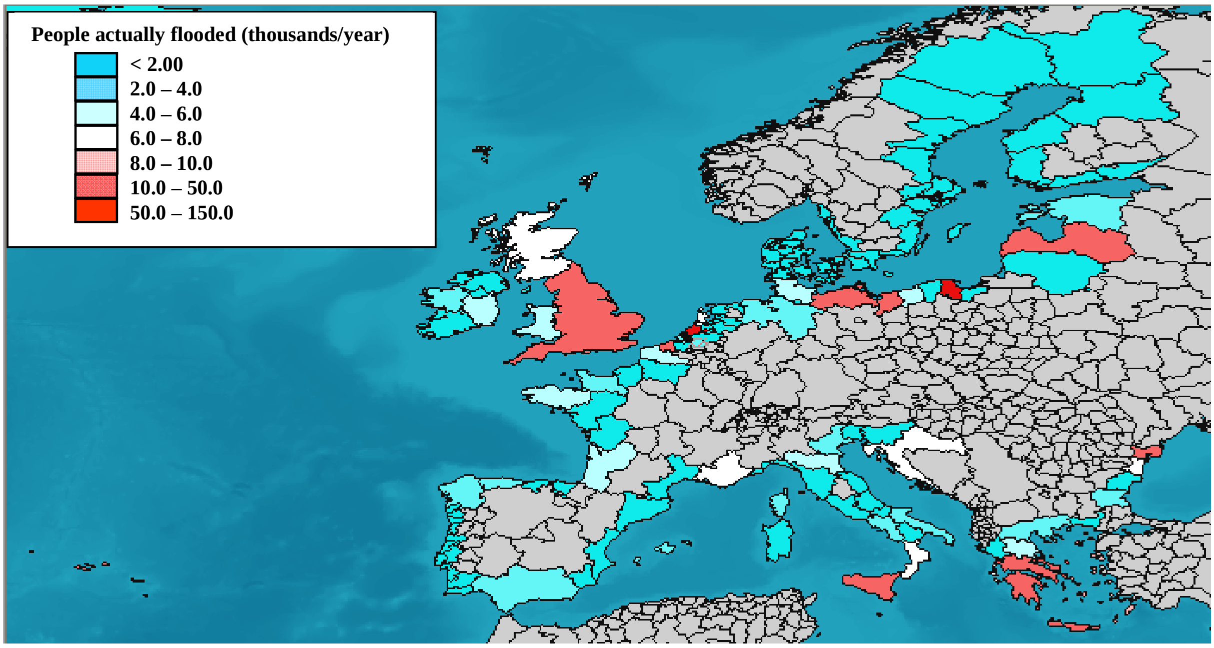


Figure 18. Coastal systems: people actually flooded (1000s/year) across Europe, for the A2 scenario, 2085 (ECHAM4, 5.4°C), without adaptation



5.3 Economic impacts

5.3.1 Direct economic effects

Table 15 and Table 16 show the range of estimates of economic damages for the 2020s and 2080s from the DIVA model with and without optimal adaptation for the low SLR and high SLR range of the IPCC TAR (9 cm and 88 cm, respectively). The tables show the three main climate cost components in coastal systems: sea floods, salinity intrusion and migration costs. The residual damage means the costs due to climate change, without considering adaptation costs. Adaptation costs include dike costs. The net benefit of adaptation is the costs without adaptation minus the residual damage and the adaptation costs.

The main results of the economic evaluation is that damage costs for the high rate of sea-level rise for 2085 are substantially higher than for a low rate of sea-level rise and both are substantially reduced if adaptation is undertaken. Costs of people migrating due to land loss through submergence and erosion are also substantially increased under a high rate of sea-level rise, assuming no adaptation, and increase over time. When optimal adaptation options are included, this displacement of people becomes a minor impact, showing the important benefit of adaptation to coastal populations under rising sea levels.

Table 15. Coastal systems: EU Aggregated Results for IPCC A2 Economic Impacts, Highest Sea-level Rise (million €/year) (1995 values)

Adaptation Scenario	Time slice	Total residual damage costs	Sea Flood Costs	Salinity Intrusion Costs	Migration (due to land loss) costs	Adaptation Costs	Sea dike costs	Net Benefit of Adaptation
	1995	**1756.4**	1159.6	588.3	0	**0**	0	**-**
No Adaptation	2020s	**6636.8**	6020.4	607.5	0.3	**0**	0	**-**
	2080s	**44605.6**	18242.5	1053.3	25242.6	**0**	0	**-**
Optimal Adaptation	2020s	**1727.2**	1116.1	607.5	0.2	**1013.4**	628.3	**3896.2**
	2080s	**2241.6**	1159.3	1053.3	20.1	**2607.8**	1356.9	**39756.2**

Table 16. Coastal systems: EU Aggregated Results for IPCC B2 Economic Impacts, Lowest Sea-level Rise (million €/year) (1995 values)

Adaptation Scenario	Time slice	Total residual damage costs	Sea Flood Costs	Salinity Intrusion Costs	Migration (due to land loss) costs	Adaptation Costs	Sea dike costs	Net Benefit of Adaptation
	1995	**1756.4**	1159.6	588.3	0	**0**	0	**-**
No Adaptation	2020s	**5020.4**	4426.9	589.3	0	**0**	0	**-**
	2080s	**10315.5**	9477.0	823.5	2.5	**0**	0	**-**
Optimal Adaptation	2020s	**1223.6**	633.2	589.3	0	**304.6**	246.4	**3492.2**
	2080s	**841.0**	14.0	823.5	2.5	**271.4**	153.5	**9203.1**

5.3.2 Overall (general equilibrium) economic effects

The general equilibrium effects of the SLR in coastal systems have been analysed with the GTAP computable general equilibrium (CGE) model, the same model used in the agriculture economic assessment (Section 3.3). The methodology applied in the coastal systems is described in Bosello *et al.* (2007). A comparative static framework has been followed, comparing the “without SLR” future scenario, where the model is re-calibrated to the year 2085, and the SLR scenarios. The economic interactions of the EU with the “rest of the world” have been taken into account. Therefore, as in the agriculture CGE analysis, the impact of future climate in the future economy (as of the 2080s) has been studied.

Compared to the methodology applied in the integration of all market impact categories within the GEM-E3 Europe model (Section 8), there are two main differences. Firstly, with the GEM-E3 assessment only the effect due to climate change is considered, without taking into account the influence of economic growth and population dynamics. Secondly, in the coastal assessment with the GEM-E3 model the impacts considered relate to migration costs and sea flood costs, while in the study with the GTAP model the impact considered is land loss.

The GTAP CGE model considers four sectors, 25 European States and the Rest of the World (Table 17). The land lost estimated by the DIVA model is introduced in the GTAP model, as this model considers land as a productive factor, in addition to labour and capital. In the optimal adaptation case the land loss would be lower, but there would be an additional investment in building dikes and beach nourishment, the two adaptation strategies considered in the DIVA model. Such investments would be carried out by the public sector.

Table 17. Coastal systems: industrial disaggregation of the CGE model

Agriculture & Food
Heavy industries and Energy sectors
Light Industry
Services

Table 18 and Table 19 present for the five EU regions of the PESETA study the main results of the simulations in the no adaptation and optimal adaptation cases, respectively. The first three columns of Table 18 present the land losses as percentage of the total surface in the region, its economic valuation, and the economic valuation as a share of GDP. The land loss as percentage of the region total is estimated to range between 0.2% of Northern Europe and 1.5% in the British Isles. For most regions, the effect of the loss of land is a minor fall in GDP, as there is less land for productive uses in the economy. For the Central Europe South region, there would be a GDP gain, mainly explained by international capital and trade flows (see Bosello *et al.*, 2007).

If the value of land loss as a share of GDP (direct cost) is compared to the overall GDP change in the economy, it is interesting to note that in three regions GDP losses are higher than the direct costs. Moreover, the ranking of losing regions according to the direct costs is changed in the final GDP effect ranking. This highlights the importance of considering such indirect effects via a general equilibrium analysis, because substitution effects across sectors and markets, and international trade play a key role.

Table 18. Coastal systems: A2 Scenario, High Sea-level Rise 2085. Main Macroeconomic Effects (no adaptation)

	Land losses			GDP (*)	Investment (*)
	% of region total	Value (Million $)	Value (% of GDP)		
Northern Europe	-0.237	47.78	0.0025	-0.0004	0.237
British Isles	-1.513	181.73	0.0032	-0.0045	0.249
Central Europe North	-0.917	899.67	0.0083	-0.0049	0.191
Central Europe South	-0.320	111.61	0.0018	0.0027	0.227
Southern Europe	-0.783	307.42	0.0044	-0.0051	0.232
Europe	**-0.657**	**1,548.21**	**0.0049**	**-0.0031**	**0.220**

(*) Values expressed as % changes with respect to A2 2085 baseline

In the optimal adaptation scenario (Table 19) the shock is smaller because there is additional demand in the economy due to the public investment in dikes and beach nourishment. In absolute terms, optimal coastal defence can be extremely costly. For example, the UK spends a total of US$ 44.5 billion (undiscounted) over the period 2001 to 2085, which is the highest expenditure in the EU. However, on an annual basis, and compared to national GDP, these costs are quite small. In this case the highest value is represented by the 0.04% of GDP in Northern Europe.

As the extra investment is financed with savings, there is less private consumption, and therefore lower welfare levels. The impact on regional GDP is mixed, with Northern Europe with gains, while the rest of regions lose slightly. These outcomes depend on the interplay between the initial land loss, the additional investment demand and the decrease and re-composition of private consumption demand. The regions that gain attract relatively higher additional investment, benefit from terms of trade improvements and usually experience a smaller contraction of private consumption. The role of consumption in sustaining GDP is quite important.

Table 19. Coastal systems: A2 Scenario, High Sea-level Rise, 2085. Main Macroeconomic Effects (optimal adaptation)

	Land losses (% of region total)	Coastal Protection Expenditure (% of GDP)	Investment (induced by coastal protection)	GDP
Northern Europe	-0.046	0.040	18.647	0.057
British Isles	-0.006	0.015	7.784	-0.021
Central Europe North	-0.038	0.011	4.685	-0.069
Central Europe South	-0.007	0.007	3.384	-0.126
Southern Europe	-0.015	0.010	4.016	-0.062
Europe	**-0.026**	**0.012**	**5.542**	**-0.062**

All values expressed as % changes with respect to A2 2085 baseline except coastal protection expenditure in % of GDP

6 TOURISM ASSESSMENT

Tourism is a major economic sector in Europe, with the current annual flow of tourists from Northern to Southern Europe accounting for one in every six tourist arrivals in the world (Mather *et al.*, 2005). Climate change has the potential to radically alter tourism patterns in Europe by inducing changes in destinations and seasonal demand structure (Scott *et al.*, 2008).

This chapter summarises the methodology and the main results of the study on the impact of climate change in tourism in Europe. Detailed information can be found in the accompanying PESETA technical report Amelung and Moreno (2009).

6.1 Tourism impact methodology

6.1.1 The modelling approach

The final aim of the endeavour was to model tourist activity, to estimate the role of climate, and to explore the effects of climate change. The changes in visitation patterns were explored in two steps. First a visitation model was estimated, based on historical data. Subsequently, the baseline and future scenarios were simulated. The historical visitation model was developed using regression techniques.

The tourism study aims at modelling the major outdoor international tourism flows within Europe. The study improves on earlier work because it integrates the climate component of tourist activity with the economic analysis of tourist demand flows. Furthermore, it is the first study to consider seasonality effects in a tourist regional demand model, a time dimension relevant to the modelling of aggregated tourist flows.

Regarding the economic analysis of tourism demand, a tourism bed night equation with regional and seasonal resolution has been statistically estimated with price levels, income, fixed seasonal effects and a climate index as explanatory variables. Concerning the climate side, the influence of the climate has been explicitly considered by having the tourism climatic index (TCI) in the demand equation. The index is developed primarily for general outdoor activities by Mieczkoswki (1985), and therefore this assessment excludes winter sports. TCI is based on the notion of 'human comfort' and consists of a weighted index of maximum and mean daily temperature, humidity, precipitation, sunshine and wind. The index was calculated for all NUTS2 regions for Europe and thus provides at high-resolution input values for the estimations.

The impact of climate change on bed nights has been simulated with the estimated demand equation changing the TCI index according to the climate scenarios, while the rest of the exogenous variables of the model remain constant. The bed nights changes are interpreted as the physical impacts of climate change. The economic impact of climate change has been estimated taking into account the EU average expenditure data per bed night.

Regarding adaptation, it is important to note that the strategies chosen by the tourism industry and the tourists themselves to adapt to climate change are likely to determine the economic impacts to a large extent (Amelung *et al.*, 2007; Amelung and Viner, 2006). Public adaptation has not been explicitly modelled in this assessment.

6.1.2 Limitations and uncertainties

The results presented must be treated with great care, as the uncertainties are very large. The predictive value of the models is not very large, suggesting that important determinants may be missing. Among other things, no institutional variables were included as no suitable data were available, although summer holidays and other institutional rigidities are known to have a significant effect on holiday patterns. The same goes for distance and travel costs. As no origin-destination flows of tourists could be established, attention was focused on the destination side, leaving the generation of tourists in the regions of origin unexplained, and the distances travelled unaccounted for.

In addition to the missing variables, the quality of the data used is sometimes uncertain. Different countries may use different methods for collecting statistics and aggregating them, and may have different levels of participation by the side of the tourist industry. For example, there were very large differences between the average receipts per tourist night, which could not be explained by the differences in price levels and wealth between countries.

Importantly, this study has only considered spatial and temporal adaptation by tourists, ignoring other options available to tourists (*e.g.* staying inside), and adaptation options available to the tourist industry and other stakeholders. Tourism businesses and destinations may try to reduce their vulnerability to climate change by offering a diverse set of holiday activities, by trying to develop all-year tourism, by developing less climate-dependent types of tourism, or by taking technical measures such as installing air conditioning. None of these adaptation options have been taken into account, as there are currently no methods available to model their effects. Because of this omission, the impacts of climate change on tourism in Europe may well have been overestimated.

6.2 Physical impacts

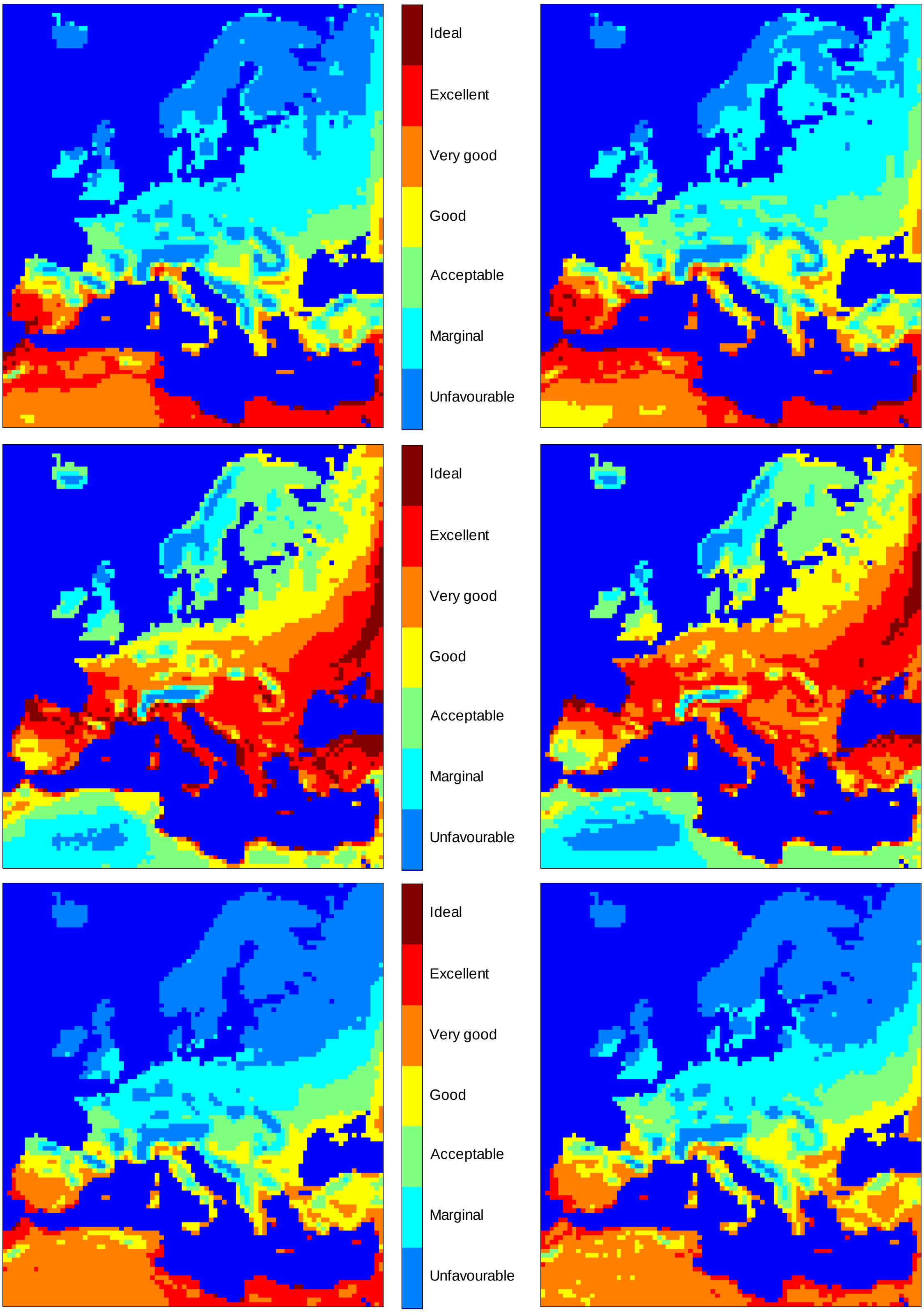
There are two kinds of physical impact that can be derived from the proposed methodology. Firstly, the climate data have been used to compute the TCI index in all scenarios. The average of the TCI index for each season and climate future scenario has been compared with the respective values of the index in the control period (1961-1990). Such comparison provides with insights on the possible changes in the climatic suitability for general summer tourism. Sections 6.2.1and 6.2.2 discuss the results for the 2020s and 2080s periods, respectively.

However, climatic suitability is only one of the influences on tourism patterns. Other crucial aspects should be considered in order to produce estimates of how tourist flows could change in the future, notably the income levels of the tourists and the prices of the tourist services. Applying the simulated TCI values in the scenarios to the estimated tourist demand equation, the simulated changes in bed nights can be computed, while keeping the other determinants of demand constant. Section 6.2.3 deals with the results in terms of bed nights changes.

6.2.1 Changes in Tourism Climate Index between the 1970s and the 2020s

Although changes between the baseline ('1970s') and the 2020s are modest, certain trends are becoming visible. In all three seasons (winter is disregarded, because conditions remain unfavourable in almost the whole of Europe), there is a poleward trend in TCI patterns (Figure 19). In spring and autumn, these changes are small, but they are positive in most areas of Europe. Changes are most significant in the Mediterranean region, where the area with very good to ideal conditions increases. In more northern regions, conditions improve but remain acceptable at best. In summer, changes are mixed. In the interior of Spain and Turkey, in parts of Italy and Greece, and in the Balkans, conditions deteriorate. In the northern and western parts of Europe, however, TCI scores increase.

Figure 19. Tourism: TCI scores in spring (top), summer (middle) and autumn (bottom) in the 1970s (left) and the 2020s (right) according to the Rossby Centre RCA3 model



6.2.2 Changes in Tourism Climate Index between the 1970s and the 2080s

By the end of the 21st century, the distribution of climatic resources in Europe is projected to change significantly. All four model-scenario combinations agree on this, but the magnitude of the change and the evaluation of the initial conditions differ.

For the spring season (Figure 20 and Figure 21), all climate model results show a clear extension towards the North of the zone with good conditions, with also better conditions in the South. Compared to the RCAO model (Figure 21), the Hirham model projects relatively modest changes, in accordance with the projected warming trends in the EU. In the 3.9°C scenario, spring conditions would have become very good to excellent in most of the Mediterranean by the end of the century. Good conditions are projected to be more frequent in France and the Balkans. The same tendency is visible in the 2.5°C scenario, albeit at a slower pace.

