Projection of Economic Impacts of Climate Change in Sectors of Europe based on Bottom up Analysis: Human Health

Paul Watkiss[1], Alistair Hunt[2]

[1] Paul Watkiss Associates, Oxford, UK: email: paul_watkiss@btinternet.com

[2]Department of Economics, University of Bath, UK

Abstract

This paper scopes a number of the health impacts of climate change in Europe (EU-27) quantitatively, using physical and monetary metrics. Temperature-related mortality effects, salmonellosis and coastal flooding-induced mental health impacts resulting from climate change are isolated from the effects of socio-economic change for the 2011-2040 and 2071-2100 time periods. The temperature-induced mortality effects of climate change include both positive and negative effects, for winter (cold) and summer (heat) effects, respectively, and have welfare costs (and benefits) of up to 100 billion Euro annually by the later time-period, though these are unevenly distributed across countries..

The role of uncertainty in quantifying these effects is explored through sensitivity analysis on key parameters. This investigates climate model output, climate scenario, impact function, the existence and extent of acclimatisation, and the choice of physical and monetary metrics. While all of these lead to major differences in reported results, acclimatisation is particularly important in determining the size of the health impacts, and could influence the scale and form of public adaptation at the EU and national level.

The welfare costs for salmonellosis from climate change are estimated at potentially several hundred million Euro annually by the period 2071-2100. Finally, a scoping assessment of the health costs of climate change from coastal flooding, focusing on mental health problems such as depression, are estimated at up to 1.5 billion Euro annually by the period 2071-2100.

1. Introduction

There is increasing policy interest in quantifying the potential physical consequences and associated economic welfare costs from climate change, as well as the role that adaptation action has in potentially reducing these consequences (CEC 2005a: 2005b, 2007a, 2007b, 2009; EEA 2007, 2008). The PESETA project (Projection of Economic Impacts of Climate Change in Sectors of Europe based on bottom up Analysis) aimed to assess a broad range of potential climate change impacts in Europe in quantitative terms, and to progress to an economic analysis of these impacts (Ciscar et al. 2009). As part of this research project, human health was identified as a priority area for assessment. This paper provides a summary of the PESETA health assessment for climate change in Europe.

Climate change has a range of complex inter-linkages with health (Menne and Ebi 2006: Confalonieri et al. 2007). It may lead to direct effects such as temperature-related illness and mortality from heat and cold, and to injuries and fatalities from extreme weather events. Other potential impacts may follow more indirect pathways such as those that give rise to water- and food-borne diseases or transmission of vector-borne disease. These health changes will have economic consequences through incurring medical treatment costs and health protection costs, the potential loss of work productivity, as well as welfare changes that can be expressed in economic terms when captured by measures of willingness to pay to avoid any pain and suffering associated with adverse health outcomes.

There is already a considerable literature relating to the health impact assessment of climate change in physical terms (e.g. the number of cases of fatalities or disease outcomes). Notable studies at the global scale include McMichael et al. (2001, 2004) and Pitcher et al. (2008), whilst studies in Europe include Kovats (2000) and Menne and Ebi (2006). Health is also a key focus area in national climate assessments (e.g. UK CCIRG (1996), USNAS

(2000), SIAM (2002), ECCE (2005), NRC (2007:2010) etc.), though much of the focus in these studies has been on heat related mortality (see also later discussion).

However, there is a more limited set of studies that assess the economic costs associated with health impacts of climate change, though these do include studies at the global scale (Tol 2002a,b; Tol 2008: Bosello et al, 2006) and at national level (e.g. Kovats et al. (2006) in the UK; SCCV (2007) in Sweden; Bambrick et al. 2008 for Australia: Carraro et al. 2008 for Italy)

Health has emerged as a priority area of assessment in studies of climate change impacts, both at the global scale, with particular concerns for developing countries (e.g. Stern et al. 2006; Parry et al. 2007) but also in relation to developed countries (e.g. Alcamo et al, 2007: Garnaut Review 2008).

The assessment reported in this paper builds upon this existing literature. It assesses the potential impacts of three climate change-related health endpoints: mortality changes related to temperature; salmonellosis cases; and coastal induced health consequences, for a large geographical area (European Union, specifically the EU27). Unlike previous studies, the assessment also uses a very high level of spatial and temporal disaggregation.

The focus on these three health endpoint reflects the existing literature on physical quantification, which is a pre-requisite to valuation: the main subject of this paper. A number of other health endpoints are also potentially important for Europe, notably temperature and morbidity, vector borne disease (mosquito and tick-borne), water-borne disease, air pollution related impacts, and the direct effects of extreme events (floods, fire, etc.). However, as reported by Kovats and Lloyd (2010), there is a lack of quantification studies for these endpoints at the European scale, and for this reason they have not been assessed here. Furthermore, a number of these impacts are associated with extreme events or are episodic in nature (e.g. water borne disease outbreaks), which makes European level quantification challenging. Because of these omissions, it is stressed that the economic costs reported in this paper are therefore likely to be an underestimate of the total health costs of climate change in Europe.

The assessment also serves to demonstrate the role of uncertainty in determining physical and monetary aggregate impact estimates. Specifically, sensitivity analysis is applied to the climate models and scenarios, the physical health impact function, treatment of autonomous adaptation, and monetary unit costs for valuation, to illustrate the effect of uncertainty on the aggregate results for Europe. A principal finding is that variations in these parameter values – alone and combined - have a significant effect on the total aggregate estimates, but also the geographical pattern of projected health impacts across Europe. They therefore have a critical role in determining appropriate adaptation responses across Europe.

A key focus of this paper is the consideration of monetary values, not least because this provides a common metric for comparing different endpoints, but also against other sectors (for example the other sector results in this special edition). In line with other sectors, and the overall approach used in PESETA, and to maximise the direct comparability for different impacts over time, the results are presented here in constant values (2005 prices), with no adjustments for future time periods, including no discounting.

The paper is structured as follows: Section 2 gives an overview of the modelling framework adopted in the study, together with a description of the generic climate and socio-economic data applied in the quantitative analysis. Sections 3, 4 and 5 then outline the method and results for the three health impacts analysed quantitatively; mortality, salmonellosis and mental health, respectively. Section 6 then draws together some implications for policy as well as highlighting a number of priorities for future research.

2. Methodology and Data

The PESETA project adopts a bottom-up impact assessment methodology, as defined in Carter et al. (2007). This approach is followed in a number of national assessments (e.g. US NAS 2000; Hunt 2008), where data from national-scale climate and socio-economic projections are used in combination with climate-impact response functions to generate estimates of physical impacts. The climate-impact response functions that link climate parameters to health outcomes are based on epidemiological studies undertaken on the basis of current climate variability. The physical metric is then converted to a monetary one by multiplying the health outcomes by a relevant unit value. Thus:

Total Impact (physical units) = change in state of environment (climate) x population at risk x impact function

Economic impact =Total impact (physical units) x unit value of impact

In common with the other sectoral studies undertaken within the PESETA project, analysis is undertaken for two time periods (the periods 2011 - 2040 and 2071- 2100), relative to a model control period (1961-1990) for two climate scenarios (IPCC SRES A2 and B2). It also considers two alternative climate model projections with different driving GCMs for the latter time period (see Christensen et al. this issue). For the 2080s, the first simulation uses the Danish Meteorological Institute (DMI) regional model / Hadley Centre's HadCM3 GCM. The second simulation repeats the analysis with an alternative RCM and GCM combination (RCM from the Swedish Meteorological and Hydrological Institute; GCM from the Max Planck Institute's ECHAM4). For the early period (2011-2040) the analysis considers the IPCC SES A2 scenario only, although the A2 and B2 scenarios are very close for this time window. For the latter period (2071-2100) the A2 and B2 scenarios are assessed separately.

The spatial scale is defined by the regional climate model outputs; the temporal scale is also highly disaggregated, adopting simulated daily data. Aggregation of this data has then been undertaken for each EU Member State, for the EU as a whole, and for the two reporting time periods.

To implement this level of dis-aggregated analysis and to automate the large number of operational calculations and runs, a relative complex integrated assessment modelling environment was developed. This built and links two modelling databases. The first is a health impact assessment model, operating within a Geographical Information System (GIS). The second is a data processing model, built within a Fortran environment. Both models use a gridded system (50 km by 50 km grid resolution) across Europe, into which climate, socio-economic data and background health incidence data are incorporated. The impact-response functions and valuation endpoints are then introduced in order to allow estimation of daily level data across the two 30-year climatological periods. The quantitative modelling aspects are illustrated in Figure 1.

Estimates are generated within the GIS. This model provides the number of additional deaths, hospital admissions and salmonella cases in each grid cell for each year. The annual estimates are averaged across the 30-year climatological period to give the projections of health impacts resulting from the coupling of climate change and socio-economic change for that time-period. The results are assessed in the following sequence. First, the number of deaths and salmonellosis cases relating to socio-economic changes alone are estimated (i.e., calculated for the future period by subtracting total health impacts estimated under present-day (baseline) climate from those estimated under projected future socio-economic conditions with no climate change). Second, the combined socio-economic and climate change effects are estimated. Finally, the difference between the health impacts from the coupled socio-economic and climate change, and those from socio-economic changes alone is estimated. This provides the additional deaths, hospital admissions and salmonella cases induced by climate change alone (i.e. the marginal effect due to climate change).

