

Technical Policy Briefing Note 5: Health

The Impacts and Economic Costs
of Climate Change on Health in Europe



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DRAFT FINAL REPORT

Key Messages

- There are a large number of potential health impacts that could arise from climate change, directly or indirectly, including heat-related mortality and morbidity, food safety and vector-borne diseases, outdoor air pollution, deaths, injuries and wider well-being from flooding, though there are also some potential benefits (reduction in cold mortality)..There are also risks to health infrastructure and other critical infrastructure (water and power supplies) from extreme weather events.
- The ClimateCost study has assessed the potential impacts and economic costs of selected health impacts in Europe, focusing on four impacts: heat related mortality, food borne disease, coastal flooding and labour productivity. This has considered future climate and socio-economic change, including the projected increase in the elderly population. .
- **Heat related mortality.** Under a medium to high emission (A1B) scenario, with no mitigation or adaptation, the study estimates an additional 26000 deaths/year from heat by the 2020s (2011-2040), rising to 89 thousand/year by the 2050s (2041-2070) and 127 000/year by the 2080s (2071-2100). While heat-related mortality in Europe is project to increase in all regions, there are relatively higher levels of climate change-attributable heat deaths in Southern Europe.
- The cost of these impacts varies significantly on the valuation method used for changes in the risk of fatality, specifically whether a Value of a Life Year Lost (VOLY) or a Value of a Statistical Life (VSL) is used. Using the latter, the estimated welfare costs are €31 billion/year by the 2020s (2011-2040), €103 billion/year by the 2050s (2041-2070) and €147 billion/year by the 2080s (2071-2100), but these values fall by over an order of magnitude when using the VOLY approach.
- Under an E1 stabilisation scenario, broadly equivalent to the EU 2° target, these impacts are reduced significantly (after 2040), falling to 69 thousand deaths/year by the 2050s (2041-2070) and a similar number in the 2080s (2071-2100). The equivalent economic costs are €80 billion/year by the 2050s (2041-2070), if the VSL approach is used.
- Including (autonomous) acclimatisation in the analysis reduces these impacts significantly. With acclimatisation, the estimated number of heat related deaths fall to 13 thousand/year in the 2020s, 44 thousand/year in the 2050s and 40 thousand per year in the 2080s under the A1B scenario. The equivalent values for the E1 scenario are 30 thousand/year in the 2050s and 18 thousand per year in the 2080s. The welfare costs fall in line with these estimates, though they are still very significant if the higher VSL estimate is used.
- **Food borne disease.** Salmonellosis is an important cause of food borne illness in Europe and is sensitive to ambient temperature. The estimates suggest that under the A1B scenario, climate change could lead to an additional 7 thousand cases/year of salmonellosis in EU27 by 2020s, rising to 13 thousand by the 2050s and 17 thousand by the 2080s, if the incidence remains at current levels, but with 5.5, 8.8 and 9.3 thousand cases/year if a baseline decline in incidence is assumed). Under the E1 scenario, these fall to around 6-7 thousand cases per year (2050s/2080s, baseline decline). The economic costs of these additional food borne illnesses has also been estimated. The welfare costs are estimated at €36 million/year in the 2020s (A1B, current baseline), rising to €68 and €89 million/year in the 2050s and 2080s respectively:(€30, 46 and 49 million/year if a decline in incidence (due to better regulation) is included.

- **Mortality due to coastal flooding** is associated with direct health impacts including fatalities. The study has assessed the impacts of climate change (sea level rise leading to 'deeper' storm surge). Climate and socio-economic change is estimated to lead to 130 deaths/year in the EU by the 2050s and 650 deaths/year in the EU by the 2080s (A1B) with two thirds of these arising in Western Europe. The associated welfare costs are estimated at €151/year in the 2050s and €750 million/year by the 2080s. These fall significantly under the E1 mitigation scenario to 100 (2050s) and 185 (2080s) fatalities/year, with welfare costs of €117/year (2050s) and €214 million/year (2080s).
- Climate change is likely to cause negative impacts on **labour productivity** in some regions. Under the A1B scenario, Southern Europe is estimated to incur a mean loss of productivity – measured here as days lost - of 0.4% to 0.9% by the 2080s (with the range reflecting different future labour structures). Total productivity losses for Europe are estimated at €300 - 740 million/ in 2080s (A1B). These are significantly reduced under the E1 mitigation scenario to €60 - 150 million per year in 2080s.
- While these cover many of the major health impacts of climate change in Europe, there are other important potential effects,. As well as health outcomes, these also include the costs of adapting health systems infrastructure, which could be high. There are also future research priorities to assess the effectiveness of specific interventions.
- It is stressed that there is a wide range of uncertainty around all these estimates – for all four health categories above - reflecting the underlying uncertainty in emissions scenario and climate-health relationships. The need to recognise and work with this uncertainty – as part of integrated and sustainable health policies – requires an iterative and flexible approach.
- There is limited information on the **costs of adaptation** to avoid or reduce health impacts. Public health (community based) heat alert systems are a relatively low cost responses for addressing heat related mortality but evidence so far indicates limited effectiveness. Change to infrastructure (space cooling, building design or spatial planning) are more expensive but are likely to be required in the long term.
- For coastal flood risks, other parts of the ClimateCost study have considered technical adaptation (dikes). Coastal adaptation can reduce risks significantly; down to less than 10 deaths per year in 2080 (from 650 without adaptation), reducing residual impacts to around €5 million/year (A1B).
- There is much less information on the costs of adaptation for other risks. The limited information available suggests that many early public health based adaptation measures are relatively cost-effective, and/or have high benefit to cost ratios. However, some options (e.g. large-scale vaccination programmes, infrastructure such as cool rooms, new water treatment) increase costs significantly. As impacts evolve over time, and risks become more cross-sectoral in nature, the cost of adaptation may also rise significantly, due to the need for larger capital investment.

1. Introduction

The objective of the ClimateCost project is to advance the knowledge on the economics of climate change, focusing on three key areas: the economic costs of climate change (the costs of inaction), the costs and benefits of adaptation, and the costs and benefits of long-term targets and mitigation. The project has assessed the impacts and economic costs of climate change in Europe and globally. This included a bottom-up sectoral impact assessment and analysis of adaptation for Europe, as well as a global economic modelling analysis with sector-based impact models and computable general equilibrium models.

This technical policy briefing note¹ (TPBN) provides an overview of a European-wide assessment of the impacts and economic costs of climate change on health as part of the ClimateCost project, and the analysis of the costs and benefits of adaptation.