Figure 20. Tourism: TCI scores in spring in the 1970s (left) and the 2080s (right), according to the HIRHAM model, 3.9°C scenario (top) and 2.5°C scenario (bottom)

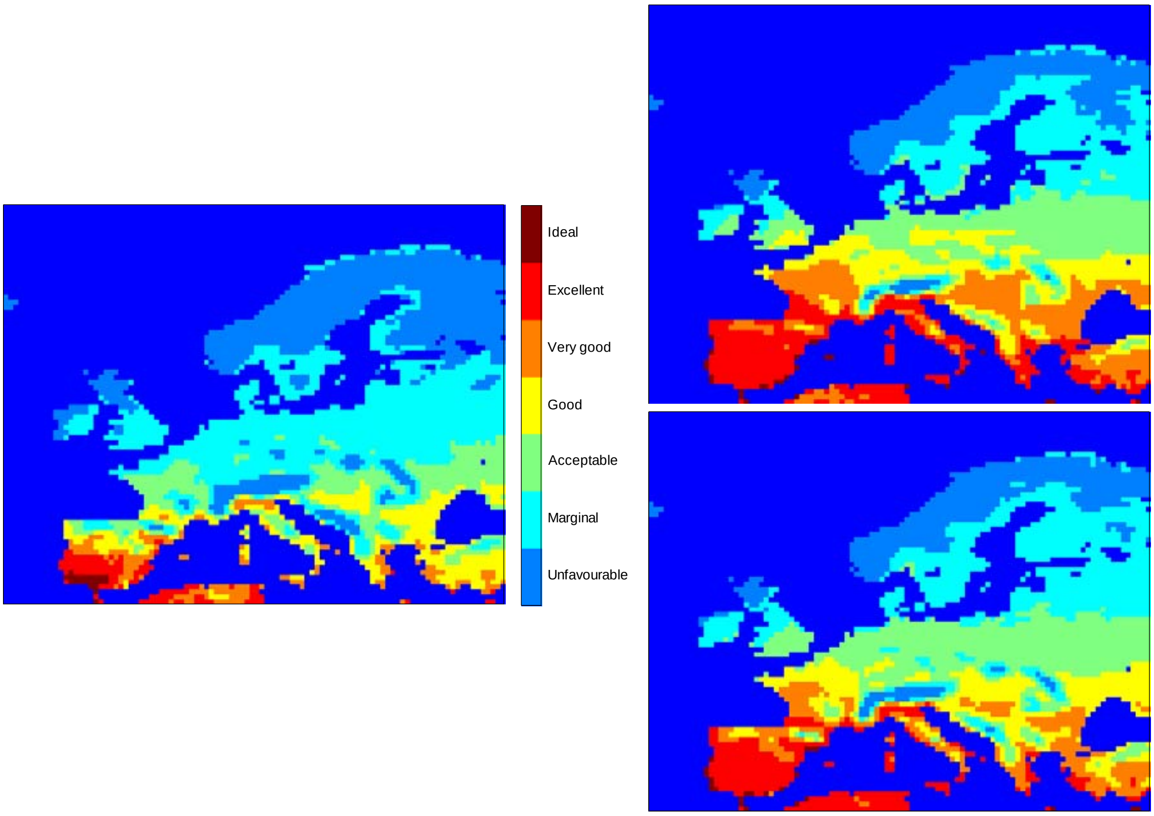


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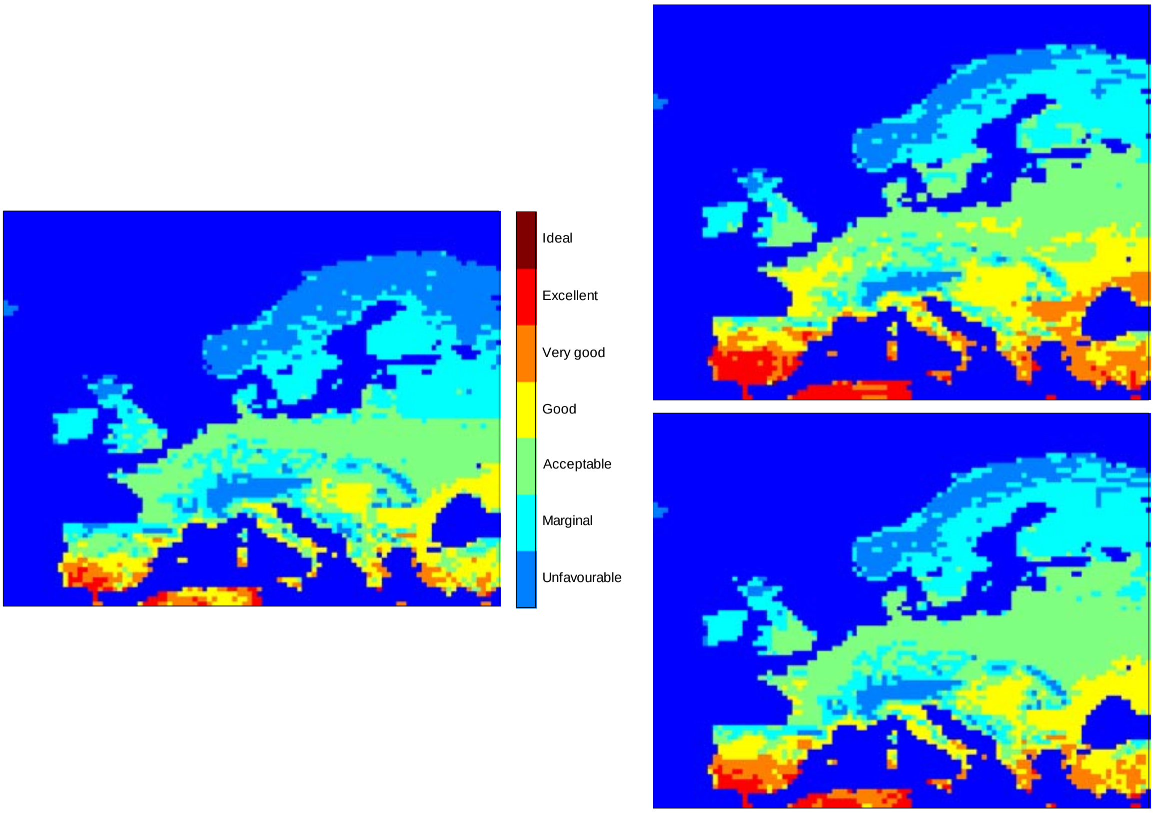
Figure 21. Tourism: TCI scores in spring in the 1970s (left) and the 2080s (right), according to the RCAO model, 5.4°C scenario (top) and 4.1°C scenario (bottom)



The direction of change in the RCAO model runs (4.1°C and 5.4°C scenarios) is similar, but its magnitude is much larger. Excellent conditions, which are mainly found in Spain in the baseline period, would have spread across most of the Mediterranean coastal areas by the 2080s. In the northern part of continental Europe, conditions improve markedly as well, from being marginal to good and even very good.

In summer (Figure 22 and Figure 23), the zone of good conditions also expands towards the North, but this time at the expense of the South, where climate conditions deteriorate. In the HIRHAM models (2.5°C and 3.9°C scenarios) conditions would become excellent throughout the northern part of continental Europe, as well as in Finland, southern Scandinavia, southern England and along the eastern Adriatic coast. In parts of Spain, Italy, Greece, and Turkey, TCI scores in summer go down by tens of points, sometimes dropping from excellent or ideal (TCI>80) conditions to marginal conditions (TCI between 40 and 50).

Figure 22. Tourism: TCI scores in summer in the 1970s (left) and the 2080s (right), according to the HIRHAM model, 3.9°C scenario (top) and 2.5°C scenario (bottom)

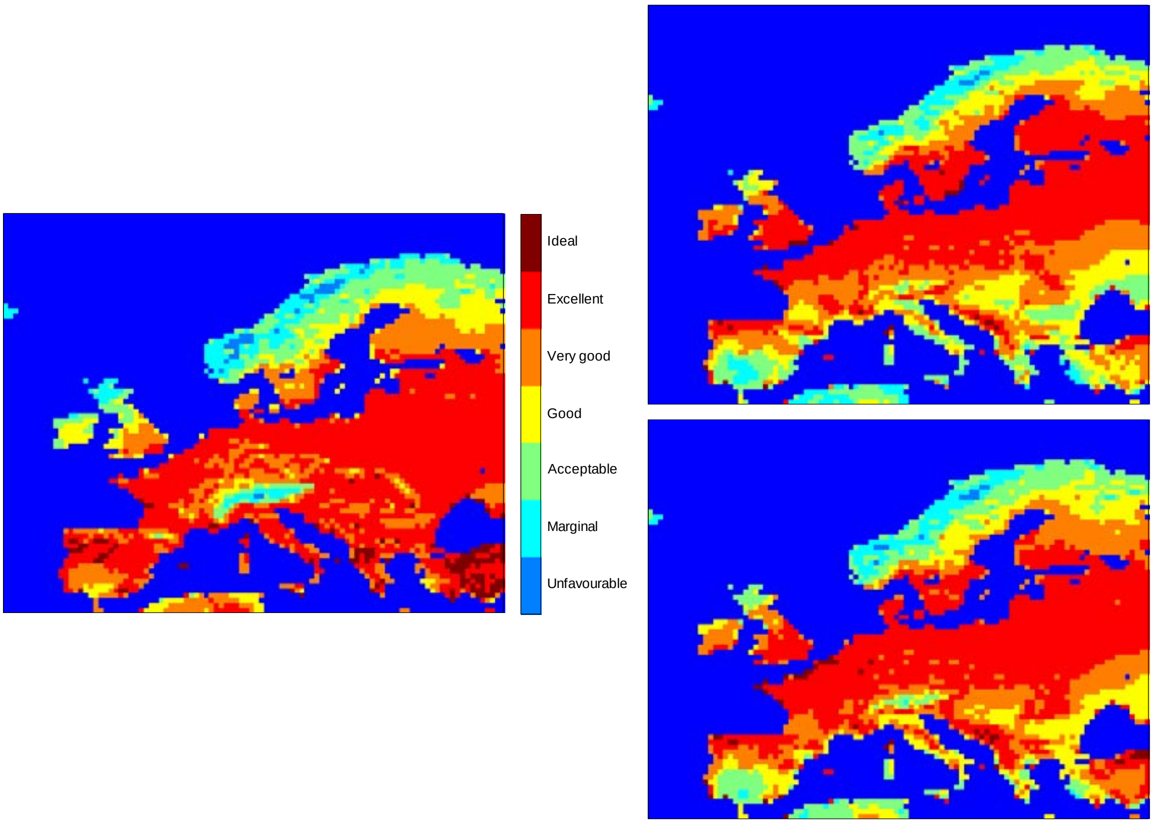


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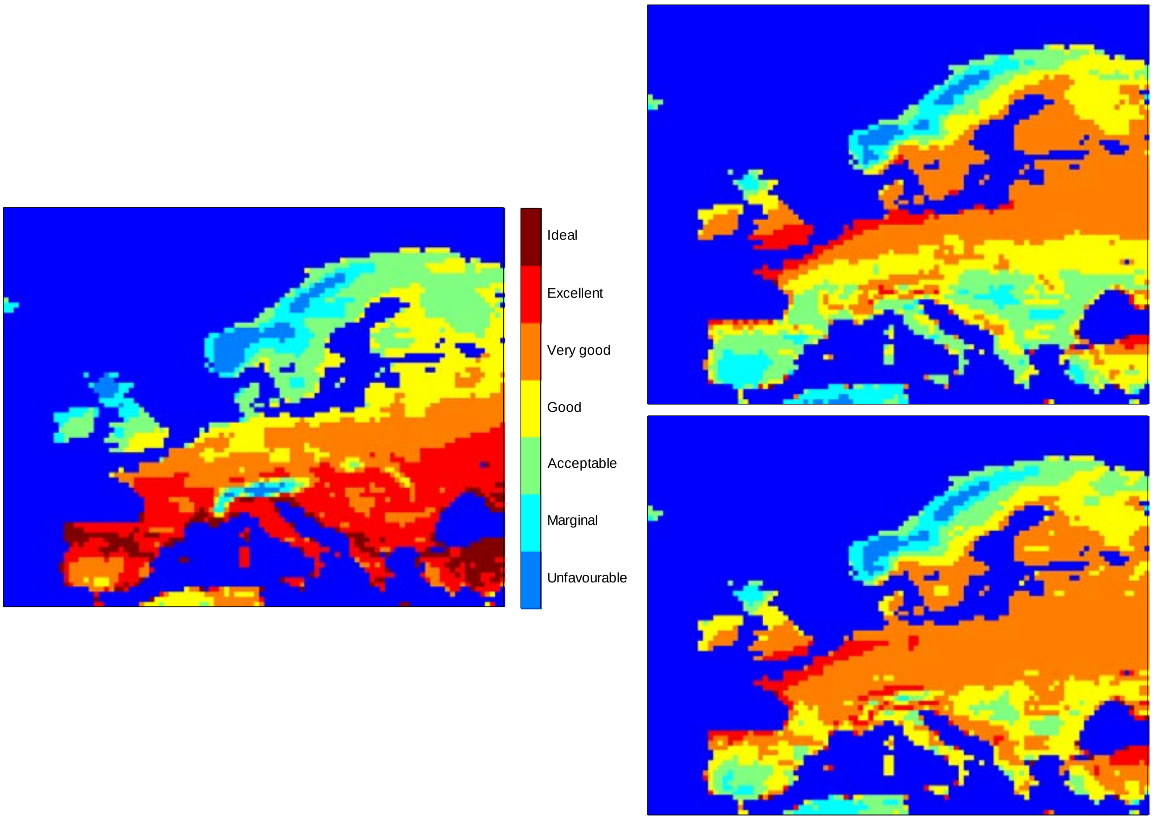
Figure 23. Tourism: TCI scores in summer in the 1970s (left) and the 2080s (right), according to the RCAO model, 5.4°C scenario (top) and 4.1°C scenario (bottom)



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Such summertime falls in the TCI index are even larger, and more extensive geographically in the RCAO model runs (4.1°C and 5.4°C scenarios). In the 4.1°C scenario, much of the Mediterranean, and in the 5.4°C scenario even much of the southern half of Europe loses dozens of TCI points, ending up in the marginal-good range, down from the very good-ideal range the region was in during the 1970s. Interestingly, according to the RCAO model, the changes are so quick that the belt of optimal conditions would move from the Mediterranean all the way up to the northern coasts of the European continent and beyond. In the 5.4°C scenario, excellent conditions can only be found in a very narrow coastal area, stretching from the North of France to Belgium and the Netherlands, and in some coastal areas in Poland. According to these results, the improvement in conditions in the northern half of Europe may be short-lived, although the UK and Scandinavia may have more time to benefit.

Changes in autumn (Figure 24 and Figure 25) are more or less comparable to the ones in spring. TCI scores improve throughout Europe, with excellent conditions covering a larger part of southern Europe and the Balkans. TCI scores in the northern parts of Europe remain lower than in the South, but the improvements are significant. Large areas attain good conditions (in the HIRHAM model, up from acceptable ones) or acceptable conditions (in the RCAO model, up from marginal ones).

Figure 24. Tourism: TCI scores in autumn in the 1970s (left) and the 2080s (right), according to the HIRHAM model, 3.9°C scenario (top) and 2.5°C scenario (bottom)

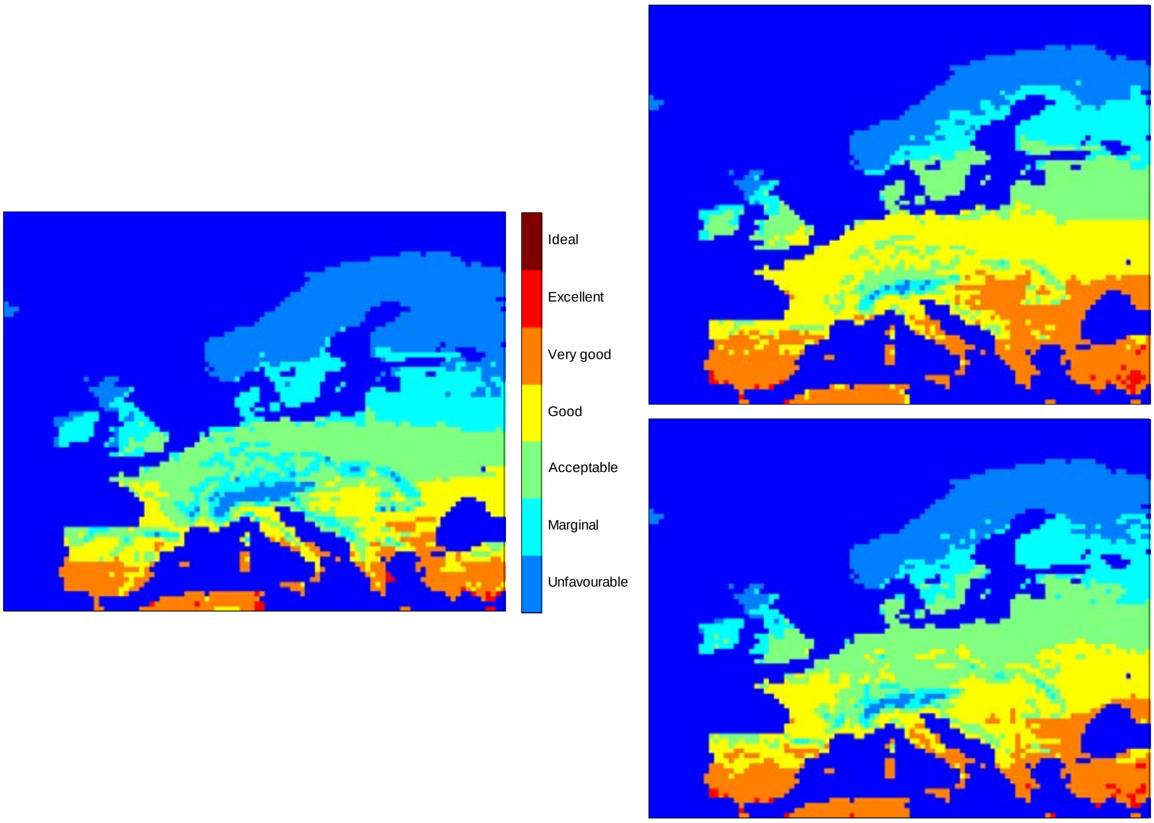

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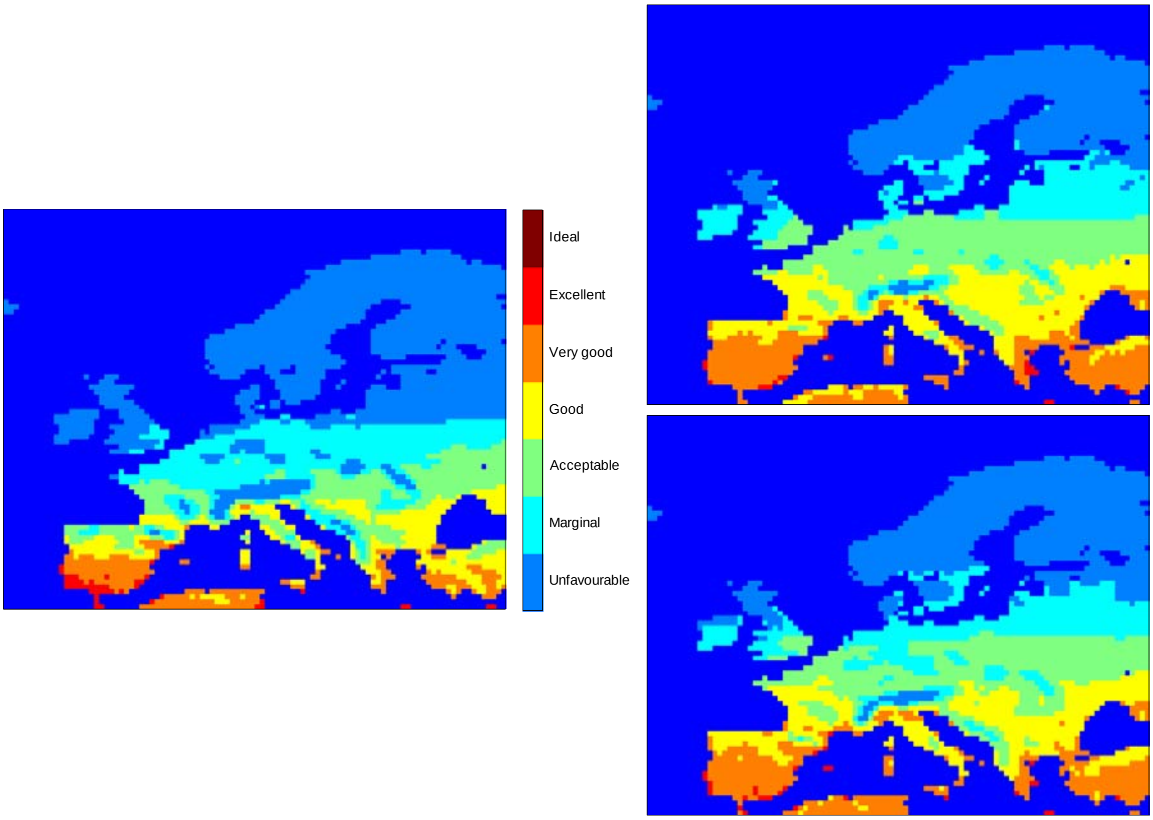
Figure 25. Tourism: TCI scores in autumn in the 1970s (left) and the 2080s (right), according to the RCAO model, 5.4°C scenario (top) and 4.1°C scenario (bottom)



Projected changes in winter (Figure 26 and Figure 27) are of much less interest than the changes in other seasons, as most of Europe is and would remain unattractive for general tourism purposes (note that winter sports are not considered in the study) in winter. There are some changes, however, in the southern-most areas in Europe. In particular in the South of Spain, conditions are projected to improve from being unfavourable to marginal or even acceptable.