<Figure 1 about here>

Information on the climate data is provided in Christensen et al. (this issue). The other key input data for the analysis of potential impacts from climate change is the use of quantified socio-economic projections. For health, the primary projections are population size and geographical location: whilst the population of Europe is mature, there are some projected changes (increases) over the next century. To apply a number of the impact-response functions, the age structure and death rates of the population are also needed. The analysis has applied the risk factors to the total population at risk, though heat stress is primarily associated with urban populations. Population data were supplied by IIASA (van Vuuren and O'Neill 2006), based on the IPCC Special Report on Emissions Scenarios (SRES), A2 and B2 scenarios, disaggregated on a 5-year interval basis, split into 5-year age bands. The data shows that total population changes are generally modest with around an 8% population growth by the 2080s under the A2 scenario, and a 3% reduction under the B2 scenario. Country specific mortality rates were taken from the UN projections and multiplied by the population projections to give the baseline number of deaths in a given time-period. On the basis of Eurostat data, these death rates were disaggregated to give age-specific death rates, for current and future time periods. For the analysis of food borne disease, baseline datasets for salmonella cases were taken from the WHO Global Salmonella Survey (GSS) (Galanis et al. 2006). No adjustments were made for future changes in rates as a result of technological or behavioural change.

It is stressed that a number of other socio-economic factors will be important in future impacts. Economic growth (and per capita income) is an important factor in reducing future impacts, both in relation to general health levels, but also specific impact categories (for example, income is a strong determinant of household air conditioning (Isaac and van Vuuren, 2009), and ownership and usage of ACs significantly reduced the effects of temperature on health outcomes to heat (Ostro et al. 2010)). However, the effect of economic growth on health outcomes has not been considered in the analysis. Furthermore, there is a wide range of other socio-economic factors, not least the wider changes in health care policy, general health status (other determinants), health inequalities, etc. and autonomous adaptation that will affect outcomes. These omissions are highlighted as a major uncertainty.

3 Analysis of Temperature (heat and cold) related mortality

3.1 Background

Climate variability already has significant effects on health, for example in relation to heat- and cold-related effects on mortality and morbidity. These effects are widely recognised and a number of epidemiological studies – primarily using time-series data - document the health effects of heat extremes and heat-waves in quantitative terms (e.g. Ballester et al. 1997: Hajat et al. 2002; O'Neill et al. 2003; Páldy et al. 2005). Such weather events have become a greater focus for policy makers in Europe following the 2003 heat-wave when a large number of premature deaths were observed across all of Western Europe, and particularly in France (Pirard et al. 2005). Studies also identify epidemiological relationships for cold-related mortality (e.g. Donaldson and Keatinge 1997; Danet et al. 1999; Eurowinter 1997). In relation to mortality, winter cold stress is often reported to be more important than summer heat stress for many countries (e.g. such as the UK, Department of Health, 2001).

The studies often report strong distributional effects within population groups. For example, the elderly are at higher risk of dying during a heat wave or from heat stroke, as seen in France in 2003 (Pirard et al. 2005). Similarly, there is frequently found to be variation by socio-economic group and correlation with income or deprivation indices (e.g. Vandentorren et al. 2004; Curriero et al. 2002; O'Neill et al. 2003; Matthies et al. 2008), though this evidence is stronger for the USA.

These studies tend to report the impacts of climate with a simple variable such as daily mean temperature, and find a temperature - health relationship in terms of a U, V or J shaped curve. In such curves, mortality rates increase above a given temperature threshold for heat (and increase below a temperature threshold for cold), thus it is the frequency and intensity of temperature divergences that are important. The thermal optimum varies from country to country across Europe, with lower threshold temperatures for heat in the north, and higher threshold temperatures in the south. The gradients of the curve also vary from country to country.

These temperature-mortality relationships can be applied to assess the potential impacts of future climate change. There are a growing number of such studies that provide quantitative estimates of future increases in heat related effects with climate change. For example, quantitative projections exist for Lisbon (Dessai 2003), Los Angeles (Hayhoe et al. 2004), New York (Kinney et al. 2006), Boston (Kirshen et al. 2004), as well as a group of 10

Australian and 2 New Zealand cities (McMichael et al. 2003). National-level studies also exist, for example for the UK (Donaldson et al. 2001; Kovats et al. 2006; DoH, 2008), and Germany (Koppe et al. 2003) amongst many others. Future climate change will also potentially reduce cold related effects (i.e. leading to benefits), though there has been less consideration of these effects in most studies of climate change, though Bosello et al. (2004) and Kovats et al. (2006) provide quantitative projections in the context of aggregated and national economic assessments respectively.

However, the spatial and transfer of these epidemiological relationships to future climate introduces significant uncertainty to the analysis. This arises from the application of functions derived for one particular location to a much broader spatial area and from the application of current time series data to future climates. The latter assumes that future temperature-mortality relationships for any specific location will be identical to past ones. However, Davis et al. (2003a; b) show that - due to demographic change and acclimatisation and adaptation - this will invariably overestimate potential future effects. There is therefore the need to incorporate non-stationary processes, though, as yet, there is little consensus on how this should be undertaken.

Other aspects of socio-economic change also have a role in determining population vulnerabilities though these have not yet been quantified. There are also uncertainties introduced in the measurement and transfer of the impact function relationships themselves, since these relationships tend to be defined with regard to the mean temperature only, which may not provide the best representation of the climate drivers such as duration and intensity that are responsible for the effects of heat extremes. This is particularly important because climate models indicate an increase in the mean and variance of temperatures with future climate change, and there is some evidence that increased variability will have an effect on winter and summer mortality (Braga et al. 2001, 2002).

3.2 Assessment Methodology

In the light of the above, it becomes clear that it is crucial for policy makers to understand the sources of uncertainty and their potential importance in determining health impacts, rather than focusing on specific single projections of the future that overly simplify the picture. A key focus of this study has therefore been to test different parameter choices and investigate their effects on the spatially disaggregated results as well as the aggregated totals. To advance this, a series of paired comparisons have been adopted. These are:

a) two socio-economic scenarios / climate model projections (SRES A2 and B2);

b) two regional climate model outputs (where available) for each of these scenarios;

c) two temperature-related mortality functions, applied to each model output;

d) two assumptions relating to acclimatisation (with and without);

e) two valuation metrics, using premature deaths and years of life lost, each with a range of two values.

Note that even this set of sensitivity analysis represents a sub-set of full uncertainty.

3.3 Climate Model data

Consistent with the other sectoral studies in PESETA, we have used climate scenario data from the Rossby Centre (for the period 2011- 2040) and the PRUDENCE project (for 2071-2100), with investigation of two different driving GCMs for the latter time period (see Section 2).

A full description of the model outputs is provided by Christensen et al. (this issue). In summary, for average summer temperatures, the largest climate changes are projected in southern and Mediterranean Europe, with up to 7 °C warming over Spain and parts of

France, Greece and Turkey under the A2 scenario by the period 2071 – 2100, and up to 5 °C under the B2 scenario. The smallest changes are projected across the British Isles and Scandinavia – with less than 2 °C under the A2 scenario. For average winter temperatures, the largest climate changes are projected in Eastern Europe, with up to 5.5 °C warming in easternmost parts of Finland, Romania, Bulgaria and Turkey under the A2 scenario, and up to 4°C under the B2 scenario. The smallest changes are projected in Western Europe, through the British Isles, France, Spain and Portugal - less than 2 °C under the B2 scenario. These differences are important in the subsequent distribution of impacts. It is highlighted that that the climate change models do not account for elevated temperatures in urban areas, i.e. from any urban heat island effects, and therefore may underestimate effects, particularly in major cities.

3.4 Impact functions

The study uses two simple functional relationships for assessing potential heat- and cold-related temperature effects. It is highlighted that there is also some evidence of other health related effects (morbidity) from temperature, but due to a lack of coverage of functions across the EU, these were not quantified here.

The first set of relationships uses a suite of country-specific epidemiological studies, using the functions reported by Menne and Ebi (2006) for seven countries across Europe. These are reported here as 'country specific' functions. These relationships were derived from statistical analysis of daily (or monthly) temperature and mortality, and provide information on the threshold level and the slope of the curve (linking temperature and mortality), both of which are used in subsequent analysis of climate change. In the absence of a full range of country-specific functions (at the time of the study), these functions were transferred to climatically and socially similar countries to allow a European wide analysis – details are provided in the supplementary information. Note that since this study, Baccini et al (2008) have provided an extended set of city specific functions across Europe as part of harmonised assessment. In the absence of age-specific country evidence, the study has used all-age mortality functions. These functions are presented in Table 1.

<Table 1 about here>

The second approach involved a statistical analysis of daily temperatures in each location, to derive a set of climate-dependent thresholds. The thresholds for each grid cell were calculated following the approach by Kovats et al. (2006), with thresholds taken at the 10th and 95th centiles of daily mean temperature for low- and high-temperature impacts, respectively. For each grid cell, the 10th and 95th centiles of the 30-year daily mean temperature series were identified. This threshold data was then utilised in combination with a single functional form from Kovats et al. (2006), which comprised of a fixed single slope-gradient, assuming a linear form beyond the grid square specific threshold point. These are reported as ‘climate dependent’ functions, presented in Table 2.

<Table 2 about here>

The two impact function approaches have different strengths and weaknesses. The country specific approach uses functions which include existing acclimatisation and adaptation, but which is limited by the geographical coverage of studies, as well as by their consistency and transferability. The climate dependent approach provides a representation of existing physiological adaptation at a high spatial scale (50 by 50 km) across Europe. Due to the use of a common functional form, the resulting impact predicted also bears a closer link to the marginal change in temperature predicted from the climate models, since the impacts are essentially a representation of the scale of temperature change directly experienced at each location. The disadvantage to this approach is that there is no explicit linkage with technical, socio-economic or behavioural factors that help determine vulnerability to climate impacts in each location. These factors are more likely to be represented in the country specific functions.