1.1. Climate change and health

Climate change is likely to impact on the health of Europeans in the coming century either directly, such as with the effects of heat and cold, or indirectly, for example, through the changes in the transmission of food, water or vector-borne diseases. Note that human health is defined here as complete physical, mental, and social well-being and not merely the absence of disease or infirmity. There are also a wider set of potential impacts of climate change on health which occur indirectly, such as through increased incidence of deaths, injuries and disease linked to the coastal and inland flooding, and the secondary effects of these events. All these health changes will have economic consequences, through the direct medical costs, health protection costs, lost time at work, and welfare changes, though they include some positive as well as negative effects. There are also risks to public health systems and infrastructure.

The current climate of Europe already leads to many health outcomes, summarised in Table 1 below, and climate change has the potential to affect these, primarily negatively though it may also lead to positive outcomes as well.

Table 1: Current Climate-Related Health Risks in Europe

Health outcome	Known effects of weather and climate variability
Heat stress	<ul style="list-style-type: none"> • Heat waves increase the risk of deaths and hospitalisations in the elderly. • High temperatures increase the risk of occupational and leisure-related heat injuries and heat stroke
Cold	<ul style="list-style-type: none"> • Low temperatures increase the risk of death from cardio-respiratory disease, and hypothermia and cold-injuries amongst the exposed (e.g. occupational, homeless)...
Air pollution-related mortality / morbidity	<ul style="list-style-type: none"> • Weather affects air pollutant concentrations, and seasonality and production of aeroallergens. Hot, dry weather increases risk of wild fires and thus smoke exposure.
Health impacts of floods and windstorms	<ul style="list-style-type: none"> • Events have direct effects (deaths and injuries) and indirect effects (e.g. long-term psychological morbidity), and may damage critical infrastructure (e.g. health services, water supply systems).
Mosquito-borne diseases, tick-borne diseases	<ul style="list-style-type: none"> • High temperatures increase rate of vector development and biting habits. • Climatic condition affect vector viability directly and via impacts on habitat and other species (e.g. hosts, predators).
Food-borne diseases	<ul style="list-style-type: none"> • Temperature affects survival for some pathogens (Salmonella) but not others (rotavirus).
Water-related diseases	<ul style="list-style-type: none"> • Drought may affect water availability and quality. • Heavy rainfall may results in infectious disease outbreaks (e.g. floods in urban areas are sometimes associated with leptospirosis).

Source: Kovats and Lloyd, forthcoming.

¹ The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007- 2013) under grant agreement n° 212774. The briefing note was prepared by Sari Kovats, Simon Lloyd and Zaid Chalabi (London School of Hygiene and Tropical Medicine), Alistair Hunt (Metroeconomica) and Paul Watkiss (Paul Watkiss Associates). The citation should be: Kovats, S, Lloyd, S, Hunt, A and Watkiss, P. (2011). Technical Policy Briefing Note 8: The Impacts and Economic Costs on Health in Europe and the Costs and Benefits of Adaptation, Results of the EC RTD ClimateCost Project. In Watkiss, P (Editor), 2011. The ClimateCost Project. Final Report. Volume 1: Europe. Published by the Stockholm Environment Institute, Sweden, 2011. ISBN 978-91-86125-35-6.

As part of the ClimateCost study review, Kovats & Lloyd (forthcoming) summarised the latest risk assessments of health and climate in Europe (see Table 1). The majority of these studies were found to be focused on the link between climate change and increased heat-related mortality. While this remains an area of interest, there is also a need to widen the list of health outcomes covered.

2. Scenarios

The ClimateCost project is assessing the impacts and economic costs across a number of sectors. To enable this analysis, a set of consistent socio-economic and emissions scenarios have been used, for specific future time periods (Christensen et al, 2010), set out below.

2.1 Socio-economic and climate scenarios

In the assessment of the future damages of climate change, assumptions have to be made about future conditions that require scenarios. The most widely used are the emission scenarios of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (the SRES, Nakicenovic et al. 2000). These define a set of future self-consistent and harmonised socio-economic conditions and emission futures that, in turn, have been used to assess potential changes in climate through the use of global and regional climate models. There is a wide range of future drivers and emissions paths associated with the scenarios. Thus, the degree of climate change varies significantly, which significantly affects the results. The ClimateCost study focused on two scenarios.

The first is the SRES **A1B scenario**. This is based on the A1 storyline with a future world of rapid economic growth, new and more efficient technologies, and convergence between regions. The A1B scenario adopts a balance across all sources (fossil and renewable) for the technological change in the energy system. This scenario has been extensively used in recent European regional climate modelling studies, notably in the ENSEMBLES study. For this reason, it was also used in ClimateCost. It reflects a medium–high emission trajectory and leads to central estimates of global average surface temperatures of around 3°C to 4°C relative to pre-industrial levels, though individual models show a wide range. For details, see the TPN 1 on climate model outputs.

The second is the ENSEMBLES **E1 scenario** (van der Linden et al., 2009; Lowe et al., 2009), which leads to long-term stabilisation at 450 ppm (450 ppm CO₂ atmospheric stabilisation in the 21st century after a peak of 535 ppm in 2045). This is a mitigation scenario that would limit the global warming to less than 2°C, relative to pre-industrial levels, with a high probability.

2.2 Future time periods

The assessments here consider the projected impacts of climate change, set against the observed climate (baseline climate defined as annual average of period covering 1961 to 1990, depending on data availability²). There is a range of potential future time periods that could be considered, reflecting different information needs. These vary from projections of short- and medium-term changes that can help inform early adaptation priorities to more significant, longer-term changes that can help inform mitigation policy. The ClimateCost health study considered three future time periods to 2100:

- the 2020s (i.e. 2011-2040);
- the 2050s (i.e. 2041-2070) and
- the 2080s (i.e. 2071-2100).

However, impacts estimated towards the end of the century should be seen as highly uncertain, due to likely changes in socio-economic and health status of the European population.

2.3 Climate model output and uncertainty

The standard approach for the development of climate scenarios is to run the above emissions scenarios in general circulation models (GCMs) and, in turn, to downscale these for a region such as

² National level, daily temperature and humidity series were assembled for the 30 year baseline period (or the part of this period for which data were available) using data from the 'Global Surface Summary of the Day' (National Climatic Data Centre (NCDC), 2011) and the 'European Climate Assessment and Dataset' datasets (European Climate Assessment and Dataset (ECAD), 2011).