Figure 26. Tourism: TCI scores in winter in the 1970s (left) and the 2080s (right), according to the HIRHAM model, 3.9°C scenario (top) and 2.5°C scenario (bottom)

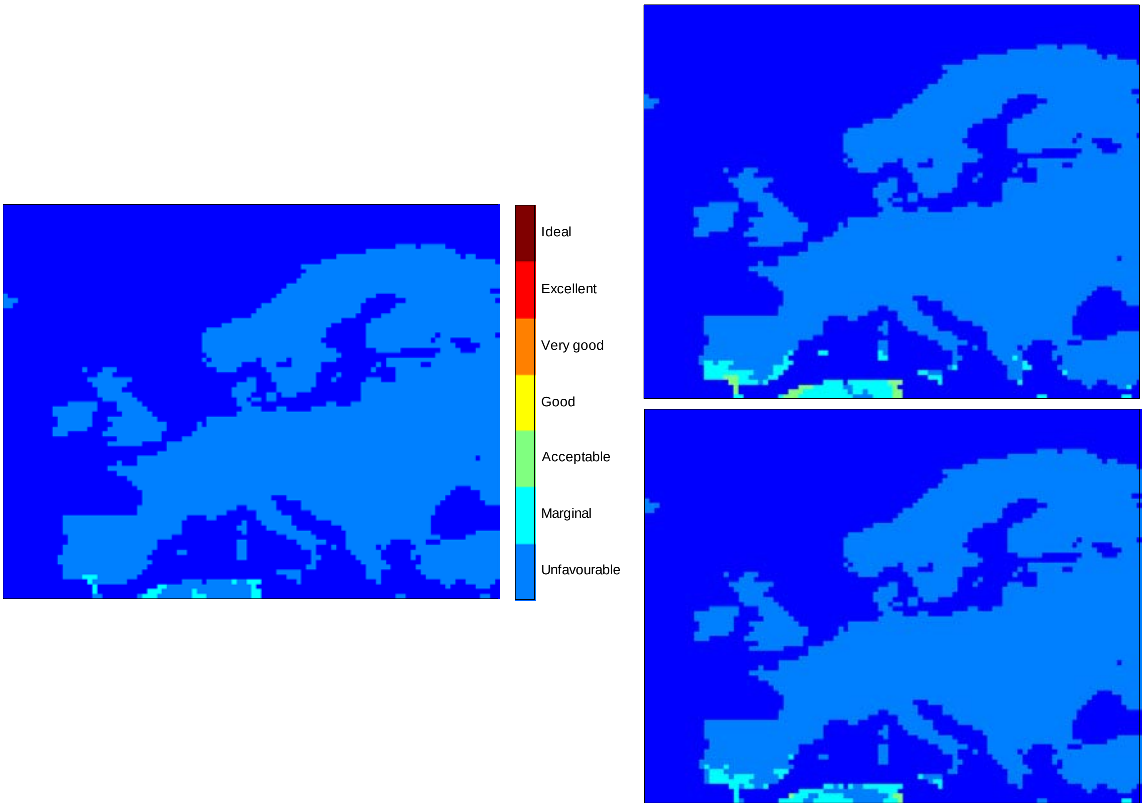
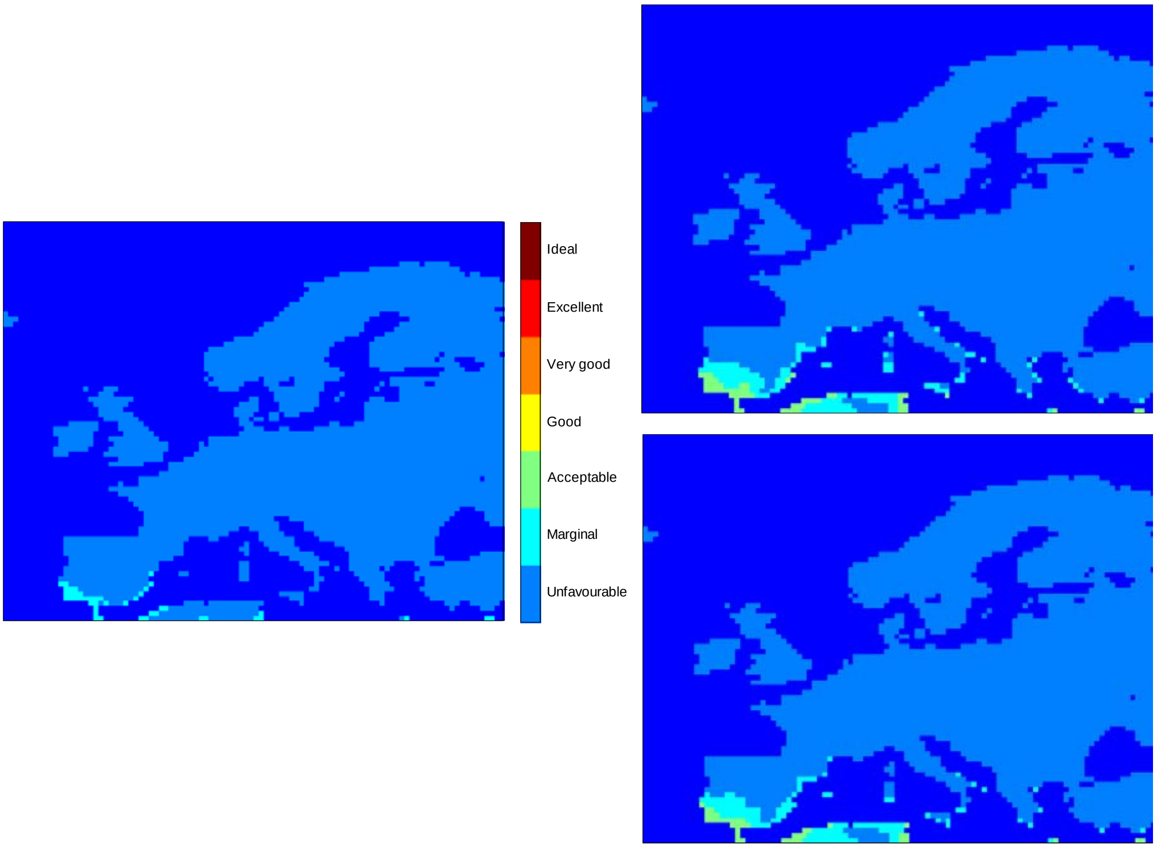


Figure 27. Tourism: TCI scores in winter in the 1970s (left) and the 2080s (right), according to the RCAO model, 5.4°C scenario (top) and 4.1°C scenario (bottom)



The changes that have been discussed above have significant changes for the length of the 'holiday season' (in a climatic sense) in Europe. This season length is defined here as the number of months with very good conditions (TCI>70), as described above. Currently, southern Europe has significantly more good months than northern Europe. Under the influence of climate change, this is projected to change, however. In both the HIRHAM and the RCAO model (Figure 28 and Figure 29), season length would become much more evenly distributed across Europe. The dominant trend in southern Europe is a decrease in good months in summer, whereas in northern Europe there would be an increase in good months in summer, spring and autumn. Interestingly, a coastal strip in southern Spain and Portugal is projected to maintain or even increase (3.9°C scenario) its current season length.

Figure 28. Tourism: Average number of months per year with very good conditions or better (TCI>70), in the 1970s (left) and the 2080s (right), according to the 3.9°C scenario (top) and 2.5°C scenario (bottom)

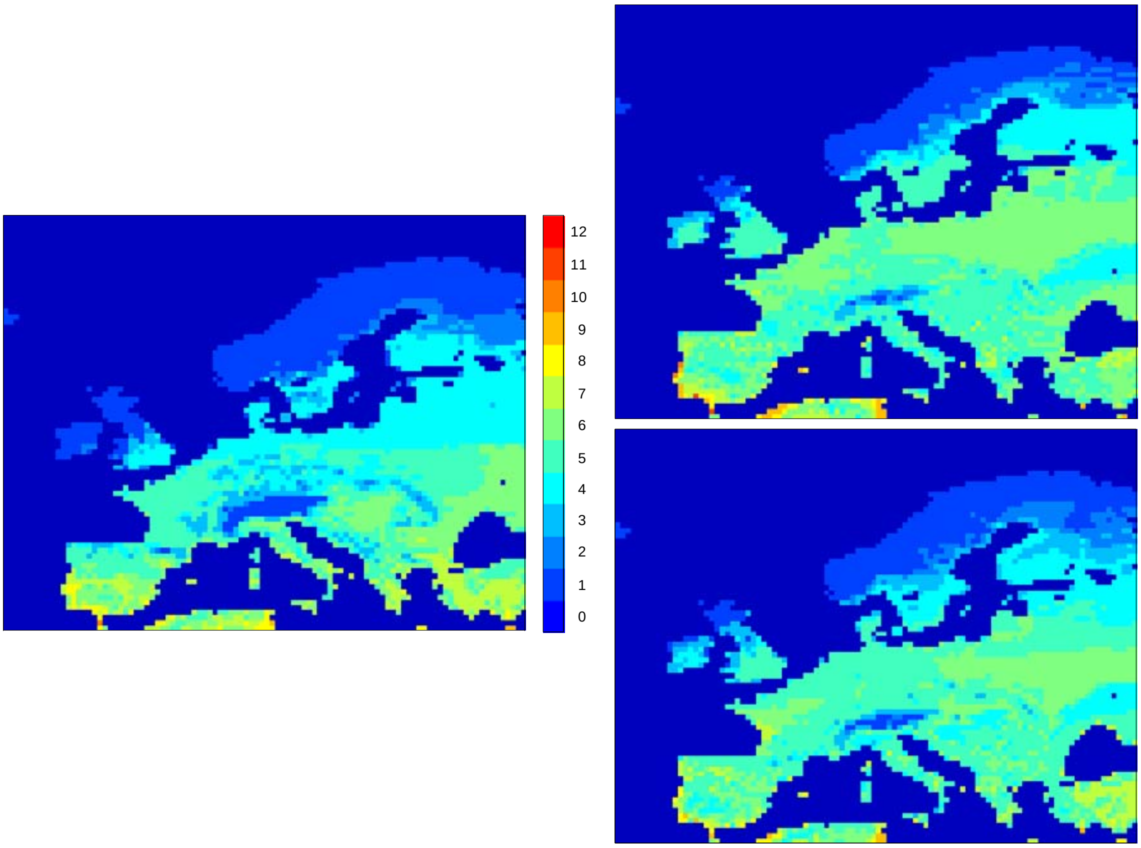
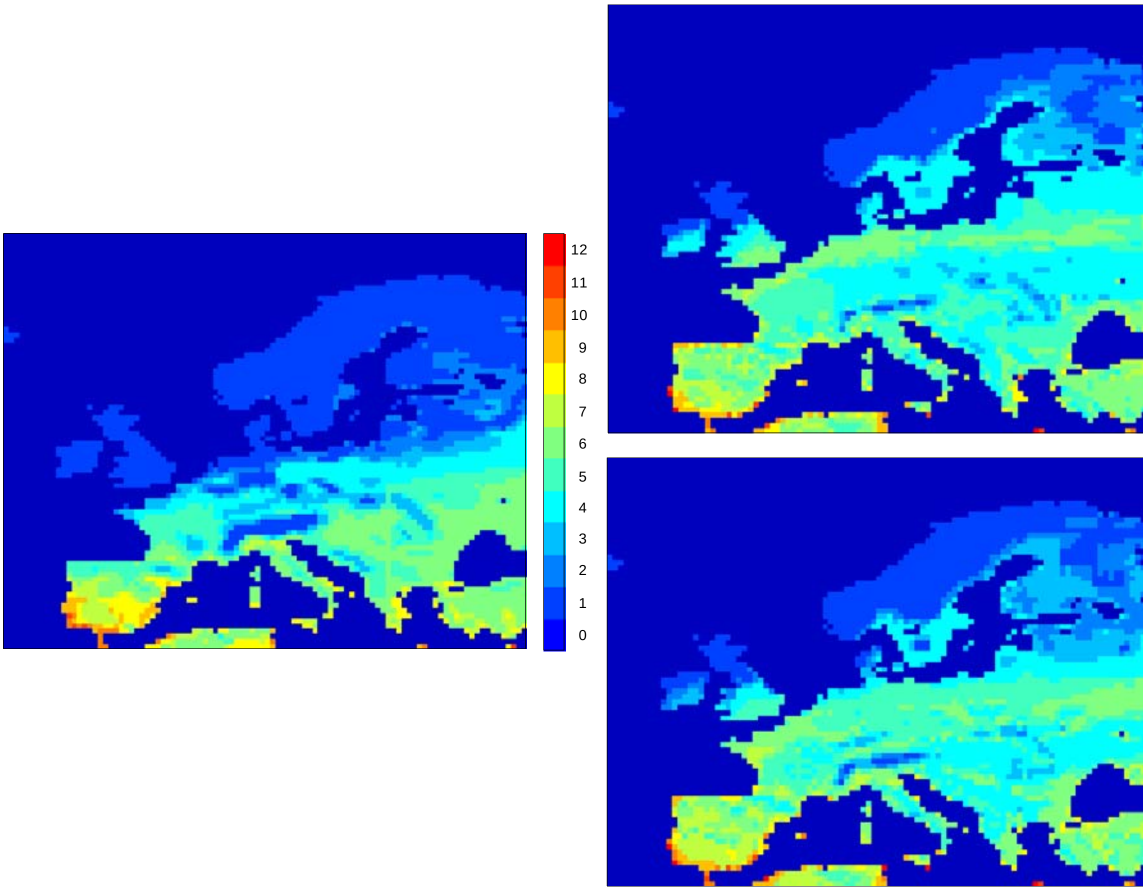


Figure 29. Tourism: Average number of months per year with very good conditions or better (TCI>70), in the 1970s (left) and the 2080s (right), according to the RCAO model, 5.4°C scenario (top) and 4.1°C scenario (bottom)



6.2.3 Changes in bed nights in the 2080s

Climate change would induce better conditions for most regions, resulting in more bed nights with a relatively small EU-wide positive impact (Table 20). Southern Europe, which currently accounts for more than half of the total EU capacity of tourist accommodation, would be the only region with a decline in bed nights, estimated to be in a range between 1% and 4%, depending on the climate scenario. The rest of Europe is projected to have large increases in bed nights, in a range of 15% to 25% for the two warmest scenarios.

Table 20. Tourism: simulated changes in bed nights in the 2080s (compared to the 1970s) and 2005 bed nights

	Change (%) in bed nights				Bed nights 2005
	B2 HadAM3h 2.5°C	A2 HadAM3h 3.9°C	B2 ECHAM4 4.1°C	A2 ECHAM4 5.4°C	
Northern Europe	4	6	20	25	30
British Isles	3	4	14	18	100
Central Europe North	2	3	13	16	100
Central Europe South	2	3	14	17	219
Southern Europe	-1	-1	-2	-4	428
EU	1	1	6	7	878

6.3 Economic impacts

The changes in bed nights can be converted into changes in tourist expenditures using a value for expenditure per bed night across EU countries. The calculation was based on the European average tourism receipt per night, because the country-based values could be biased by the different reporting methods of the various countries.

Two different cases have been assessed in addition to the central case as simulated with the estimated demand equation. In the central case total EU tourist demand can change, as well as the seasonal distribution of demand. This case is called 'flexible overall EU and seasonal demand'. In a first variant the total annual demand in terms of bed nights for the EU remains constant. In this way, as demand model does not pay attention to the generation of tourists in the countries of origin, it could be the case that there is an overestimation of overall tourist demand, which would be corrected by fixing the overall EU demand in the 2080s to that of the 1970s. This case sheds some light on the effects of relative consequences within Europe in the climate as expressed by the TCI scores. Tourists are thus assumed to be fully flexible, and not bound by any institutional or other constraints that would limit their temporal ‘window of opportunity’. The phenomenon of ageing in Europe may give this assumption some credibility, as elderly people tend to have more temporal flexibility than younger people in their working lives. This case is called 'fixed overall demand with seasonal flexibility'.

In the second variant, the assumption of full seasonal flexibility is discarded. In this case, not only the total number of bed nights is considered to be fixed, but also the monthly number of bed nights. In other words, the seasonal distribution of bed night volumes is kept constant. This case allows for the assessment of a scenario in which institutional constraints remain firmly in place. Traditionally, school holidays have been important in the holiday planning of many families. Other sectors, such as the construction sector in some countries, can also have periods of forced leave. While such institutional and cultural arrangements are subject to change, in this case, the institutional influence on tourism seasonality remains strong. This case is called 'fixed overall demand without seasonal flexibility'.

6.3.1 Base case: flexible overall EU and seasonal demand

Table 21 shows the changing tourism receipt in million € for the aggregated EU regions. As the results suggests Southern countries face considerable negative consequences, but the positive effects in northern countries, and in particular in the Central European regions are much larger, resulting in a positive overall effect for the EU in the case where no limitation was placed on the tourist seasonal flows. As expected the changes show similar pattern in both the A2 and B2 cases, with the A2 scenario entailing higher income changes in both directions (higher benefits in North of Europe and higher losses in the South). Additionally the warmer climatic scenarios (of the ECHAM family) show substantially higher impacts on the tourism flows, consequently on the tourism receipts as well. The results seem to suggest that the higher the temperature increase in Europe, the higher and more divergent the changes in tourist receipts across European regions. Impacts might not be linear when compared to the average temperature change, but rather exhibit a more than proportional relationship. The regional and seasonal results (not included in the table) shows clear changes in the seasonal distribution of bed nights spent in Europe, following the patterns discussed in the previous section where the TCI index in the various seasons has been assessed. Activity in July and August diminishes strongly with an increase in the 'shoulder' spring and autumn seasons.

Table 21. Tourism: change in expenditure receipts in the 2080s, central case (million €)

	B2 HadAM3h 2.5ºC	**A2 HadAM3h 3.9ºC**	**B2 ECHAM4 4.1ºC**	**A2 ECHAM4 5.4ºC**
Norhern Europe	443	642	1,888	2,411
British Isles	680	932	3,587	4,546
Central Europe North	634	920	3,291	4,152
Central Europe South	925	1,763	7,673	9,556
Southern Europe	-824	-995	-3,080	-5,398
EU	**1,858**	**3,262**	**13,360**	**15,268**

6.3.2 Fixed overall EU demand and flexible seasonal demand

Under this variant climate change in itself does not induce changes in the total tourism volumes in Europe. It only leads to seasonal and geographical redistribution. This case could be interpreted as a ‘zero-sum’ game: there cannot be only winners across Europe. This case therefore paints a more contrasted picture of the winners and losers. Table 22 shows the estimated changes in total expenditure by European region. The Southern European region is worse than under the previous case considered because of the absence of the extra tourist demand in Europe. This highlights even further the sensitive position of that region. Indeed, the improvement in climate conditions in the Mediterranean in spring and autumn, as measured by the TCI index, cannot fully compensate the deteriorated conditions in summer.

Table 22. Tourism: change in expenditure receipts in the 2080s, annual case (million €)

	B2 HadAM3h 2.5ºC	**A2 HadAM3h 3.9ºC**	**B2 ECHAM4 4.1ºC**	**A2 ECHAM4 5.4ºC**
Norhern Europe	344	465	1,122	1,507
British Isles	529	664	2,375	3,105
Central Europe North	429	558	1,729	2,322
Central Europe South	413	857	3,772	5,003
Southern Europe	-1,715	-2,544	-8,997	-11,937
EU	**0**	**0**	**0**	**0**

6.3.3 Fixed overall EU demand and fixed seasonal demand

This case sketches a situation in which the seasonal visitation patterns remain as they were in the simulated baseline period, *i.e.* they remain firmly summer peak. As could be expected, this case accentuates the geographical shift of the belt with pleasant summer conditions from the Mediterranean region towards the North (Table 23). As tourists cannot adapt by holidaying in another season, they are forced to visit other destinations if they decide that the climate in their traditional holiday destination has become unattractive. This further deteriorates the position of Southern Europe compared to the previous case, but the main patterns in the tourism flows remain similar to the previous case considered.