It is stressed that the analysis above does not fully capture the potential changes – and the associated health effects – from increasing intensity and frequency of extreme temperatures (heat-waves) due to climate change. The study has also used linear response functions applied to daily average temperatures, which is likely to under-estimate the health impacts of extreme events, not least because it omits non-linear increases in mortality at very high temperatures, and does not take into account the cumulative effect of sustained heat load (or sustained night-time temperatures), etc. The omission of the additional impacts of such events is important in evaluating the results below.

3.5 Acclimatisation

Physiological and behavioural acclimatisation to the changing climate is likely to occur across European populations. Some consideration has been given to this factor in studies to date (Dessai 2003; Kovats et al.2006), and these indicate that acclimatisation is likely to reduce potential increases in heat-related mortality. Whilst there is no consensus on the potential extent of acclimatisation, here, we have adopted the approach used by Dessai (2003) and assumed acclimatisation to 1ºC warming would occur every three decades. This should be regarded as a very approximate assumption, especially given that McMichael et al. (2004) suggest that acclimatisation rates will be region- and scenario-specific, being contingent on a host of socio-economic determinants. It is uncertain whether there will also be a decline in the sensitivity of mortality to cold, as there is no specific literature on this subject. As an indicative sensitivity test, the study has investigated the potential effects for a decline in the sensitivity of mortality to cold, using similar temporal rates as assumed for heat, though particularly care should be taken in interpreting these results. No account has been taken of other adaptation measures.

3.6 Valuation

A substantial literature exist on the monetary valuation of health end-points and mortality; more specifically, the trade-offs that may be made between income, wealth and health (see Freeman 2003 for an overview of this literature). Valuation of a health end-point comprises the sum of three components which each capture different parts of the total welfare effect of the end-point. These components include: resource costs i.e. medical treatment costs and the opportunity costs, in terms of lost productivity; and dis-utility i.e. pain or suffering, concern and inconvenience to family and others. Note that in the instance of valuing a reduction in the risk of premature death in an elderly population, the first two components may be negligible.

Techniques have also been developed to estimate in monetary terms the non-market - dis-utility - component of health impacts on welfare. These techniques estimate the 'willingness to pay' or the 'willingness to accept compensation' for a particular health outcome, using survey-based "stated" preference methods and/or "revealed" preferences methods that are based on observed expenditures such as on consumer safety. We make use of existing unit value estimates and adopt established value transfer procedures to apply these values, derived in one context, in the climate change futures context of this paper. There are currently no unit values for the willingness-to-pay (WTP) derived in the context of avoiding a climate change-induced increase in mortality risk. However, whilst most of the available mortality estimates, such as road transport fatality values, differ in their defining characteristics (e.g. having a much greater loss of life on average), a much closer fit is with valuation of (avoidance of) air pollution-mortality risks, within which context recent empirical studies have been undertaken. For mortality risks, two metrics are currently used: 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. Both metrics were used in the ex-ante analysis of the EU Thematic Strategy on air pollution, including the cost-benefit analyses undertaken in the formulation of the Clean Air For Europe (CAFE) strategy (see e.g. Holland et al. 2005), and this has also been the approach used here. It should be noted, however, that use of these metrics remains somewhat controversial. For instance, the degree to which it is legitimate to assume additive separability of the value of a number of remaining life-years for an individual is not agreed upon (Murphy and Topel, 2006).

Alberini et al. (2006a) used a contingent valuation stated preference technique to derive VSL values and their results are particularly useful for application in the European context since they are derived from pooled observations in three different EU countries. Through a procedure described in Rabl (2003), these VSL estimates were converted to equivalent VOLY estimates. Thus, the central VSL from Alberini et al. (2006a) of €1.11 million equates to €59,000 for a VOLY. The VOLY is applied to the average period of life lost for mortality, assumed here to be 8 years, a value that has been used in previous assessments (Kovats et al. 2006),. Note a smaller period of life lost, closer to that used in the air pollution literature for acute mortality (see Holland et al, 2005), would reduce final valuation significantly. Whilst there remains significant uncertainty surrounding the most appropriate estimates of VSLs and VOLYs to use – see Viscusi and Aldy (2003) for a comprehensive review of global estimates of VSLs - the adoption of the unit value results from Alberini et al. (2006a) relies on the fact that they are derived from WTP to avoid risk changes of the size anticipated under climate change scenarios, and that they adopt best current methodological practice. These results are supported by the findings of a second study (Alberini et al. 2006b) which applied a similar method to Italy and the Czech Republic to derive VSLs.

3.7 Results and discussion – physical impacts

In Table 3, the results for the quantification of heat-related and cold-related temperature mortality across the EU for the 2011-2040 climate (A2) and 2071-2100 time-slices (A2 and B2) are presented. This shows the heat-related mortality impacts. Mortality is reported in terms of absolute numbers of excess deaths for the two time periods, and two IPCC SRES scenarios (A2 and B2), with two sets of impact functions (climate dependent and country specific functions), in both cases with and without acclimatisation being included. The different combinations are assigned run numbers to aid subsequent discussion. The accompanying change in mortality rate due to climate change alone is shown in Figure 2. In Table 3, the results are presented for a) socio-economic change alone; b) both socio-economic and climate change, and; c) the net impacts of climate change alone. This disaggregation serves to highlight the fact that significant increases in mortality may be expected on the basis of an increasing and aging European population, i.e. irrespective of any future climate change. It also explicitly demonstrates the marginal impact of climate change (over and above the changes due to socio-economic drivers that would occur even in the absence of climate change). Note that in some cases, also, the applied rate of acclimatisation exceeds the extra heat-related deaths thereby negating any effect, and resulting in zero values.

<Table 3 about here>

<Figure 2 about here>

It is immediately clear from the heat-related mortality totals that the wide-ranging results reflect the uncertainties in the parameters adopted – most particularly the scenario, choice of model, function and acclimatisation assumption chosen, as shown in in the runs representing alternative combinations of input and analysis approaches. Even within one fixed climate scenarios and time period (e.g. A2, 2071-2100), the range of uncertainty is at least one order of magnitude. It should also be stressed that the parameters and models adopted here only constitute a sub-set of those available, so that one might expect the true range of uncertainty to be substantially larger. However, certain observations can be made. First, it is clear that changes in population and age structure will lead to potential changes and future changes in vulnerability even in the absence of climate change. Under some parameter choices, the effects of socio-economic change are almost as significant as that of climate. Second, by the 2020s (the mid-point of 2011-2040), a small increase in the European average heat-related numbers of deaths due to climate change is projected, over and above that as a result of changing populations and demographics (see runs 1 to 4 in Table 3). Both sets of impact functions (country specific and climate dependent) give similar results, with just over 25,000 extra heat related deaths per year, in the absence of acclimatization (see the climate induced changes in the final column for runs 1 and 3). Third, the inclusion of acclimatisation is critical to the impact estimation. The results show that its inclusion in this earlier time period leads to a reduction of mortality by approximately a factor of 5 (see runs 2 and 4, which include acclimatization), reducing annual impacts down to 4000 cases 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 zero.

The same trends are exacerbated for the later time period, centered on the 2080s (the mid-point average of the period 2071-2100). For the A2 scenario, with a single model (HIRHAM/Had3H), both sets of impact functions estimate similar additional numbers of cases, at just under 110,000 extra heat related deaths per year (see climate induced changes, final column, runs 5 and 7). However, the use of an alternative climate model (RCA/ECHAM4) with the same function leads to 50% more fatalities – estimated at over 160,000 extra heat related deaths per year (see run 9). Including acclimatisation in the analysis again reduces the number of cases by a factor of 5, to just under 20,000 per year across the EU (see runs 6 and 8).

Under the B2 scenario, using the HIRHAM/Had3H model, the numbers of deaths estimated are reduced by approximately 50%, compared to the A2 scenario (see runs 11 and 13, compared to 5 and 7), and when acclimatisation is included within this single model analysis, its effects exceed the extra heat-related deaths otherwise generated (run 12 and 14) reported as a zero value. There is thus no net effect of climate change – the changes are within coping capacity. However, when an alternative model output is used (RCA/ECHAM4), very different results are obtained. Under this model output, estimated mortality is much higher, at almost 95,000 extra heat related deaths even for the B2 scenario (run15). This is equi-distant between the HIRHAM/Had3H A2 and B2 estimates. When acclimatisation is built into this assessment (run 16), there are still almost 20,000 residual heat related impacts – the same number as predicted for HIRHAM/Had3H A2 with acclimatisation. The results for cold-related mortality (reported as the change in mortality rate, for climate induced change only) are summarized in Figure 3.

<Figure 3 about here>

The results presented in Figure 3 imply that at the same time that there are increases in heat related deaths (see Figure 2), there will also be a decrease in the European average cold-related numbers of deaths (i.e. a benefit). The uncertainties are again very substantial between assumptions; the use of alternative impact functions within a single model and projection (HIRHAM/Had3H A2) alone showing a factor of two difference. The use of an alternative model output for the same projection (RCA/ECHAM4 A2) increases the estimates by 50% further. The results are reduced significantly if a decline in the sensitivity of mortality to cold is included, such that under B2 scenarios, there is no net benefit, however, it is highlighted this assumption is included only as a sensitivity test in the absence of literature in this area.

