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Paul Watkiss, Lisa Horrocks, Stephen Pye, Alison Searl and Alistair Hunt

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AEA Technology plc

# Preface

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 effects induced by climate change in Europe over the 21st century. PESETA studies the following impact categories: 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 estimates of the impacts for alternative climate futures. The project estimates the impacts for large geographical regions of Europe.

The Joint Research Centre (JRC) has 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.

The final report of the PESETA project (please visit http://peseta.jrc.ec.europa.eu/) is accompanied by a series of technical publications. This report presents in detail the human health impact assessment, methodology and results.

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# Summary

The aim of the PESETA project is to assess the impacts of climate change in Europe, including health effects. The most important health effects from future climate change are projected to include:

- Increases in summer heat related mortality (deaths) and morbidity (illness);
- Decreases in winter cold related mortality (deaths) and morbidity (illness);
- Changes in the disease burden e.g. from vector-, water- or food-borne disease;
- Increases in the risk of accidents and wider well being from extreme events (storms and floods).

The PESETA health project has assessed these effects in Europe. These include both positive and negative effects on health, and show strong patterns of regional variation across Europe.

The analysis has undertaken a detailed bottom-up analysis of summer and winter temperature-related mortality. This shows that Europe's changing climate will have significant additional effects on heat and cold related mortality, measured in tens of thousand of deaths each year (and economic effects measured in tens of billions of Euro). With a warmer climate, it is expected that there will be more heat related deaths in Europe, but also fewer cold-related deaths. A number of approaches have been applied in this study, using different temperature-mortality relationships and assumptions. Taking Europe as a whole, the climate change induced winter benefits from reduced cold-related mortality are generally larger than the climate change induced summer impacts from higher heat-related mortality. However, this is not the case for the A2 scenario using one of the sets of functions. It is clear that the net effects predicted and the spatial distribution across Europe varies according to the quantification method, and most specifically the assumptions about acclimatisation. Because of this, the results presented here should only be considered as an initial, interim assessment until better information becomes available and some parts of the methods are elaborated in more detail.

The analysis has also undertaken a detailed bottom-up analysis of food borne disease in Europe which shows that the additional number of cases (particularly with under reporting of disease levels) could be significant in terms of both physical impacts (tens of thousands of cases per year) and economic costs (billions). Finally the study has progressed an initial

analysis of the mental health effects of coastal flooding (linking the output from one of the other PESETA projects), which shows that under high sea level rise scenarios, the number of cases and economic costs could also be significant.

The analysis also shows that there are significant differences in effects between alternative future climate scenarios (e.g. between the A2 and B2 scenarios). For some endpoints, the difference is very noticeable, e.g. with a 40 to 50 % reduction in physical impacts for heat related mortality and cases of salmonella between the A2 and B2 scenarios for the 2071-2100 time period. The impact of different climate model data is also important. Two models were used for the analysis and these gave results that differed by as much as 50 %. This highlights that the uncertainties with prediction are significant (especially when wider uncertainty are taken account of).

A consideration of adaptation, whether through addressing heat exposure, through control of food borne disease, or through flood protection, shows that it offers significant reductions in impacts at potentially low cost.

A number of possible policy responses are identified. The most important of these relate to further extension or refinement of the heat health warning systems emerging in Europe. There is also a need to consider adaptation responses such as air conditioning that can help populations cope with future temperature extremes, but which raise an important link with mitigation efforts - conventional systems will increase energy consumption and increase GHG emissions. There is therefore a need to decouple responses to warmer climates from energy intensive air conditioning, e.g. with passive ventilation systems, behavioural changes, etc.

Finally, it is highlighted that there are likely to be many other health effects from climate change in Europe, in addition to those assessed here. These are identified in outlining a set of possible research priorities, which include direct effects within Europe, cross-sectoral effects, and the implications to Europe from global health effects (particularly in developing countries).

# 1. Introduction

Traditionally the policy debate on climate change has focused on the costs of greenhouse gas emissions reductions, i.e., mitigation. However, there is increasing interest in the economic costs of climate change impacts (also known as the 'costs of inaction') and the role that adaptation has in reducing these impacts.

The *PESETA* project (*Projection of Economic Impacts of Climate Change in Sectors of Europe based on bottom up Analysis*) aims to assess the impacts of climate change in Europe, and to progress to an economic analysis of these impacts. It aims to help progress the research priorities identified in the European Communication on Climate Change[1]. As part of this research project, human health has been identified as one of the priority areas for assessment. This report provides a summary of the detailed PESETA analysis of health effects of a climate change in Europe.

The final report of the PESETA project is available at the Institute for Prospective Technological Studies (JRC-IPTS) website (please visit http://peseta.jrc.ec.europa.eu/) (Ciscar *et al.*, 2009).

## 1.1. Climate change impacts on human health

Climate change has a range of complex inter-linkages with health. These include direct impacts, such as temperature-related illness and death, and the health impacts of extreme weather events. It also includes other impacts that follow more indirect pathways such as those that give rise to water- and food-borne diseases; vector-borne diseases; or food and water shortages. It can also include wider effects on health and well-being[2].

**Temperature**

There is a direct relationship between mortality and temperature that differs by climatic zone and geographical area. High ambient temperature is associated with mortality from heat

[1] Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions 'Winning the Battle Against Climate Change (SEC(2005)180.

[2] It is also highlighted that good public health depends on safe drinking water, sufficient food, secure shelter, and good social conditions, all of which may be affected by a changing climate – and are likely to particularly important in the developing country context.

stroke, and also illnesses (e.g. cardiovascular diseases). The most vulnerable are those over the age of 65 years. Climate projections indicate an increase in average temperatures and also increased incidence of heatwaves that are expected to increase these impacts.

There have been some observed effects of heat related mortality in recent years in Europe. The summer heat waves in 2003 claimed more than 35 000 excess deaths across Europe (EEA 2004: Pirard, et al. 2005)). There are also some predictions of the future increase in heat related mortality (e.g. McMichael, 2004) but these tend to be at a highly aggregated resolution for example looking at Europe as a whole region or a small number of sub-regions.

However, rising temperatures will also reduce winter excess deaths. At present cold temperatures leads to more deaths than warm/hot temperatures in Europe. A warmer climate will have particular benefits in northern latitudes of Europe.

**Food borne disease**

Temperature can influence the transmission of salmonella infections (food borne disease), and has been estimated to be associated with about 35 % of all recorded cases (including in the Netherlands, England, Poland, Switzerland and Spain) (Kovats et al., 2004). Cases of salmonella increase by around 5–10 % for each degree increase in weekly temperatures, above a threshold of around 5 °C (with key factors being inappropriate food preparation and storage preceding consumption).

**Vector-borne disease**

Climate is important in determining the geographical range of vectors carrying a range of diseases. There have been increases in incidence of malaria, tick-borne encephalitis, Lyme disease, and Leishmaniasis in Europe over recent decades, though there are many additional factors associated with these increases (e.g. the influence of increased travel, changes in leisure activity affecting exposure, levels of reporting etc.). These vector borne diseases are more of a concern in global studies due to their potential importance in developing countries (e.g. Parry et al, 2001: 2004: McMichael, 2004), though climate induced changes (localised outbreaks) are possible in Europe.

**Extreme events – floods and storms**

Floods and storms are the most common natural disasters causing loss of life and economic damage in Europe. Adverse health impacts associated with flooding include direct physical effects (drowning and injuries), but also wider effects on well being (e.g. mental illnesses from the effect of flooding and displacement). Between 1975 and 2001, the annual number of flood events increased and the number of people affected by floods rose significantly (EEA, 2004).

### Acclimatisation and Adaptation

The health outcomes above are influenced by acclimatisation and adaptation. Acclimatisation includes those elements of physiological and behavioural change that take place autonomously and automatically by individuals and within populations, whilst adaptation are defined here as those actions taken specifically in a planned and proactive way to address climate change.

There are emerging studies on adaptation strategies that can be implemented by health sectors (e.g. see the cCASHh project[3]), most of which build on well-established public health approaches.

[3] Menne and Ebi (Eds), 2006: Climate change and adaptation strategies for human health. WHO (Europe).

## 2. Methodology

This report presents a summary of the assessment of impacts of climate change on human health in Europe, using a quantified bottom-up modelling analysis of the impact of high and low temperatures on mortality across Europe, and of temperature on cases of salmonella.

Impacts have been explored for two time periods (the period 2011 to 2040 and 2071- 2100), for two climate scenarios (based on IPCC A2 and B2), and a number of different climate model projections. In addition a more exploratory analysis has been made on the potential health effects from flooding and there is a discussion of the impacts from vector-borne diseases in Europe.

### 2.1. General approach

The analysis in PESETA uses a detailed bottom-up impact pathway approach. The method for combines current health impact assessment and valuation models (built within databases and Geographical Information Systems) with daily climate data and empirical climate-health relationships (derived from epidemiological studies), processed within a Fortran environment. This enables the analysis to estimate the additional deaths attributable to heat and cold stress, and additional cases of salmonella attributable to warmer temperatures across Europe.

The analysis works on a 50 km by 50 km grid resolution across Europe. The daily responses are aggregated to provide an average annual percentage change in mortality (or numbers of hospital admissions or salmonella cases) within each grid cell, for each year within a 30-year climatological period. Different assumptions for acclimatisation are combined with the climate-health functions. The quantitative modelling aspects are illustrated below.

The annual figures for temperature-related changes are combined with gridded socio-economic data on population and mortality in a database environment to provide the average number of additional deaths (or hospital admissions or salmonella cases) in each grid cell for each year. The annual estimates are averaged across the 30-year climatological period to give the projection of health impacts of climate change coupled with socio-economic change for that period. These projections can then be compared with the number of deaths, hospital admissions and salmonella cases relating to socio-economic changes alone (i.e., calculated for the future period from a combination of present-day (baseline) climate and projected future socio-economic conditions). The difference between these two values provides the additional deaths, hospital admissions and salmonella cases induced by the climate change alone.