Europe, with the use of coupled regional climate models (RCMs). The ClimateCost study followed this approach using the results of the ENSEMBLES project. However, different models may lead to very different results. Thus, the choice of GCM and/or coupled GCM-RCM makes a large difference to modelled future climate change, and to the impacts and economic costs.

Whereas projections of average changes in temperature are relatively robust across climate models, there is still considerable variability. It is stressed that the variation between model outputs for any given emissions scenario is as large – and in cases larger - than across different scenarios. The background to the climate models and the outputs for Europe are set out in TPBN 1 on climate models and uncertainty.

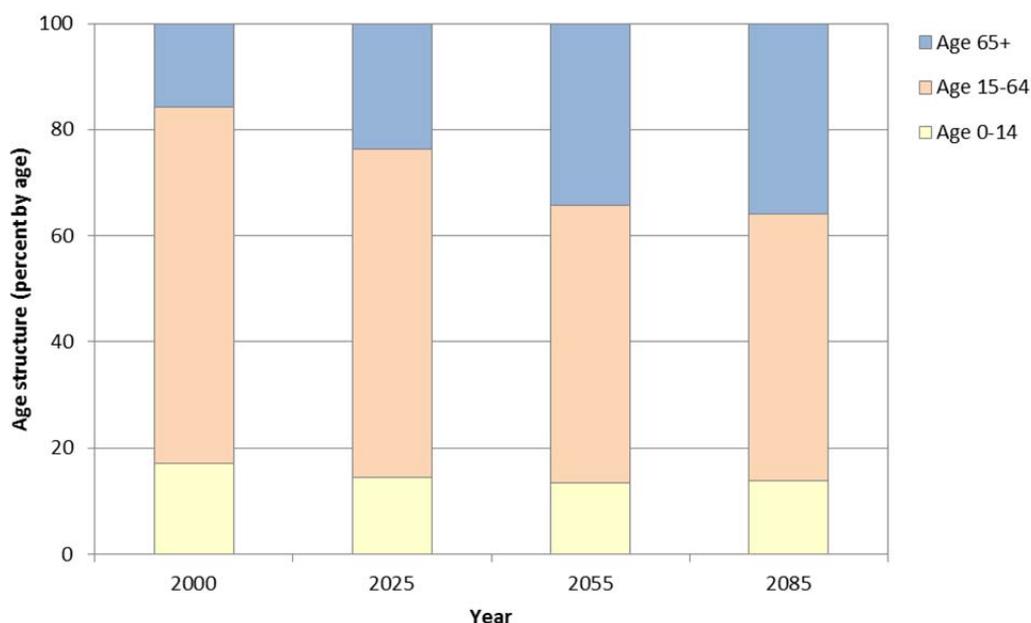
It is good practice in impact assessment to therefore use multi-model information to capture at least some of the uncertainties associated with climate modelling and projections. The ClimateCost project has followed this practice, and reports how the variability between the models affects health damages. The results presented in this TPBN for the A1B and E1 scenario are based on simulations from 12 different global climate models (a so called multi-model ensemble).

2.4 Population scenarios and data

The socio-economic emission scenarios are derived from a wide range of other determinants that are important in influencing future impacts. These include important primary drivers including economic growth and demographic change (population). Previous work has shown that these socio-economic drivers are as important, in determining the size of future impacts and economic costs (Evans et al, 2004; Watkiss and Hunt, 2011), as the change from climate change. While including these effects is challenging, they need to be considered across the time frames of interest here, otherwise this implies that projected future climates will take place in a world similar to that of today.

The ClimateCost project applied consistent climate and socio-economic scenarios, across sectors, to ensure comparability across the study. In this health analysis, a single age-specific population scenario (A1) was used (Grubler et al, 2006). The population level in the EU27 is projected to remain broadly stable (between 450 and 500 million people) and further urbanisation is not a strong trend. However, population ageing is very significant and the numbers of elderly and very elderly are projected to increase (Figure 1). By 2050, over one third of the population will be aged over 65 (around 160 million people).

Figure 1. Age-specific population projections for EU27 (A1) (%).



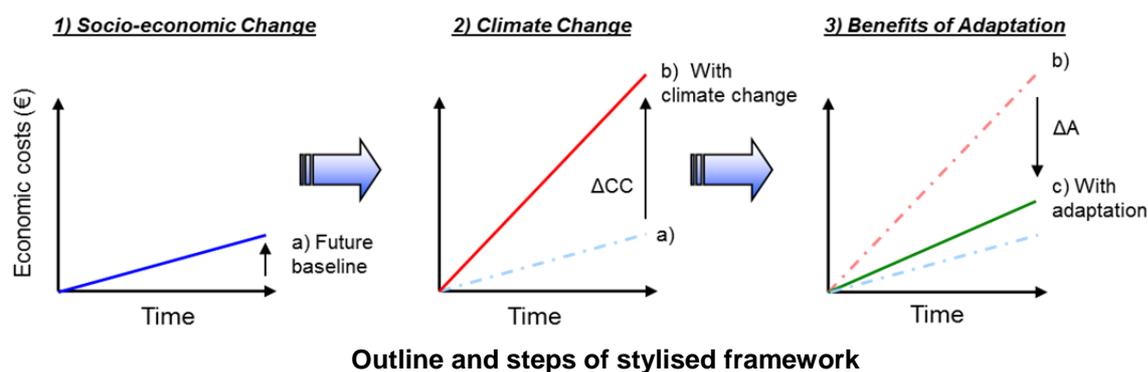
2.5 Separating climate, population, and other future drivers of population health

When reporting the results of studies such as ClimateCost, a key issue is to report transparently on the outcomes due to socio-economic change and the outcomes due to climate change, rather than reporting the two together (because the impacts from socio-economic change would have occurred even in the absence of climate change)

Following this, while the causation of human disease and mortality is complex, in broad terms it is possible to split climate and socio-economic factors (though the two interact), and it is even possible to split the latter into those related to population size and structure, and those related to national income and associated services and technologies.

In the sections below, the results first report the future health outcomes under a scenario of no climate change. This is the level of change that would occur in the absence of climate change, i.e. from socio-economic change only. It then considers the combined effects of socio-economic and climate change together. This is important to allow the subsequent estimation of the marginal effects of climate change, while noting that adaptation policy will need to address the combined effects of climate and socio-economic change acting together. The analysis then assesses the effects of adaptation, noting that there will still be residual damages even with adaptation. These three steps are shown in Figure 2.

Figure 2. Stylised framework relating economic costs with socio-economic change, then building on climate change and realising the benefits of adaptation (adapted from Boyd and Hunt, 2006).