When single estimates are directly compared, i.e. using a specific model, projection, functional form, and acclimatisation assumptions, in the earlier time period (2010-2040) the reduction in cold related deaths is generally found to outweigh the increase in heat related deaths. While this is generally also the case in the later period, for some model runs, heat-related effects outweigh cold-related effects. However, some care must be taken in comparing cold and heat related deaths, not least because the latter exclude the urban uplift and do not fully account for the potential impact of heat extremes.

A disaggregation of the results at a national scale is better able to demonstrate the geographical distribution of the impacts. This distribution is of importance in informing an adaptation response, given that much adaptation takes place in a local context. The figures present the change in death rate. Note that figures are not presented for the absolute change, expressed as numbers of deaths, because these maps would be dominated by population density and just reflect urbanisation patterns on a 50 by 50 km resolution across Europe.

Figure 4, demonstrates that – for the A2 scenario towards the end of the 21st century - there is a significant regional variation across Europe for both heat- and cold-related mortality impacts. Further, the distributional patterns vary according to the climate impact function used, i.e. whether this is the climate dependent or country specific function.

With the climate dependent functions, the pattern is relatively uniform across Member States, with the largest potential mortality increases from climate change (expressed as the relative increase in death rates) occurring in Mediterranean countries, and to a lesser extent the south-eastern countries. Smaller relative increases occur in more northerly and north-west countries. These changes mirror the underlying climate signal (see Section 3.3), because this approach adopts a common gradient in the functional relationship (though note it uses different thresholds across countries).

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 (expressed as relative risks), reflecting higher gradients in the functions. These broad patterns are reflected in both the A2 and B2 scenario, and the use of an alternative model (RCA/ECHAM4, not shown) also provided a similar pattern (though with higher relative rates).

<Figure 4 about here>

3.8 Results and discussion – economic valuation

The physical impact estimates presented in the previous section can be expressed in monetary terms by a simple multiplication with unit values described earlier. The results for heat related impacts are summarised in Table 4, with the same combinations and run numbers as Table 3.

In addition to the uncertainty considered for the climate model outputs and impact analysis, two alternative valuation metrics are applied to the mortality impacts – the VSL and the VOLY. For the results presented here, values are provided in constant values (2005 prices, with no adjustments for future time periods, including no discounting).

<Table 4 about here>

In expressing the broad dimensions of the different model runs, the monetary results reflect the physical results. However, the monetary values presented in Table 4 illustrate other findings. First, the choice of valuation metric (VOLY or VSL) is important, the VSL results being 2-3 times greater than those using the VOLY metric. Second, the welfare costs are potentially significant. In model runs without acclimatisation, economic costs due to climate change induced effects - in current day values - are 12 to 30 billion/year by the 2020s (runs 1 and 3); though this reduces down to 2 to 4 billion/year when acclimatisation is included (runs 2 and 4). By the 2080s, under an A2 scenario, the values range from 50 to 180 billion Euro (according to the choice of function and climate model) without acclimatisation, and 8 to 80 billion Euro/year with acclimatisation. The mortality welfare costs in the early time period are equivalent to 0.1 to 0.7% of current GDP (EU25 GDP in 2005). For the latter time period, they are equivalent to 0.3 to 3% of current GDP without acclimatisation, falling to between 0% and 1% with acclimatisation.

Third, applying the same unit values to the reduction in cold-related deaths in Figure 3 clearly leads to estimates of welfare benefits, at least comparable and generally higher than the welfare costs associated with the heat-related deaths. However, the differential adaptation needs suggested by the two temperature-related effects, combined with the multiple uncertainties including the omission of extreme and urban heat island effects, cautions against the reporting of net welfare effects.

4 Food-borne disease

Climate sensitive infectious diseases, such as salmonellosis, are directly affected by temperature (Kovats et al. 2004; Britton et al. 2010). This disease accounts for some 70 % of all laboratory-confirmed outbreaks of food-borne disease in Europe (WHO, 2001), and a significant proportion of recorded cases is attributable to changes in temperature. An increase of 5–10 % in the number of cases for each degree increase in weekly temperatures has been estimated above a threshold of approximately 5 °C (Kovats et al. 2004), with inappropriate food preparation and adequate storage preceding consumption being important determining factors. There is therefore a potential impact from climate change. Some studies have applied such functional relationships to assess potential future climate effects (see Bambrick et al. 2008 for Australia). This study estimates the effects of climate change-induced salmonellosis in physical and monetary terms for Europe, again using a dis-aggregated spatial and temporal analysis.

4.1 Method and data

The methodology adopts the impact relationships provided in Kovats et al. (2004), which includes linear temperature-disease functions for eight European countries, based on 2-month mean temperatures, with the disease incidence lagged by one month. These are presented in Table 5. In the absence of a full set of individual country functions, this set of relationships were transferred to climatically and socially similar countries to allow a European wide analysis – details are provided in the supplementary information. The mode, then computes the running two-month mean temperatures in each grid cell for each day in the climate datasets.

<Table 5 about here>

Baseline data on cases across Europe were derived from the WH Global Salmonella Survey (GSS) (Galanis et al. 2006), which reports cases of *Salmonella Enteritidis* and *S. Typhimurium* in the period 2000-2003. A European average baseline incidence rate was used. Under baseline climate, the European average rate of temperature-related salmonellosis is approximately 15 per 100,000 people. However, given that the GSS only records voluntarily reported incidence, it is possible that these values under-report cases. Chalker and Blasé (1988) estimate that 1-5% of all Salmonellosis cases are actually reported. Therefore, a sensitivity run was made on the basis of a 5% reporting level. In the absence of a strong rationale, no adjustments were made in the incidence rate as applied to the future time periods. The analysis also did not consider acclimatisation or any autonomous (including behavioral) or planned adaptation.

4.2 Valuation

Based on the information from reported studies (Adak et al. 2002; Fisker et al. 2003; Niels et al. 2003; Ternhag et al. 2006) an incidence and outcome model found that out of every 1,000 cases of Salmonellosis, approximately 31 would be admitted to hospital, 5 would die, 680 would visit a doctor (GP) and 284 would not see a doctor. The incidence rates of these different severities were used to derive a weighted value per case. For each level of severity, the relevant cost components - treatment costs, opportunity costs and dis-utility costs – were estimated using available data. The main data sources used to estimate these cost components were Curtis and Netten (2006) for medical treatment costs, the UK Chartered Institute of Personnel and Development (CIPD) survey (2005) for opportunity costs of lost productivity, and the UK Health and Safety Executive (HSE) (1999) estimates for monetary value of pain, grief and suffering i.e. disutility. After summing the cost component estimates, the range of unit values for a case of salmonella, weighted by the incidence of a range of severities, was between €3,500 and €7,000, reflecting uncertainty in the component unit cost estimates. 'This range is comparable to the WTP to avoid poultry-borne illness (with symptoms similar to Salmonellosis) estimated by Van der Pol et al. (2003), using stated preference techniques, to be in a range between €3,300 and €3,400. These values are also similar to other studies, notably Buzby et al. (1996) and FSA (2006).

4.3 Results – physical impacts

The number of cases for the two time periods and under the two climate scenarios are presented in Table 6. As with the mortality results, the results are given for an aggregation of both socio-economic (population-based) change and climatic change, alongside the total for the effect of climate change alone.

<Table 6 about here>

The results show that by the 2020s, the average annual number of temperature-related cases of salmonellosis may have increased by a total of almost 20,000 as a result of climate change in Europe under the A2 scenario (though note in this period, there is little difference between the A2 and B2 scenarios), in addition to increases expected from population changes. By the 2071-2100 period, it is projected that climate change could result in up to 50% more cases of temperature-related cases than would be expected on the basis of population change alone. Under the A2 scenario, the climate change induced increase in temperature-related cases could be around 40,000 annually, for the whole of Europe, though this would fall by 40% to 25,000 cases annually under the B2 scenario. The largest increases in number of cases, relative to population, are projected to occur in the UK, France, Switzerland and the Baltic countries.

Some care should be taken in interpreting these values since the analysis is built around constant baseline incidence rates, and does not include acclimatisation, other forms of technological advance, or adaptation, including behavioural change. Thus, since these aspects may be expected to reduce incidence rates, our results may be seen as likely over-estimates. However, this upward bias is likely to be low in relation to under-reporting in the baseline incidence estimation procedure (see discussion above).

4.4 Results – economic values

The numbers of physical cases shown in Table 6 above are converted into economic values to give estimates of the welfare costs attributable to climate change only, under alternative climate scenarios. The results are shown in Table 7, using the low value of Euro 3,500 and the high unit value of Euro 7,000 and. Values are provided in constant values (2005 prices, with no adjustments for future time periods including no discounting). A sensitivity (not shown here) with under-reporting on the basis of a 5% reporting level would increase the values upwards by over an order of magnitude. The welfare costs of the additional cases of salmonellosis resulting from climate change effects in the period 2071-2100 ranges from €140 million to €280 million/year for the A2 scenario, to €90 million and €180 million/year for the B2 scenario, the range reflecting alternative valuation unit costs only.

<Table 7 about here>

5 Health effects of coastal flooding

The impacts of climate change upon European coastal zones have been quantified in Bosello et al. (this issue), and this provides details of the impact assessment method. One of the results of the coastal assessment are estimates of the numbers of people affected by coastal flooding and this provides an input to allow quantification and valuation of health impact of this risk. This has considered both the direct risks (fatalities and injuries) but also the indirect effects on mental well-being.