Table 23. Tourism: change in expenditure receipts in the 2080s, annual case (million €)

	B2 HadAM3h 2.5ºC	A2 HadAM3h 3.9ºC	B2 ECHAM4 4.1ºC	A2 ECHAM4 5.4ºC
Norhern Europe	390	558	1,570	2,392
British Isles	474	580	2,409	3,432
Central Europe North	365	427	1,563	2,112
Central Europe South	560	1,034	3,916	4,917
Southern Europe	-1,789	-2,599	-9,459	-12,853
EU	**0**	**0**	**0**	**0**

7 HUMAN HEALTH ASSESSMENT

Human health will be affected by climate change, in direct and indirect ways (Costello *et al*., 2009). Effects include increases in summer heat related mortality, decreases in winter cold related mortality, changes in the disease burden *e.g.* from vector-, water- or food-borne disease, and increases in the risk of accidents and wider well being from extreme events (storms and floods).

This chapter summarises the methodology and the main results of the study on the impact of climate change in human health in Europe. Here the results concerning direct temperature mortality changes are discussed. Detailed information on the methodology and other results (*e.g.* temperature-related cases of salmonella) can be found in the accompanying PESETA technical report Watkiss *et al.* (2009).

7.1 Human health model

7.1.1 Modelling approach

The human health impact assessment of the PESETA project estimates projected mortality from temperature changes for the 2020s and the 2080s across Europe.

The projections were based on relationships between mortality and current temperature (epidemiological studies) available at the time. These mainly draw on the EU-funded cCASHh project Menne and Ebi (2006) and work by Kovats et al (2006). Since the study was undertaken, a set of country specific summer mortality functions for Europe have been published, as part of the PHEWE study (Baccini *et al.*, 2008).

The study used daily projected temperature information at a 50 km by 50 km grid resolution across Europe, combined with country specific socio-economic scenario data for population, age structure and background health incidence data for both current and future periods.

Impacts were estimated using temperature-response functions, which provide relationships of daily mortality against daily temperature. These are usually represented as separate functions for heat and cold effects, reflecting the fact that mortality increases at low or high temperatures above certain threshold levels, *i.e.* around a broad central range over which there is little response. The functional form of the relationships can vary, but in this study the functions were applied linearly above (heat) or below (cold) specific thresholds, noting that different thresholds were used for each grid cell or country.

It is stressed that applying functions from the current climate to future modelled projections is extremely uncertain. There are issues of which functions to use, what level of spatial scale and location they are appropriate for (their transferability), how well they capture changes in both the mean and variance of future temperatures and how applicable they are to future societies. Another key issue is the degree of autonomous acclimatisation over time (physiological and behavioural) – discussed below - that is likely to occur among European populations.

While the overall PESETA study has considered some limited analysis of the uncertainty of climate projections through the use of two alternative models and two socio-economic scenarios, the added uncertainty from the impact functions (and valuation, see later) will also have a very large effect on the results and the subsequent policy messages. The health study has therefore applied alternative functions and assumptions to investigate the effects on the results – at an aggregated level – and in relation to the distribution of effects by location.

The study has used two approaches for assessing heat- and cold-related temperature effects

- Country specific functions, which are based on functions identified under the cCASHh project (Menne and Ebi, 2006) for specific European countries (where available). These included functions for Norway, Finland, Bulgaria, UK, Netherlands, Spain and Greece, each of which has a specific threshold level and a specific slope (or gradient). These functions were applied to each country and to climatically and socially similar countries nearby. These functions more accurately represent current physiological and social conditions, the existing adaptation to the current climate and sensitivity to existing climate variation. However, the functions derived have a partial coverage and come from different studies. Note that since this study, a consistent set of heat related functions have been published by Baccini *et al.* (2008).

- Climate-dependent functions, based on an extension of an approach adopted by Kovats *et al.* (2006). This involved a more complex approach, first estimating heat and cold thresholds for each 50 by 50 km location in Europe using a statistical analysis of daily temperatures. This established thresholds in each grid cell for low- and high-temperatures. The study then applied a single consistent function (a fixed single slope) for each of heat and cold related mortality in each cell, assuming a linear form beyond the threshold point. The advantage of this approach is it has a higher resolution and allows greater coverage across all specific locations and a potentially better representation of local thresholds. It also allows a more direct comparison of the relative level of warming seen across Europe in the model output, as it adopts a more directly comparable approach. The downside is the application of a single function (identical slope) in all grid cells and thus the lack of consideration of country specific vulnerability.

The study also considered acclimatisation, which is likely to reduce potential increases in heat-related mortality. Whilst some studies incorporate acclimatisation into future projections of temperature-related mortality there is no consensus on the analytical approach. The study has adopted the fixed rate approach used by Dessai (2003) and assumed acclimatisation to 1ºC warming occurs every three decades. This is only very approximate, but it does provide some representation of physiological adaptation. Note that in practice, acclimatisation rates will be scenario- and location- specific according to the rate of warming experienced and the susceptibility or resilience to future changes. Note that this acclimatisation does not include additional planned adaptation. The study assumes that populations acclimatise to a warmer climate in the future, modelled through a shift in threshold temperatures. It is noted that there are many assumptions in this approach and it can only be considered indicative. It is uncertain whether there will also be a decline in the sensitivity of mortality to cold. There is no specific literature on this subject but some anecdotal evidence. As a sensitivity, the study has investigated the potential effects for a decline in the sensitivity of mortality to cold, using similar rates as assumed for heat. It is highlighted that the confidence in this estimate is low.

In addition to acclimatisation, planned, proactive adaptation may have a strong role in reducing potential health risks, particularly in relation to extremes. There are emerging studies on adaptation strategies that can be implemented by health sectors (Menne and Ebi, 2006), most of which build on well-established public health approaches. They include

- Strengthening of effective surveillance and prevention programmes
- Sharing lessons learned across countries and sectors
- Introducing new prevention measures or increasing existing measures
- Development of new policies to address new threats

The main problem with assessing the potential for adaptation to reduce impacts is a lack of information on the effectiveness of adaptation measures in reducing potential impacts. While some estimates of potential costs are starting to emerge, such as heatwave health plans in France and Paris (Mairie de Paris, 2007) it remains difficult to estimate and attribute potential benefits. For these reasons, an explicit assessment of the costs and benefits of adaptation for heat related effects has not been undertaken.

There is also a strong link between the potential temperature effects on human health and demand for energy, in relation to the role of air conditioning as an adaptation. As countries experience warmer climates, there will be a need to control these new environments or adjust human behaviour to deal with these changes. Health (and well-being) will be a strong driver in this respect. One response is through air conditioning, though this will have implications for increasing energy use (see the energy study). Planned adaptation therefore also has a major role in looking at alternatives to air conditioning (through ventilation such as passive systems, but also through behavioural change).

The results have been generated for two scenarios. First, assessing future heat and cold related effects from socio-economic effects *only*, *i.e.* with no change in climate, and second, estimating the future heat and cold related effects with the future socio-economic and the climate predictions. The difference between these two results is then presented as the additional or marginal “climate change induced” effect. This distinction is important, because there will be increases in future vulnerability due to the increases in population and the projected shift in age distribution, *i.e.* the aging European population, irrespective of any future climate change. While there is a need for adaptation policy to look at the total effects of socio-economic and climate change together, these are not all attributable to climate change.

The impacts quantified do not fully represent the effects of urban zones (for example, elevated temperatures in urban areas and possible interactions with air quality, especially ground-level ozone), due to the resolution of the data and lack of urban heat island considerations within the climate models. They also do not include some of the additional impacts that may result from extended periods of extreme high temperatures (heat-waves). The omission of urban and additional heatwave effects means that the heat-related results here may be underestimates. The results also do not capture the future variance of temperatures and the potential effects of increased variability. There are also other health effects from climate change that should be considered alongside heat and cold related mortality, particularly heat and cold related morbidity (illness).

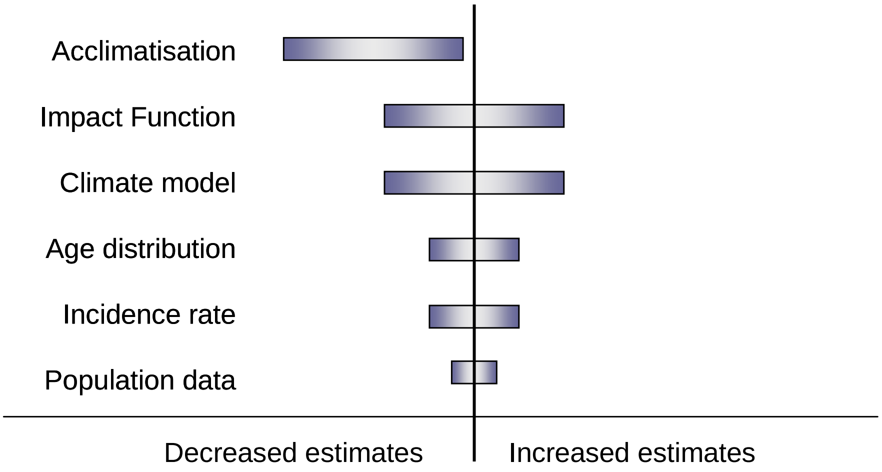
The economic valuation of the mortality changes also uses two alternative approaches, reflecting the two metrics used in applied environmental cost-benefit analysis. The first approach values mortality results using the value of a statistical life (VSL) metric which is directly applied to the numbers of cases (deaths) estimated above. This approach is widely used in European policy appraisal, for example to value road transport accidents (noting that such deaths are spread across the population and so on average a typical life expectancy lost is some 40 years). The second approach considers an alternative metric termed the value of a life year lost (VOLY), which provides a means of explicitly recognising the loss of life expectancy involved. This is important as many deaths (though not all) from cold and heat related mortality occur in the elderly, and thus the period of life lost is much shorter than for accidental death. The VOLY estimates are combined with the estimated number of life years lost to provide values: however, this requires an estimate of the average period of life lost and there is no empirical data for this. The unit values for each of these economic metrics were taken from the EC-funded NEWEXT research project (Markandya *et al.*, 2004), with estimates of €1.11 million per VSL, equivalent to €59,000 VOLY, derived from a pooled three-country analysis. Both metrics are consistent with recent analysis for DG Environment under the CAFE (Clean Air For Europe Programme).

7.1.2 Limitations and uncertainties

In order to assess the results, it is essential to take account of the uncertainties present in the analysis. These relate to the climate projections, socio-economic scenarios, choice of health impacts, the quantification methods (including impacts and acclimatisation) and the valuation. It is stressed that the individual uncertainties, both on physical impacts and economic valuation, are very high, and that when these are combined with uncertainty over projections and socio-economic scenarios, the bounded range is very wide, thus the reporting of single central estimates is extremely misleading.

The study has very partially represented this uncertainty by working with a sub-set of alternative assumptions, notably with two climate model projections, two socio-economic scenarios, two alternative functional relationships, with and without acclimatisation and using two alternative valuation estimates. Even with this constrained sampling of uncertainty, the results vary extremely widely. The relative importance of each of the assumptions is provided in Figure 30, using some simple sensitivity analysis and judgement – noting that this does not present the full uncertainty, only the range reflected in the partial sampling here. The further the analysis proceeds through the analysis pathway from climate to impact assessment to valuation, the greater the potential uncertainty in the final estimate (simply because more parameters are introduced, each bringing their own level of uncertainty to the analysis).

Figure 30. Human health: Illustrative uncertainty for temperature related health quantification and valuation



Note: range reflects uncertainty considered in the analysis – not full uncertainty.

The analysis shows that the choice of climate projection, whether acclimatisation is included and the impact functions all have a large influence on the results. The socio-economic data (*e.g.* population, age distribution and incidence) have a lower effect, though the analysis above does not reflect other important parameters (*e.g.* future wealth, health care levels). When all the uncertainties are considered, it is clear that the range of estimates is extremely large, probably at least two orders of magnitude. Therefore, the results presented can only be considered as an indicative assessment until better information becomes available and some parts of the methodology are elaborated in more detail.

7.2 Physical impacts

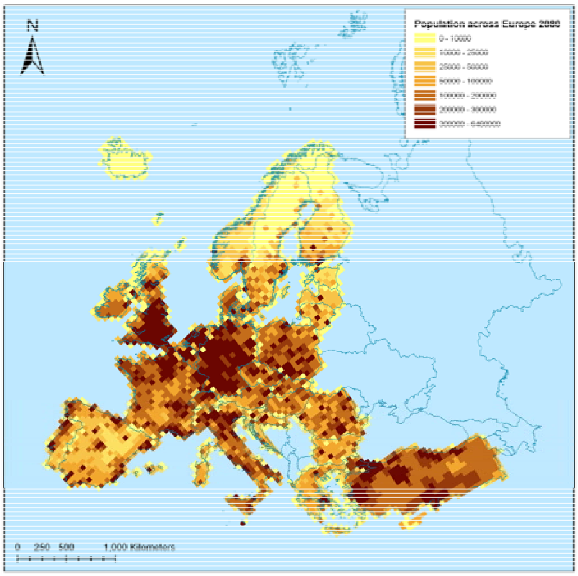
All the results that follow are the mortality changes compared to the baseline period without acclimatisation, unless otherwise stated. As already noted, the results reflect the marginal change due to climate change only, *i.e.* they are net of the socio-economic change considered (as the extra cases from future socio-economic scenarios would occur anyway, even in the absence of climate change). Values for climate and socio-economic change together are included in Watkiss *et al.* (2009).

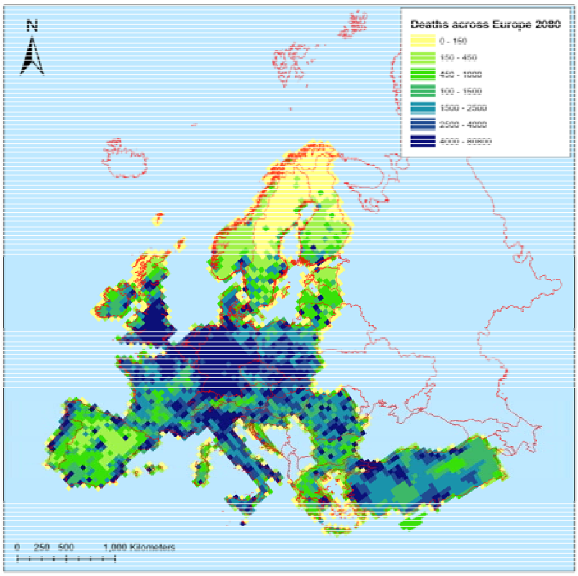
Results are not presented as net figures (*i.e.* the sum of cold and heat-related effects), because there is too much uncertainty in the estimates to present such a number with confidence.

Furthermore, there is no central or best estimate recommended across the alternative estimates, though more recent studies tend to cite values with heat acclimatisation included, *i.e.* suggesting the population is capable of adapting to warmer conditions.

The European population is projected to increase in the 2080s by 8% under the A2 socioeconomic scenario and by around 3% under the B2 scenario. As an illustration, Figure 31 shows the average distribution of population and average annual projected number of deaths across Europe for the 2080s under the 3.9°C scenario. The death rate is largely a function of population, thus the figures show the same distributional pattern.

Figure 31. Human health: population (left) and annual deaths (right) in Europe for 2080s (3.9°C scenario)





7.2.1 Mortality changes in the 2020s

Table 24 shows the heat- and cold-related mortality rates changes per 100,000 habitants in the 2020s (2011-2040 simulation period). In general, the estimated increase in heat-related mortality is projected to be lower than the estimated decrease in cold-related mortality.

For heat-related mortality, the results of the two impact function approaches are similar. Thus the increase in Europe is projected to be approximately 25,000 extra deaths per year (assuming an EU population of around 500 million), with relatively high increases in the Central-south and Southern Europe regions and lower increases in northern Europe, Islands and Central north parts of Europe. When acclimatisation is included (a fixed rate of 1°C per three decades), the estimated increases fall by a factor of six, down to 4000 extra deaths per year.

Table 24. Human health: heat-related and cold-related mortality rate projections for the 2020s - death rate (per 100,000 population per year)

	Heat		*Cold*	
	climate-dependent	country-specific	climate-dependent	country-specific
Northern Europe	4	5	-18	-7
British Isles	5	1	-7	-26
Central Europe North	5	4	-11	-13
Central Europe South	6	8	-10	-19
Southern Europe	7	6	-9	-29
EU	6	5	-10	-20

Note: A positive sign represents an increase in the mortality rate, *i.e.* an increased number of mortality cases. A negative sign represents a decrease.

Regarding cold-related mortality, the analysis projects a fall in mortality, with potentially some 50,000 to 100,000 cold-related deaths avoided. In this case the impact functions produce very different results, varying by a factor of two. The introduction of a decline in the sensitivity of mortality to cold, whilst only undertaken as a sensitivity, does show very large reductions in the predicted changes (*i.e.* in this case much lower levels of reduced cold related deaths), with a factor of five to ten reduction depending on the approach.

Figure 32 and Figure 33 show the 50 km x 50 km resolution maps for the heat and cold-related death rates using the two kinds of exposure-response functions. Note that figures are not presented for the absolute change, expressed as numbers of deaths, because these maps would be dominated by population density, and just reflect urbanisation patterns on a 50 by 50 km resolution across Europe.

Figure 32. Human health: average annual heat-related (left) and cold-related (right) death rates per 100,000 population, for the 2020s, using the climate-dependent health functions (no acclimatisation)

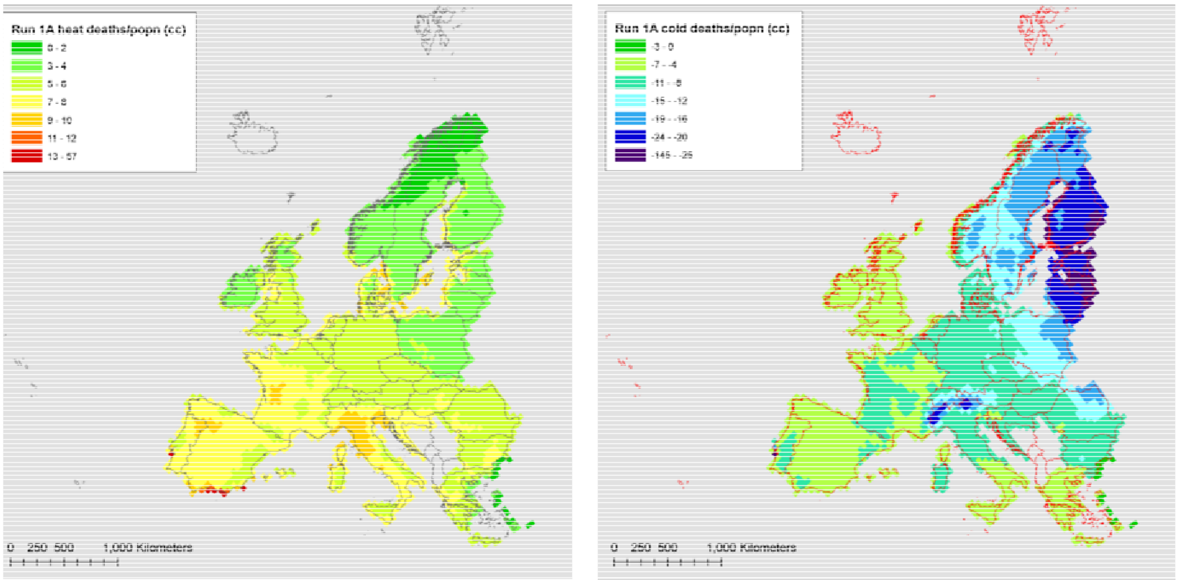
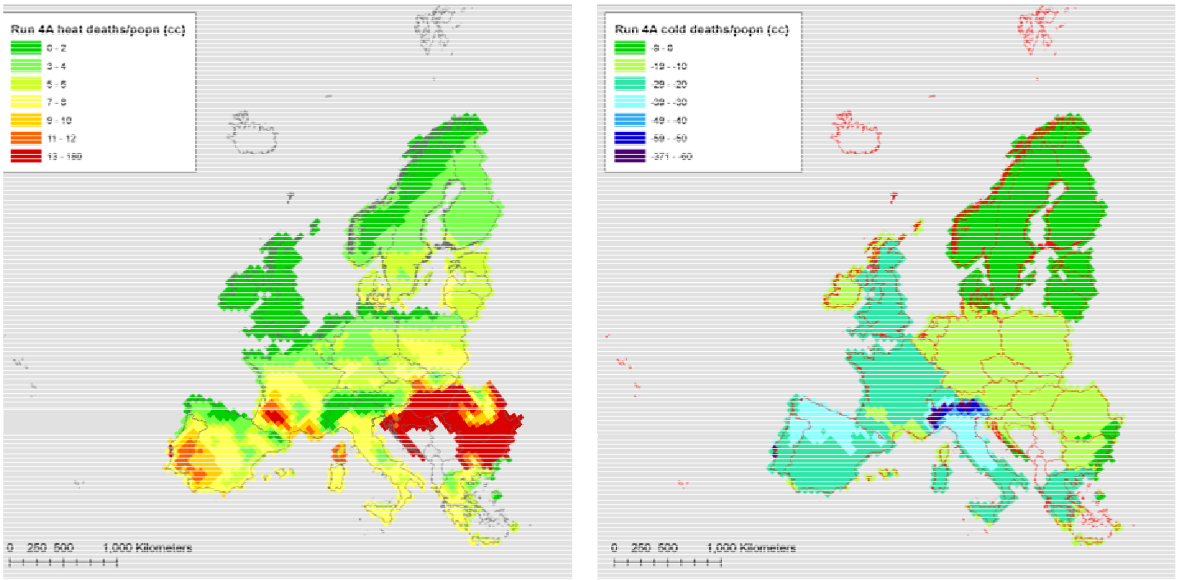


Figure 33. Human health: average annual heat-related (left) and cold-related (right) death rates per 100,000 population, for the 2020s, using the country-specific health functions (no acclimatisation)



7.2.2 Mortality changes in the 2080s

The results for the 2080s are presented according to the two climate models for each of two socio-economic scenarios, noting that these two projections are a sub-set of the climate model variation.