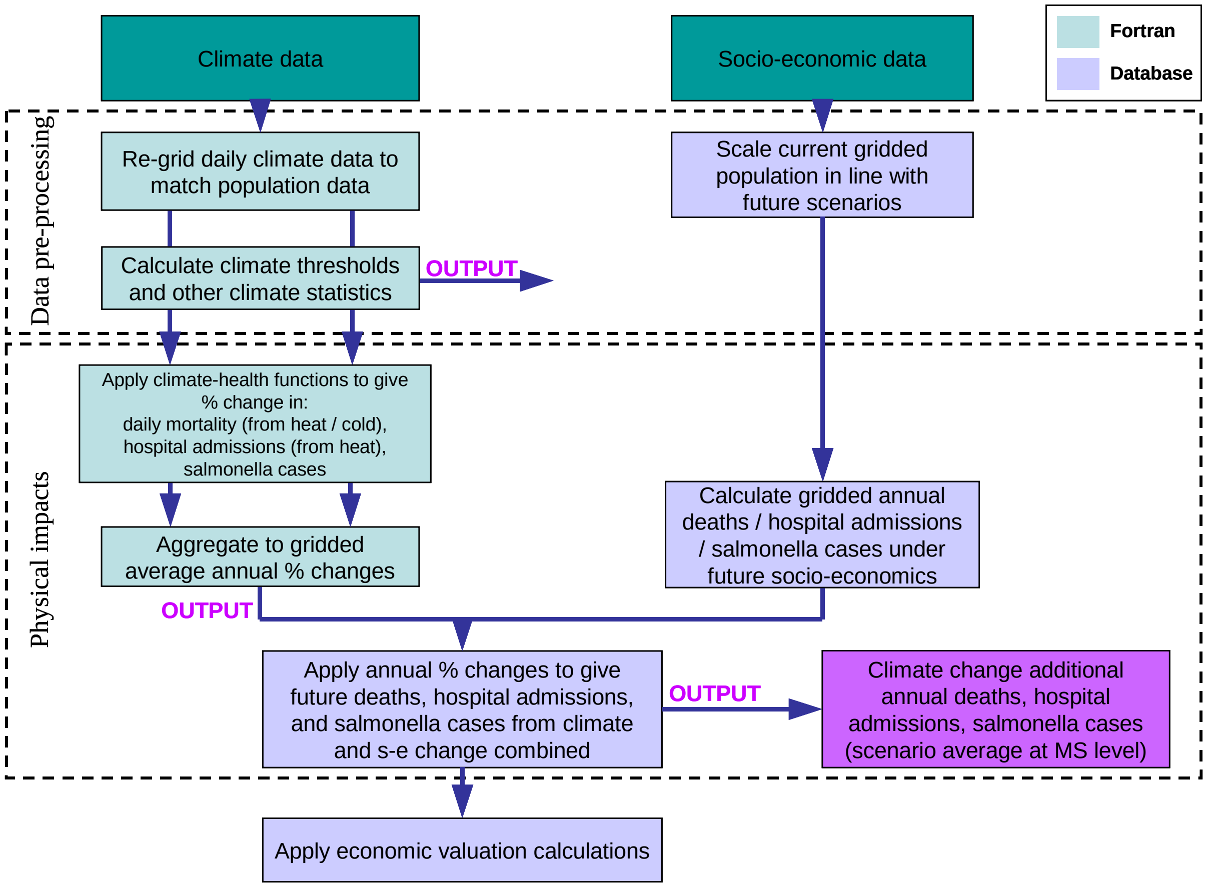



***Figure 1*** ***Modelling overview***

## 2.2. High and low temperature mortality

The shape of the temperature-mortality association is approximately U-shaped or V-shaped, with mortality increasing at both low and high temperatures. To quantify the effect of temperature on mortality, a linear relationship is assumed above (and below) a threshold temperature(s). In the studies that we have considered here, estimates for the threshold and slope describing the relationship were derived from epidemiological models that take into account the seasonal and other long-term patterns in the outcome measure, in order to reveal any short-term effects of temperature. Based on a review of the literature, the study has used two temperature-mortality relationships:

- Climate-dependent functions, with thresholds based on the average climate in a specified location (such as a particular centile in the daily mean temperature series for the location), and linear relationships (e.g., Kovats et al., 2006).
- Country specific epidemiological studies, consisting of thresholds and linear relationships based on statistical analysis of daily (or monthly) temperature and mortality (e.g., McMichael et al., 2005; Kovats and Jendritzky, 2006).

In each case, thresholds tend to vary from country to country across Europe, with lower threshold temperatures in the north, and higher threshold temperatures in the south. The analysis here has used both approaches to investigate the effect on the results.

**Climate-dependent functions**

The climate-dependent thresholds for heat and cold functions are based on a statistical analysis of daily temperatures in each location, based on a separate fixed single slope (gradient) for heat and cold related mortality. Climate-dependent thresholds in each grid cell have been calculated following the approach by Kovats et al (2006) in a recent study for the UK. Thresholds are taken as the 10th and 95th centiles of daily mean temperature, for low- and high-temperature impacts respectively. For each grid cell, the 30-year daily mean temperature series was examined and the 10th and 95th centiles identified. This approach therefore captures the existing climate variability across Europe accurately.

**Country specific functions**

At the time of this study, epidemiological studies quantifying absolute temperature-mortality relationships have not been carried out exhaustively in each country or each climate region in Europe. The study took functions identified under the cCASHh project for specific countries (where available), which have specific slopes and thresholds, and then apply relationships derived in one country to climatically and socially similar countries nearby. We have focused on studies relating all-age mortality to temperature since there are too few age-specific studies to provide coverage across Europe. This approach captures the existing variability to some extent, and also captures existing acclimatisation and adaptation to existing climate in Europe, but suffers from the relatively few number of studies and issues of consistency between studies.

An illustration of the two sets of functions are presented below.

Note that for the country specific functions, the slope and threshold differ between each country study. For the climate dependent functions, the slope is constant, but the threshold is derived individually for each spatial grid cell

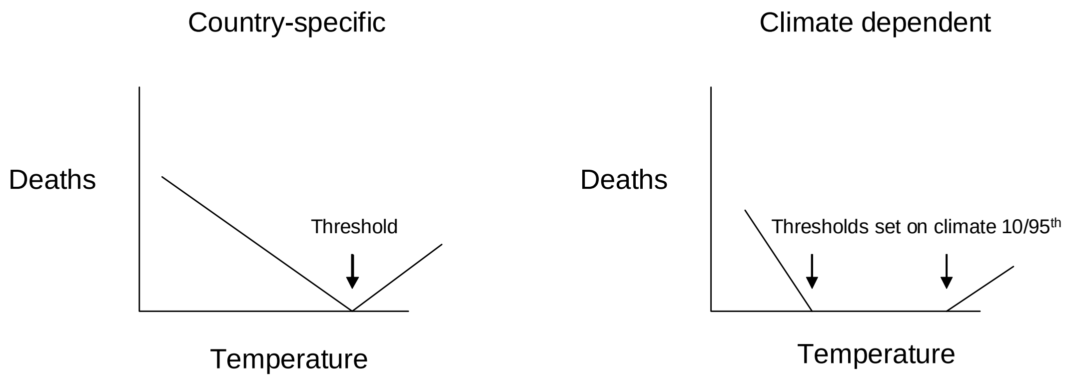



***Figure 2*** ***Illustration of exposure-response approaches linking temperature and mortality***

It is highlighted that there is some evidence of other health related effects (morbidity) from temperature, but due to a lack of coverage of functions, it has not been possible to quantify these within the project.

**Acclimatisation**

Some physiological and behavioural acclimatisation to the changing climate will occur autonomously among European populations. Few studies have attempted to incorporate acclimatisation into future projections of temperature-related mortality, but all studies indicate that acclimatisation would reduce potential increases in heat-related mortality. It is therefore incorrect to simply apply the temperature-mortality relationships defined under today's climate to future climates, as this will overestimate impacts. Previous studies have included acclimatisation: Dessai (2003) assumed that, on average, acclimatisation to a 1 °C warming would occur every three decades, whilst McMichael et al. (2004) suggested that acclimatisation rates would be region- and scenario-specific to reflect the rate of warming experienced, and could thus be proportional to projected changes in average temperatures. In PESETA, acclimatisation has been modelled simply as a shift in threshold temperatures, but tested using both assumptions, i.e. as a fixed amount (using the rate indicated by Dessai) or linked to the changing climate in each region (climate dependent).

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.

No additional account has been taken of adaptation measures, though these are potentially important.

As a final note, a Commission-funded research project, PHEWE, is due to report soon and will increase the knowledge base on the impacts of climate on health. This project has examined health statistics alongside meteorological data in 16 cities across Europe, to produce statistical functions relating weather and health endpoints.

## 2.3. Food-borne disease

For food-borne disease we have built on the work of Kovats *et al*., (2004), and used salmonella cases as an indication of the potential risks (within Europe, salmonella accounts for some 70 % of all laboratory-confirmed outbreaks of food-borne disease:, WHO, 2001). The estimation of climate-related salmonella cases follows a similar approach to that for hot temperature mortality. Linear functions linking temperature with reported salmonella cases are available in the literature for a number of European countries (Kovats et al, 2004) and we have applied relationships derived in one country to climatically and socially similar countries nearby. The functions link the previous two-month mean temperature with the reported case of salmonella. We replicate this process in our modelling, by computing running two-month mean temperatures in each grid cell for each day in the climate datasets. There is likely, however, to be a substantial under-reporting of cases. To consider this, two sensitivities runs were made, based on estimates (Chalker and Blaser, 1988) that only 1-5 percent of all cases of Salmonellosis are actually reported

## 2.4. Other climate impacts on health

The impacts of climate change upon flooding in Europe and upon European coastal zones are being quantified by two other PESETA projects. Neither of these sectoral studies has included the consequent health impacts, although they calculate numbers of people affected by flooding. Work by McMichael et al. (2004) reported the health impacts of flood events included in the EM-DAT database. For European regions, they indicate that the annual incidence of death caused by coastal floods is around 1 per 100,000,000 population in 2000 – which translates to low annual risk for the European population, while the annual incidence of death caused by inland floods and landslides may be around 40 per 10,000,000 population. It has not been possible to project future incident rates associated with flooding accurately, but the approximate increases in flood risks from the river and coastal PESETA project can be used as a first proxy for the increase in future risk. The PESETA project has, however, used some of the data from the coastal flooding study to investigate and quantify the potential wider effects of flooding on well being (e.g. mental illnesses from the effect of flooding and displacement). There are no good functional relationships for this, and instead the study has used assessments of incidence rates (e.g. for depression, from Reacher et. al. (2004) study) in flooded communities to provide an order of magnitude assessment. These incidence rates may alter over time, even in the absence of climate change, depending on the balance between factors that decrease vulnerability (particularly improving flood defences), and those which increase vulnerability (particularly increasing population density in coastal zones and other flood-prone areas).

A qualitative assessment of vector-borne diseases has been undertaken, based on a literature review.

# 3. Data sources

## 3.1. Socio-economic data

A key stage in the analysis of potential impacts from climate change is the use of quantified socio-economic projections to assess how the population vulnerability will change in future. The vulnerability of the population is likely to be affected primarily[4] by:

- Changes in the number of people and their geographical location. The population size of Europe is mature, but there are some projected increases.
- Changes in the age structure and death rate of the population. The age distribution is important as many studies show that the elderly are more at risk from temperature related mortality, and Europe's population distribution is ageing.

The key sources of socio-economic data needed to develop our assessments of future health impacts are therefore population, mortality and illness rates. Projected country population totals have been supplied by IIASA[5]. These are based on two IPCC Special Report on Emissions Scenarios (SRES) scenarios, A2 and B2, for consistency with the climate projections. Population estimates have been provided on a 5 yearly interval basis, and are split into 5-year age bands, across Europe. Changes in total population are fairly modest: under the A2 scenario, the population grows by around 8 % by 2080, whereas under the B2 scenario it reduces by around 3 %. Mortality rates have been taken from the UN website,[6] and applied to the population projections to derive the baseline number of deaths in a given year. The death rates have been adjusted to give age specific death rates on the basis of Eurostat data, for current and future death rates.

Data on baseline datasets for salmonella cases were taken from the WH Global Salmonella Survey[7] (GSS) (Galanis et al, 2006). In the absence of data, no adjustments were made for future changes in rates and this is highlighted as a major uncertainty.

[4] Though many other socio-economic aspects will have some influence on vulnerability and exposure to health risks, including wealth, education, travel habits, technological and medical advances, etc.