The global study on the health burden of climate change (McMichael et al. 2004) reports baseline fatalities and injuries of flood events for European regions. The annual incidence of death caused by coastal floods is estimated to be approximately 1 per 100 million population in 2000 and compares with the annual incidence of death caused by inland floods and landslides of 400 per 100 million population. These rates can be combined with the projections of flood incidence to derive indicative fatalities and injuries. However, there are other potential effects of flooding on well-being, including increased rates of anxiety and depression. These illnesses commonly stem from geographical displacement and damage to personal property (Hajat et al. 2005).

Whilst there is insufficient evidence to provide robust and transferable estimates of the psychological impacts of flooding, these impacts are becoming of increasing interest in the discussions of the health impacts of climate change. Their consideration also allows the consideration of cross-sectoral linkages between sectors (a potential advantage of major multi-sectoral assessments), to explore whether these indirect pathways are important, and to examine the potential order of magnitude of economic costs. It is highlighted that flooding also has the potential to lead to other health outcomes, from indirect pathways such as from vector borne and water borne disease outbreaks, from water pollution, from access to water sources and sanitation, etc. While these are also likely to be important, the outputs from the coastal models (Bosello et al, this issue) do not allow their quantification at the European scale, and they are likely to be associated with specific local events that require more detailed analysis.

To quantify well-being, we apply the results of a recent study in the UK by Reacher et al. (2004) to the results derived by Nicolls et al. (this issue) for the European coastal flooding context, to provide an assessment of the potential order of magnitude.

The Reacher et al. (2004) study used a questionnaire approach to elicit the impacts on mental and physical health of the October-November 2000 floods in Lewes, UK. A principal finding was that prevalence of psychological stress was found to be four times greater in the flooded population than in the un-flooded population in the town. If we employ the assumption that a multiplier of 4 can be applied to any context where flooding occurs then, with information on the baseline prevalence, it is straightforward to calculate the size of the population impacted by psychological stress.

In order to find the additional number of people flooded as a result of climate change we subtract the number flooded under the "no sea-level rise" from the number under the low and high sea level rise scenarios. We use a baseline prevalence rate of 8% of depressive disorders across the EU (European Communities, 2003) and so assume that "psychological stress", the term used by Reacher et al. (2004), is equivalent or more specifically typical of "depressive disorders".

The results are presented in Table 8. These show a 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 coastal flooding analysis, these would presumably be significantly reduced with adaptation.

<Table 8 about here>

Since the psychological stress most frequently manifests itself in terms of mild depression (Reacher et al. 2004), we use cost estimates associated with the treatment of this illness from Bower et al. (2000). These estimates average approximately €1000 per case, with a low unit value of €700 and a high unit value of €1,100. Opportunity costs and disutility costs have not been identified and so are not included in the analysis.

The results are presented in Table 9. Values are provided in constant values (2005 prices, with no adjustments for future time periods, including no discounting). Potential costs in 2071-2100 under the high sea level rise A2 scenario could be 1.0 to 1.4 billion/year, whilst under the B2 scenario, these costs are estimated at 0.8 to 1.1 billion/year. Under low sea level rise assumptions, however, the results are three to four orders of magnitude lower. Differences in time period, unit value and climate scenario are low compared to the sea level rise assumption.

<Table 9 about here>

6. Conclusions

This paper scopes three health impacts of climate change in Europe (EU-27) quantitatively, using physical and monetary metrics. We find that by the 2080s, the number of premature deaths from climate change-induced heat-related effects range broadly from 20,000 to 160,000 under an A2 climate scenario (0 to 100,000 under a B2 scenario), whilst the associated annual welfare costs of premature deaths range from €20 billion to €180 billion (€0 to €100 billion). The numbers of premature deaths avoided, and the associated welfare benefits of reduced cold-related mortality are comparable or greater to the scale of the heat-related impacts. The number of additional cases of salmonellosis resulting from climate change effects (assuming no acclimatisation or autonomous adaptation) in the 2080s ranges from 40,000 (A2 scenario) to 25,000 (B2 scenarios), with associated welfare costs of up to €280 million (A2) and €90 million (B2), but would be much higher than this if current under-reporting is taken into account. Annual welfare costs from climate change coastal flood-induced mental health problems such as depression are indicatively estimated at up to 1.5 billion by the 2080s under a scenario of high sea level rise.

The paper has adopted a disaggregated analysis to generate these values. This provides additional information on the distribution of health impacts across Europe. This shows that the health impacts of climate change are likely to be unevenly distributed, and further, that the choice of different assumptions can have a large effect on the relative results. As examples, the relative increase in heat related mortality is greater in Mediterranean and Central-eastern countries. This finding highlights the need for spatially disaggregated data in future research, and it is stressed that EU-wide estimates need to be complemented by information on the local variability of impacts.

The modelling exercise undertaken to generate these results for heat and cold related mortality adopts a range of alternative assumptions relating to a number of parameters, including the choice of: climate model, climate scenario, impact function, the existence and extent of acclimatisation, and the choice of physical and monetary metrics. The resulting uncertainties in impact estimation are significant and have implications for adaptation assessment and strategy. For example, the potential role of physiological acclimatisation in determining the scale of temperature-related mortality is likely to influence both the form and scale of planned adaptation responses such as heat warning systems. The wide uncertainties also suggest that the types of adaptation implemented should be robust to a range of possible future impacts, and that research resources should be devoted to reducing these methodological uncertainties in advance of adaptation investment.

In addition to the reduction of methodological uncertainties, research in this area needs to be undertaken at more disaggregated spatial scales, where representation of impacts fits with the geographical coverage of public administration authorities responsible for the provision of specific forms of health care, education and other public goods that may ameliorate the types of health impact identified. Future research in quantitative health impact assessment and valuation should also extend its coverage to a wider range of health impacts, including the temperature and morbidity, the spread of vector and water borne, air pollution, and the direct (and indirect) effects of extreme events, as well as a more rigorous treatment of the mental health impacts of extreme weather events. Adaptation research might be usefully targeted at assessing the likely effectiveness of adaptation options under alternative climate and socio-economic scenarios, and their appraisal using a range of decision rules that explicitly incorporate consideration of uncertainties in the assessment of adaptation option benefits.

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References

Adak GK, Long SM, O'Brien SJ (2002) Trends in Indigenous Food-borne Disease and Deaths, England and Wales - 1992 to 2000. Gut. 51:832–841

Alberini A, Hunt A, Markandya A (2006a) Willingness to Pay to Reduce Mortality Risks: Evidence from a Three-country Contingent Valuation Study. Environmental and Resource Economics 33(2):251-264

Alberini A, Chiabai A, Nocella G (2006b) Valuing the Mortality Effects of Heat-waves. In: Menne B, Ebi KL (eds) Climate Change and Adaptation Strategies for Human Health, Steinhkopff Verlag Darmstadt for World Health Organisation

Alcamo J, Moreno JM, Nováky B, Bindi M, Corobov R, Devoy RJN, Giannakopoulos C, Martin E, Olesen JE, Shvidenko A (2007) Europe. Climate Change 2007: Impacts, Adaptation and Vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,. Cambridge University Press, Cambridge, UK, 541-580

Baccini M, Biggeri A, Accetta G, Kosatsky T, Katsouyanni K, Analitis A, Ross Anderson H, Bisanti L, D'Ippoliti D, Danova J, Forsberg B, Medina S, Paldy A, Rabczenko D, Schindler C, Michelozzi P (2008) Effects of apparent temperature on summer mortality in 15 European cities: results of the PHEWE project. Epidemiology 19 (5)

Ballester F, Corella D, Perez-Hoyos S, Saez M, Hervas A (1997) Mortality as a function of temperature. A study in Valencia, Spain, 1991-1993. International Journal of Epidemiology 26:551-561

Bambrick H, Dear K, Woodruff R, Hanigan I, McMichael A (2008) The impacts of climate change on three health outcomes: temperature-related mortality and hospitalisations, salmonellosis and other bacterial gastroenteritis, and population at risk from dengue. Commissioned for the Garnaut Climate Change Review. http://www.garnautreview.org.au/CA25734E0016A131/WebObj/03-AThreehealthoutcomes/$File/03-A%20Three%20health%20outcomes.pdf

Bosello F, Roson R, Tol RSJ (2004) Economy-Wide Estimates of the Implications of Climate Change: Human Health. Research Unit Sustainability and Global Change FNU-57, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg

Bosello F, Nicholls R, Richards J, Roson R, Tol RSJ (this issue) Economic impacts of climate change in Europe: sea-level rise. Climatic Change

Bower P, Byford S, Sibbald B, Ward E, King M, Lloyd M, Gabbay M (2000) Randomised controlled trial of non-directive counselling, cognitive behaviour therapy, and usual general practitioner care for patients with depression. II: Cost effectiveness. British Medical Journal 321:1389-1393

Braga AL, Zanobetti A, Shwartz J (2001) The time course of weather-related deaths. Epidemiology 12:662-667

Braga AL, Zanobetti A, Shwartz J (2002) The effect of weather on respiratory and cardiovascular deaths in 12 U.S. cities. Environmental Health Perspectives 110:859-863.

Britton E, Hales S, Venugopal K, Baker MG (2010) Positive association between ambient temperature and salmonellosis notifications in New Zealand, 1965-2006. Australian and New Zealand Journal of Public Health 34(2):126.