Table 25 presents the heat-related mortality rate changes projections for the two impact functions. For the country-specific functions, four 2080s scenarios are covered. The estimated increase in mortality rates is between 12 deaths/100,000 population per year for the lowest warming scenario to 33 for the highest warming case, which leads to an estimate of increase in mortality of 50,000 to 160,000 cases per year, respectively. When acclimatisation is included, the death rate and total number of deaths falls by a factor of two to six for the A2 scenarios, to 20,000 to 70,000 cases per year, with the lower relative reduction occurring under the higher temperature projection (because the fixed rate of acclimatisation does not keep us as fast). Under the B2 scenario, they fall to effectively zero, *i.e.* the rate of acclimatisation exceeds the rate of climate change projected (noting the limitations of the analysis, above). The highest increase in relative mortality (measured by the increase in population adjusted death rate) is projected to occur in Central and Southern Europe, mainly in the Central South Europe area. For the climate-dependent functions, the two scenarios with lower warming are available. For Europe as a whole they lead to results similar to those of the other function.

Table 25. Human health: heat-related mortality rate projections for the 2080s - - death rate (per 100,000 population per year)

	Country-specific function				Climate-dependent function	
	B2 HadAM3h 2.5°C	A2 HadAM3h 3.9°C	B2 ECHAM4 4.1°C	A2 ECHAM4 5.4°C	B2 HadAM3h 2.5°C	A2 HadAM3h 3.9°C
Northern Europe	8	15	9	14	7	17
British Isles	4	8	7	10	8	18
Central Europe North	12	24	19	33	9	20
Central Europe South	17	31	31	52	12	24
Southern Europe	11	18	18	28	12	23
EU	12	22	19	33	10	22

Note: change in death rate per 100,000. Positive sign means a rise in mortality.

Table 26 shows the estimated changes in cold-related mortality rates. The warmer projections show reduced mortality. For the country-specific function, the range of reduced mortality in Europe is between 100,000 and 250,000 per year. The British Isles and the Southern Europe regions are estimated to be the areas with the highest fall in mortality. According to the projections from the climate-dependent function, which relate only to the 2.5°C and 3.9°C scenarios, the fall in deaths is around 60,000, approximately half of those from the other impact approach. If a decline in the sensitivity of mortality to cold is considered, noting this is included as a sensitivity only, then the fall in mortality becomes much lower, with very large reductions in the projected changes and almost no benefits are then projected under the B2 scenarios.

Table 26. Human health: cold-related mortality rate projections for the 2080s - - death rate (per 100,000 population per year)

	Country-specific function				Climate-dependent function	
	B2 HadAM3h 2.5°C	A2 HadAM3h 3.9°C	B2 ECHAM4 4.1°C	A2 ECHAM4 5.4°C	B2 HadAM3h 2.5°C	A2 HadAM3h 3.9°C
Northern Europe	-8	-13	-11	-16	-15	-21
British Isles	-27	-48	-57	-75	-9	-15
Central Europe North	-14	-25	-26	-37	-14	-21
Central Europe South	-20	-37	-39	-53	-12	-19
Southern Europe	-28	-52	-49	-64	-8	-12
EU	-21	-37	-39	-52	-12	-17

Note: A positive sign represents an increase in the mortality rate, *i.e.* an increased number of mortality cases. A negative sign represents a decrease.

As highlighted above, due to the high uncertainty in the analysis, and the different assumptions inherent in the analysis of heat- and cold related effects, it is inappropriate to present these results as net figures. Nonetheless, the analysis indicates that in the short-term (2020s), the reduction in cold related deaths is likely to outweigh the increase in heat related deaths. In the longer term (2080s), different net results are obtained depending on the parameter choices. While in many cases there are net benefits predicted (cold-related effects outweigh heat-related effects), for some model runs, the opposite was found. Moreover, with acclimatisation (and a decline in the sensitivity of mortality to cold) included the country specific functions show similar levels of heat and cold-related mortality.

The large differences in the regional patterns of heat- and cold-related mortality (Figure 34 to Figure 37) illustrate the influence of the impact function on the distributional pattern of relative effects.

Figure 34. Human health: average annual heat-related (left) and cold-related (right) death rates per 100,000 population, for the 2080s, 2.5°C scenario, using climate-dependent health functions (no acclimatisation)

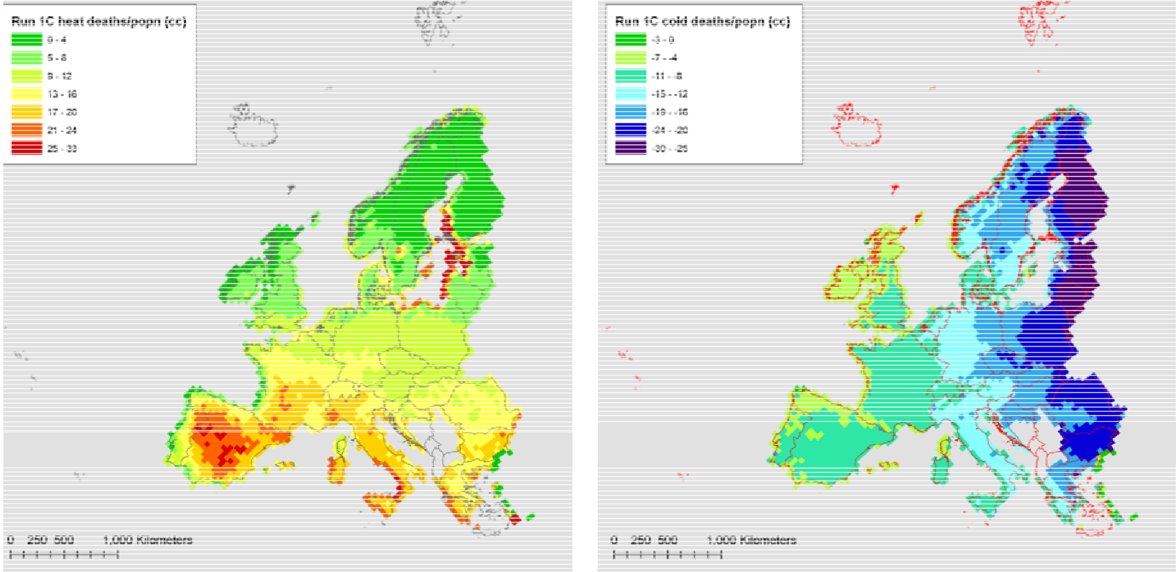
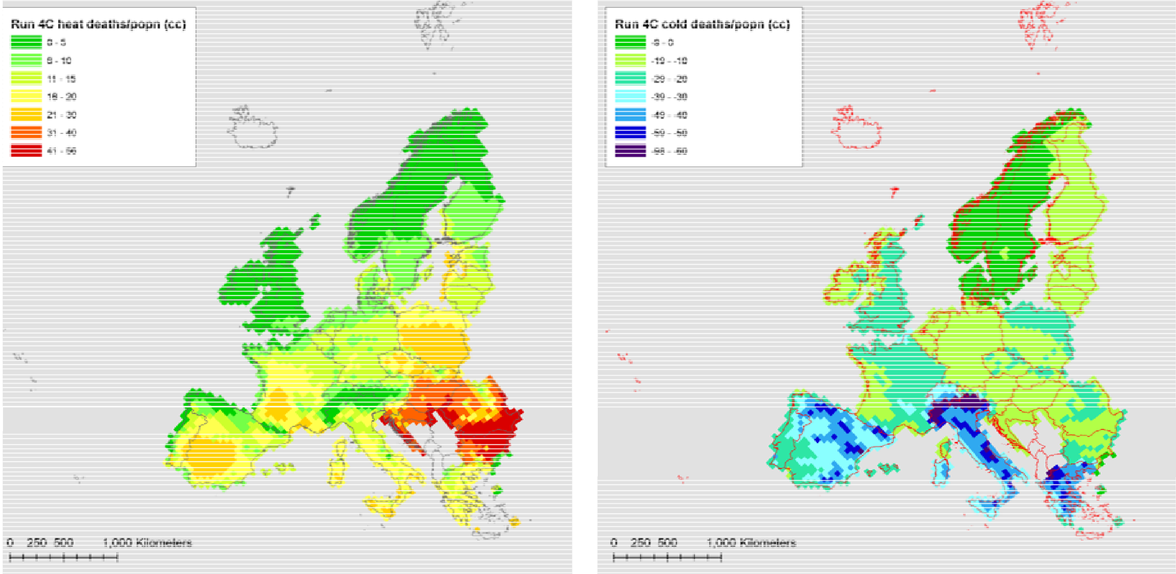


Figure 35. Human health: average annual heat-related (left) and cold-related (right) death rates per 100,000 population, for the 2080s, 2.5°C scenario, using country-specific health functions (no acclimatisation)



For instance, the spatial patterns concerning the 3.9°C scenario (

Figure 36 and Figure 37) show that for heat related mortality:

- With the climate dependent functions, the pattern is relatively uniform across Member States, though the largest potential mortality increases from climate change occur in Mediterranean and south-eastern European countries and the smallest potential increases in more northerly and north-west countries. This reflects the relative level of warming projected in the models, because this approach uses a consistent slope function (though different thresholds) and so more closely reflects climate parameters.
- With the country specific functions, there is more variability between Member States, reflecting the larger difference in the underlying functions derived from individual country studies. Central-eastern countries show the strongest climate change induced increases, reflecting the higher gradients in the functions for these regions.

The spatial patterns show that for cold related mortality:

- With the climate dependent functions, the largest potential cold-mortality benefits from climate change occur in Baltic and Scandinavian countries, while the smallest benefits are found in Ireland, Luxembourg, UK and some Mediterranean countries – again matching the underlying pattern from the climate model projections.
- With the country specific functions, the largest potential cold-mortality benefits from climate change occur mainly in Mediterranean countries, reflecting the relative slope of the functions, while the smallest benefits are in Baltic and Scandinavian countries.

Figure 36. Human health: average annual heat-related (left) and cold-related (right) death rates per 100,000 population for the 2080s, 3.9°C scenario, using climate-dependent health functions (no acclimatisation)

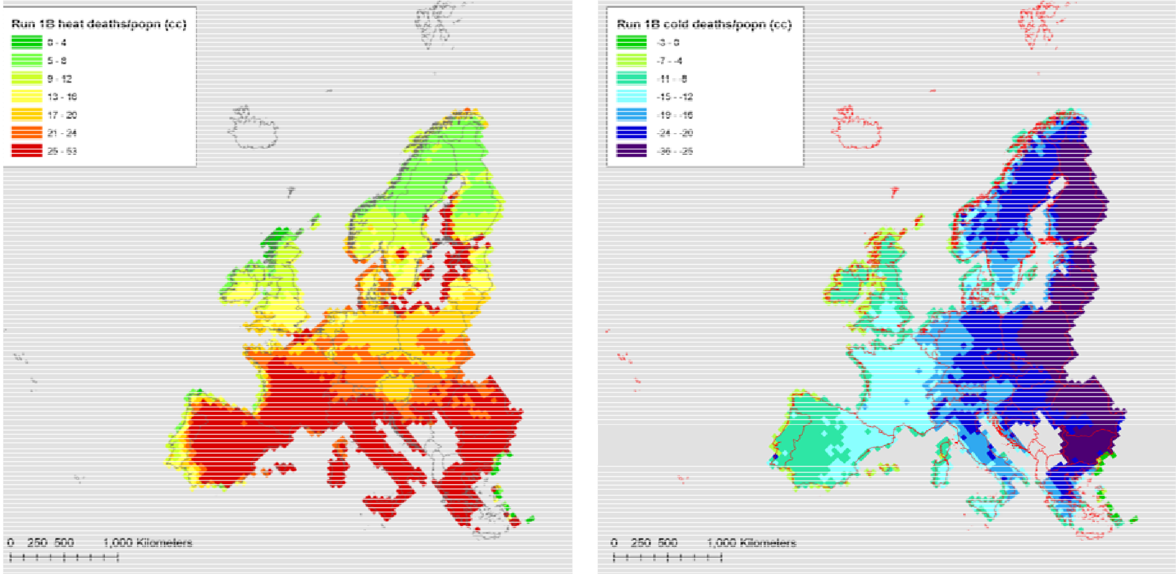
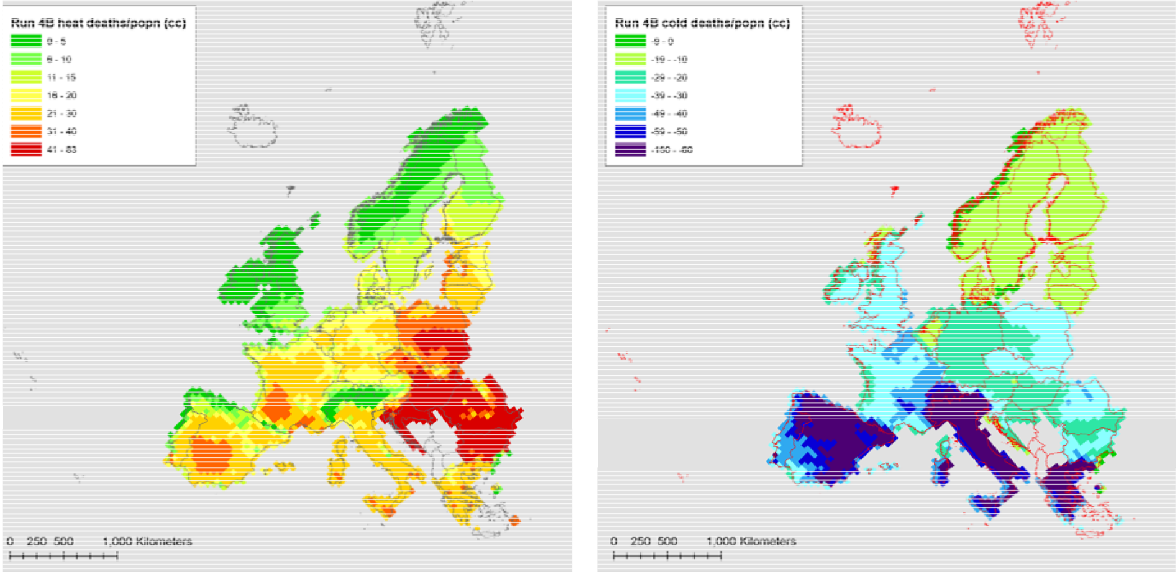
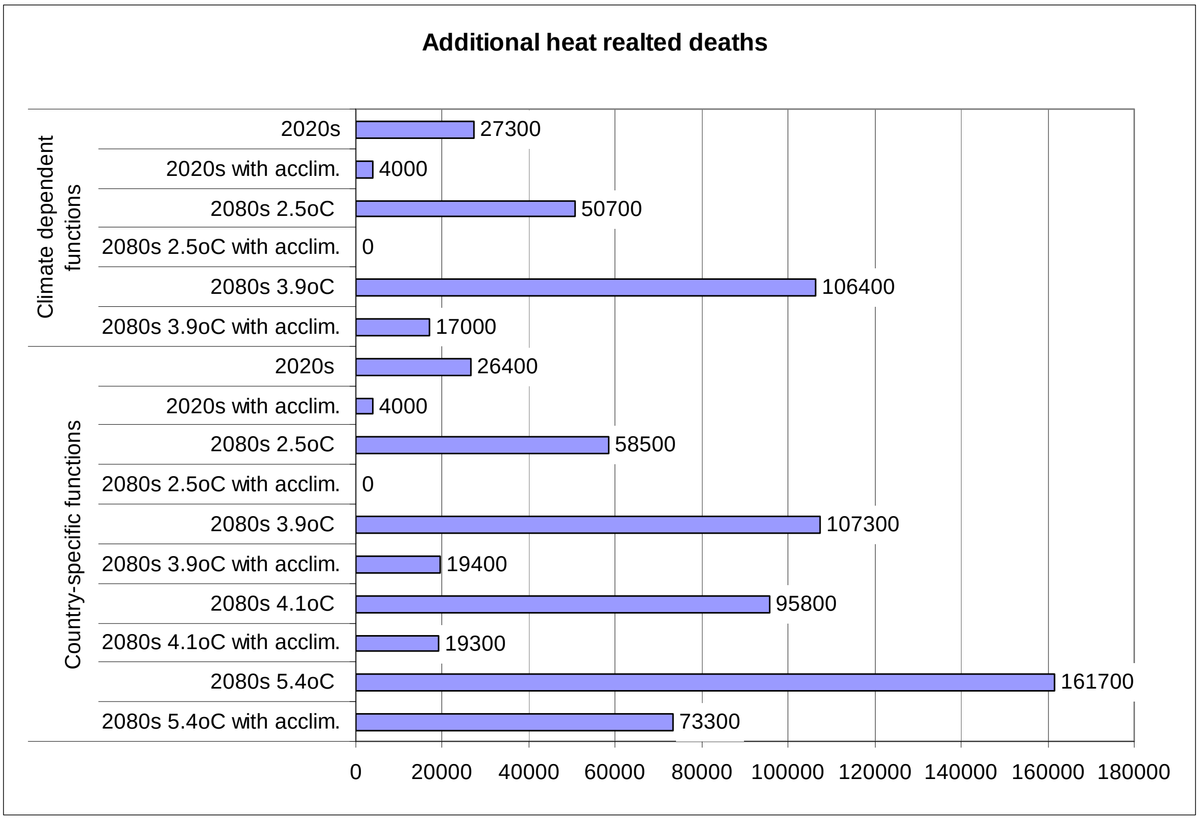


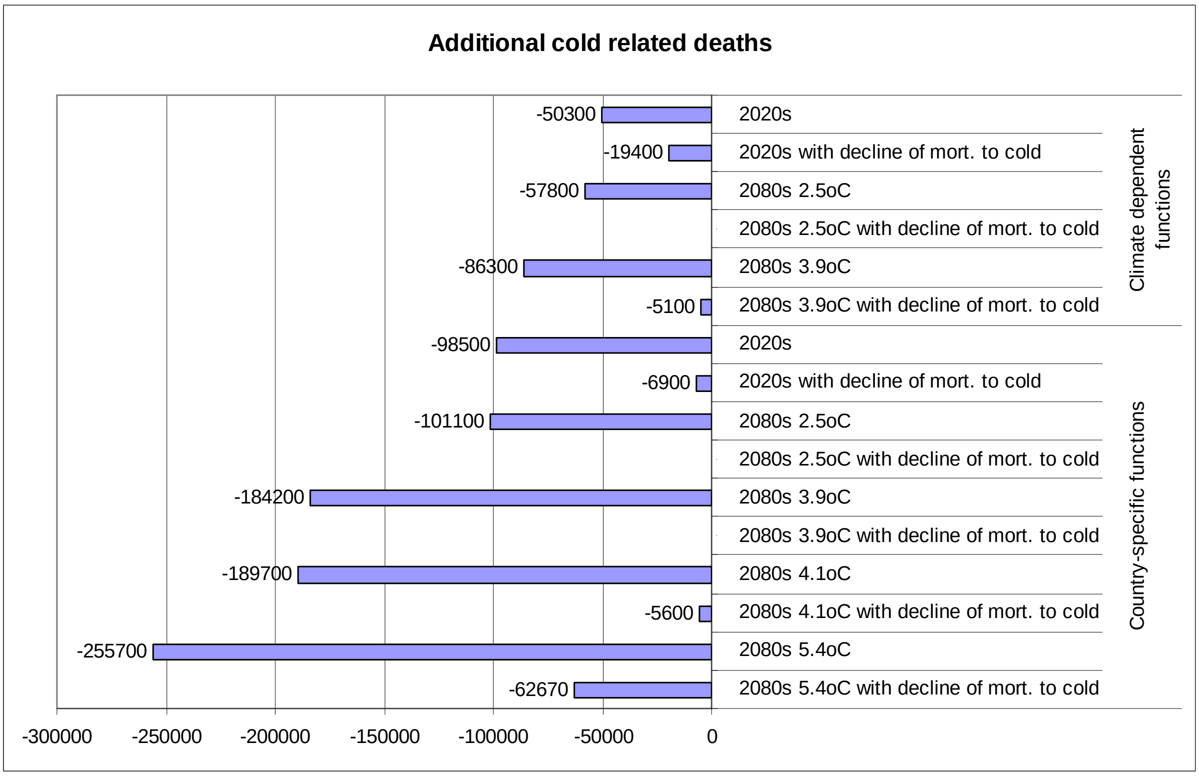
Figure 37. Human health: average annual heat-related (left) and cold-related (right) death rates per 100,000 population for the 2080s, 3.9°C scenario, using country-specific health functions (no acclimatisation)



An overview of all the physical impacts is provided in Figure 38.