[5] http://www.iiasa.ac.at/Research/PCC/index.html

[6] United Nations Population Division, http://www.un.org/esa/population/unpop.htm

[7] WHO Global Salm-Surv is a web-based data resource available at www.who.int/salmsurv

## 3.2. Climate change data

In common with the other PESETA projects, we have used climate scenario data from the Rossby Centre[8] and from the PRUDENCE project[9]. The Rossby Centre data are a transient set of climate runs from 1961 to 2100. In common with the other PESETA projects, we are using the 2011–2040 time period (A2 scenario only) to provide the short-term policy-relevant results. The PRUDENCE project provides a number of European regional climate model simulations, based on different driving GCMs, for the period 2071-2100. Our primary scenarios have been generated from the Danish Meteorological Institute (DMI) regional model, based on the Hadley Centre HadCM3 GCM, for both A2 and B2 emissions scenarios. For comparative purposes, we have also repeated a limited number of impact calculations using climate data from an alternative RCM and GCM combination (RCM from the Swedish Meteorological and Hydrological Institute; GCM is the Max Planck Institute's ECHAM4). HadAM3H has very high sensitivity with respect to summer warming, while ECHAM4/OPYC3 shows a much stronger warming than HadAM3H driven models (Christensen and Christensen, 2006). The climate scenario data sources are summarised below.

***Table 1 Summary of climate data sources used in the study***

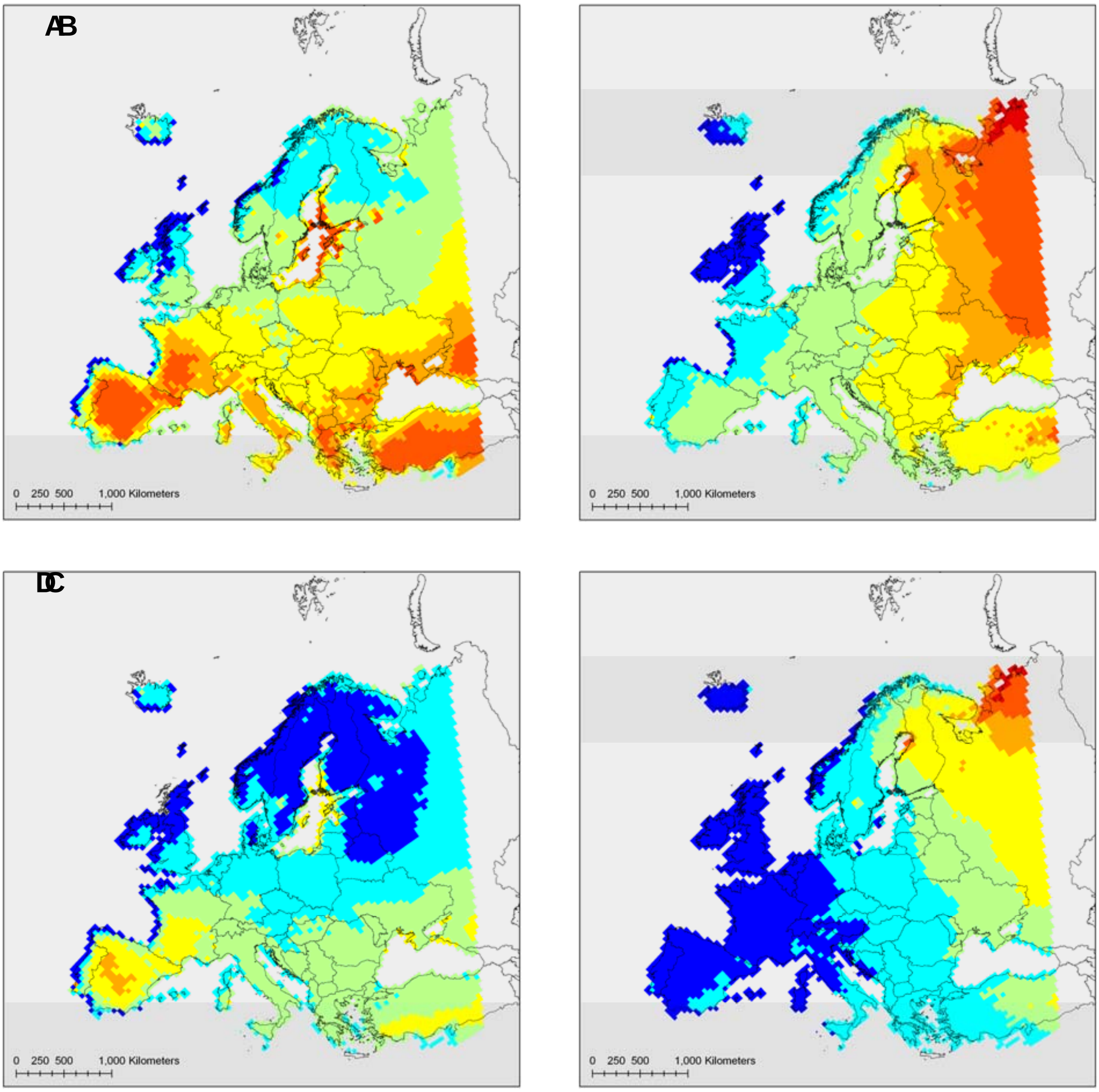
| | | Time period | 2011–2040 | 2071–2100 | | 1961–1990 |
|---|---|---|---|---|---|---|
| | | **Scenario** | **A2** | **A2** | **B2** | **baseline** |
| **Data source** | **GCM** | **RCM / Institute** | **Dataset Code** | | | |
| Rossby Centre | ECHAM4/OPYC3 | RCA3 / SMHI | Rossby RUN | | | Rossby CTL |
| PRUDENCE1 | HadAM3H/HadCM3 | HIRHAM / DMI | | HS1 | HB1 | HC1 |
| PRUDENCE2 | ECHAM4/OPYC3 | RCA / SMHI | | MPIA2 | MPIB2 | MPICTL |

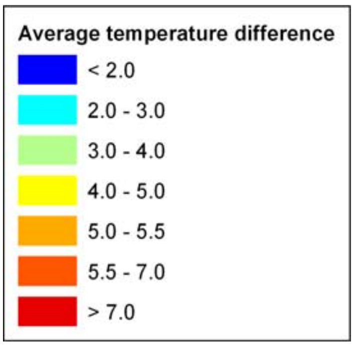
For average summer temperatures, the largest climate changes occur in southern and Mediterranean Europe, with up to 7 °C warming over Spain and parts of France, Greece and Turkey under the A2 scenario (up to 5 °C under B2 scenario). Smallest changes occur across the British Isles and Scandinavia (as little as 2 °C in some places under the A2 scenario). For average winter temperatures, the largest climate changes occur in eastern Europe, with up to 5.5 °C warming in easternmost parts of Finland, Romania, Bulgaria and Turkey under the A2 scenario (generally less than 4 °C under the B2 scenario). Smallest changes occur in western

[8] The Rossby Centre is part of the Swedish Meteorological and Hydrological Institute, www.smhi.se

[9] All data generated from the PRUDENCE project are available from http://prudence.dmi.dk

Europe, through the British Isles, France, Spain and Portugal (less than 2 °C under the B2 scenario). On average, summer warming is slightly larger than winter warming across Europe by the period 2071-2100.




A – Average summer temperature change by 2080s, A2 scenario
B – Average winter temperature change by 2080s, A2 scenario
C – Average summer temperature change by 2080s, B2 scenario
D – Average winter temperature change by 2080s, B2 scenario

Differences calculated as seasonal average daily temperature for 2071-2100 minus seasonal average daily temperature for 1961-90 baseline, HIRHAM/HadAM3H model data.

*Figure 3* ***Difference in summer (left) and winter (right) average daily temperatures between the 2071-2100 model projections and the 1961-1990 model baseline, for A2 (top) and B2 (bottom)***

## Heatwaves

The analytical method for heat related events above does capture daily high temperatures, including those that arise from heat-waves, but may not fully cover all the important parameters associated with these effects (i.e. the additional aspects of longer cumulative heat extremes). Heatwaves are one of several so-called “extreme events”. Events are often classified as “extreme” on the basis of three criteria: rarity (i.e., that occur with relatively low frequency/rate); intensity (i.e., characterized by relatively small or large values compared to the norm); and severity (i.e., that result in large socio-economic losses). The definition of heat waves is necessarily subjective, and can vary from country to country. A number of possible measures have been used to investigate heatwaves under current and future climates[10]. These kinds of measures can be combined to provide a picture of the number, frequency, duration, and intensity of heat waves over a given period. The PESETA study compiled some of the studies on European heat-waves to provide some additional commentary to the analysis of heat related effects as predicted above:

- Initial work by the Hadley Centre on the 2003 European heat-wave showed this was a 1 in 1000 event. According to projections under a medium-high emissions scenario with the Hadley Centre’s climate model, the occurrence of similar European summer temperatures would be roughly average by the 2040s.
- A European Environment Agency study (EEA, 2004) reported that by 2080, nearly every summer in many parts of Europe was projected to be hotter than the 10 % hottest summers in the current climate. Under high emission scenarios, every second summer would be as hot or hotter than 2003, by the end of the century. In southern Europe, these changes are projected to occur sooner.
- An early working paper from the PRUDENCE project (Holt and Palutikof, 2004), examined likely changes in the duration of heat waves in the Mediterranean. Under the A2 scenario, the models project that by the end of the century, annual maximum heat waves could be up to 55 days longer, compared to the present climate (1961-90). The European countries most affected are southern and central Iberia, southern France, Italy, Greece, and Turkey.

[10] including the number of consecutive days with temperatures above a threshold, e.g., 30 °C, the occurrences of 3 or 6 consecutive days with temperatures above the 90th percentile of daily temperature at a given location, the value of 90th and/or 99th percentile of daily maximum temperature, and the length of episode with sustained heat load that affects human health.

- Beniston et al. (2006) investigated how extreme events are projected to change from 1961–1990 to 2071–2100 in the PRUDENCE climate models. They defined a heatwave as a spell of at least six consecutive days with maximum temperature exceeding the 1961–90 calendar day 90th percentile. They calculated four heatwave indices for each year. By the end of the 21st century under the A2 scenario, they found that the mean heatwave duration increases by a factor of between one and eight over most of Europe. Much higher increases of at least a factor of seven are predicted for the mean intensity, the mean number of heat waves and the frequency of heat-wave days, with greatest changes (more than ten-fold increases) in the south of France and Spain. Their results indicate that for the A2 scenario by the end of the century, countries in central Europe will experience the same number of hot days as are currently experienced in southern Europe. The intensity of extreme temperatures increases more rapidly than the intensity of more moderate temperatures over the continental interior due to increases in temperature variability. The findings were consistent across all of the global and regional climate models that they studied.

# 4. Results: Physical impacts assessment

## 4.1. Introduction

The results of the analysis are presented in the following section. It is highlighted that the analysis has estimated the physical impacts by:

1) projecting future heat and cold related effects assuming the future socio-economic scenario (e.g. future population), with no change in climate, and
2) estimating the future heat and cold related effects with the future socio-economic scenario (e.g. future population) and the future climate predictions.

The difference between these two results is then presented as the additional "climate change induced" effect. This is an essential distinction to make, as significant increases in mortality may be expected on the basis of the increasing and aging European population, regardless of the impact of climate change: for this study and other climate studies, we are interested to quantify what impact climate change may have in addition to the socio-economic effects (i.e. in a policy context, the difference from the 'with' and 'without' case).

Figures of the physical impact results across Europe, plus overall summaries of numbers, are presented below. We have not presented temperature-related deaths as net figures, but rather have kept the numbers of cold-related benefits and heat-related impacts separate. Results are presented for the two sets of impact relationships (climate dependent and country specific functions) for both "no acclimatisation" and "with acclimatisation (heat)" or with a 'decline in sensitivity of mortality to cold'. However, we have excluded results in which the applied rate of acclimatisation was too rapid and resulted in either heat-related deaths reducing in future, or cold-related deaths increasing.