Bosello F, Roson R, Tol RSJ (2006) Economy Wide Estimates of the Implication of Climate Change: Human Health. Ecological Economics 58(3):579-591

Buzby JC, Roberts T, Lin C-TJ, MacDonald JM (1996) Bacterial Food-borne Diseases: Medical Costs and Productivity Losses. USDA, Economic Research Services, AER-741, August 1996

Carraro C, Sgobbi A (2008) Climate Change Impacts and Adaptation Strategies in Italy: An Economic Assessment. Available at www.feem.it/userfiles/attach/Publication/NDL2008/NDL2008-006.pdf

Carter TR, Jones RN, Lu X, Bhadwal S, Conde C, Mearns LO, O'Neill BC, Rounsevell MDA, Zurek MB (2007) New Assessment Methods and the Characterisation of Future Conditions. Climate Change 2007: Impacts, Adaptation and Vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, 133-171

CEC (2005a) Winning the Battle against Global Climate Change, Communication from the Commission to the Council, the European Parliament, the European Economics and Social Committee and the Committee of the Regions COM(2005) 35 final, Commission of the European Communities, Brussels

CEC (2005b) Winning the Battle against Global Climate Change. Background Paper, Commission Staff Working Paper, Commission of the European Communities, Brussels

CEC (2007a) Limiting Global Climate Change to 2 degrees Celsius The way ahead for 2020 and beyond. Brussels. COM(2007) Commission of the European Communities, Brussels

CEC (2007b) Green Paper Adapting to climate change in Europe – options for EU action. Brussels. COM(2007) 354 final 29.6.2007. Commission of the European Communities, Brussels

CEC (2009) White Paper: Adapting to climate change: Towards a European framework for action. Commission of the European Communities. Brussels. COM(2009) 147/4. Commission of the European Communities, Brussels

Chalker RB, Blase MJ (1988) A review of human salmonellosis. III. Magnitude of Salmonella infection in the United States. Review of Infectious Diseases 10:111-124

Christensen OB, Goodess CM, Ciscar JC (this issue) Methodological framework of the PESETA project on the impacts of climate change in Europe. Climatic Change

CIPD (2005) *Recruitment, Retention and Turnover: Annual survey report 2005*, Chartered Institute of Personnel and Development, London.

Ciscar JC, Iglesias A, Feyen L, Goodess CM, Szabó L, Christensen OB, Nicholls R, Amelung B, Watkiss P, Bosello F, Dankers R, Garrote L, Hunt A, Horrocks L, Moneo M, Moreno A, Pye S, Quiroga S, van Regemorter D, Richards J, Roson R, Soria A (2009) Climate change impacts in Europe. Final report of the PESETA research project. EUR 24093 EN. Joint Research Centre

Confalonieri U, Menne B, Akhtar R, Ebi KL, Hauengue M, Kovats RS, Revich B, Woodward A (2007): Human health. Climate Change 2007: Impacts, Adaptation and Vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, 391-431

Curriero FC, Heiner KS, Samet JM, Zeger SL, Strug L, Patz JA (2002) Temperature and mortality in 11 cities of the eastern United States. American Journal of Epidemiology 155:80-87

Curtis L, Netten A (2006) *Unit Costs of Health and Social Care 2005*, PSSRU, University of Kent, Canterbury

Danet S, Richard F, Montaye M, Beauchant F, Lemaire B, Graux C, Cottel D, Marecaux N, Amouyel P (1999) Unhealthy effects of atmospheric temperature and pressure on the occurrence of myocardial infarction and coronary deaths. Circulation 100:1-7

Davis RE, Knappenberger PC, Michaels PJ, Novicoff WM (2003a) Changing heat-related mortality in the United States. Environmental Health Perspectives 111:1712-1718

Davis RE, Knappenberger PC, Novicoff WM, Michaels PJ (2003b) Decadal changes in summer mortality in US cities. International Journal of Biometeorology 47:166-175

Demeritt D, Rothman D (1998) Comments on J.B. Smith (Climatic Change 32, 313-326) and the Aggregation of Climate Change Damage Costs. *Climatic Change* 40:699-704

Department of Health (2001). Health effects of climate change in the UK. Published by Department of Health, London, UK, 2001.

Dessai S (2003) Heat stress and mortality in Lisbon Part II. An assessment of the potential impacts of climate change. International Journal of Biometeorology 48:37-44

DoH (2008) Health Effects of Climate Change in the UK 2008 – An update of the Department of Health Report 2001/2002. Edited by Sari Kovats. Department of Health and Health Protection Agency www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_080702

Donaldson GC, Keatinge WR (1997) Mortality related to cold weather in elderly people in southeast England, 1979-94. British Medical Journal 315:1055-1056

Donaldson G, Kovats R S, Keatinge W R et al. (2001) Heat-and-cold-related mortality and morbidity and climate change. In: Health effects of climate change in the UK. London, Department of Health; p. 70–80

European Environment Agency (2007) Climate Change: the Cost of Inaction and the Cost of Adaptation. Paul Watkiss, Francesco Bosello, Barbara Buchner, Michela Catenacci, Alessandra Goria, Onno Kuik and Etem Karakaya. Published December 2007. EEA Technical report No 13/2007. ISSN 1725–2237. ISBN 978-92-9167-974-4 EEA, Copenhagen, 2007. Available at: http://reports.eea.europa.eu/technical_report_2007_13/en

ECCE (2005) A Preliminary Assessment of the Impacts in Spain due to the Effects of Climate Change. ECCE Project - Final Report. Chapter 16. Impacts on Health. Julio Díaz, Ferrán Ballester and Rogelio López-Vélez

EEA (2008) Impacts of Europe's changing climate - 2008 indicator-based assessment. EEA Report No 4/2008. Available at: http://reports.eea.europa.eu/eea_report_2008_4/en/

European Communities (2003) Health Statistics: Key Data on Health 2002. Luxembourg: Office for Official Publications of the European Communities

Eurowinter (1997) Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe. The Lancet 349:1341-1346

FSA (2006) Food-borne Disease: Final Report on Delivery Of The 2001-06 Target. Foods Standards Agency, Pro 06/10/01, Agenda Item 4.1, 12 October 2006

Fankhauser S (1995) *Valuing climate change. The economics of the Greenhouse*. Earthscan, London

Fisker N, Vinding K, Mølbak K, et al. (2003) Clinical review of non-typhoid Salmonella infections from 1991 to 1999 in a Danish country. Clinical Infectious Diseases 37(4):47-52

Freeman AM (2003) The Measurement of Environmental and Resources Values: Theory and Methods, Washington DC: Resources for the Future

Galanis E, Lo Fo Wong DMA, Patrick M, Binsztein N, Cieslik A, Chalermchaikit T et al. (2006) Web-based surveillance and global Salmonella distribution, 2000–2002. Emerg Available from http://www.cdc.gov/ncidod/EID/vol12no03/05-0854.htm

Garnaut Review (2008) The Garnaut Climate Change Review: Final Report Commonwealth of Australia 2008 http://www.garnautreview.org.au/CA25734E0016A131/pages/garnaut-climate-change-review-final-report

Hajat S, Kovats RS, Atkinson RW, Haines A (2002) Impact of hot temperatures on death in London: a time series approach. Journal of Epidemiology and Community Health 56:367-372

Hajat S, Ebi KL, Kovats RS, Menne B, Edwards S, Haines A (2005) The Human Health Consequences of Flooding in Europe: a Review. In: Kirch W, Menne B, Bertollini

R (eds) Extreme Weather Events and Public Health Responses. Published on behalf of the World Health Organisation Regional Office for Europe by Springer-Verlag

Hayhoe K et al. (2004) Emissions pathways, climate change, and impacts on California. Proc Natl Acad Sci USA. August 24, 101(34): 12422–12427

Holland M, Watkiss P, Pye S (2005) Cost-benefit analysis of policy option scenarios for the Clean Air for Europe programme for Service Contract for carrying out cost-benefit analysis of air quality related issues, in particular in the clean air for Europe (CAFE) programme. European Commission DG Environment

HSE (1999) The Costs to Britain of Workplace Accidents and Work-related Ill Health in 1995-96, Health and Safety Executive, London

Hunt A (2008) Informing adaptation to climate change in the UK: Some sectoral impact costs. Integrated Assessment Journal 8(1):41–71.

Isaac M, van Vuuren DP (2009) Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. Energy Policy 37:507–521

Kinney PL, Rosenthal JE, Rosenzweig C, Hogrefe C, Solecki W, Knowlton K, Small C, Lynn B, Civerolo K, Ku JY, Goldberg R, C Oliveri (2006) Assessing the Potential Public Health Impacts of Changing Climate and Land Use: The New York Climate & Health Project. In: Ruth M, Donaghy K, Kirshen P (eds) Climate Change and Variability: Consequences and Responses, U.S. Environmental Protection Agency, Washington, D.C.

Kirshen PH, Ruth M, Anderson W, Lakshmanan TR, Chapra S, Chudyk W, Edgers L, Gute D, Sanayei M, Vogel R (2004) Climate's long-term impacts on metro Boston.