Figure 38. Human health: Overview of mortality changes in all scenarios for a range of projections, models, functions and with and without acclimatisation. Top – heat related: Bottom- cold related effects





Note: (-) implies a benefit (fewer deaths), (+) implies an impact (more deaths). For the acclimatisation, a fixed rate of 1°C per three decades has been used to shift thresholds, relative to baseline climates. For cold related deaths, the decline in the sensitivity of mortality to cold labelled acclimatisation) is included only a sensitivity.

7.3 Economic impacts

Table 27 shows the results for all cases according to the two valuation methods. In general the monetary values follow the pattern of physical impacts above and so no additional detailed description is included here. Heat and cold related annual effects are valued in terms of tens to hundreds of billions of Euros.

For the 2020s without acclimatisation, the heat-related effects are valued at 13 billion € when applying the VOLY method and at 30 billion € applying the VSL approach (assuming that on average, eight years of life is lost per case), though drop to 2 to 4 billion € when acclimatisation is included. For the results presented here, values are provided in constant values (year 2005, no uplift, no discounting) to allow direct comparison across periods. The benefit due to the reduction of cold-related deaths are valued at 23 to 46 billion € according to the VOLY method and 55 to 110 billion € with the VSL method, though again these become less significant if a decline in the sensitivity of mortality to cold is included (note again that the same period of life lost is assumed for the VOLY, though different periods of life are likely to be lost, on average, for heat- and cold-related mortality).

By 2100 under an A2 projection, the values range from 50 to 180 billion Euro (according to choice of function and climate model) without acclimatisation, and 8 to 80 billion Euro/year with acclimatisation. Similar or higher benefits are projected for the reduction in cold-related mortality. In respect of valuation, some additional points emerge. The choice of valuation metric (VOLY or VSL) is important, as is the period of life lost that is assumed for mortality (when using the VOLY). The choice of VOLY or VSL metric leads to a factor of 2 to 3 difference (with higher estimates when applying VSL values). This adds to uncertainty additional to that already highlighted above.

Because of the uncertainties, we caution against the reporting of net economic effects. Nevertheless, whilst noting the caveats above in relation to the sum of heat- and cold-related effects, the results show that depending on the parameter choices, the benefits from the reduction in cold-related deaths are usually at least as large, and under many scenarios, larger than the increase in heat-related deaths. However, the results here exclude additional effects from heatwaves. More importantly, for many the other health categories covered in the main report, *i.e.* temperature-related cases of salmonella, flood related heath effects, there are no positive related effects from climate change, only impacts.

Table 27. Human health: economic valuation of mortality effects in all scenarios

	European total number of deaths	Million €/year	
HEAT-RELATED DEATHS		**Valuation using VOLY central (€59k)**	**Valuation using VSL Central (€1.11 M)**
a) Climate-dependent functions			
2020s	27,337	12,903	30,344
2020s with acclimatisation	3,978	1,878	4,416
2080s 2.5°C scenario	50,665	23,914	56,238
2080s 2.5°C scenario with acclimatisation			
2080s 3.9°C scenario	106,419	50,230	118,125
2080s 3.9°C scenario with acclimatisation	17,080	8,062	18,959
b) Country-specific functions			
2020s	26,372	12,448	29,273
2020s with acclimatisation	3,938	1,859	4,371
2080s 2.5°C scenario	58,508	27,616	64,944
2080s 2.5°C scenario with acclimatisation			
2080s 3.9°C scenario	107,339	50,664	119,146
2080s 3.9°C scenario with acclimatisation	19,449	9,180	21,588
2080s 4.1°C scenario	95,822	45,228	106,362
2080s 4.1°C scenario with acclimatisation	19,346	9,131	21,474
2080s 5.4C scenario	161,694	76,320	179,480
2080s 5.4°C scenario with acclimatisation	73,322	34,608	81,387
COLD-RELATED DEATHS			
a) Climate-dependent functions			
2020s	- 50,272	-23,728	-55,802
2020s with decline in sensitivity of mortality to cold	- 19,422	-9,167	-21,558
2080s 2.5°C scenario	- 57,823	-27,292	-64,184
2080s 2.5°C scenario with decline in sensitivity of mortality to cold			
2080s 3.9°C scenario	- 86,291	-40,729	-95,783
2080s 3.9°C scenario with decline in sensitivity of mortality to cold	- 18,835	-8,890	-20,907
b) Country-specific functions			
2020s	- 98,529	-46,506	-109,367
2020s with decline in sensitivity of mortality to cold	- 6,893	-3,253	-7,651
2080s 2.5°C scenario	- 101,112	-47,725	-112,234
2080s 2.5°C scenario with decline in sensitivity of mortality to cold			
2080s 3.9°C scenario	- 184,222	-86,953	-204,486
2080s 3.9°C scenario with decline in sensitivity of mortality to cold			
2080s 4.1°C scenario	- 189,742	-89,558	-210,614
2080s 4.1°C scenario with decline in sensitivity of mortality to cold	- 5,645	-2,664	-6,266
2080s 5.4C scenario	- 255,696	-120,689	-283,823
2080s 5.4°C scenario with decline in sensitivity of mortality to cold	- 62,679	-29,584	-69,574

Note: Results include the EU plus Norway, Switzerland and Croatia.

8 INTEGRATED ECONOMIC ASSESSMENT OF MARKET IMPACTS: THE GEM-E3 PESETA MODEL

8.1 Introduction

The physical and economic results of the four market impact categories of the PESETA project (*i.e.* agriculture, river floods, coastal systems, and tourism) have been integrated into the computable general equilibrium (CGE) GEM-E3 Europe model in order to have a comparable vision of impacts across sectors. The ultimate purpose of this preliminary analysis has been to get insights on which aspects of the European economy and which geographical areas are more vulnerable to climate change, without considering public adaptation.

In other words, the aim has been to explore where and why climate change matters in Europe potentially, so that the results can shed some light in prioritizing adaptation in Europe across sectors and countries, a clear policy need as noted in the White Paper on Adaptation (European Commission, 2009a).

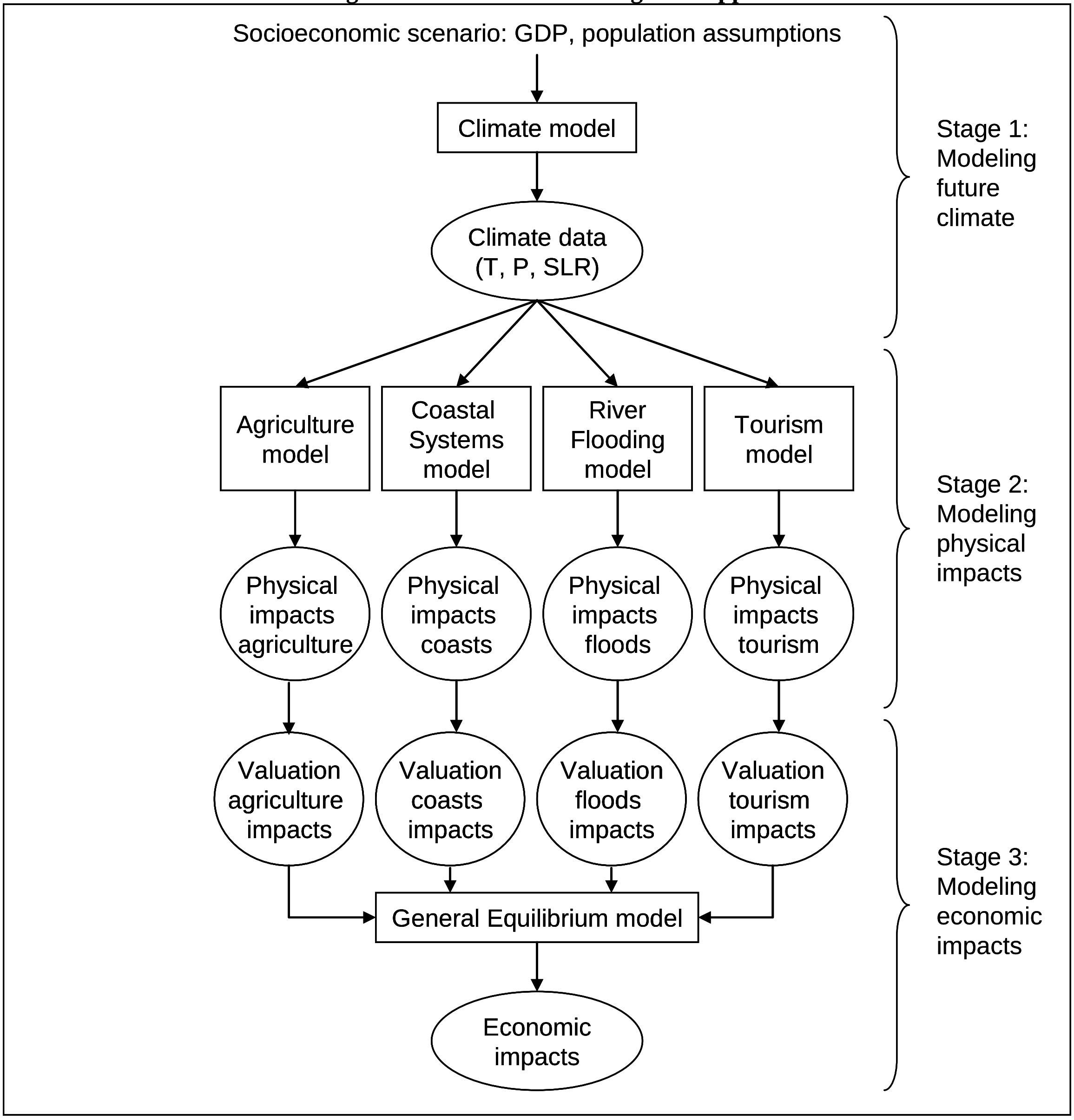
The four scenarios for the 2080s, common to all sectoral studies, have been considered (Section 2.3.4), named after the average increase in temperature in the EU, compared to the 1961-1990 period: 2.5°C, 3.9°C, 4.1°C, and 5.4°C.

Given the limited sectoral scope of the PESETA project, other sectors and impact might as well matter. From this point of view, the results of this analysis need to be interpreted carefully. This chapter presents the main elements of the methodology and the key results.

8.2 Methodology of integration

Figure 39 indicates the various stages of the research project. The rectangles symbolize models and the circles input data or numerical results. The first stage is the modelling of climate futures. The selected socioeconomic scenarios make assumptions on the drivers of climate change *i.e.* economic growth and population dynamics. The resulting greenhouse gas (GHG) emissions are the input to the climate models, which yield the climate variables (Section 2.3).

Figure 39. The PESETA Integrated approach



The second stage is the physical impact assessment, using as input the climate variables. Several impact models have been employed. While the agriculture, coastal systems and river flooding impact models are process-based, the tourism model is based on the statistical relationship between climate variables and tourism demand. The DSSAT crop models have been used to quantify the physical impacts on agriculture, in terms of yield changes (Section 3.1). Estimates of changes in the frequency and severity of river floods are based on simulations with the LISFLOOD model and extreme value analysis (Section 4.1). Impacts of sea level rise in coastal systems have been quantified with the DIVA model (Section 5.1). The tourism study has modelled the major intra-Europe tourism flows assessing the relationship between bed nights and a climate-related index of human comfort (Section 6.1).

The third stage relates to the evaluation of the direct and indirect economic effects of the physical impacts. A multi-sector CGE model for Europe, the GEM-E3 Europe model, has been run to assess the effects of the various impacts on consumer welfare and GDP. Multi-country CGE models provide an explicit treatment of the interactions between different economic sectors and markets (production factors and goods and services), while taking into account the trade flows between countries. This framework captures not only the direct effects of a particular climate impact but also the indirect effects in the rest of the economy. The CGE model ultimately translates the climate change scenarios into consumer welfare and GDP changes, compared to the baseline scenario.

8.3 Effect of 2080s climate in the current economy

The assessment evaluates the economic effects of future climate change (projected for the 2080s) on the current economy, as of 2010. Several authors have followed this approach (*e.g.* Fankhauser and Tol, 1996; Halsnæs *et al.*, 2007). This static analysis would be the equivalent of having the 2080s climate in today's economy.

The alternative approach, followed *e.g.* in Bosello *et al.* (2007), would be to model the effect of future climate in the future economy. Implementing a static approach has the advantage that assumptions on the future evolution of the economy over the next eight decades are not introduced, minimizing the number of assumptions, and, moreover, that the interpretation of the results becomes simpler and more understandable. Impacts are also presented undiscounted. Time discounting is a key and controversial issue in evaluating the impacts of climate change (Nordhaus, 2007; Stern and Taylor, 2007).

A baseline scenario has been run for 2010. The alternative scenario considered the influence of climate change in the economy. The results of the CGE analysis compare the values of welfare and GDP of the climate scenario to those of the baseline scenario.

8.4 Potential impacts and adaptation

Potential impacts of climate change are defined by the IPCC as 'all impacts that may occur given a projected change in climate, without considering adaptation' (IPCC, 2007b; Levina and Tirpak, 2006). The assessment of potential impacts in various sectors facilitates the identification of priorities in adaptation policies.

In the various models applied in this analysis only private adaptation actions have been taken into account (*e.g.* farm level adaptation, change in tourism flows, migration to safer areas) but no explicit public adaptation policy has been considered. While the DIVA model uses a more sophisticated cost-benefit framework (Tol, 2005) to determine the optimal level of adaptation, in this assessment this option has been disabled in order to measure the potential impact of SLR, as for the other impact categories.

8.5 Overview of physical impacts

Table 28 presents the main physical impacts for the impact studies. Regarding agriculture, Southern Europe would experience yield losses, which would become relatively high for the 5.4°C scenario. Central Europe regions would have moderate yield changes. The Northern Europe region would benefit from positive yield changes in all scenarios, and to a lesser extent the British Isles for the 4.1°C and 5.4°C scenarios.

River flooding would affect 250,000 to 400,000 additional people per year in Europe by the 2080s, more than doubling the number with respect to the 1961–1990 period. In coastal areas, around one million additional people would be subject to flooding every year due to SLR. For the highest SLR scenario (88 cm), an additional 5.5 million people per year are exposed to flooding in the EU.

For tourism, climate change would induce better conditions for most regions, resulting in more bed nights and inducing a relatively small EU-wide positive impact. Southern Europe, which currently accounts for more than half of the total EU capacity of tourist accommodation, would be the only region with a decline in bed nights.

Table 28. Physical annual impacts in agriculture, river basins, coastal systems and tourism of 2080s climate change scenarios in the current European economy

European regions*	Southern Europe	Central Europe South	Central Europe North	British Isles	Northern Europe	EU
Physical impacts as estimated by the agriculture model						
Yield Change (%)‡						
2.5°C	0	5	-1	-9	37	3
3.9°C	-12	5	-3	-11	39	-2
4.1°C	-4	3	2	15	36	3
5.4°C	-27	-3	-8	19	52	-10
Physical impacts as estimated by the river flooding model						
People affected (1000s/year)†						
2.5°C	46	117	103	12	-2	276
3.9°C	49	101	110	48	9	318
4.1°C	9	84	119	43	-4	251
5.4°C	-4	125	198	79	-3	396
Physical impacts as estimated by the coastal systems model						
People flooded (1000s/year)††						
2.5°C	258	82	345	70	20	775
3.9°C	456	144	450	136	40	1,225
4.1°C	313	85	347	86	20	851
5.4°C	474	158	459	207	56	1,353
A2 IPCC (upper range)	1,091	512	2,398	1,279	272	5,552
Physical impacts as estimated by the tourism model						
Bed Nights Change (%)**						
2.5°C	-1	2	2	3	4	1
3.9°C	-1	3	3	4	6	1
4.1°C	-2	14	13	14	20	6
5.4°C	-4	17	16	18	25	7

*European regions: Southern Europe (Portugal, Spain, Italy, Greece, and Bulgaria), Central Europe South (France, Austria, Czech Republic, Slovakia, Hungary, Romania, and Slovenia), Central Europe North (Belgium, The Netherlands, Germany, and Poland), British Isles (Ireland and UK), and Northern Europe (Sweden, Finland, Estonia, Latvia, and Lithuania). ‡Yield changes compared to 1961–1990 period and weighted by the country agriculture value added. †Differences compared to the 1961–1990 period. ††Differences compared to 1995. **Differences compared to 2005.

8.6 The GEM-E3 PESETA model

The sectoral effects of climate change have been integrated into a computable CGE model for Europe, the General Equilibrium Model for Energy-Economy-Environment interactions (GEM-E3) Europe model (van Regemorter, 2005). The GEM-E3 model is used regularly to assess European Commission policies on climate change (European Commission, 2009b; Russ *et al.*, 2009; Ciscar *et al.*, 2009).

The CGE methodology has both solid data and economic theory foundations (Shoven and Whalley, 1992). The data core of the model is the so-called Social Account Matrix (SAM), an input-output table of the economy extended to account for the transactions between all the agents of the economy: households, firms, public sector and external sector. The CGE models integrate the optimal behaviour of firms (minimizing costs) and households (maximizing welfare), taking explicitly into account the interactions between all the markets (factors and goods and services) and agents in the economy as well as trade-related effects. Thus a CGE model such as GEM-E3 allows for the estimation of the direct and indirect effects of climate change in the overall economy. The direct effect on a sector would lead to indirect effects in the rest of the goods and services markets through adjustments in the factor markets (capital and labour markets) and in trade to attain equilibrium between supply and demand in all markets.

The GEM-E3 economic, energy and emissions data are based on EUROSTAT databases (input-output tables, national accounts data and energy balances). Twenty-four EU economies haven been individually modelled (the whole EU with the exception of Malta, Cyprus and Luxemburg), with eighteen sectors in each country with full bilateral trade.

As a benchmark it has been assumed that all markets are fully flexible, *i.e.* prices in all markets adjust so that demand equals supply. Such a neoclassical paradigm has been used to represent the new equilibrium in the long-term when all market adjustments have occurred. This framework is assumed in many integrated assessment models (*e.g.* Nordhaus, 1994).

8.7 Integration of impacts into the GEM-E3 PESETA Model

Each impact category has been modelled differently in the GEM-E3 model, depending on the interpretation of the direct effect.

The yield changes computed with the agriculture model have been interpreted as a productivity shock to the production side of the agriculture sector in the economy.

The main economic impacts of river flooding relate to damages in residential buildings (around 80% of the total impact). It has been assumed that households would repair buildings and replace lost equipment. This is interpreted as additional expenditure needed. The damages related to productive sectors are modelled as production and capital losses in the economy, representing only 20% of the damage from flood and thus only marginally affecting GDP.

In the coastal system assessment, the two main economic impacts estimated by the DIVA model are sea floods and migration costs. It has been assumed that sea floods lead to capital losses, while migration costs induce additional expenditure by households. For both river floods and coastal systems, this additional expenditure does not provide any welfare gain: it represents indeed a welfare *loss*, since households are forced to it due to climate change.