2.6. Reporting of economic values (including adjustments and discounting)

Consistent with all sector-based analysis in ClimateCost, the economic valuation results below are presented in terms of constant 2010 prices in Euros for the three time periods considered (i.e. the 2020s, 2050s and 2080s), without any adjustments or discounting. The results are presented in this way to facilitate direct comparison, over time, and between sectors.

However, the use of the values in subsequent policy analysis (e.g. in looking at the costs and benefits of adaptation options to reduce these impacts), would need to work with present values (i.e. values that are adjusted and discounted as with standard economic appraisal). This analysis is included in other parts of the ClimateCost study

A number of other notes on valuation are also highlighted. The analysis applies constant unit values for the impact categories covered across time for both scenarios, though there is a discussion of the potential change in these values with future GDP growth. Further, the values presented represent direct costs only. They do not consider the wider economic costs associated with damage costs or adaptation, nor do they consider potential feedbacks on price levels and demand, though this analysis is included in the Computable General Equilibrium analysis undertaken in other parts of the ClimateCost study.

3. Methods

The ClimateCost project adopts an impact assessment methodology (Carter et al, 2007), where data from climate and socio-economic projections are used in combination with climate-impact response functions to generate estimates of sectoral impacts. These are then converted to a monetary value by multiplying the health outcomes by a relevant unit cost.

The ClimateCost study has considered four separate health impacts from climate change in Europe:

- Heat related mortality;
- Food borne disease;
- Coastal flood impacts;
- Labour productivity.

A brief description of the methods used are presented below.

3.1 Heat Mortality

High temperatures have demonstrable impacts on daily mortality. This has been clearly shown by recent extreme heat waves in Europe (especially France) in 2003 and in Eastern Europe (especially Russia) in 2010.

Epidemiological studies – which identify patterns of ill-health and associations with environmental factors - have found a U-shaped association between temperature and daily mortality, when adjustments for season and other factors such as air pollution are taken into account. While these relationships are locally specific and show significant heterogeneity (Curriero et al., 2002), there are European estimates (pooled population estimates) available from the PHEWE project (Baccini et al., 2008, see Appendix Table A1) and these were used in the ClimateCost project. While these relationships provide information for assessing the risk of current climate variability, they can also be applied to estimate the future health outcomes of climate change.

The functions assume a linear increase in mortality risk above an upper threshold value, and are provided for the Mediterranean and North-continental regions. The functions were applied to derive national estimates of current and future heat exposures (above temperature threshold values). To do this the current distribution of daily apparent temperature (AT) was estimated for each EU country – and each climate scenario - by shifting the currently observed temperature distributions by the projected change in mean temperatures for the summer season³. The functions were applied to the urban populations only, in recognition that temperature-mortality functions were derived from urban populations. The proportion of each country's population in urban areas (ranging from 50% in Slovenia to 97% in Belgium) was derived from World Bank data (World Bank 2011).

The study also considered the effects of acclimatisation (autonomous adaptation). Future individuals will respond to higher temperatures through physiological and behavioural adjustments (Dessai, 2003). Studies that build in acclimatisation show much lower future health impacts (see Watkiss and Hunt, 2011). However, there is still little information or evidence on which to base acclimatization assumptions (although it can be seen that warmer countries are adapted compared to colder countries in Europe). It is therefore difficult to estimate the rate of change of adaptation to climate warming. The analysis in ClimateCost has assessed heat impacts using a change in the heat threshold of 0.5 degree per 30 years for acclimatisation. Future research on this subject is a key priority.

It is also stressed that temperature increases projected with climate change will also lead to potential benefits, from the reduction in cold related mortality and morbidity. These effects are not considered in ClimateCost, but are potentially significant.

3.2 Food borne disease

Climate sensitive infectious diseases, such as salmonellosis, are affected by temperature (Kovats et al, 2004), and are therefore potentially affected by climate change. Salmonellosis is an important

³ Information on future changes in humidity/dewpoint temperature were not available for this assessment. Not including future increases in humidity is likely to lead to an underestimate of future impacts in more humid countries (e.g. in southern Europe).

cause of foodborne diseases in Europe. Salmonellosis pathogens are known to be temperature-sensitive and show a distinct seasonal pattern (with peaks in the summer months). The main causes of salmonellosis are poor food preparation and inadequate storage preceding consumption.

The ClimateCost study used a pooled estimate for the impact of temperature on salmonellosis cases, derived from a Europe wide time-series study with independent control for seasonal variations and long-term trends (Kovats et al., 2004).

National notification rates for salmonellosis were obtained from the European Centre for Disease Control surveillance report (EU27 countries) (ECDC 2009). It is highlighted that there is a significant under-reporting of these cases, thus these rates (and estimated future rates) may under-estimate the true incidence of the disease. However, the incidence of salmonellosis is likely to decline in the future (a continuation of current trends) due to improved food hygiene regulation. Recent studies have indicated that the effect of temperature on food poisoning had declined in England and Wales in the last two decades (Lake et al., 2009). In ClimateCost, future incidence rates were therefore considered for current levels and with a projected decline due to the implementation of specific measures. The latter used the 20% target reduction in the incidence of foodborne disease achieved in the UK. That is, a 20% reduction was assumed from 2000 to 2030, and from 2030 to 2050, and from 2050 to 2080. Many of the measures associated with these baseline policies to improve food safety can also be considered as “no regret” adaptation policies.

3.3 Coastal Flooding

While flooding is the most frequent weather related disaster in Europe, the number of direct deaths and injuries is low due to high levels of flood preparedness and protection. This is likely to remain the case in the future even with projected increases in river and coastal flooding. Nonetheless, there are additional risks from climate change.

The coastal assessment in ClimateCost (Brown et al, TPBN 2) provided estimates of the numbers of people affected by coastal flooding and this allows subsequent quantification and valuation of the direct health risks from climate change. The analysis in this TPBN reports the assessment of direct risks (deaths) from coastal flooding, derived using the storm surge-attributable mortality data (as average annual deaths) from the EM-DAT disaster events database (CRED, 2011), using data for Europe for the period 1990 to 2007⁴. Note that as well as causing direct impacts, flood events also affect wider well-being (mental health, stress and depression), as well as having potential indirect effects as a consequence of infectious diseases associated with flooding (Ahern et al, 2005, Floyd et al, 2003). These effects have not been considered here.