Final Report to the US EPA. Office of Research and Development, Washington, DC http://www.net.org/reports/CLIMB_Final.pdf and full report at: http://www.tufts.edu/tie/pdf/CLIMBFV1-8_10pdf.pdf

Koppe C, Jendritzky G, Pfaff G (2003) Die Auswirkungen der Hitzewelle 2003 auf die Gesundheit. In: DWD (ed) Klimastatusbericht 152–162

Kovats RS (2000) Chapter 13. Health. In: Parry ML (ed) Assessment of Potential Effects and Adaptations for Climate Change in Europe: The Europe Acacia Project. Jackson Environment Institute. University of East Anglia, Norwich, UK, 2000, p 320

Kovats RS, Edwards S, Hajat S, Armstrong B, Ebi KL, Menne B (2004) The effect of temperature on food poisoning: time series analysis in 10 European countries. Epidemiology and Infection 132:443-453

Kovats S, Lachowyz K, Armstrong B, Hunt A, Markandya A (2006). Chapter 2. Health. In. Climate Change Impacts and Adaptation: Cross-Regional Research Programme Project E – Quantify the cost of future impacts. Report to the UK Department for Environment, Food and Rural Affairs. Metroeconomica Limited (UK) May 2006.Kovats S and Lloyd S (2010) Health effects of climate change: a review of impact studies. ClimateCost project. London School of Hygiene and Tropical Medicine, London.

Matthies E, et al. (Eds.) (2008). Heat health action plans: Guidance. Published by the World Health Organisation (WHO) Regional Office for Europe. ISBN 978 92 890 7191 8. Available at: http://www.euro.who.int/__data/assets/pdf_file/0006/95919/E91347.pdf

McMichael AJ et al. (2004) Climate change. In: Ezzzati M, Lopez AD, Rodgers A, Murray CJ (eds) Comparative quantification of health risks: global and regional burden of disease due to selected major risk factors, Volume 2. World Health Organisation, Geneva, 1543–1649

McMichael AJ, Githeko A, Akhtar R, Carcavallo R, Gubler D, Haines A, Kovats RS, Mart´ns P, Patz J, Sasaki A (2001) Human health. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ White KS (eds) Climate Change 2001: Impacts, adaptation and vulnerability, Cambridge University Press, Cambridge, pp 451-485

McMichael A, Woodruff R, Whetton P, Hennessy K, Nicholls N, Hales S, Woodward A, Kjellstrom T (2003) Human Health And Climate Change. In Oceania: A Risk Assessment 2002, Commonwealth of Australia http://nceph.anu.edu.au/Staff_Students/Staff_pdf_papers/Rosalie_Woodruff/Health_Climate_Change_Impact_Assessment_2002.pdf

Menne B, Ebi KL(eds) (2006) Climate change and adaptation strategies for human health WHO (Europe)

Murphy KM, Topel RH (2006) The Value of Health and Longevity. Journal of Political Economy 114(5):871-904

Niels F, Vinding K Mølbak Hornstrup MK (2003) Clinical Review of Non-typhoid Salmonella Infections from 1991 to 1999 in a Danish County. Clinical Infectious Diseases, 37: 47–52.Natural Resources Canada (2004). Lemmen DS, Warren FJ, editors. Climate Change Impacts and Adaptation: A Canadian Perspective; Government of Canada, Ottawa, ON, 174 p.

Natural Resources Canada (2007) From Impacts to Adaptation: Canada in a Changing Climate. edited by Lemmen DS, Warren FJ, Lacroix J, Bush E; Government of Canada, Ottawa, ON

O'Neill MS, Zanobetti A, Schwartz J (2003) Modifiers of the temperature and mortality associations in seven US cities. American Journal of Epidemiology 157:1074-1082.

Ostro O, Rauch S, Green R, Malig B, Basu R (2010) The Effects of Temperature and Use of Air Conditioning on Hospitalizations. American Journal of Epidemiology 172(9). DOI: 10.1093/aje/kwq231

Páldy A, Bobvos J, Vámos A, Kovats RS, Hajat S (2005) The effect of temperature and heat waves on daily mortality in Budapest, Hungary, 1970-2000. In: Kirch W, Bertollini R, Menne B Extreme Weather Events and Public Health Responses, Springer Berlin Heidelberg

Parry ML, Canziani OF, Palutikof JP et al. (2007) Technical Summary. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds), Cambridge University Press, Cambridge, UK, 23-78

Pirard P, Vandentorren S, Pascal M, Laaidi K, Ledrans M (2005) Summary of the mortality impact assessment of the 2003 heat-wave in France. Euro Surveillance 10(7/8)

Pitcher HM, Eb, KL, Brenkert AL (2008) A population health model for integrated assessment models. Climatic Change 88:35–57. DOI 10.1007/s10584-007-9286-8

Reacher M, McKenzie K, Lane C, Nichols T, Kedge I, Iversen A, Hepple P, Walter T, Laxton C, Simpson J on behalf of the Lewes Flood Action Recovery Team

(2004). Health impacts of flooding in Lewes: a comparison of reported gastrointestinal and other illness and mental health in flooded and non-flooded households. Communicable Disease and Public Health 7:1-8

Rabl A (2003) Interpretation of air pollution mortality: Number of deaths or years of life lost?. Journal of the Air & Waste Management Association 53(1):41-50

SCCV (2007) Sweden facing climate change - threats and opportunities. Final report from the Swedish Commission on Climate and Vulnerability Stockholm 2007. http://www.regeringen.se/sb/d/574/a/96002

SIAM (2002). Santos FD, Forbes K, Moita R (eds.) Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures - SIAM Project. Gradiva, Lisbon, Portugal (456 pp). http://www.siam.fc.ul.pt/siam.html

Stern N, Peters S, Bakhshi V, Bowen A, Cameron C, Catovsky S, Crane D, Cruickshank S, Dietz S, Edmondson N, Garbett S, Hamid L, Hoffman G, Ingram D, Jones B, Patmore N, Radcliffe H, Sathiyarajah R, Stock M, Taylor C, Vernon T, Wanjie H, Zenghelis D (2006) The Economics of Climate Change. Cabinet Office – HM Treasury. Cambridge University Press

Ternhag A, Törner A, Ekdahl K, Giesecke J (2006) Salmonella Associated Deaths, Sweden, 1997–2003. Emerging Infectious Diseases, 12 (2), February 2006

Titus JG (1992) The Costs of Climate Change to the United States, in Majumdar SK, Kalkstein LS, Yarnal BM, Miller EW, Rosenfeld LM, eds., *Global Climate Change: Implications, Challenges and Mitigation Measures*. Easton: Pennsylvania Academy of Science, pp. 384–409

Tol RSJ (1995) The damage costs of climate change: Towards more comprehensive calculations. Environmental and Resource Economics 5:353-374

Tol RSJ (2002a) New estimates of the damage costs of climate change, Part I: Benchmark estimates. Environmental and Resource Economics 21(1):47-73

Tol RSJ (2002b) New estimates of the damage costs of climate change, Part II: Dynamic estimates. Environmental and Resource Economics 21(1):135-160

Tol RSJ (2008) Climate, development and malaria: an application of FUND. Climatic Change 88:21–34

CCIRG (1996). Climate Change Impacts Review Group, 1996. Review of the Potential Effects of Climate Change on the United Kingdom. Department of the Environment, HMSO, London. 247pp.

US NAS (2000) Climate Change Impacts on the United States The Potential Consequences of Climate Variability and Change. National Assessment Synthesis Team, US Global Change Research Program. http://www.usgcrp.gov/usgcrp/nacc/

Van Der Pol M, Ryan M, Donaldson C (2003) Valuing Food Safety Improvements Using WTP. Applied Health Economics and Health Policy, 2(2): 99-107

van Vuuren D, O'Neill BC (2006) The Consistency of IPCC's SRES Scenarios to 1990–2000 Trends and Recent Projections. Climatic Change 75

Vandentorren S, Suzan F,, Medina S, Pascal M, Maulpoix A, Cohen J-C, Ledrans M (2004) Mortality in 13 French Cities During the August 2003 Heat Wave. American Journal of Public Health 94:1518–1520

Viscusi WK, Aldy J (2003) The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World. Journal Risk and Uncertainty 27:5-76

WHO (2001) Schmidt K, Tirado C (eds) WHO Surveillance Programme for Control of Food-borne Infections and intoxications in Europe, Seventh Report 1993-1998

Figures

(please see attached files)

Tables

Table 1. Country-specific absolute functions linking all-cause daily mortality (all ages) with temperature.

	HEAT FUNCTION ***		COLD FUNCTION	
Country	Threshold (°C)	% change in mortality per °C above threshold	Threshold (°C)	% change in mortality per °C below threshold
Norway	10	0.7		
Finland*			18	0.29
Bulgaria**	18	2.21	18	0.7
UK**	18	1.3	18	1.4
Netherlands*	16.5	1.2	18	0.6
Spain	20.3	1		
Greece*			18	2.2

* Cold functions from Eurowinter (1997); ** Cold functions from Pattenden et al. (2003); *** All heat functions from Menne and Ebi (2006), and references therein.

Table 2. Climate-dependent functions linking all-cause mortality with temperature

Heat Function			Cold Function		
Increase in mortality per 1°C above threshold			Increase in mortality per 1°C below threshold		
0–64 years	65–74 years	over 75 years	0–64 years	65–74 years	over 75 years
1.6 %	2.0 %	3.1 %	3.5 %	4.9 %	6.0 %

Source: Kovats et al. (2006).

Table 3.Total additional heat-related deaths/year across time periods, scenarios, functions and with and without acclimatisation.