## 4.2. Baseline Analysis of Heat and Cold Related Mortality

The baseline rates, as estimated by the model, for heat and cold related mortality in Europe, are shown below, for the two sets of impact relationships (climate dependent and country specific). These represent the current (present-day) impacts as implied by the climate change models (i.e. rather than based on actual observed data).

*Table 2* ***Total heat and cold-related deaths, and average annual death rates, under baseline climates (modelled) and with current socio-economic conditions (populations, mortality rates)***

| Climate model | PRUDENCE HC1 | | Rossby CTL | |
|---|---|---|---|---|
| | **European total number of deaths** | **Average death rate (per 100,000)** | **European total number of deaths** | **Average death rate (per 100,000)** |
| | **HEAT-RELATED DEATHS** | | | |
| Climate-dependent functions | 10340 | 2.1 | 9402 | 1.9 |
| Country-specific functions | 48778 | 9.8 | 30058 | 6.1 |
| | | | | |
| | **COLD-RELATED DEATHS** | | | |
| Climate-dependent functions | 76953 | 15.5 | 64671 | 13.1 |
| Country-specific functions | 423165 | 85.4 | 432637 | 87.3 |

## 4.3. High and low temperature mortality, in the period 2011 to 2040

Results for the quantification of high and low temperature mortality under the **2011-2040** climate (from the Rossby Centre model) are provided below. Results are presented as total European numbers of deaths, and as average annual temperature-related death rates for the 30-year period, for the two sets of impact relationships (climate dependent and country specific functions), with and without acclimatisation or with and without a decline in sensitivity of mortality to cold. The values shown are the climate change induced difference only, i.e. after adjusting for future changes from socio-economic scenarios (see above).

*Table 3* ***Total heat and cold-related deaths, and average annual death rates, under the period 2011-2040, with and without acclimatisation***

Note climate change induced difference shown.

| | Climate change induced difference - no acclimatisation | | * Climate change induced difference – with acclimatisation / decline in sensitivity | |
|---|---|---|---|---|
| | **European total number of deaths** | **Average death rate (per 100,000)** | **European total number of deaths** | **Average death rate (per 100,000)** |
| | **HEAT-RELATED DEATHS** | | | |
| Climate-dependent functions | 27337 | 5.5 | 3978 | 0.8 |
| Country-specific functions | 26372 | 5.3 | 3938 | 0.8 |
| | | | | |
| | **COLD-RELATED DEATHS** | | | |
| Climate-dependent functions | - 50272 | - 10.0 | - 19422 | - 3.9 |
| Country-specific functions | - 98529 | - 20 | - 6893 | - 1.4 |

(-) implies a benefit (fewer deaths), (+) implies an impact (more deaths).

* Note: for the acclimatisation / decline in the sensitivity of mortality to cold results presented in this table, a fixed rate of 1 °C per three decades has been used to shift thresholds, relative to baseline climates.

The results show:

- By the 2020s (average of 2011-2040), the analysis estimates that there will be a small increase in the European average heat-related numbers of deaths and the death rate due to climate change (over and above that as a result of changing populations and demographics). Both sets of functions give similar results, with just over 25 000 extra heat related deaths per year.
- Acclimatisation (physiological and some behavioural acclimatisation) could have a very significant effect in reducing these (by a factor of 5). With a fixed rate of acclimatisation of 1 °C per three decades, then the extra heat related effects are estimated to be reduced to around 4000 per year. A further analysis (not shown) with acclimatisation aligned to the climate scenario (through a recalculation of threshold temperatures), reduces these effects to almost figures.
- At the same time the analysis estimates that there will be a small decrease in the European average cold-related numbers of deaths (i.e. a benefit) and the death rate due to climate change (over and above that as a result of changing populations and demographics). There is greater variation in the analysis, with some 50 000 to 100 000 estimated cold related deaths avoided.
- It is unclear whether populations will experience decline in sensitivity of mortality to cold temperatures as the climate warm. To investigate this as a sensitivity, we have applied the assumptions of decline in sensitivity for the cold mortality calculations. This shows very large reductions in the predicted changes (i.e. in this case much lower levels of reduced cold related deaths).
- The net effect indicates that in the short-term the reduction in cold related deaths is likely to outweigh the increase in heat related deaths. However, the magnitude of effects is strongly influenced by the choice of exposure response function, and the assumption of acclimatisation.

These results serve as an initial, interim assessment until better information becomes available and some parts of the methodology are further developed.

It is also interesting to look at the distributional patterns across Europe. These patterns vary according to the climate impact function used, i.e. for climate dependent or country specific functions. The spatial patterns 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 countries, and the smallest potential increases in more northerly countries (e.g. Norway, Finland).
- 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

and 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.
- With the country specific functions, the largest potential cold-mortality benefits from climate change indicated in Table 21 occur mainly in Mediterranean countries, while the smallest benefits are in Baltic and northern countries: this pattern reflects the relative functional slope and intriguingly gives the opposite pattern to the climate dependent analysis.

Again the uncertainties and assumptions set out above are highlighted.

## 4.4. High and low temperature mortality, 2071 to 2100 A2 Scenario

Results of the quantification of high and low temperature mortality under the 2071-2100 climate (from the PRUDENCE project, and the HIRHAM RCM model nested in the Hadley Centre GCM) are provided below. Results are presented as changes in total European numbers of deaths, and average annual temperature-related death rates for the 30-year period. Values are presented for the two sets of impact relationships (climate dependent and country specific functions), with and without acclimatisation or decline in sensitivity to cold. The values shown are the climate change induced difference only, i.e. after adjusting for future changes from socio-economic scenarios (see above). The analysis is shown first for the A2 scenarios.

*Table 4 Total heat and cold-related deaths, and average annual death rates, under the period 2071-2100, with and without acclimatisation*

Note climate change induced difference shown

| Scenario | Climate change induced difference - no acclimatisation | | * Climate change induced difference – with acclimatisation / decline in sensitivity | |
|---|---|---|---|---|
| | European total number of deaths | Average death rate (per 100,000) | European total number of deaths | Average death rate (per 100,000) |
| **A2 Scenario** | **HEAT-RELATED DEATHS** | | | |
| Climate-dependent functions | 106,419 | 21.1 | 17,080 | 3.4 |
| Country-specific functions | 107,339 | 21.3 | 19,449 | 3.9 |
| | | | | |
| **A2 Scenario** | **COLD-RELATED DEATHS** | | | |
| Climate-dependent functions | - 86,291 | - 17.1 | - 18,835 | - 3.7 |
| Country-specific functions | - 184,222 | - 36.5 | | |

(-) implies a benefit (fewer deaths), (+) implies an impact (more deaths).

* Note: for the acclimatisation results presented in this table, a fixed rate of 1 °C per three decades has been used to shift thresholds, relative to baseline climates, for the heat-related impacts. For the cold-related impacts, decline in sensitivity to cold was applied to the climate-dependent functions; no adjustment is shown for the country-specific functions because the fixed rate was too high.

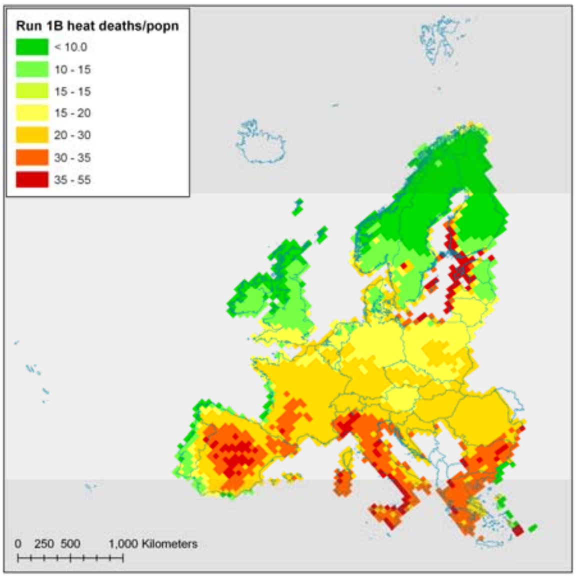
The results show:

- By the 2080s (average of 2071-2100), the analysis estimates that there will be a significant increase in the European average heat-related numbers of deaths and the death rate due to climate change (over and above that as a result of changing populations and demographics). Both sets of functions give similar results, with around 105 000 extra heat related deaths per year.
- Acclimatisation (physiological and some behavioural acclimatisation) could have a very significant effect in reducing impacts (by a factor of 5). With a fixed rate of acclimatisation of 1 °C per three decades, the climate change-induced heat related effects are estimated to be reduced to around 20 000 per year. A further analysis (not shown) with acclimatisation aligned to the climate scenario (through a recalculation of threshold temperatures), reduces these effects much further.
- At the same time the analysis estimates that there will be a significant decrease in the European average cold-related numbers of deaths (i.e. a benefit) and the death rate due to climate change (over and above that as a result of changing populations and demographics). There is greater variation in the analysis, with some 86 000 to 184 000 estimated cold related deaths avoided.

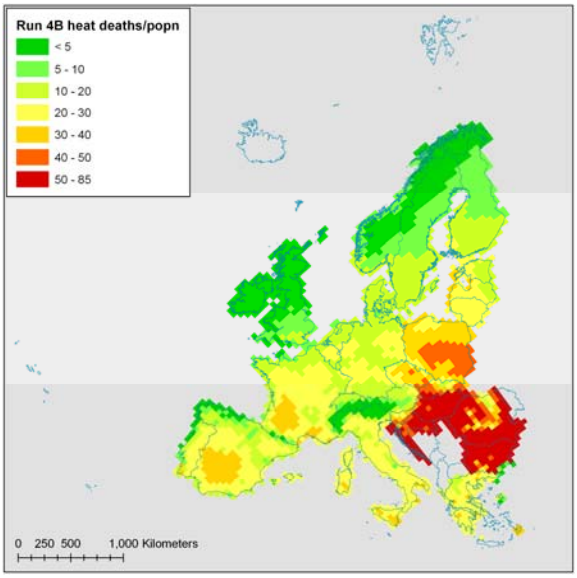
- It is unclear whether there will be a decline in sensitivity of mortality to cold as the climate warms. As a sensitivity, we have applied these assumptions for the cold mortality calculations and these again show very large reductions in the predicted changes.
- The net effect is determined by the functions used. With the climate dependent functions, the rise in extra heat related mortality is greater than the decrease in cold related mortality. With the country specific functions, the opposite occurs (cold related mortality benefits are greater, and quite significant so, than heat related mortality). With acclimatisation / with a decline in sensitivity of mortality to cold, the country specific functions show similar levels of heat and cold related mortality. Therefore, the magnitude of the impacts and benefits is strongly influenced by the choice of exposure response function, and the assumption of acclimatisation.
- These results serve as an initial, interim assessment until better information becomes available and some parts of the methods are elaborated in more detail.

The spatial pattern of the change (the difference) in heat and cold related mortality are shown in the figures below, expressed as changes in the death rate, normalised by population. (Note that this parameter is used as it is much harder to identify the relative changes with the presentation of absolute numbers of deaths, as the values are dominated by population density, so more populous countries dominate the pattern).