There are also increases in river floods, see Feyen and Watkiss, 2011. However, it has been more difficult to translate these results through to estimates of future health impacts (as the river flood models do not provide an appropriate indicator of the population flooded) and they are not included here.

3.4 Labour Productivity (Health)

Heat stress has implications for occupational health. There are well-established physiological limits for an active individual and when the external temperature rises above certain limits, individuals must either slow down productivity (or stop working) otherwise they will become ill from heat exhaustion and other heat conditions. With climate change, workers may need to work longer hours, or more workers may be required, to achieve the same output and there will be economic costs of lost production in the absence of intervention or adaptation.

A model to estimate daily labour productivity was previously developed for the ENSEMBLES project (Kjellstrom et al., 2009). This quantifies the relationship between WBGT (wet bulb globe temperature, a combined measure of heat and humidity exposure) and labour productivity by work intensity, with the threshold WBGT for labour loss decreasing as intensity of labour increases (see Appendix). For the analysis here, it was assumed that an intensity of 400W corresponds to agricultural labour, 300W to industrial labour, and 200W to work in the service industry (with adjustments made to account for indoor temperature (for both industrial and service workers) though the analysis does not consider the

⁴ Note that the coastal assessment (TPBN 2) assumes that the future frequency and intensity pattern of storm surge events remain unchanged from baseline. We make the same assumption in this assessment; that is, the impact associated with climate change is due to sea level rise alone.

effects of building overheating. The analysis derived current baseline distributions and applied the information from the climate model scenarios.

Baseline labour distributions across agriculture, industry, and service, and GDP/capita, were obtained for each country from the World Bank Development Indicators (WBDI) database for 2000 or the nearest available year (World Bank, 2011). However, the impact of climate change on labour productivity will be heavily influenced by the future labour productivity split in Europe. For this reason, two scenarios were considered. The first assumed that the distributions remained at the current baseline level. The second assumed that in the future, labour distributions in Northern and Western Europe would remain constant (they are dominated by service and have small proportions of agricultural workers), and that distributions in Eastern and Southern Europe would broadly converge to those seen in Western Europe as GDP/capita approached current levels in Western Europe.

3.5 Monetary Valuation

The impacts on human health are more difficult to value than many other sectors, because there are no observed market prices. However, it is possible to derive monetary values for this non-market sector, by considering the total effect on society's welfare. This requires analysis of three components which each capture different parts of the total effect:

- The resource costs i.e. medical treatment costs;
- The opportunity costs, in terms of lost productivity; and
- Dis-utility i.e. pain or suffering, concern and inconvenience to family and others.

The first two components can be captured relatively easily. Techniques are also available to capture the third component, by assessing the 'willingness to pay' or the 'willingness to accept compensation' for a particular health outcome. These are derived using survey-based "stated" preference methods and/or "revealed" preferences methods that are based on observed expenditures such as on consumer safety.

ClimateCost has made use of existing unit estimates for health based impacts, and adopts established benefit value transfer procedures to apply these values.

There are several approaches for valuing the change in the **risk of mortality**, for the analysis of heat and flood deaths. These can be valued using a long-established metric, the value of statistical life (VSL - also known as the value of a prevented fatality, VPF) and this is used for flood related deaths. However, in the case of heat mortality, an alternative metric can be used: the Value of a Life Year Lost (VOLY). While the VSL is more commonly used in economic appraisal, the VOLY provides a means of explicitly accommodating differing lengths of remaining life expectancy. This is relevant for the heat assessment, because studies have shown that a high proportion of heat-attributable deaths brought forward in the elderly (short term mortality displacement). Both metrics have been used in various EC Impact Assessments (CEC, 2005) and both have strengths and weaknesses. For heat, ClimateCost has therefore used both valuation metrics.

This analysis adopts central values from recent empirical studies for air pollution impacts on mortality (Alberini et. al. 2006a: b); Desaiques et. al. 2011; Lindhjem et. al. 2011). These values have also been used in impact assessment by the European Commission (CEC, 2005). The values (in 2010 prices) are:

- Value of a Prevented Fatality: €1.16m
- Value of a Life Year: €63,000.

The same monetary values for mortality risk are used for all European countries.

For heat mortality, there is little robust empirical evidence regarding the length of time lost on average, and in practice this will vary by age at death, region and level of exposure. For the analysis here, based on studies of air pollution impacts, the analysis has used an average value of 0.5 years of life is lost for each heat-related death.

For **Salmonellosis**, the analysis has used recent values from Watkiss & Hunt (2011), which estimate the relevant cost components of the disease, i.e. treatment costs, opportunity costs and dis-utility costs. The sum of these components provides a range of unit values for a case of salmonellosis,

weighted by the incidence of a range of severities, of between €3,500 and €7,000, with a central value of €5,250 for all countries.

For the **loss of labour productivity**, a value is derived from the GDP per labour force member. This represents the loss to society, differentiating it from a loss of earnings measure that reflects the loss for the individual, only. Data on average labour productivity for EU member states was based on available EUROSTAT data (European Commission, 2011), with assumptions about effective working days per year. This does show considerable variation across EU27 countries but in the EU analysis below, the summary results are presented using EU27 average productivity cost value of €287 per day.

Consistent with all sector-based analysis in ClimateCost, the economic valuation results below are presented in terms of constant prices in Euros over future years, without any adjustments or discounting to facilitate direct comparison, over time, and between sectors.

3.6 Impacts of climate change not quantified in this assessment

While the analysis above captures many of the most important impacts of climate change on health, there are other potential effects, as shown in Table 1. The ClimateCost project has been explicit about what is included or excluded in the analysis and reported values.

The analysis only considers the four categories of health effects listed. A number of other health risks of climate change are important when considering the full effects and are summarised below (based on Confalonieri et al, 2007; Menne and Ebi, 2004; Kovats and Lloyd, forthcoming).

Vector-borne diseases: Although climate change may alter some local risks of vector-borne diseases, such events are sporadic and unpredictable. Climate change studies have been limited to mapping the potential distributions of vector species (e.g. *Albopictus* and ticks). The risk of current malaria current transmissions is low and it is very unlikely that malaria could become re-established in Europe because of public health measures, though local transmission of a few cases may occur. However, Health Authorities need to remain alert to the possibility of outbreaks in some European countries and to the possibility that more effective vectors (e.g. different species of mosquito, with different diseases) may arrive from outside Europe. The maintenance of surveillance is an important and cost-effective measure.