For tourism, it has been assumed that the redistribution of tourism within Europe leads to changes in exports; some countries have more international tourists that lead to higher expenditure within the country in the form of additional exports but leading also to reaction on the supply capacity. The reported results in tourism refer to the year 2040 in order to allow the model to adjust to the new export flows of the sector.

GDP and welfare have selected as the main variables to synthesize the economic impact. Welfare in CGE models measures the utility derived from household consumption and leisure time. Its evolution reflects the benefits for households from growth, while GDP growth reflects more the domestic economic activity growth. In the long-term reference scenario both indicators would evolve in parallel, but policies or climate change damage might induce some activity growth without generating welfare improvements (*e.g.* repairing houses after floods). The results of this study show that a significant share of welfare increase could be eroded by climate change induced damages (0.2%-1% annual losses).

8.8 Economic Impact Results

The consequences of climate change of the four impact categories can be valued in monetary or economic terms as they directly affect markets and, via the cross-sector linkages, the overall economy. The impacts of climate change affect GDP and the consumption behaviour of households, and therefore the welfare of households. Many economic impact assessments focus on the impacts on GDP. However, in the framework of the PESETA project the impact of climate change on household welfare seems the most appropriate metric to measure the influence of climate change on the economy for two reasons. Firstly, in CGE models (*i.e.* the GEM-E3 model) households usually maximise their utility or welfare level and not GDP. From this point of view, welfare changes give an indication of the deviation from the optimum situation the household would achieve without climate change (the reference scenario). GDP can be rather interpreted as a measure of the adjustment in the production or supply-side of the economy because of climate change.

A second reason to employ welfare changes rather than GDP is the way the climate sectoral shocks have been interpreted and implemented into the CGE GEM-E3 model. Indeed, while some impact categories (*e.g.* agriculture) have a direct effect on the production side of the economic system, other impacts, notably the damages due to floods, affect mainly the consumption possibilities of households and, therefore, household welfare, with and indirect effect on production activities.

The next subsections summarise the main results in welfare and GDP terms.

8.8.1 Welfare effects of climate change in Europe

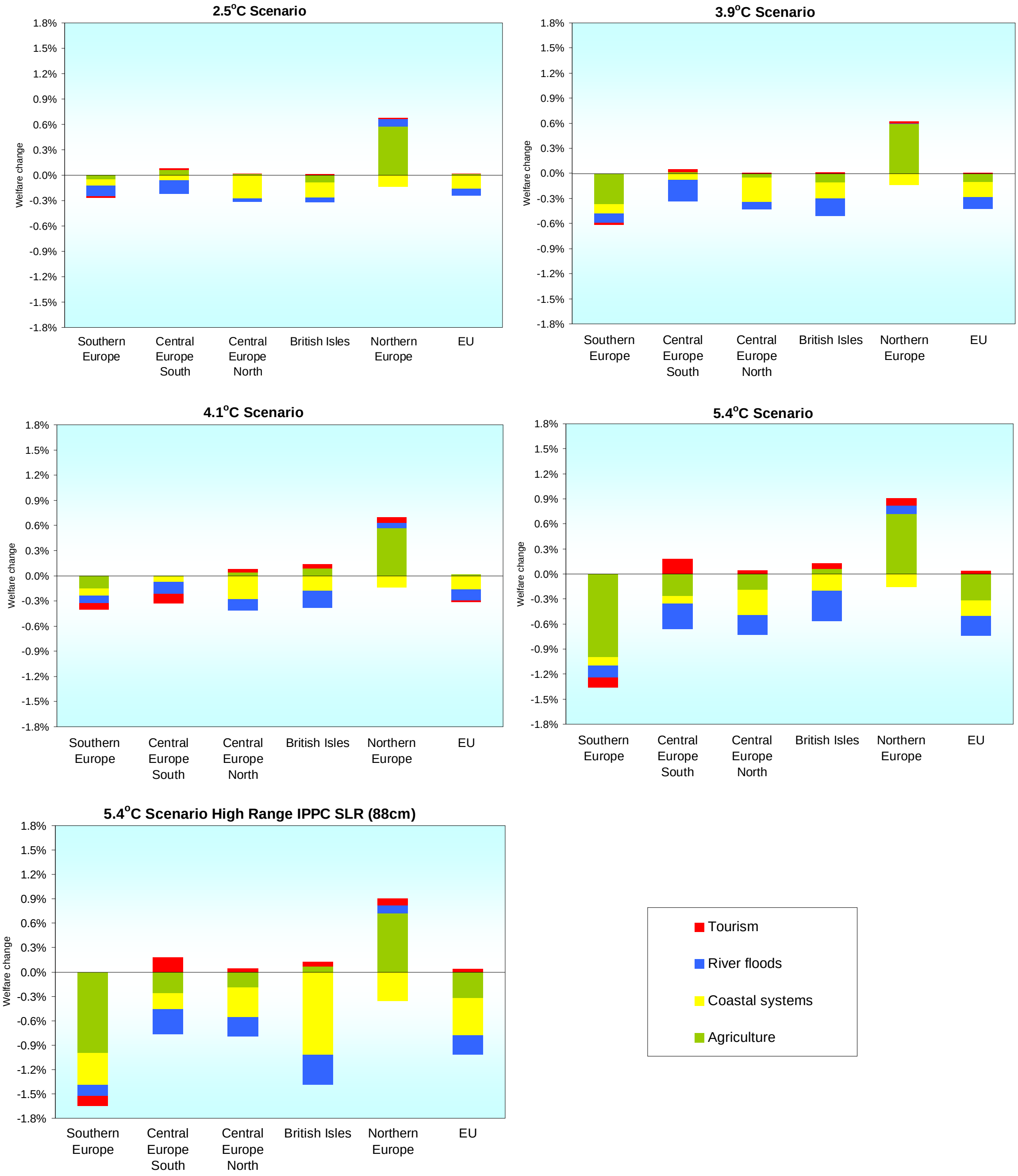
Table 29 presents the annual welfare changes by European region for the five climate futures considered in the 2080s: the four 2080s scenarios plus a the 5.4°C scenario with the highest range of SLR of the IPCC (88 cm). Figure 40 presents the same information with the sectoral breakdown.

Table 29. Household welfare annual effects in all impact categories for 2080s climate change scenarios in the current European economy

European regions*	Southern Europe	Central Europe South	Central Europe North	British Isles	Northern Europe	EU
Total Welfare Change (%)†						
2.5°C	-0.27	-0.14	-0.30	-0.31	0.55	-0.22
3.9°C	-0.62	-0.28	-0.42	-0.50	0.48	-0.42
4.1°C	-0.41	-0.33	-0.34	-0.24	0.56	-0.29
5.4°C	-1.36	-0.48	-0.68	-0.44	0.75	-0.70
5.4°C High Range IPCC SLR (88cm)	-1.65	-0.58	-0.75	-1.26	0.55	-0.98

*European regions: Southern Europe (Portugal, Spain, Italy, Greece, and Bulgaria), Central Europe South (France, Austria, Czech Republic, Slovakia, Hungary, Romania, and Slovenia), Central Europe North (Belgium, The Netherlands, Germany, and Poland), British Isles (Ireland and UK), and Northern Europe (Sweden, Finland, Estonia, Latvia, and Lithuania). †Household welfare is compared to the 2010 values of the baseline scenario.

Figure 40. 2080s climate in the current European economy: sectoral decomposition of annual household welfare changes for the EU and European regions



The aggregated impact on the four categories would lead to an EU annual welfare loss between 0.2% for the 2.5°C scenario and 1% per year for the 5.4°C scenario variant with a high SLR (88cm). In general, EU-aggregated economic impact figures hide a high variation across regions, climate scenarios and impact categories. In all scenarios, most regions would undergo welfare losses, with the exception of Northern Europe, where gains are in a range of 0.5% to 0.8% per year, largely driven by the improvement in agriculture yields. Southern Europe could be severely affected by climate change, with welfare losses around 1.4% for the 5.4°C scenario.

The sectoral and geographical decomposition of welfare changes under the 2.5°C and the 3.9°C scenarios shows that aggregated European costs of climate change are highest for agriculture, river flooding and coastal systems, much larger than for tourism. The British Isles, Central Europe North and Southern Europe appear the most sensitive areas. Moreover, moving from a European climate future of 2.5°C to one of 3.9°C aggravates agriculture impacts, river flooding potential and coastal systems impacts in almost all European regions. In the Northern Europe area, these impacts are offset by the increasingly positive effects related to agriculture.

The 5.4°C scenario leads to an annual EU welfare loss of 0.7%, with more pronounced impacts in most sectors in all EU regions and a non-linear response of damages to rising temperature. The agriculture sector is the most important impact category in the EU average: the significant damages in Southern Europe and Central Europe South are not compensated by the gains in Northern Europe. Impacts from river flooding are also more important in this case than in the other scenarios, with particular aggravation in the British Isles and Central Europe. In the 5.4°C scenario variant with the high SLR (88 cm), damages in coastal regions would become the most important impact category in the EU, especially in the British Isles.

8.8.2 GDP effects

The impact of climate change in GDP terms is estimated to be in a range between 0.2 and 0.5% for the EU depending on the climate scenario (Table 30), which would mean between 20 billion € for the 2.5°C scenario and 65 billion € for the 5.4°C scenario with high SLR. EU-wide production impacts due to river floods would be minor, around 0.1% GDP loss, mainly because most of the damage would be to residential buildings, *i.e.* welfare of households. Tourism impacts would also be very low in the EU, being between -0.1% and -0.03% in the Southern Europe region and for a similar range across all European regions in the 5.4°C scenario.

Agriculture-related productive impacts would be negative in most scenarios for all European regions, and mainly in Southern Europe, with the exception of Northern Europe, where gains would be in a range of 0.8% to 1.1% of GDP. The EU-aggregated effect would be in a range between 0% and -0.3% for the scenarios considered.

Concerning the impacts of SLR in coastal systems, GDP losses would happen in all European regions and all scenarios. Production losses would occur mainly in the Central Europe North and British Isles regions. Aggregated impacts for the EU would be in the neighbourhood of -0.2%.

Table 30. Annual economic impacts in agriculture, river basins, tourism and coastal systems for 2080s climate change scenarios in the current European economy

European regions*	Southern Europe	Central Europe South	Central Europe North	British Isles	Northern Europe	EU
Economic impacts as estimated by the agriculture model						
Welfare Change (%)‡						
2.5°C	-0.05	0.06	0.01	-0.09	0.58	0.01
3.9°C	-0.37	0.02	-0.05	-0.11	0.59	-0.10
4.1°C	-0.15	-0.01	0.04	0.09	0.56	0.02
5.4°C	-1.00	-0.27	-0.19	0.06	0.72	-0.32
GDP Change (%)‡						
2.5°C	-0.13	0.11	-0.02	-0.10	0.81	0.02
3.9°C	-0.52	0.06	-0.06	-0.11	0.85	-0.09
4.1°C	-0.22	0.00	0.05	0.12	0.76	0.04
5.4°C	-1.26	-0.28	-0.17	0.16	1.09	-0.29
Economic impacts as estimated by the river flooding model						
Welfare Change (%)‡						
2.5°C	-0.13	-0.16	-0.04	-0.06	0.09	-0.08
3.9°C	-0.11	-0.25	-0.09	-0.21	0.01	-0.14
4.1°C	-0.09	-0.15	-0.13	-0.20	0.07	-0.13
5.4°C	-0.14	-0.31	-0.24	-0.37	0.10	-0.24
GDP Change (%)‡						
2.5°C	-0.01	-0.01	0.00	0.00	0.00	-0.01
3.9°C	-0.01	-0.01	-0.01	-0.01	0.00	-0.01
4.1°C	0.00	-0.01	-0.01	-0.01	0.00	-0.01
5.4°C	0.00	-0.01	-0.02	-0.02	0.00	-0.01
Economic impacts as estimated by the coastal system model						
Welfare Change (%)‡						
2.5°C	-0.07	-0.06	-0.27	-0.17	-0.13	-0.16
3.9°C	-0.11	-0.08	-0.29	-0.19	-0.14	-0.18
4.1°C	-0.09	-0.06	-0.28	-0.18	-0.14	-0.17
5.4°C	-0.10	-0.09	-0.30	-0.20	-0.15	-0.18
5.4°C High Range IPCC SLR (88cm)	-0.38	-0.19	-0.37	-1.02	-0.35	-0.46
GDP Change (%)‡						
2.5°C	-0.05	-0.05	-0.38	-0.23	-0.11	-0.19
3.9°C	-0.05	-0.05	-0.41	-0.24	-0.12	-0.20
4.1°C	-0.05	-0.05	-0.39	-0.23	-0.11	-0.20
5.4°C	-0.05	-0.05	-0.42	-0.25	-0.13	-0.21
5.4°C High Range IPCC SLR (88cm)	-0.04	-0.06	-0.50	-0.26	-0.16	-0.24
Economic impacts as estimated by the tourism model						
Welfare Change (%)‡						
2.5°C	-0.02	0.02	0.01	0.01	0.01	0.00
3.9°C	-0.03	0.03	0.01	0.01	0.02	0.01
4.1°C	-0.08	-0.11	0.03	0.05	0.07	-0.02
5.4°C	-0.12	0.18	0.04	0.06	0.08	0.04
GDP Change (%)‡						
2.5°C	-0.01	0.00	0.00	0.00	0.00	0.00
3.9°C	-0.01	0.01	0.00	0.00	0.00	0.00
4.1°C	-0.03	-0.03	0.01	0.01	0.02	-0.01
5.4°C	-0.05	0.03	0.02	0.01	0.02	0.01

*European regions: Southern Europe (Portugal, Spain, Italy, Greece, and Bulgaria), Central Europe South (France, Austria, Czech Republic, Slovakia, Hungary, Romania, and Slovenia), Central Europe North (Belgium, The Netherlands, Germany, and Poland), British Isles (Ireland and UK), and Northern Europe (Sweden, Finland, Estonia, Latvia, and Lithuania). ‡Household welfare and GDP are compared to the 2010 values of the baseline scenario.

9 CONCLUSIONS

How much would climate change damage the European economy? Which geographical areas will be the most affected? Which sectors are most vulnerable? These questions are relevant for designing climate adaptation policies, which minimise adverse impacts and take advantage of existing opportunities.

The PESETA integrated assessment aims at better understanding the geographical and sectoral patterns of the physical and economic effects of climate change in Europe. PESETA considers the impacts of climate change in agriculture, river basins, coastal systems, tourism and human health. Other key impacts, such as effects on forestry, impacts in ecosystems and biodiversity and catastrophic events, have not yet been analysed. Moreover, the damages due to climate change has been evaluated, without taking into account the fact that economic growth will mean higher exposure and vulnerability to climate change. Therefore, the PESETA project underestimates the impacts of climate change in Europe to a large extent.

The study has implemented a detailed bottom-up methodology using high resolution climate data (50 km x 50 km, daily) and sector-specific impact models. Such approach allows quantifying potential impacts of climate change at regional and sectoral dimensions relevant for decision makers in adaptation policy.

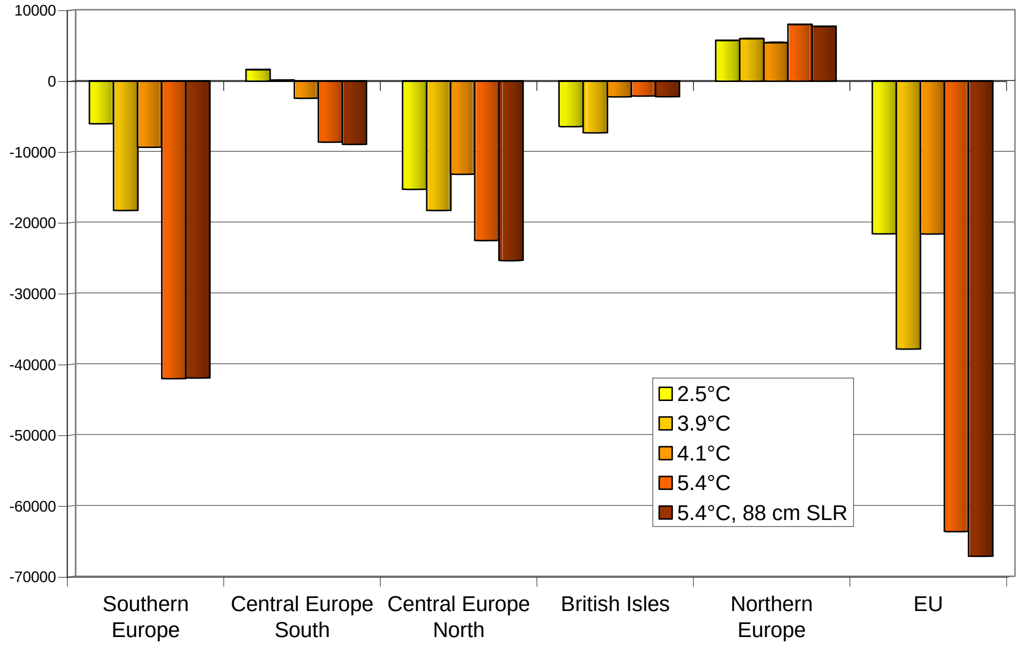
The assessment has been made for the 2020s and the 2080s. Four future climate scenarios are considered for the 2080s to account for the uncertainty in emission drivers and climate modelling. The sea level rise (SLR) in the scenarios ranges between 49 cm and 88 cm. The projected increase of global temperature by the 2080s, compared to that of the 1970s, is in a range between 2.3°C (B2 SRES scenario) and 3.1°C (A2 SRES scenario). Note that compared to the preindustrial level, the global temperature increase of the PESETA scenarios are in a range between 2.6°C and 3.4°C.

According to the regional climate models of the project, the temperature increase in the EU compared to the 1970s would be larger, in a range between 2.5°C and 5.4°C. In the text the four 2080s scenarios considered are named after the EU temperature increase: 2.5°C, 3.9°C, 4.1°C and 5.4°C.

9.1 Main Findings

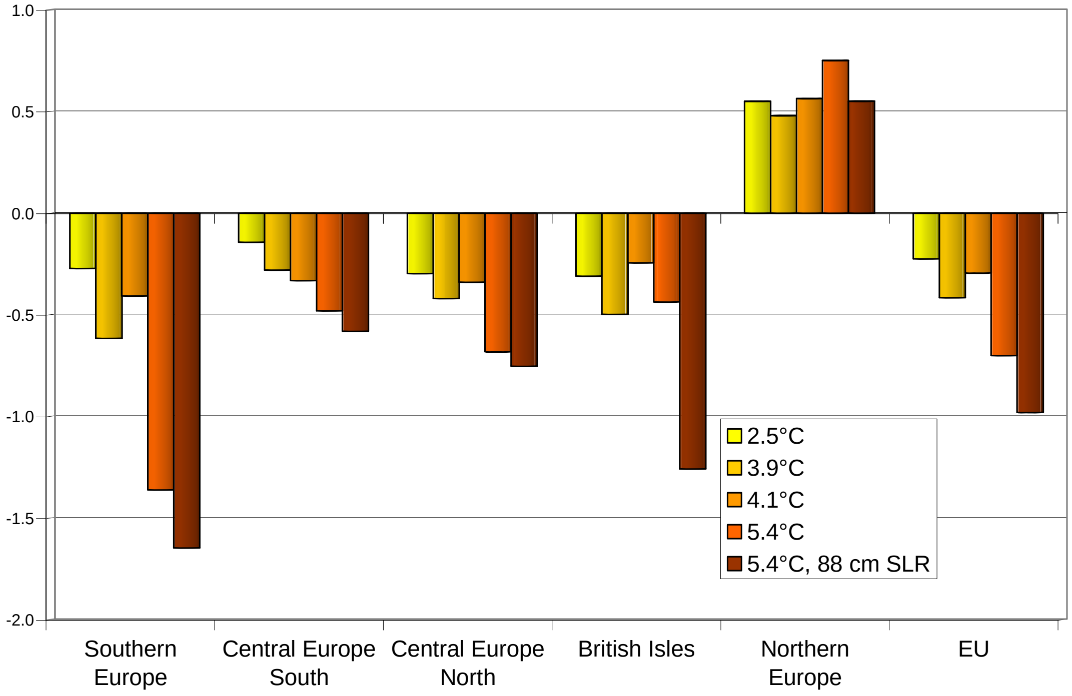
Without public adaptation to climate change and if the climate of the 2080s occurred today, the annual damage of climate change to the EU economy in terms of GDP loss is estimated to be between 20 billion € for the 2.5°C scenario and 65 billion € for the 5.4°C scenario (Figure 41). Damages would occur mainly in the Southern Europe and Central Europe North regions.