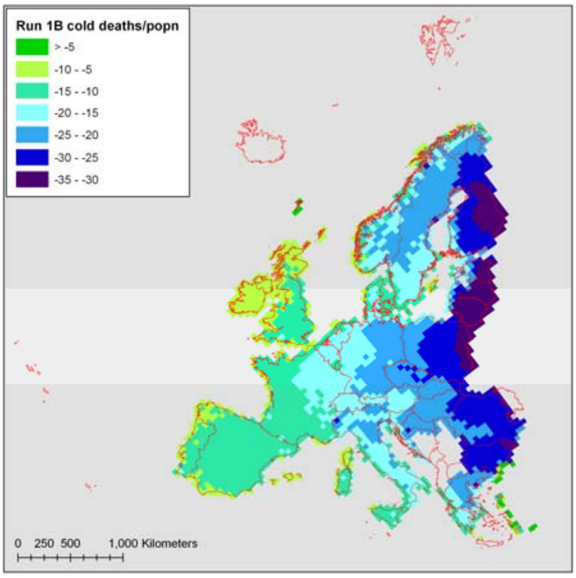
The analysis indicates that relative climate change is a strong driver controlling estimated mortality where climate-dependent exposure-response functions are used, and this more closely shows the pattern of temperature change. With the country specific functions, there is a slightly different pattern compared to the absolute climate change levels across Europe. A much wider variability in mortality rates across Europe is evident from the use of these functions, together with a correspondence across those countries for which the same choice of function has been applied. The large differences in the patterns of heat- and cold-related mortality illustrate the importance of the choice of exposure-response function in controlling the outcome of the health impact modelling. It is clear that there are large uncertainties in the mortality results linked directly to the range of possible outcomes from the different response functions.



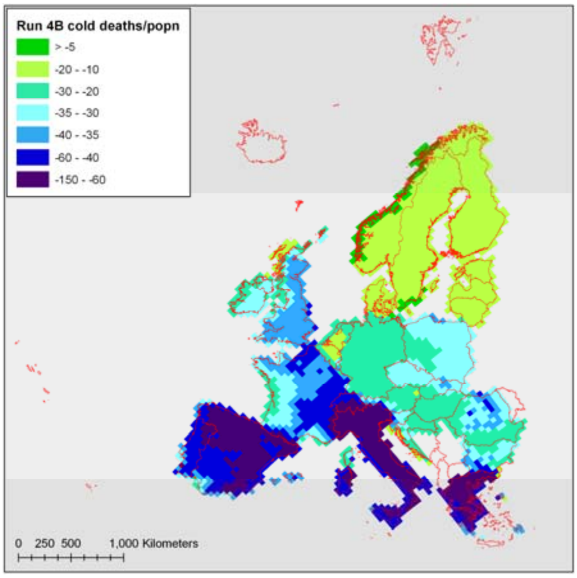

**Heat related - Climate Dependent function**




**Heat related – Country Specific function**




**Cold related - Climate Dependent function**




**Cold related - Country Specific function**

***Figure 4*** ***Average annual heat-related and cold-related death rates per 100,000 population, for 2071-2100 A2 scenario, using the HS1 climate data. Climate-dependent and country specific health functions (no acclimatisation / decline in the sensitivity of mortality to cold)***

The spatial patterns show that for heat related mortality:

- With the climate dependent functions, the pattern across Member States is relatively uniform; the largest potential mortality increases from climate change occur in Italy, Bulgaria, Estonia, Greece and Spain, and the smallest potential increases in Norway, Ireland, the UK and Sweden.

- 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

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.

- With the country specific functions, the largest potential cold-mortality benefits from climate change occur mainly in Mediterranean countries, while the smallest benefits are in Baltic and Scandinavian countries.

Again the uncertainties and assumptions set out above are highlighted.

## 4.5. High and low temperature mortality, 2071 to 2100 B2 Scenario

The equivalent data for the B2 scenario is shown below (using PRUDENCE HB1 climate data).

***Table 5 Total heat and cold-related deaths, and average annual death rates, under the period 2071-2100, with and without acclimatisation***

Note climate change induced difference shown

| Scenario | Climate change induced difference - no acclimatisation | | * Climate change induced difference –with acclimatisation / decline in sensitivity | |
|---|---|---|---|---|
| | European total number of deaths | Average death rate (per 100,000) | European total number of deaths | Average death rate (per 100,000) |
| **B2 Scenario** | **HEAT-RELATED DEATHS** | | | |
| Climate-dependent functions | 50,665 | 11.4 | | |
| Country-specific functions | 58,508 | 13.2 | | |
| | | | | |
| **B2 Scenario** | **COLD-RELATED DEATHS** | | | |
| Climate-dependent functions | -57,823 | -13.1 | | |
| Country-specific functions | -101,112 | -22.8 | | |

(-) implies a benefit (fewer deaths), (+) implies an impact (more deaths).

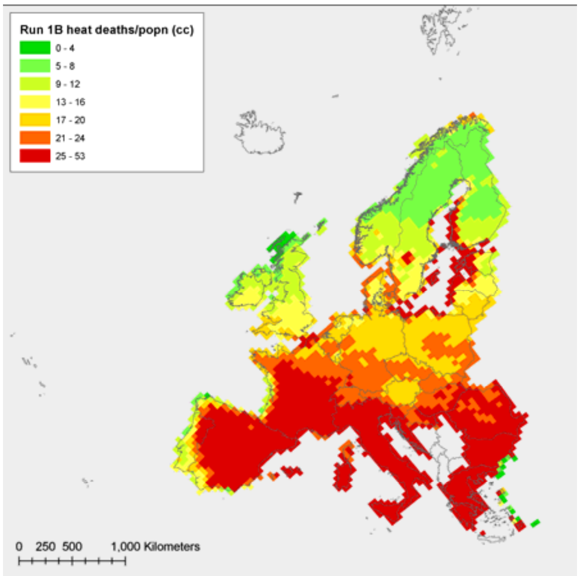
* Note: for the acclimatisation results / decline in the sensitivity of mortality to cold results presented in this table, a fixed rate of 1 °C per three decades has been used to shift thresholds, relative to baseline climates, for the heat-related impacts. For the B2 scenario, the fixed rate acclimatisation assumption is too high and is not presented.

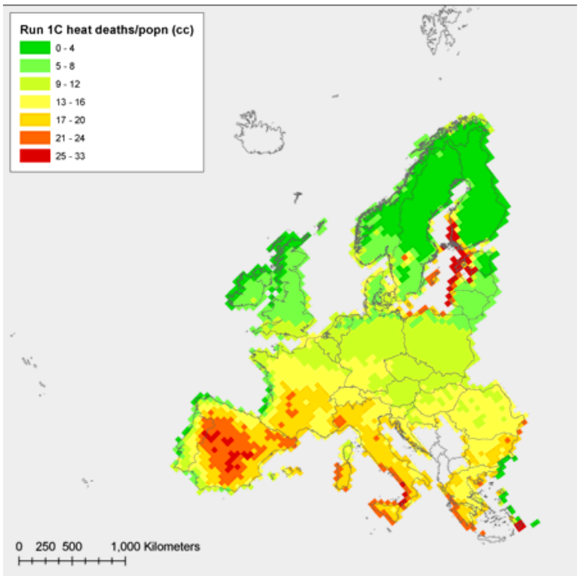
The results show:

- By the 2080s (average of 2071-2100), the analysis estimates that there will be a significant difference between the A2 and B2 scenarios in the European average heat-related numbers of deaths and the death rate due to climate change. The climate dependent and country specific functions give similar results, showing a reduction from around 105 000 extra heat related deaths per year under the A2 scenario to 51 000 to 58 000 under the B2 scenario (no acclimatisation). This is a reduction of approximately 50 % from the A2 scenario. This means that the B2 scenario leads to a benefit over the A2 scenario of 49 000 to 56 000 avoided deaths per year.
- At the same time the analysis estimates that there will be a significant decrease in the European average cold-related numbers of deaths avoided i.e. a decrease in benefits) in moving from the A2 to the B2 scenario. There is greater variation in the analysis, with some 58 000 to 101 000 estimated cold related deaths avoided (benefits) estimated under the B2 scenario (no acclimatisation). This is a reduction of approximately 33 to 45 % from the A2 scenario. This means that the B2 scenario leads to a reduction in benefits of 28 000 to 83 000 deaths per year compared to the A2 scenario.
- With the climate dependent functions, the number of heat and cold related deaths under the B2 scenario are broadly similar. Under the country specific functions, the reduced cold related deaths exceed the extra heat related deaths.
- Again it is highlighted that these results serve as an initial, interim assessment until better information becomes available and some parts of the methods are elaborated in more detail.

The pattern of heat-related and cold-related mortality across European countries under the B2 scenario matches that seen for A2. The comparison between A2 and B2 scenarios is shown for heat and cold related mortality below.

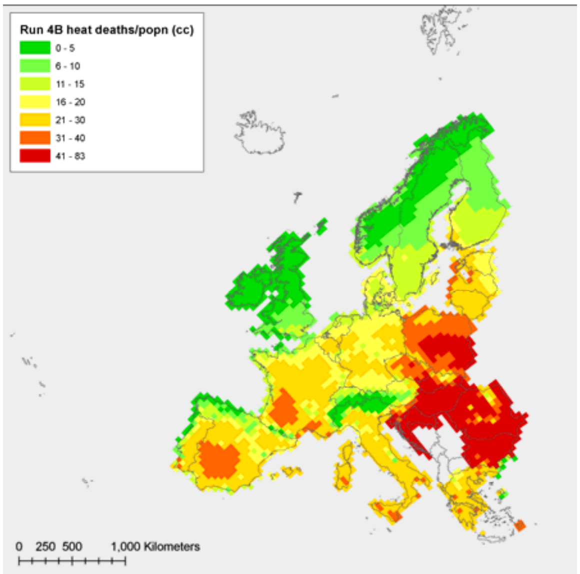
The appearance of the maps is slightly different due to the use of different colour bar scales above in order to present A2 and B2 scenarios using identify scales.