Water-borne disease outbreaks: There is very little evidence that waterborne disease outbreaks in Europe are associated with heavy precipitation events. However, there is insufficient evidence to assume a robust association for quantification here. Regulation and maintenance of domestic water supplies is a key determinant of future risks in countries with well established systems (as in the EU27). However, private wells are likely to be at risk unless well maintained.

Climate change may affect future levels of ground level **solar ultraviolet (UV) radiation**. Increased exposure to UV radiation is associated with an increased risk of skin cancer and possibly cataracts. It is also possible that warmer summers may lead to changes in behaviour (increased sun exposure) that will also increase exposure to UVR. However, an increase in sunshine may also have potential health benefits through increased outdoor physical activity and general wellbeing. Exposure to sunlight is also essential for vitamin D formation, which is essential for good health.

Another potential risk relates to the effects of climate change on **air pollution and health**. The impact of climate change on future background levels of particulates and tropospheric ozone are uncertain. The ClimateCost study has assessed the co-benefits to health from reductions in particulates associated with climate policies (mitigation), Holland et al (2011), but it has not considered how climate change might affect ozone or particulate concentrations and associated health outcomes.

Allergic diseases. There is now good evidence that the seasonality of certain pollens has changed (leading in some locations to longer pollen seasons). This would imply an earlier onset of allergic rhinitis, and possibly an extension of the duration (depending on the pollen species to which the individual is allergic). Climate change may also lead to changes in the distribution of pollens, associated with changing ecological zones.

Finally, **the impacts of weather events on health services (hospitals and clinics)** has received little attention to date, but is a key future priority.

4. Results

The results of the analysis are presented by health outcome in the following sections.

4.1 Heat Related Mortality

The ClimateCost results are first presented in terms of the number of heat related deaths, for the A1B and the E1 (mitigation) scenario for the EU27 over time. These estimates were converted into years of life lost for valuation.

Table 2 reports as the change due to population growth and ageing, first, then the impact with climate change as well. Finally, the marginal impact of climate change is estimated by subtracting one from the other.

The analysis shows that under **the A1B scenario**, the total number of heat related deaths is projected to be 109,000 by the 2020s (2011-2040), 229,000 by the 2050s (2041-2070) and 264,000 by the 2080s (2071-2100), as a result of climate and population change (without acclimatisation or adaptation). The marginal impact of climate change alone is 26,000 by the 2020s (2011-2040), 89,000 by the 2050s (2041-2070) and 127,000 by the 2080s (2071-2100). It is highlighted that the underlying age structure of Europe would increase heat related risks, even in the absence of climate change.

Under an E1 mitigation scenario, deaths are significantly reduced in the medium- to long-term⁵, with a reduction of 20,000 by the 2050s (2041-2070) and 57,000 by the 2080s (2071-2100), accounting for both climate and population change. The marginal impact of climate change alone is 29 000 by the 2020s (2011-2040), 69 000 by the 2050s (2041-2070) and 70 000 by the 2080s (2071-2100). The marginal benefit of the E1 scenario is therefore 57 000 cases per year by the 2080s.

It is stressed that there is a considerable variation across the climate models: the values in the table are for the central mean value only.

Table 2. EU27 Annual Heat Mortality (additional deaths compared to baseline climate (1961-1990), for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario (ensemble mean) and E1 (ensemble mean). No acclimatisation.

Heat deaths/year for EU27, A1B scenario – NO ACCLIMATISATION			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population growth only (no climate)	82,503	139,996	136,878
Climate and population change	108,806	228,648	263,605
Marginal climate change impact	26,303	88,652	126,727
Heat deaths/year for EU27, E1 mitigation scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population growth only (no climate)	82,503	139,996	136,878
Climate and population change	111,611	208,581	206,777
Marginal climate change impact	29,108	68,585	69,899

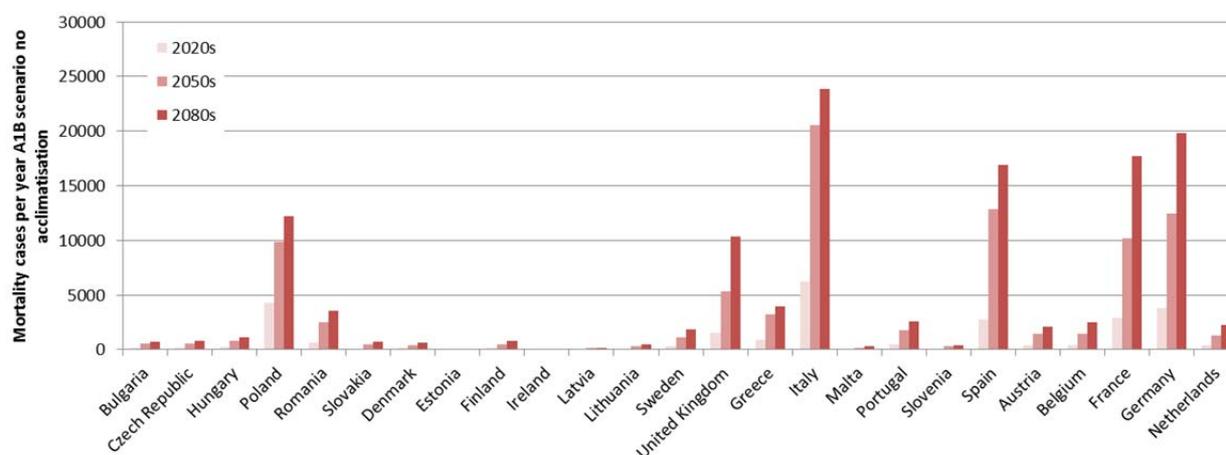
Note that deaths are primarily in the elderly population and may be due to short term mortality displacement – that is deaths that would have occurred in any case within days, weeks or months.

⁵ The climate model ensemble for E1 gives a slightly higher warming signal than A1B, see TPBN1, hence the values appear slightly higher in this first period.

The number of additional heat deaths is estimated at 127 thousand/year in the 2080s (A1B, EU27, marginal climate only, no acclimatisation). Under the mitigation scenario, these fall to 70 thousand/year (E1, 2080), reducing the number of deaths by over 57,000 deaths/year

There is a wide distribution of these impacts across Europe. The number of cases under the **A1B scenario (no acclimatisation)** is shown for each member state is shown in the figure below.

Figure 3. Annual Heat Mortality (compared to baseline climate (1961-1990)), for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario (ensemble mean). No acclimatisation.



Note that deaths are primarily in the elderly population and may be due to short term mortality displacement – that is deaths that would have occurred in any case within days, weeks or months.