					Additional deaths per year		
Run	SRES scenario / Time period	Climate Model used	Impact Function	Acclim-atisation (yes/no)	Future socio-economic, no climate change	Climate and socio-economic induced	Climate change induced only
1	A2 2011 - 2040	Rosby	Climate dependent	No	11,100	38,500	27,300
2	A2 2011 - 2040	Rosby	Climate dependent	Yes		15,100	4,000
3	A2 2011 - 2040	Rosby	Country specific	No	34,000	60,400	26,400
4	A2 2011 - 2040	Rosby	Country specific	Yes		37,900	3,900
5	A2 2071 - 2100	HIRHAM/HadAM3H	Climate dependent	No	14,400	120,800	106,400
6	A2 2071 - 2100	HIRHAM/HadAM3H	Climate dependent	Yes		31,500	17,000
7	A2 2071 - 2100	HIRHAM/HadAM3H	Country specific	No	62,200	169,500	107,300
8	A2 2071 - 2100	HIRHAM/HadAM3H	Country specific	Yes		81,600	19,400
9	A2 2071 - 2100	RCA/ECHAM4	Country specific	No	59,200	220,900	161,700
10	A2 2071 - 2100	RCA/ECHAM4	Country specific	Yes		132,500	73,300
11	B2 2071 - 2100	HIRHAM/HadAM3H	Climate dependent	No	12,500	63,200	50,700
12	B2 2071 - 2100	HIRHAM/HadAM3H	Climate dependent	Yes		10,900	0
13	B2 2071 - 2100	HIRHAM/HadAM3H	Country specific	No	54,000	112,500	58,500
14	B2 2071 - 2100	HIRHAM/HadAM3H	Country specific	Yes		47,600	0
15	B2 2071 - 2100	RCA/ECHAM4	Country specific	No	51,300	147,100	95,800
16	B2 2071 - 2100	RCA/ECHAM4	Country specific	Yes		70,600	19,300

Key to table. The analysis has undertaken sixteen runs, which cover different combinations of the time period of interest (2011-2040 or 2071-2100), the SRES scenario (A2 or B2), the climate model output (Rosby or HIRHAM/HadAM3H or RCA/ECHAM4), the impact function (climate dependent or country specific) and acclimatisation (with or without). Each row in the table sets out the specific parameters across these six fields.

* 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.

Table 4. Total additional heat-related economic costs in Million Euro/year across time periods, scenarios, functions and with and without acclimatisation.

					Million Euro/year		Million Euro/year	
Run	SRES scenario / Time period	Climate Model used	Impact Function	Acclim-atisation (yes/no)	Climate and socio-economic induced		Climate change induced only	
		Model			VOLY	VSL	VOLY	VSL
1	A2 2011 - 2040	Rosby	Climate dependent	No	18,172	42,350	12,886	30,030
2	A2 2011 - 2040	Rosby	Climate dependent	Yes	7,127	16,610	1,888	4,400
3	A2 2011 - 2040	Rosby	Country specific	No	28,509	66,440	12,461	29,040
4	A2 2011 - 2040	Rosby	Country specific	Yes	17,889	41,690	1,841	4,290
5	A2 2071 - 2100	HIRHAM/HadAM3H	Climate dependent	No	57,018	132,880	50,221	117,040
6	A2 2071 - 2100	HIRHAM/HadAM3H	Climate dependent	Yes	14,868	34,650	8,024	18,700
7	A2 2071 - 2100	HIRHAM/HadAM3H	Country specific	No	80,004	186450	50,646	118,030
8	A2 2071 - 2100	HIRHAM/HadAM3H	Country specific	Yes	38,515	89,760	9,157	21,340
9	A2 2071 - 2100	RCA/ECHAM4	Country specific	No	104,265	242,990	76,322	177,870
10	A2 2071 - 2100	RCA/ECHAM4	Country specific	Yes	62,540	145,750	34,598	80,630
11	B2 2071 - 2100	HIRHAM/HadAM3H	Climate dependent	No	29,830	69,520	23,930	55,770
12	B2 2071 - 2100	HIRHAM/HadAM3H	Climate dependent	Yes	5,145	11,990	0	0
13	B2 2071 - 2100	HIRHAM/HadAM3H	Country specific	No	53,100	123,750	27,612	64,350
14	B2 2071 - 2100	HIRHAM/HadAM3H	Country specific	Yes	22,467	52,360	0	0
15	B2 2071 - 2100	RCA/ECHAM4	Country specific	No	69,431	161,810	45,218	105,380
16	B2 2071 - 2100	RCA/ECHAM4	Country specific	Yes	33,323	77,660	9,110	21,230

Key to table. The analysis has undertaken sixteen runs, which cover different combinations of the time period of interest (2011-2040 or 2071-2100), the SRES scenario (A2 or B2), the climate model output (Rosby or HIRHAM/HadAM3H or RCA/ECHAM4), the impact function (climate dependent or country specific) and acclimatisation (with or without). Each row in the table sets out the specific parameters across these six fields. VOLY = value of a life year lost. VSL = Value of a Statistical Life.

Table 5. Country-specific absolute functions linking reported salmonella cases with temperature.

Country	Threshold (°C)	% change in number of salmonella cases per °C above threshold
England & Wales	5	12.4
Netherlands	7	9.3
Switzerland	3	8.8
Denmark	15	1.1
Estonia	13	18.3
Poland	6	8.7
Slovak Republic	6	2.5
Spain	6	4.9

Table 6. Average annual temperature-related cases of salmonellosis across the EU-27, for 2011-2040 and 2071-2080 (A2 and B2 scenarios)

	Average annual temperature-related cases of salmonellosis							
Time period	**2011-2040**			**2071-2100**				
Scenario		**A2**			**A2**		**B2**	
	Future socio-economic, no climate change	Climate and socio-economic induced	Climate change induced only	Future socio-economic, no climate change	Climate and socio-economic induced	Climate change induced only	Climate and socio-economic induced	Climate change induced only
Cases/yr	**73,511**	**93,365**	**19,854**	**82,337**	**122,862**	**40,525**	**107,678**	**25,341**

Table 7. Annual welfare costs of annual temperature-related cases of salmonellosis across EU-27, under A2 and B2 climate scenarios for two future time periods. (2005 prices).

	Average annual temperature-related cases of salmonellosis		
Time period	**2011-2040**	**2071-2100**	
Scenario	A2 climate induced change	A2 climate induced change	B2 climate induced change
No. of cases/year	**19,854**	**40,525**	**25,341**
Total cost (€m)/year (low unit value)	69	142	89
Total cost (€m)/year (high unit value)	139	284	177

Table 8 Annual Cases of mild depression attributable to coastal flooding from climate change in the EU under IPCC climate scenarios

Climate / SLR scenario	Year	Cases of mild depression ('000s/year)
Low sea level rise A2	2025	1
	2085	24
High sea level rise A2	2025	13
	2085	5,573
Low sea level rise B2	2025	1
	2085	21
High sea level rise B2	2020	12
	2080	4,290

Using estimates of number of people flooded from Bosello et al (this issue), which include climate and socio-economic change.

Table 9. Annual Costs of climate change-induced Depression from Coastal Flooding in EU-27 (€m, 2005)

Climate / SLR scenario	Time Period	€million/year Low unit value	€million/year High unit value
Low sea level rise A2	2020	0.3	0.4
	2080	4	6
High sea level rise A2	2020	2	3
	2080	1,006	1,408
Low sea level rise B2	2020	0.2	0.3
	2080	4	5
High sea level rise B2	2020	2	2
	2080	774	1,084

Using estimates of number of people flooded from Bosello et al (this issue), which include climate and socio-economic change.

Supplementary Information

The Table below indicates which of the country specific functions are applied to each country included in the analysis for temperature and sal.

Absolute temperature-mortality functions applied to individual EU countries

	Country-specific absolute functions	
EU country	**HEAT FUNCTION**	**COLD FUNCTION**
Austria	Netherlands	Netherlands
Belgium	Netherlands	Netherlands
Bulgaria	Bulgaria	Bulgaria
Croatia	Bulgaria	Bulgaria
Cyprus	Spain	Greece
Czech Republic	Bulgaria	Bulgaria
Denmark	Norway	Finland
Estonia	Norway	Finland
Finland	Norway	Finland
France	UK	UK
Germany	Netherlands	Netherlands
Greece	Spain	Greece
Hungary	Bulgaria	Bulgaria
Iceland	Norway	Finland
Ireland	UK	UK
Italy	Spain	Greece
Latvia	Norway	Finland
Lithuania	Norway	Finland
Luxembourg	UK	UK
Malta	Spain	Greece
Netherlands	Netherlands	Netherlands
Norway	Norway	Finland
Poland	Bulgaria	Bulgaria
Portugal	Spain	Greece
Romania	Bulgaria	Bulgaria
Slovakia	Bulgaria	Bulgaria
Spain	Spain	Greece
Sweden	Norway	Finland
Switzerland	UK	UK
Turkey	Spain	Greece
United Kingdom	UK	UK

Absolute temperature Salmonellosis functions applied to individual EU countries

EU country	Country-specific function applied	EU country	Country-specific function applied
Austria	Switzerland	Latvia	Estonia
Belgium	Netherlands	Lithuania	Estonia
Bulgaria	Slovak Republic	Luxembourg	Netherlands
Croatia	Slovak Republic	Malta	Spain
Cyprus	Spain	Netherlands	Netherlands
Czech Republic	Poland	Norway	Denmark
Denmark	Denmark	Poland	Poland
Estonia	Estonia	Portugal	Spain
Finland	Denmark	Romania	Slovak Republic
France	Switzerland	Slovakia	Slovak Republic
Germany	Netherlands	Spain	Spain
Greece	Spain	Sweden	Denmark
Hungary	Slovak Republic	Switzerland	Switzerland
Iceland	Denmark	Turkey	Spain
Ireland	England & Wales	United Kingdom	England & Wales
Italy	Spain		