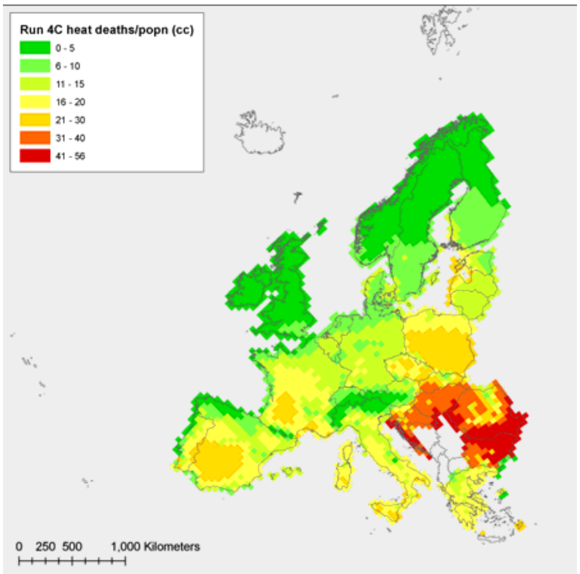



**Heat related - Climate Dependent function A2**

**Heat related – Country Specific function B2**

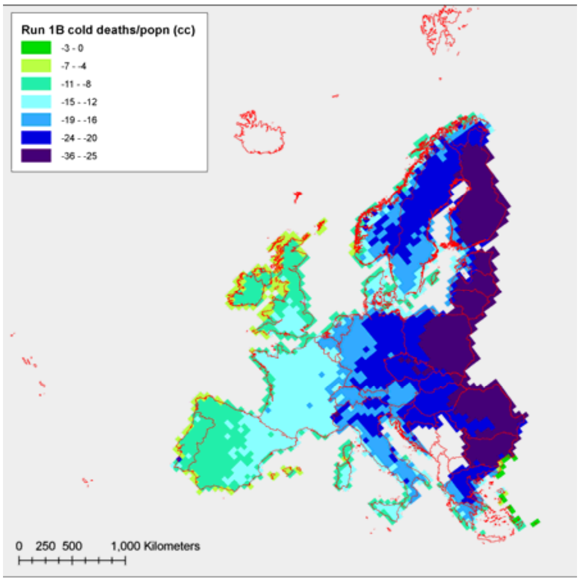


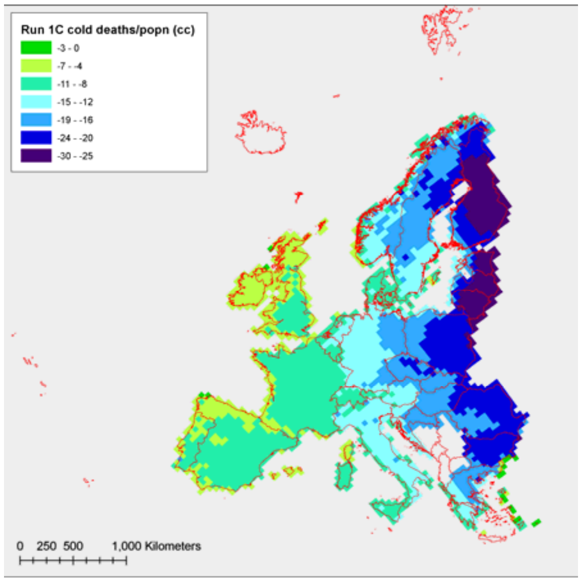




**Heat related - Climate Dependent function A2**

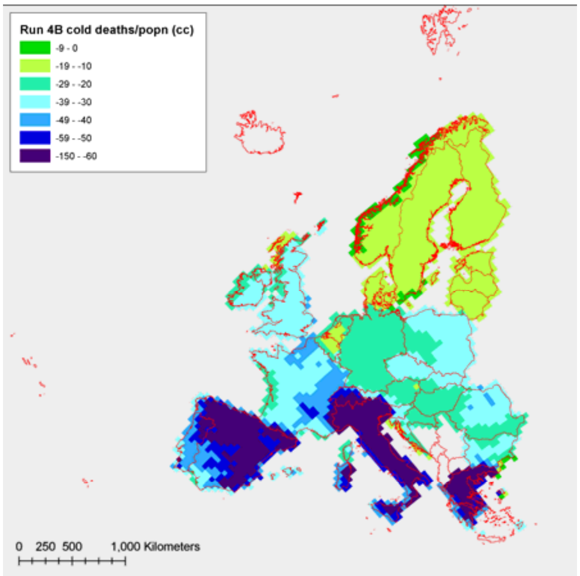
**Heat related - Country Specific function A2**

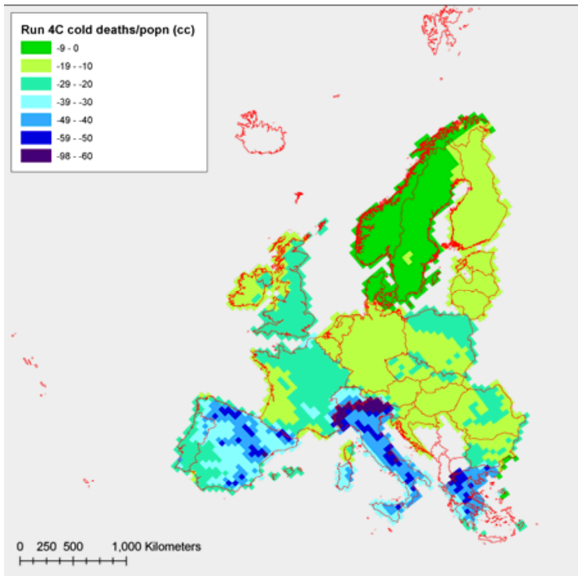
*Figure 5* *Average annual heat-related death rates per 100,000 population, for 2071-2100 A2 and B2 scenario. Climate-dependent and country specific health functions (no acclimatisation)*




**Cold related - Climate Dependent function A2** **Cold related – Country Specific function B2**




**Cold related - Climate Dependent function A2** **Cold related - Country Specific function B2**

***Figure 6*** ***Average annual cold-related death rates per 100,000 population, for 2071-2100 A2 and B2 scenario. Climate-dependent and country specific health functions (no decline in the sensitivity of mortality to cold)***

## 4.6. Climate Model Variability: 2071 to 2100 A2 and B2 Scenarios

The study has also undertaken a limited number of runs to examine the impact that different climate model data can have on the calculated impacts, for the A2 scenario and B2 in 2071 - 2100 The climate data are from a different RCM (RCA) nested in a different GCM (ECHAM4) from the main results presented above. The RCA/ECHAM4 combination produces larger increases in average summer temperature in both Northern and Southern Europe than the HIRHAM/HadAM combination. The analysis has been undertaken for the country specific analysis and shows:

- The increase in the European average heat-related numbers of deaths by the 2080s (average of 2071-2100) is estimated at 162 000 deaths per year under the A2 scenario, compared to the HIRHAM/HadAm estimate of 105 000 extra heat related deaths per year for the same scenario (around a 50 % greater impact).
- The reduction in European cold-related numbers of deaths (i.e. benefit) increases from 184 000 estimated cold related deaths avoided with HIRHAM/HadAm to 256 000 (around a 40 % greater benefit).
- The analysis shows that for both heat and cold related mortality, the results are much higher with the alternative climate data, indicating the range of potential climate change impacts possible from different climate model projections, and the need to take this variability into account.

## 4.7. Salmonella cases

This section presents the results of the quantification of temperature-related cases of salmonella.

Under baseline climates, the European average rate of temperature-related salmonella cases are between 14 and 16 per 100,000 people, depending on the climate model data. This represents around 40 % of the total background rate of salmonella infection that we determined based on reported cases of salmonella in the GSS. For this analysis, the two sensitivities are also undertaken, representing under-reporting (for 5 % and 1 % reporting levels).

***Table 6*** ***Total heat and cold-related deaths, and average annual death rates, with and without acclimatisation***

Note climate change induced difference shown

| **Scenario** | **Climate change induced difference - no acclimatisation** | | |
|---|---|---|---|
| | **European total number of cases** | ***Sensitivity 5 % report rate*** | ***Sensitivity 1 % report rate*** |
| A2 2011- 2040 | 19854 | *397080* | *1985400* |
| | | | |
| A2 2071- 2100 | 40525 | *810500* | *4052500* |
| B2 2071- 2100 | 25341 | *506820* | *2534100* |

By the 2020s, the average annual number of temperature-related cases of salmonella may have increased by a total of almost 20,000 as a result of climate change in Europe (on top of any increases expected from population changes). Under the A2 scenario for the 2080s, the climate change induced increase in temperature-related cases of salmonella could be around 40,000 annually, on average for the whole of Europe, though this would fall significantly under the B2 scenario. The largest increases in number of cases (relative to population) occur in the UK, France, Switzerland and the Baltic countries, but this is due to the pattern across different countries because different country specific functions are used.

A number of other food-borne diseases could follow similar trends, although salmonella is the most common form of food-related illness in Europe. However, it is very likely that adaptations such as improvements in food storage and preparation would be able to reduce these potential increases significantly (and background rates might change with socio-economic development).

## 4.8. Health Effects from Flooding

The analysis has derived estimates of the number of cases of psychological stress for the IPCC climate scenarios only, for the 2020s and 2080s, based on the coastal flooding analysis in PESETA. These are presented in below. These show significant number of cases under the high sea level rise – A2 scenario by the period 2071-2100, potentially as high as 5 million additional cases per year, though consistent with the flooding analysis, these would be significantly reduced with adaptation.

*Table 7* ***Cases of mild depression attributable to coastal flooding from climate change in the EU under IPCC climate scenarios***

| Climate scenario | Year | Cases of mild depression ('000s) |
|---|---|---|
| Low sea level rise | 2020 | 1 |
| A2 | 2080 | 24 |
| | | |
| High sea level rise | 2020 | 13 |
| A2 | 2080 | 5573 |
| | | |
| Low sea level rise | 2020 | 1 |
| B2 | 2080 | 21 |
| | | |
| High sea level rise | 2020 | 12 |
| B2 | 2080 | 4290 |

## 4.9. Vector-borne diseases

Climate change has the potential to affect the burden of disease from vector-borne causes, by increasing incidence or changing distributions of disease[11]. Potential increases in vector-borne disease related to climate change may be significant in countries outside Europe, particularly in developing countries, and this could have knock on effects within Europe. However, within Europe, climate is only one of many influences on the incidence and prevalence of vector-borne disease. For a vector-borne disease to be viable in humans, there must be a sufficient reservoir of infection in the human population (or animal host population) and sufficient interaction between vector and humans for transmission to occur. Factors such as pest control programmes, vaccination and disease prevention programmes, environmental hygiene (particularly waste management practice, sanitation and the provision of clean drinking water), agricultural practice, human activity patterns and the design of the built environment, all have an important influence on the occurrence of vector-borne disease.

The study has considered the potential impacts of climate change on the occurrence of a range of mosquito, tick, flea and rodent-borne infections in Europe. The analysis concludes:

- Overall, there are currently no climatic barriers to any of these diseases becoming established in some areas of Europe, and their current incidence is largely governed by factors other than climate.
- Mosquito-borne diseases are not currently endemic in Europe, but thousands of cases of malaria occur in travellers who have been infected elsewhere in the world. A small

[11] Climate change (temperature, rainfall, humidity) may affect the development and longevity of vectors, pathogen development (e.g. growth of parasitic species within insects) and vector and host habitat and thus abundance. The interaction of all these factors may alter the geographical distribution of diseases, the prevalence of disease within hosts and vectors, the risk of infection within regions where the disease is endemic and length of the season during which transmission is possible.

number of cases of Dengue fever and Yellow Fever also occur in travellers. Although the risk of outbreaks of a range of vector-borne diseases may increase in response to increased temperatures in Europe, rainfall will also affect vector distribution. The actual incidence and prevalence of these diseases are, however, unlikely to substantially increase as a result of climate change, due to appropriate public health care measures and it is not expected that climate change will lead to the re-establishment of malaria in Europe in the foreseeable future.

- Diseases such Hantavirus, leptospirosis, tularaemia that are carried by rats and other small rodents and tick-borne diseases are uncommon in Europe. Cases primarily occur in individuals who become exposed to infection as a result of their occupation or leisure activities. It is unclear what the potential disease risk with climate change is, but it is not considered high.

- A few hundred cases of Leishmaniasis occur in humans in Europe, most commonly in immuno-compromised individuals. There may be some potential increased disease risk with climate change, but this is considered very low. Plague is not present in Europe and is confined to rare cases in travellers.

- Lyme borreliosis incidence has been increasing in Europe, with highest rates in central Europe,, though there are issues with differences in data sources used. Lyme disease is already endemic in Europe: climate change may slightly extend the range of the disease and there may also be changes in human behaviour that could lead to an increased contact with ticks (leisure) but public education could be used to effectively control the effects in Europe. Tick borne encephalitis is also already endemic in Europe and is most common in northern and central Europe (but there is inconsistencies in case definitions throughout Europe). The areas in which tick-borne diseases are endemic may potentially extend to higher altitudes and latitudes with climate change but this will be dependent on habitat availability for ticks and their mammal hosts.

- There is some potential for flooding to have a greater influence in increasing the risks of some diseases, e.g. through providing areas that are more suitable for some vectors, or by reducing the adequacy of public health responses.