While the figures are largest for those member state with high populations (reflecting the population at risk), there are higher values for Italy and Spain reflecting the higher relative risks to Mediterranean countries from the combination of the relative climate warming (see TPBN 1) and the risk factors.

These cases can be converted to life years lost, which allows use of the VOLY metric. However, this is problematic because there is no evidence base on the period of life lost, on average, from heat related mortality. Previous work (Kovats et al, 2006; Watkiss and Hunt, 2011) have used value of 8 years on average. However, other areas that look at environmental risks in the context of air quality, has used 0.5 – 2 years of life. In this assessment, the most conservative estimate was used: 0.5 years of life lost per death.

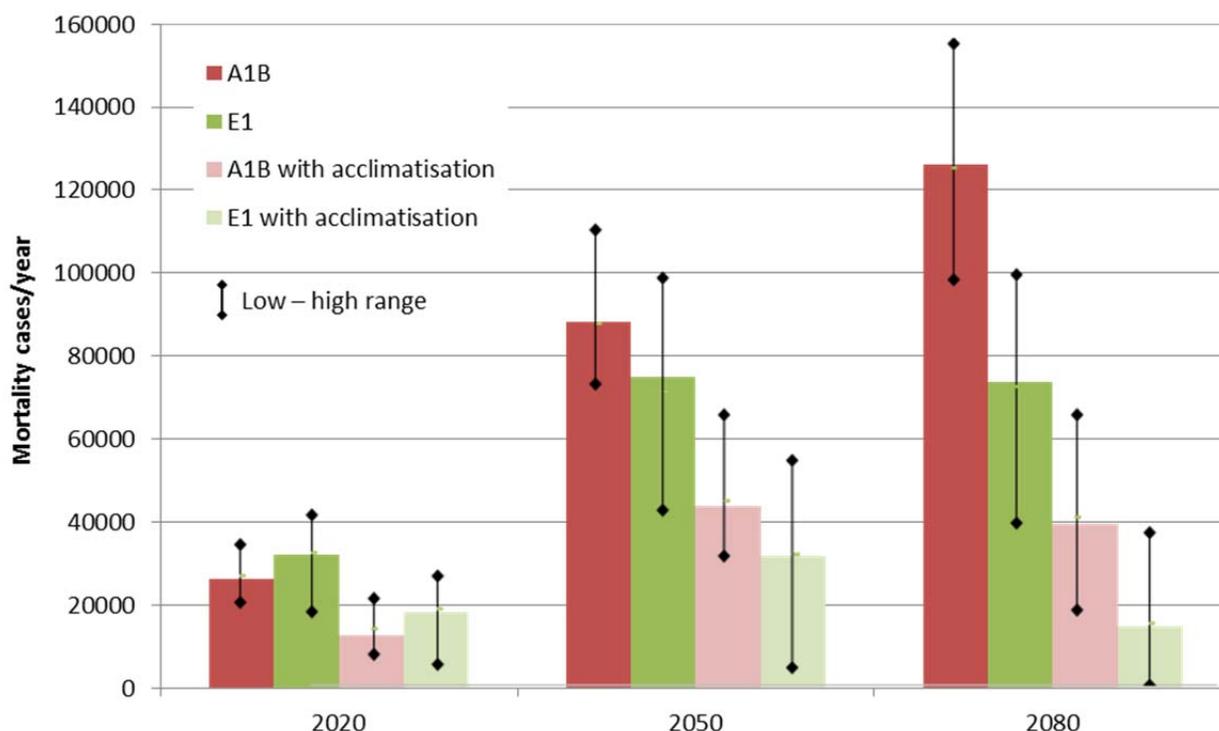
The same scenarios with acclimatisation included – at 0.5 degree per 30 years - are shown below. It can be seen that this reduces the impacts significantly. Under **the A1B scenario**, the marginal impact of climate change alone is reduced to 13 000 by the 2020s (2011-2040), 44 000 by the 2050s (2041-2070) and 40 000 by the 2080s (2071-2100). Acclimatisation therefore reduces the marginal impacts of climate change by around half in the first two time periods, and by much more than this in the later time period. The reductions for the E1 scenario lead to even lower levels, (absolute and relative), reflecting the greater impact of acclimatisation with a slower rate of climate change.

Table 3. EU27 Annual Heat Mortality (compared to the baseline period (1961-1990) for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario (ensemble mean) and E1 (ensemble mean). **With acclimatisation.**

Heat related deaths/year for EU27, A1B scenario – WITH ACCLIMATISATION			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate change)	85,451	145,187	142,282
Climate and population change	98,362	189,110	181,987
Marginal climate change impact	12,911	43,923	39,705
Heat related deaths/year for EU27, E1 mitigation scenario- WITH ACCLIMATISATION			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate change)	85,451	145,187	142,282
Climate and population change	103,698	175,517	159,923
Marginal climate change impact	18,247	30,330	17,641

European-level estimates for climate change-attributable deaths are plotted below by climate scenario. There is a significant range around the ensemble means, with at least a factor of two lower and higher across the spread of the models (shown as high low lines on the figure)

Figure 4. EU27 Annual Heat Mortality for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario (ensemble mean) and E1 (ensemble mean) for climate attributable deaths (above baseline from socio-economics). With and without acclimatisation. High – low lines show the low and high climate model outputs.



These impacts have been monetised, using the two approaches outlined above. The results are shown in Table 4 for the **A1B** scenario and **E1** scenarios. The numbers, presented in constant 2010 prices (no future adjustments or discounting), reflect the mean ensemble results across the models.

Table 4. EU27 Welfare Costs of Annual Heat Mortality in millions of Euros (2010 prices, undiscounted) for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario (ensemble mean) and E1 (ensemble mean). No acclimatisation. **Valuation using VOLY estimate.**

Million Euro/year for EU27, A1B scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate change)	2,599	4,410	4,312
Climate and population change	3,427	7,202	8,304
Marginal climate change impact	829	2,793	3,992
Million Euro/year for EU27, E1 mitigation scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate change)	2,599	4,410	4,312
Climate and population change	3,516	6,570	6,513
Marginal climate change impact	917	2,160	2,202

Notes: These values are presented as current prices without adjusting future unit economic values or discounting. No adaptation is included.

Under **the A1B scenario**, the estimated costs of the heat deaths are projected to be €3.4 billion by the 2020s (2011-2040), €7.2 billion by the 2050s (2041-2070) and €8.3 billion by the 2080s (2071-2100), as a result of climate and population change (without acclimatisation or adaptation, current prices, no discounting). The marginal impact of climate change alone is €0.8 billion by the 2020s (2011-2040), €2.8 billion by the 2050s (2041-2070) and €4.0 billion by the 2080s (2071-2100).