Figure 41. Annual damage in terms of GDP loss (million €)



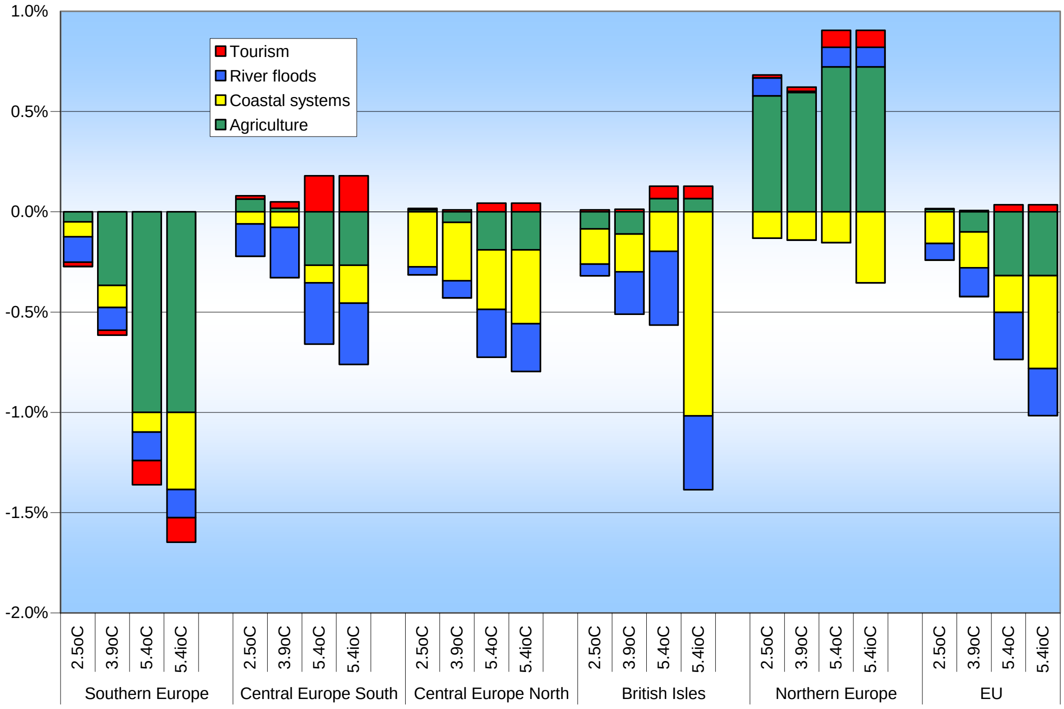
Yet those figures underestimate the losses in terms of welfare. For instance the repairing of damages to residential buildings due to river floods increases production while reducing the consumption possibilities of households and, therefore, their welfare. The future climate as today would lead to an EU annual welfare loss (Figure 42) of between 0.2% for the 2.5°C scenario and 1% for the 5.4°C scenario with high SLR (88 cm). When compared to the historic EU annual growth of welfare (around 2%), climate change could reduce the annual welfare improvement rate to between 1.8% (for the scenario with a 0.2% welfare loss) and 1% (for the scenario with a 1% welfare loss).

Figure 42. Annual damage in terms of welfare change (%)



Another finding of the study is that the aggregated estimates of impacts mask large sectoral and regional variability (Figure 43). Under the 5.4°C scenario with high SLR (5.4i°C in Figure 43), most losses occur because of the damages in the agricultural sector (production losses), river floods (damages to residential buildings) and, particularly, coastal systems (sea floods and migration costs).

Figure 43. Sectoral decomposition of regional welfare changes



Concerning the regional pattern of damages, the Southern European area is the region with highest welfare losses, ranging between 0.3% and 1.6%. Welfare in this region steeply deteriorates in the scenario with the highest temperature increase. All impact categories are negative, the damages in the agricultural sector being the most important ones. Tourism revenues could diminish up to 5 billion € per year.

Central Europe is also affected by climate change. The welfare losses in the Central Europe South region range between 0.1% and 0.6%. The damage due to river floods seems to be the most important impact category. The warmest scenario would largely damage the agricultural sector. The tourism sector would benefit from climate change.

The Central Europe North region would experience welfare losses between 0.3% and 0.7%. The major negative impacts are damages to coastal systems. Impacts due to river floods could reach a cost of 5 billion € per year. The projected impact on the tourism sector is slightly positive.

The British Isles would face welfare losses in a similar range as Central Europe, with the exception of the 5.4°C scenario with high SLR, where the welfare loss would reach 1.3%. Impacts due to river floods are quite negative in all scenarios, as well as impacts to coastal systems, particularly under an SLR of 88 cm. The impacts on the tourism sector are positive, with up to 4.5 billion € in additional tourist revenues.

Northern Europe is the only EU area with welfare gains in all scenarios, ranging between 0.5% and 0.7%, mainly thanks to the large positive impacts in the agricultural sector, fewer river floods damages and higher tourism revenues. However, damages in coastal systems could be significant.

Public adaptation measures have only been modelled in the coastal areas assessment, due to data gaps and methodological limitations in the rest of sectors. The PESETA study shows that adaptation can largely reduce the impacts in coastal systems. Earlier assessments also indicate that adaptation policies could be particularly cost-efficient there (Tol *et al.*, 2008).

Additionally, PESETA analyses the impacts of climate change on human health in the 2080s without acclimatisation. The estimated range of increase in annual heat-related mortalities is between 60,000 and 165,000, while the range of diminution of cold-related mortalities is between 60,000 and 250,000. Acclimatisation to warmer climate in summer would reduce the projected mortality changes by a factor of five. Heatwaves have not been considered in the project.

The aggregated damages of PESETA can be compared to other studies. The PESETA estimates are lower because the coverage of impacts with market effects is narrower in the PESETA project and the non market components of the damages are not taken into account either. Thus, for instance, Fankhauser and Tol (1996) estimate the overall GDP loss for the EU at 1.4%, under a scenario doubling the CO_2–equivalent concentration (to 550 ppmv), compared to preindustrial levels. The PESETA 5.4°C scenario with high SLR, which would lead to a concentration level of 710 ppmv, has an estimated annual GDP and welfare loss of 0.5% and 1%, respectively.

9.2 Caveats and Uncertainties

When interpreting the results from the PESETA project, it is essential to take into account the many caveats of the research project, mainly arisen from the many uncertainties affecting all stages of the integrated assessment.

Uncertainties are inherent to climate impact assessment as they are present in all stages of the integrated assessment (IPCC, 2004) and, in particular, are associated with each of the specific models used: climate models, sectoral physical impact models and economic valuation models. Uncertainty appears in the input side of the model (value uncertainty) and in the structural specification of the model (structural uncertainty).

There are four main sources of uncertainty in the overall assessment, associated with:

- The socioeconomic scenarios driving global GHG emissions.
- The sensitivity of the climate model to GHG concentration.
- The assessment of the physical impact for a given climate scenario.
- The economic valuation of the physical impacts.

Four climate scenarios for the 2080s have been considered in order to address the two first items (Section 2). The climate scenarios can affect very significantly the results.

Concerning the third source of uncertainty (related to the physical impact models), each sectoral physical model has its own set of uncertain parameters, and some cases have been explored.

Regarding the economic valuation, in order to avoid making assumptions about the (uncertain) characteristics of the economy in the 2080s, the overall impact is measured against the current economic structure. This approach is justified because PESETA does not aim at making projections or forecasts, but rather at putting in relative terms the sectoral and spatial pattern of impacts in the EU under different climate scenarios.

As already noted, the PESETA study assessment cannot capture the complete range of the many possible impacts of climate change on the European economy. Not all impacts that are valued by markets have been considered (*e.g.* transport, energy, forestry). The explicit consideration of the effect due to climate extremes has only been made in the analysis of river floods, and partly in coastal systems (sea floods). Non-market impact categories have been studied to a very limited extent (human health effects related to changes in average temperatures). Most of the non market components in the welfare losses for the impact categories considered are not included either. Other key impacts, *e.g.* on biodiversity loss, have not been taken into account. Major economic damages because of catastrophic events have not been considered either.

Furthermore, from a methodological point of view, while the five impact models have employed the same climate data, possible inter-sectoral effects could be further explored, such as the consistency of the tourism, agriculture and river floods sectors concerning water supply and demand.

Another limitation of the study is that the effects of climate change in the rest of the world and their impact for the EU have not been taken into account. For instance, migration issues or potential rising agriculture costs globally could have costs or benefits in the EU. Land use-specific policies have not been considered either.

9.3 Further research

What follows is a tentative list of possible relevant issues which could orientate future research, without intending to be exhaustive (Carter *et al.*, 2007). As the Commission White Paper on adaptation remarks (European Commission, 2009a), there will be a growing need of high resolution in climate change impact, adaptation and vulnerability (CCIAV) assessments, mainly for the design and implementation of adaptation policies. This general need has the following dimensions:

- Space: the regional and local (municipality) scales.

- Time horizon: includes particularly the next few decades, in addition to the usual time window of the end of the XXI century.

- Sectors and effects: further develop and improve modelling systems able to quantify the consequences of climate change both on market and non-market sectors, also considering the effects due to changes in climate variability and extremes, in addition to the usual analysis of the climate variable mean-related effects. In particular, there seems to be a need to develop methods to quantify the effects of catastrophic events.

- The cost-benefit analysis of adaptation strategies is not readily available on a European scale and it is a research area that deserves further efforts.

Moreover, equity issues could be considered more explicitly, going beyond the standard efficiency analysis. Gainers and losers *e.g.* per social or income group could be identified for the space and time resolution of the adaptation assessments.

Concerning the methodological framework, firstly, the cascade of uncertainties in CCIAV assessments could be dealt with in a more systematic way, *i.e.* with a probabilistic approach. Secondly, the consistency of the CCIAV assessments could be improved *e.g.* by introducing dynamic land-use scenarios and cross-sectoral consistency issues.

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11 ANNEX. RESULTS FOR THE EU AND EUROPEAN REGIONS

The tables of this Annex present for all the scenarios the following information: the main climate data (temperature, precipitation and SLR), the annual physical impacts for each impact category and the annual welfare effects (computed by the GEM-E3 PESETA model).

Table 31. Summary of results for the EU

Climate Change Scenarios					
	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Δ Temperature (ºC) *	2.5	3.9	4.1	5.4	5.4
Δ Precipitation (%) *	1	-2	2	-6	-6
SLR (cm)	49	56	51	59	88
Annual Physical Impacts (changes)					
	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Agriculture ‡					
Yields (%)	3	-2	3	-10	-10
River floods †					
Affected Population (1000s/year)	276	318	251	396	396
Economic damage (million €)	7,728	11,469	8,852	15,032	15,032
Coastal systems (non adaptation) ††					
People flooded (1000s/year)	775	1,225	851	1,353	5,552
Tourism **					
Bed nights (%)	1	1	6	7	7
Tourism expenditure (million €)	1,858	3,262	13,360	15,268	15,268
Human Health (country-specific function) *					
Heat-mortality rate (per 100,000)	12	22	19	33	33
Cold-mortality rate (per 100,000)	-21	-37	-39	-52	-52
Annual Welfare Impacts (not considering human health)					
	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Agriculture	0.01%	-0.10%	0.02%	-0.32%	-0.32%
River floods	-0.08%	-0.14%	-0.13%	-0.24%	-0.24%
Coastal systems (no adaptation)	-0.16%	-0.18%	-0.17%	-0.18%	-0.46%
Tourism	0.00%	0.01%	-0.02%	0.04%	0.04%
TOTAL	-0.22%	-0.42%	-0.29%	-0.70%	-0.98%

*Increase in the period 2071–2100 compared to 1961–1990. ‡Yield changes compared to 1961–1990 period and weighted by the country agriculture value added. †Differences compared to the 1961–1990 period. ††Differences compared to 1995. **Differences compared to 2005.

Table 32. Summary of results for Northern Europe

Climate Change Scenarios	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Δ Temperature (ºC) *	2.9	4.1	3.6	4.7	4.7
Δ Precipitation (%) *	10	10	19	24	24
SLR (cm)	49	56	51	59	88

Physical Impacts	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Agriculture ‡					
Yields (%)	37	39	36	52	52
River floods †					
Affected Population (1000s/year)	-2	9	-4	-3	-3
Economic damage (million €)	-325	20	-100	-95	-95
Coastal systems (non adaptation) ††					
People flooded (1000s/year)	20	40	20	56	272
Tourism **					
Bed nights (%)	4	6	20	25	25
Tourism expenditure (million €)	443	642	1,888	2,411	2,411
Human Health (country-specific function) *					
Heat-mortality rate (per 100,000)	8	15	9	14	14
Cold-mortality rate (per 100,000)	-8	-13	-11	-16	-16

Welfare Impacts (not considering human health)	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Agriculture	0.58%	0.59%	0.56%	0.72%	0.72%
River floods	0.09%	0.01%	0.07%	0.10%	0.10%
Coastal systems (no adaptation)	-0.13%	-0.14%	-0.14%	-0.15%	-0.35%
Tourism	0.01%	0.02%	0.07%	0.08%	0.08%
TOTAL	0.55%	0.48%	0.56%	0.75%	0.55%

*Increase in the period 2071–2100 compared to 1961–1990. ‡Yield changes compared to 1961–1990 period and weighted by the country agriculture value added. †Differences compared to the 1961–1990 period. ††Differences compared to 1995. **Differences compared to 2005.

Table 33. Summary of results for British Isles

Climate Change Scenarios	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Δ Temperature (ºC) *	1.6	2.5	3.2	3.9	3.9
Δ Precipitation (%) *	-5	-2	10	5	5
SLR (cm)	49	56	51	59	88

Physical Impacts	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Agriculture ‡					
Yields (%)	-9	-11	15	19	19
River floods †					
Affected Population (1000s/year)	12	48	43	79	79
Economic damage (million €)	755	2,854	2,778	4,966	4,966
Coastal systems (non adaptation) ††					
People flooded (1000s/year)	70	136	86	207	1279
Tourism **					
Bed nights (%)	3	4	14	18	18
Tourism expenditure (million €)	680	932	3,587	4,546	4,546
Human Health (country-specific function) *					
Heat-mortality rate (per 100,000)	4	8	7	10	10
Cold-mortality rate (per 100,000)	-27	-48	-57	-75	-75

Welfare Impacts (not considering human health)	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Agriculture	-0.09%	-0.11%	0.09%	0.06%	0.06%
River floods	-0.06%	-0.21%	-0.20%	-0.37%	-0.37%
Coastal systems (no adaptation)	-0.17%	-0.19%	-0.18%	-0.20%	-1.02%
Tourism	0.01%	0.01%	0.05%	0.06%	0.06%
TOTAL	-0.31%	-0.50%	-0.24%	-0.44%	-1.26%

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*Increase in the period 2071–2100 compared to 1961–1990. ‡Yield changes compared to 1961–1990 period and weighted by the country agriculture value added. †Differences compared to the 1961–1990 period. ††Differences compared to 1995. **Differences compared to 2005.

Table 34. Summary of results for Central Europe North

Climate Change Scenarios	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Δ Temperature (ºC) *	2.3	3.7	4.0	5.5	5.5
Δ Precipitation (%) *	3	1	6	-1	-1
SLR (cm)	49	56	51	59	88

Physical Impacts	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Agriculture ‡					
Yields (%)	-1	-3	2	-8	-8
River floods †					
Affected Population (1000s/year)	103	110	119	198	198
Economic damage (million €)	1,497	2,201	3,006	5,327	5,327
Coastal systems (non adaptation) ††					
People flooded (1000s/year)	345	450	347	459	2,398
Tourism **					
Bed nights (%)	2	3	13	16	16
Tourism expenditure (million €)	634	920	3,291	4,152	4,152
Human Health (country-specific function) *					
Heat-mortality rate (per 100,000)	12	24	19	33	33
Cold-mortality rate (per 100,000)	-14	-25	-26	-37	-37

Welfare Impacts (not considering human health)	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Agriculture	0.01%	-0.05%	0.04%	-0.19%	-0.19%
River floods	-0.04%	-0.09%	-0.13%	-0.24%	-0.24%
Coastal systems (no adaptation)	-0.27%	-0.29%	-0.28%	-0.30%	-0.37%
Tourism	0.01%	0.01%	0.03%	0.04%	0.04%
TOTAL	-0.30%	-0.42%	-0.34%	-0.68%	-0.75%

*Increase in the period 2071–2100 compared to 1961–1990. ‡Yield changes compared to 1961–1990 period and weighted by the country agriculture value added. †Differences compared to the 1961–1990 period. ††Differences compared to 1995. **Differences compared to 2005.

Table 35. Summary of results for Central Europe South

Climate Change Scenarios

	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Δ Temperature (ºC) *	2.4	3.9	4.4	6.0	6.0
Δ Precipitation (%) *	2	-2	-4	-16	-16
SLR (cm)	49	56	51	59	88

Physical Impacts

	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Agriculture ‡					
Yields (%)	5	5	3	-3	-3
River floods †					
Affected Population (1000s/year)	117	101	84	125	125
Economic damage (million €)	3,495	4,272	2,876	4,928	4,928
Coastal systems (non adaptation) ††					
People flooded (1000s/year)	82	144	85	158	512
Tourism **					
Bed nights (%)	2	3	14	17	17
Tourism expenditure (million €)	925	1,763	7,673	9,556	9,556
Human Health (country-specific function) *					
Heat-mortality rate (per 100,000)	17	31	31	52	52
Cold-mortality rate (per 100,000)	-20	-37	-39	-53	-53

Welfare Impacts (not considering human health)

	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Agriculture	0.06%	0.02%	-0.01%	-0.27%	-0.27%
River floods	-0.16%	-0.25%	-0.15%	-0.31%	-0.31%
Coastal systems (no adaptation)	-0.06%	-0.08%	-0.06%	-0.09%	-0.19%
Tourism	0.02%	0.03%	-0.11%	0.18%	0.18%
TOTAL	-0.14%	-0.28%	-0.33%	-0.48%	-0.58%

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*Increase in the period 2071–2100 compared to 1961–1990. ‡Yield changes compared to 1961–1990 period and weighted by the country agriculture value added. †Differences compared to the 1961–1990 period. ††Differences compared to 1995. **Differences compared to 2005.

Table 36. Summary of results for Southern Europe

Climate Change Scenarios

	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Δ Temperature (ºC) *	2.6	4.1	4.3	5.6	5.6
Δ Precipitation (%) *	-7	-15	-13	-28	-28
SLR (cm)	49	56	51	59	88

Physical Impacts

	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Agriculture ‡					
Yields (%)	0	-12	-4	-27	-27
River floods †					
Affected Population (1000s/year)	46	49	9	-4	-4
Economic damage (million €)	2,306	2,122	291	-95	-95
Coastal systems (non adaptation) ††					
People flooded (1000s/year)	258	456	313	474	1091
Tourism **					
Bed nights (%)	-1	-1	-2	-4	-4
Tourism expenditure (million €)	-824	-995	-3,080	-5,398	-5,398
Human Health (country-specific function) *					
Heat-mortality rate (per 100,000)	11	18	18	28	28
Cold-mortality rate (per 100,000)	-28	-52	-49	-64	-64

Welfare Impacts (not considering human health)

	2.5°C	3.9°C	4.1°C	5.4°C	5.4°C high SLR
Agriculture	-0.05%	-0.37%	-0.15%	-1.00%	-1.00%
River floods	-0.13%	-0.11%	-0.09%	-0.14%	-0.14%
Coastal systems (no adaptation)	-0.07%	-0.11%	-0.09%	-0.10%	-0.38%
Tourism	-0.02%	-0.03%	-0.08%	-0.12%	-0.12%
TOTAL	-0.27%	-0.62%	-0.41%	-1.36%	-1.65%

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*Increase in the period 2071–2100 compared to 1961–1990. ‡Yield changes compared to 1961–1990 period and weighted by the country agriculture value added. †Differences compared to the 1961–1990 period. ††Differences compared to 1995. **Differences compared to 2005.

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Abstract

The PESETA research project integrates a set of high-resolution climate change projections and physical models into an economic modelling framework to quantify the impacts of climate change on vulnerable aspects of Europe. Four market impact categories are considered (agriculture, river floods, coastal systems, and tourism) and one non-market category (human health).

Considering the market impacts, without public adaptation and if the climate of the 2080s occurred today, the EU annual welfare loss would be in the range of 0.2% to 1%, depending on the climate scenario. However, there is large variation across different climate futures, EU regions and impact categories. Scenarios with warmer temperatures and higher sea level rise result in more severe economic damage for the EU. Southern Europe, the British Isles and Central Europe North appear to be the most sensitive regions to climate change. Northern Europe is the only region with net economic benefits, mainly driven by the positive effects in agriculture. Concerning the contribution to the overall effects, coastal systems, agriculture and river flooding are the most important ones.

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