- However, overall, socio-economic and economic factors will be influential in disease burden, in that increased wealth is likely to lead to higher standards of environmental hygiene, reduced risks of disease transmission and better prevention and control measures. It may, however, increase the risks of imported disease cases in travellers (though increases in tourism). Nonetheless, disease control and prevention are likely to help any potential outbreaks. increased availability of leisure time and wealth may lead to an increased participation in outdoor activities and water sports and thus exposure to waterborne diseases or to an increased use of forestry and open spaces where ticks are present.

## 4.10. Adaptation

We have considered the potential role of acclimatisation (or a decline in the sensitivity of mortality to cold) via autonomous physiological and behavioural changes in individuals or populations in the calculations of the high and low temperature mortality and hospital admissions presented above. It is clear that these processes of acclimatisation can reduce the potential health impacts of the changing climate significantly. However, the rate of acclimatisation suggested in the literature seems to be too fast why? in relation to the rates of climate change suggested by most of the climate model projections that we have used and further research and analysis needed. Where we included acclimatisation aligned with the climate scenario, for climate-dependent exposure-response functions, we found that rather than removing all the potential climate change related impacts and benefits, some impacts and benefits remained. This indicates that climate variability and the relationship between extreme and mean temperatures may be changing in the future scenarios compared to baseline climates.

In addition to acclimatisation, planned, proactive adaptation may have a strong role in reducing potential health risks, particularly in relation to extremes. The cCASHh project has indicated that most of the measures required for adaptation to future climate change in the health sector already exist, and most of them build on well-established public health approaches. They will 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

Some of these are already starting to emerge, such as heat wave health plans in France and other European countries, and the use of heat wave alerts to minimise heat-related deaths.

Education to advise people of appropriate behaviour during hot weather is an essential component of heat-death prevention.

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, and health (and well-being) will be a strong driver in this respect. One response is through air conditioning, but this will have implications for increasing energy use. Adaptation therefore also has a major role in looking at alternatives to air conditioning (both through ventilation such as passive systems, but also through behavioural change).

The most important mechanisms to prevent food- and water-borne disease are surveillance and monitoring, microbial risk assessment, risk management and risk communication (Menne and Ebi, 2006). Contamination of food products usually arises from improper handling, preparation or storage of food. New technologies may need to be developed alongside appropriate legislation, and education of consumers and professional food handlers.

## 4.11. Uncertainty

In order to assess the implications of the results above, it is essential to take account of the various uncertainties that are present in the analysis. These can relate to uncertainty over which health impacts occur (per se), and those over the methodology for quantification, as well as the uncertainty in the different steps of the analysis (climate prediction, etc). It is highlighted that the uncertainties on impact analysis (and also valuation in the next section) are very large in the analysis undertaken here. It is not possible to represent accurately the uncertainty introduced by each parameter in the quantification of health impacts, but an indication of the relative size of the effect is provided below, using some simple sensitivity analysis and judgement. The further the analysis proceeds through the chain from climate to exposure to impact assessment to valuation, the greater is the potential uncertainty in the final estimate (simply because more parameters, each bringing their own level of uncertainty to the analysis, are introduced).

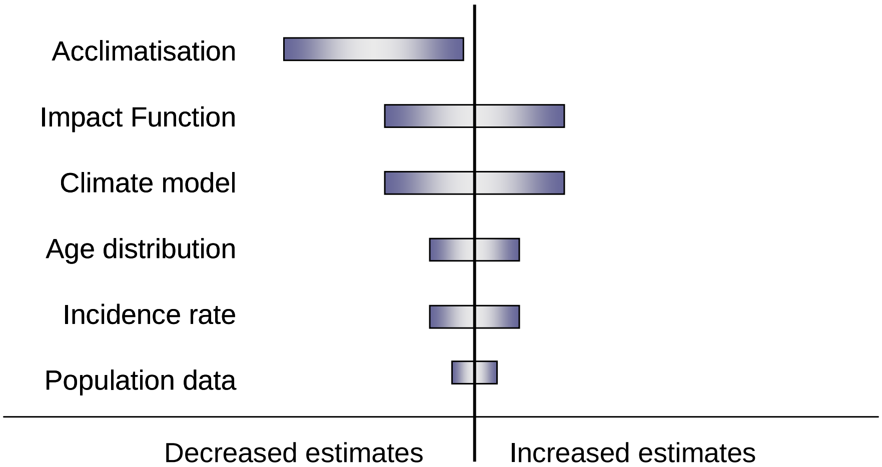



***Figure 7*** ***Illustrative uncertainty for cold and heat related health quantification and valuation***

The analysis shows that after climate sensitivity, the choice of acclimatisation (or decline in the sensitivity of mortality to cold) and exposure response function have most influence on the results. There is also a relatively high uncertainty on given climate scenarios from different models. The socio-economic data (e.g. population, age distribution and incidence) have a lower effect, though the analysis above does not fully reflect the uncertainties of projecting these forward and the effect of other parameters (e.g. future wealth or health care). Many of the issues identified in the bias analysis above add further uncertainty to the results.

When all the uncertainties are considered together, it is clear that the range around the quantified values are extremely large, and, we judge, probably at least two orders of magnitude.

# 5. Valuation and Economic Results

## 5.1. Introduction and Unit Values

The analysis in PESETA has continued through to the valuation of health effects. The study has reviewed the economic estimates for health effects as undertaken in the environmental economics literature. Consistent with this, in health valuation there are three elements that need to be considered in estimating the total effect of the impact on society's welfare. These elements are:

- Resource costs i.e. medical costs;
- Opportunity costs i.e. the cost in terms of lost productivity, and
- Dis-utility i.e. pain or suffering and concern and inconvenience to family and others

The unit health valuation estimates have been derived (where possible) on this basis:

- For mortality, Two metrics are currently used: the value of a prevented fatality (VPF), also known as the Value of a Statistical Life (VSL) and the value of a life year (VOLY), the latter providing a means of explicitly accommodating differing lengths of remaining life expectancy. The work in this area has benefited from recent DG Research studies (notably the NEWEXT study) and estimates have been used of €1.11 million as a central Value of a Statistical Life (VPF), equivalent to 59000 euro for a Value of a Life Year (VOLY)[12.] Both metrics are applied, consistent with recent analysis for DG Environment under the CAFE (Clean Air For Europe Programme). A central illustrative range is used, though a wider range has been considered.
- For salmonella, the analysis has considered the range of outcomes and probabilities associated with disease, which include a small proportion of fatalities. Consideration of resource, opportunity and dis-utility costs for the different outcomes have been compiled and used to produce an overall weighted value per case, with a range of between €3,500 and €7,000.
- Finally, for mild depression, a unit value based on cost of treatment has been used (in the absence of full societal costs).

[12] Note there remain important gaps on the average period of life lost from heat and cold related mortality, in relation to the application of the VOLY approach. The value here assumes that 8 years of life, on average, is lost, but this is a major uncertainty.

## 5.2. Economic Results

The physical impact results in the previous section have been valued. The valuation analysis allows consideration of the importance of different health categories, and the monetary benefits of different future scenarios.

The results show that the mortality related effects are likely to dominate the (known and quantifiable) health effects of climate change in Europe. The overall summary of heat and cold related mortality is shown in the table below. In general heat and cold related effects are valued in terms of billions of Euros (each year, in current prices, though this includes positive and negative effects).

The values follow the pattern of physical impacts above and so no additional description is included here.

*Table 8* *Summary of Heat and Cold Related Mortality – All Scenarios. Current prices, with no uplift or discounting. Million Euro/year*

| HEAT-RELATED DEATHS | Million Euro/year | | |
|---|---|---|---|
| | European total number of deaths | Valuation using VOLY central (€59k) | Valuation using VSL Central (€1.11 M) |
| **a) Climate-dependent functions** | | | |
| 2011-2040 | 27337 | 12903 | 30344 |
| 2011-2040 with acclimatisation | 3978 | 1878 | 4416 |
| 2071-2100 A2 (HIRHAM/HadAM3H) | 106,419 | 50230 | 118125 |
| 2071-2100 A2 (HIRHAM/HadAM3H) with acclimatisation | 17,080 | 8062 | 18959 |
| 2071-2100 B2 (HIRHAM/HadAM3H) | 50,665 | 23914 | 56238 |
| 2071-2100 B2 (HIRHAM/HadAM3H) with acclimatisation | | | |
| **b) Country-specific functions** | | | |
| 2011-2040 | 26372 | 12448 | 29273 |
| 2011-2040 with acclimatisation | 3938 | 1859 | 4371 |
| 2071-2100 A2 (HIRHAM/HadAM3H) | 107,339 | 50664 | 119146 |
| 2071-2100 A2 (HIRHAM/HadAM3H) with acclimatisation | 19,449 | 9180 | 21588 |
| 2071-2100 B2 (HIRHAM/HadAM3H) | 58,508 | 27616 | 64944 |
| 2071-2100 B2 (HIRHAM/HadAM3H) with acclimatisation | | | |
| 2071-2100 A2 (RCA/ECHAM4) | 161,694 | 76320 | 179480 |
| 2071-2100 A2 (RCA/ECHAM4) with acclimatisation | 73,322 | 34608 | 81387 |
| 2071-2100 B2 (RCA/ECHAM4) | 95,822 | 45228 | 106362 |
| 2071-2100 B2 (RCA/ECHAM4) with acclimatisation | 19,346 | 9131 | 21474 |
| **COLD-RELATED DEATHS** | | | |
| **a) Climate-dependent functions** | | | |
| 2011-2040 | - 50272 | -23728 | -55802 |
| 2011-2040 with acclimatisation | - 19422 | -9167 | -21558 |
| 2071-2100 A2 (HIRHAM/HadAM3H) | - 86,291 | -40729 | -95783 |
| 2071-2100 A2 with decline in sensitivity of mortality to cold' | - 18,835 | -8890 | -20907 |
| 2071-2100 B2 (HIRHAM/HadAM3H) | - 57,823 | -27292 | -64184 |
| 2071-2100 B2 with decline in sensitivity of mortality to cold' | | | |
| **b) Country-specific functions** | | | |
| 2011-2040 | - 98529 | -46506 | -109367 |
| 2011-2040 with acclimatisation | - 6893 | -3253 | -7651 |
| 2071-2100 A2 (HIRHAM/HadAM3H) | - 184,222 | -86953 | -204486 |
| 2071-2100 A2 with decline in sensitivity of mortality to cold' | | | |
| 2071-2100 B2 (HIRHAM/HadAM3H) | - 101,112 | -47725 | -112234 |
| 2071-2100 B2 with decline in sensitivity of mortality to cold' | | | |
| 2071-2100 A2 (RCA/ECHAM4) | - 255,696 | -120689 | -283823 |
| 2071-2100 A2 with decline in sensitivity of mortality to cold' | - 62,679 | -29584 | -69574 |
| 2071-2100 B2 (RCA/ECHAM4) | - 189,742 | -89558 | -210614 |
| 2071-2100 B2 with decline in sensitivity of mortality to cold' | - 5,645 | -2664 | -6266 |

The analysis has also valued the temperature-related cases of salmonella. The valuation results are summarised below, for future time periods, and for both A2 and B2 scenarios. The analysis has undertaken two sensitivities taking under-reporting of cases into account. The results (expressed in current prices without adjustment or discounting) show that:

- By the period 2011 – 2040, the valuation of the average annual number of temperature-related cases of salmonella may have increased by 70 to 140 million/year as a result of climate change in Europe. Taking under-reporting into account, these could be as large as 1.4 to 2.8 billion/year (5 % report level) or 6.9 to 14 billion (1 % report level).
- By the period 2071 – 2100 under the A2 scenario, the valuation of the average annual number of temperature-related cases of salmonella may have increased by 142 to 284 million/year as a result of climate change in Europe. Taking under-reporting into account, these could be as large as 2.8 to 5.7 billion/year (5 % report level) or 14 to 28 billion (1 % report level).
- By the period 2071-2100 under the B2 scenario, the valuation of the average annual number of temperature-related cases of salmonella is predicted to have increased much less (than A2) by 89 to 177 million/year as a result of climate change in Europe. Taking under-reporting into account, these could be as large as 1.7 to 3.5 billion/year (5 % report level) or 8.9 to 17.7 billion (1 % report level).
- The potential benefits of the B2 scenario over the A2 scenario are therefore 53 to 107 million/year. Taking under-reporting into account, the benefits could be as large as 1.1 to 2.1 billion/year (5 % report level) or 5.3 to 10.6 billion (1 % report level).
- Note however that adaptation would be expected to have a major role in reducing these impacts.

The study has also undertaken some preliminary scoping work to look into the potential range of annual costs per case of treating depression symptoms resulting from coastal flood events. The results (expressed in current prices without adjustment or discounting, and without adaptation) show:

- Potential costs in 2071-2100 under the high sea level rise A2 scenario could be 1.0 to 1.4 billion/year.
- Under the B2 scenario, these are estimated (high sea level rise B2) at 0.8 to 1.1 billion/year.

The results also show a substantial difference in impacts between the two time periods centred on 2025 and 2085 (the costs in the former period are orders of magnitude lower). The A2 scenario costs are higher than those for the B2 scenario, reflecting in part the differences in population size between the scenarios and also the extent of climate change.

It has not been possible to quantify or value the potential costs of vector borne disease, but consideration of other study results show the economic costs are likely to be low in relation to the other categories of effects above.

# 6. Discussion and Research Priorities

## 6.1. Discussion

The PESETA study has advanced the bottom-up analysis of physical impact assessment and economic valuation of the health effects of climate change in Europe.

The analysis shows that there are estimated to be significant increases in heat related mortality in future years due to climate change, with associated economic costs, but that these are likely to be offset (or exceeded) by benefits from the reduction in winter mortality. Populations will partly acclimatise to future temperatures, and there is also the potential for adaptation beyond this, for example with the current heat alert systems. The analysis has shown, however, that the future net effects are determined by the choice of impact function and the assumptions about acclimatisation, and these are key outstanding sources of uncertainty.

It is hard to decide which of the two sets of results (climate-dependent or country-specific) should be considered more robust and reliable. The choice of functions also determine the distribution of impacts across Europe (e.g. between the Mediterranean and Scandinavia). This relates to whether we expect that all people respond similarly to climate (albeit from different starting positions of mortality thresholds and current climate), or whether there should be variability in responses from one area to another, because of different socio-economic confounding factors (including acclimatisation/ adaptation), Climate-dependent exposure-response functions contain an assumption that all Europeans react similarly to the same absolute temperature changes imposed on top of their own local climate. The largest heat-related impacts using these functions occurred in southern or central-eastern countries, while the smallest heat-related impacts were in north-western Europe. These results match the spatial patterns of climate change across Europe. Country-specific exposure-response functions contain an assumption that people in different countries can have very differently responses to the climate, but there are issues with the fact that functions are taken from independent empirical studies carried out by different research teams at different times and in different ways (i.e. consistency). The country-specific functions also implicitly contain the effects of confounding socio-economic issues, which may exacerbate apparent inter-country differences in climate response. The outcome of using country-specific functions was that greatest heat-related impacts were calculated in central-eastern countries, where we applied the highest rates of change, and the climate change compared to the threshold temperature was relatively large. We may have expected to find more significant heat-related mortality impacts in the hottest parts of Europe, such as the Mediterranean countries (as was the case with the results from climate-dependent functions), but the empirically-derived response function used in these countries had a lesser sensitivity to temperature change. The epidemiology on which these functions are based indicates that mortality in the hotter countries of Europe is less dependent on high temperatures than in central-eastern European countries. This may be because the southern European populations are already well-acclimatised to high temperatures, though there are also many other reasons why these differences could occur e.g. socio-economic factors and additional adaptation. There are similar issues with respect to acclimatisation, and the potential importance of socio-economic factors (not least heating and healthcare).

Because there are significant differences between the results calculated using the different sets of climate-health response functions, in terms of both the spatial patterns and the all-Europe aggregated totals, it is important to consider the assumptions implicit in the two different types of approach. As a consequence, the results presented here should only be considered as an initial, interim assessment until better information becomes available and some parts of the methods are elaborated in more detail. Several assumptions underlie the calculating of these impacts, and should be kept in mind when interpreting the results.

The analysis also shows that there are significant differences in levels of effects between different future scenarios (e.g. between the A2 and B2 scenarios). For some endpoints, the difference is very noticeable, e.g. with generally a 40 to 50 % reduction in physical impacts (e.g. for heat related mortality).

The impact of different climate model data is also important. The second set of climate data that we considered (from the RCA RCM nested in the ECHAM4 GCM) indicated a larger average temperature rise by the 2080s than the first set of climate data (from HIRHAM/HadAM3H). This resulted in larger climate change induced mortality impacts and benefits, up to as much as 50 % larger for the A2 scenario, although the distributional pattern between European countries were similar. There are also much wider issues of uncertainty that mean that the estimates here should only be treated as indicative.

The analysis has also progressed a detailed bottom-up analysis of food borne disease in Europe, and show that the additional number of cases (particularly under a scenario of current under reporting of disease levels) could be important in terms of both physical impacts and economic costs. It is stressed that these cases of food borne disease are additional impacts (i.e. there are no competing positive and negative aspects as with temperature related mortality above). Further work is needed to account for future socio-economic scenarios and the role of adaptation in these estimates.

The study has also progressed an initial analysis of the wider effects of coastal flooding (linking the output from one of the other PESETA projects), which shows that under high sea level rise scenarios, the number of cases and economic costs could also be significant. It has also reviewed the potential for vector borne disease. While climate change during this century is likely to lead to an increase in the potential areas in which a number of vector-borne diseases could become established in Europe, it is not anticipated that these disease will be established in Europe. Whilst increasing affluence, more leisure time, and a climate more conducive to outdoor lifestyles could increase population exposure to disease risks in some parts of Europe, and rates of infection related to travel outside Europe may also increase (continuing current trends), we expect that health care protection systems in Europe are likely to improve, and so we anticipate that climate change induced increases in incidence of vector-borne diseases within Europe will be negligible.

Across all areas, adaptation has a role in reducing all impact categories, and whether through heat related alert systems or other measures to address heat exposure, control of food borne disease, or through flood protection, a common theme seems to be that adaptation should be able to offer significant reductions in impacts at relatively low cost.

## 6.2. Policy Responses

In terms of possible policy responses, it would seem sensible to investigate further extension or refinement of the heat health warning systems emerging in Europe across all countries, but particularly those in the Mediterranean and Southern New Member States. This might warrant regional-led responses and information sharing, e.g. in climate prediction and dissemination.

There is also a need to consider adaptation responses that can help populations cope with future temperature extremes, but this raises an important link with climate change mitigation strategies. One obvious response to cope with warmer conditions is through increased use of air conditioning, but an increase in conventional air conditioning systems will require increased energy consumption and may contribute to increasing greenhouse gas emissions. There is therefore a need to decouple responses to warmer climates from energy intensive air conditioning, perhaps through use of passive ventilation systems, behavioural changes, etc.

Another important health effect that has been identified is the potential rise in food-borne disease under a warmer climate. This is one area where the appropriate adaptation measures are largely already in existence, with regard to appropriate food preparation and storage conditions: these could be introduced via information dissemination, or through more formal standard-based legislation.

The potential for the spread of vector-borne disease (such as malaria) is a policy concern, but with the anticipated continued improvement of healthcare systems and preventative measures, the risks to Europe are expected to be low. This is one area where there is a clear need for sharing of information and experience, plus inter-country collaboration, to mitigate the potential risks. There are potential adaptation options for many of these risks (e.g. preventative medicine/action) though this may lead to some additional health care costs. However, for some diseases, further research is also required.

The final major area identified in the study is the potential increased risk from floods and other extreme events. While the absolute numbers of deaths and injuries from these events is likely to remain relatively low (compared to the effects above), there are much wider effects on well-being that arise among communities affected by these events, and these could bring longer-term socio-economic impacts. The adaptation measures for these events are dealt with in other PESETA studies.

## 6.3. Research priorities

The analysis has identified a number of research gaps and additional health effects that have not been considered here and that are potentially important. These form the research priorities and include:

- The need for consistent and comparable epidemiological studies to provide the basis for a more robust set of temperature-mortality exposure-response functions applicable across Europe. The PHEWE project is likely to help in this regard. However, there is also a need for greater understanding of the role and rates of acclimatisation to changing temperatures in Europe;

- More detailed analysis of the urban effects of heat related impacts (e.g. taking account of the urban heat island effects which are not fully represented within the models), and additional impacts that may result from longer periods of extreme high temperatures (heat waves). The omission of additional urban heatwave effects may mean that the climate change induced heat-related mortality impacts calculated here are possible underestimates;
- Further work to explore heat and cold related morbidity;
- Consideration of other food borne disease (in addition to salmonella);
- Possible interactions between climate and air pollution, particularly the potential rates of ground level formation of ozone in summer and health effects;
- Analysis of direct health impacts and wider effects on well-being from river flooding in Europe;
- The implications of health impacts globally, particularly in developing countries, on Europe;
- The potential impact of climate change on emerging health issues, such as increased allergies in Europe;
- The potential for surprises, i.e. new health burdens that might emerge;
- Monetary valuation of the health end-points above in the climate change context;
- Development and evolution of decision making rules e.g. CBA, MCA etc. in the context of adaptation to climate change;
- Possible interactions between the health and energy sectors, with heat related health concerns driving interactions with energy use and air conditioning (with potential feed-backs on energy use and emissions);
- Examination of other cross-cutting effects, such as health and tourism, water availability, etc.

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Abstract

The most important health effects from future climate change are projected to include: increases in summer heat related mortality (deaths) and morbidity (illness); decreases in winter cold related mortality and morbidity; changes in the disease burden e.g. from vector-, water- or food-borne disease; increases in the risk of accidents and wider well being from extreme events (storms and floods). The PESETA health project has assessed these effects in Europe. These include both positive and negative effects on health, and show strong patterns of regional variation across Europe.

The analysis has undertaken a detailed bottom-up analysis of summer and winter temperature-related mortality. This shows that Europe's changing climate will have significant additional effects on heat and cold related mortality, measured in tens of thousand of deaths each year (and economic effects measured in tens of billions of Euro). The analysis has also undertaken a detailed bottom-up analysis of food borne disease in Europe which shows that the additional number of cases (particularly with under reporting of disease levels) could be significant in terms of both physical impacts (tens of thousands of cases per year) and economic costs (billions). Finally, the study has progressed an initial analysis of the mental health effects of coastal flooding (linking the output from one of the other PESETA sectoral projects), which shows that under high sea level rise scenarios, the number of cases and economic costs could also be significant.

A consideration of adaptation, whether through addressing heat exposure, through control of food borne disease, or through flood protection, shows that it offers significant reductions in impacts at potentially low cost. A number of possible policy responses are also identified. The most important of these relate to further extension or refinement of the heat health warning systems emerging in Europe.

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