Under an E1 mitigation scenario, these are significantly reduced in the mid- to long-term⁶, with a reduction of €0.6 billion by the 2050s (2041-2070) and €1.8 billion by the 2080s (2071-2100), accounting for both climate and population change. The marginal impact of climate change alone is €0.9 billion by the 2020s (2011-2040), €2.2 billion by the 2050s (2041-2070) and is €2.2 billion by the 2080s (2071-2100). The marginal benefit of the E1 scenario is therefore is €1.8 billion per year by the 2080s.

With acclimatisation these fall in line with the estimates in the table above. Under the A1B scenario, the marginal impacts of climate change with acclimatisation included are €0.4 billion by the 2020s (2011-2040), €1.4 billion by the 2050s (2041-2070) and €1.3 billion by the 2080s (2071-2100). Under the E1 scenario, the marginal impacts of climate change fall to €0.6 billion by the 2020s (2011-2040), €1.0 billion by the 2050s (2041-2070) and €0.6 billion by the 2080s (2071-2100).

However, using the alternative valuation metric of the VSL, the monetary values rise significantly and are many time higher.

With the VSL metric, the results show that under **the A1B scenario**, the estimated costs of the heat related deaths are projected to be €126 billion by the 2020s (2011-2040), €265 by the 2050s (2041-2070) and €306 by the 2080s (2071-2100), as a result of climate and population change (without acclimatisation or adaptation, current prices, no discounting). The marginal impact of climate change alone is €31 billion by the 2020s (2011-2040), €103 billion by the 2050s (2041-2070) and €147 billion by the 2080s (2071-2100).

⁶ The climate model ensemble for E1 gives a slightly higher warming signal than A1B, see TPBN1, hence the values appear slightly higher in this first period.

Table 5. EU27 Welfare Costs of Annual Heat Mortality in millions of Euros (2010 prices, undiscounted) for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario (ensemble mean) and E1 (ensemble mean). No acclimatisation. **Valuation using VSL estimate.**

Million Euro/year for EU27, A1B scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate)	95,703	162,395	158,778
Climate and population change	126,215	265,232	305,782
Marginal climate change impact	30,511	102,836	147,003
Million Euro/year for EU27, E1 mitigation scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate)	95,703	162,395	158,778
Climate and population change	129,469	241,954	239,861
Marginal climate change impact	33,765	79,559	81,083

Notes: These values are presented as current prices without adjusting future unit economic values or discounting. No adaptation is included.

Under an E1 mitigation scenario, these are significantly reduced in the mid- to long-term⁷, with a reduction of €23 billion by the 2050s (2041-2070) and €66 billion by the 2080s (2071-2100), accounting for both climate and population change. The marginal impact of climate change alone is €34 billion by the 2020s (2011-2040), €80 billion by the 2050s (2041-2070) and €81 billion by the 2080s (2071-2100). The marginal benefit of the E1 scenario is therefore is €66 billion per year by the 2080s.

These fall with acclimatisation, though they still remain significant. Under the **A1B scenario**, the marginal impacts of climate change with acclimatisation are €15 billion by the 2020s (2011-2040), €51 billion by the 2050s (2041-2070) and €46 billion by the 2080s (2071-2100). Under the E1 scenario, the marginal impacts of climate change fall to €21 billion by the 2020s (2011-2040), €35 billion by the 2050s (2041-2070) and €20 billion by the 2080s (2071-2100).

As a result of climate change, the expected annual EU costs from heat related mortality are €30 billion by the 2020s, €100 billion by the 2050s and almost €150 billion by the 2080s (VSL, A1B mid, undiscounted, no acclimatisation). Under a mitigation (E1) scenario, these fall to €80 billion by the 2080s - a benefit of €70 billion/year

It is stressed that these results do not include the potential effects of current adaptation policies, notably the heat alert systems in place in Europe (see later adaptation section). These existing policies would be expected to reduce the impacts above.

Further, it is stressed that there is an important cross-sectoral linkage to other parts of the ClimateCost study, notably the analysis of energy use for cooling (Mima et al, 2011). The energy sector analysis in ClimateCost projects a high uptake of building cooling (as air conditioning) in Europe with the warmer temperatures associated with climate change. However, it also stresses that AC levels would rise under a baseline scenario (without climate change) due to per capita income increases, see Isaac and van Vuuren (2009). Only one study has clearly demonstrated a benefit of household air conditioning on heat-related morbidity (hospital admissions) (no estimates for mortality)

⁷ The climate model ensemble for E1 gives a slightly higher warming signal than A1B, see TPBN1, hence the values appear slightly higher in this first period.

(Ostro et al, 2010). The estimated impacts above do not take account of the potential benefits of baseline increases in air conditioning, or the increased use under scenarios of climate change. Some care must be taken when aggregating sectoral estimates because of the potential for some double counting.

4.2 Food borne disease (salmonellosis)

The estimated number of climate change-attributable cases of salmonellosis, under the A1B and E1 emission scenarios, are shown in table 6. In each case the analysis has considered a case with and without declining baseline rates. It is stressed that there is a considerable variation across the climate models: the values in the table are for the central mean value only.

Table 6. EU27 Estimated climate change-attributable salmonellosis cases per year in the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario (ensemble mean) and E1 (ensemble mean).

Additional salmonellosis cases/year for EU27, A1B scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only, constant rate			
Climate change, constant case rate	6848	13,030	16,915
Climate change, decreasing case rate	5614	8834	9319
Additional salmonellosis cases/year for EU27, E1 mitigation scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only, constant rate			
Climate change, constant rate	8375	10,881	10,407
Climate change, decreasing rate	6856	7346	5709

Under the **A1B scenario**, under a scenario of decreasing baseline rates, the total number of additional cases per year of salmonellosis is estimated to be 5600 by the 2020s (2011-2040), 8800 by the 2050s (2041-2070) and 9300 by the 2080s (2071-2100) (without adaptation). If, on the other hand, the current case rate is not reduced in the future (i.e. it remains as in the year 2000), annual climate-change attributable cases will be 6800 by the 2020s (2011-2040), 13,030 by the 2050s (2041-2070) and 16,915 by the 2080s (2071-2100) (without acclimatisation or adaptation).

Under an **E1 mitigation scenario**, the number of annual cases falls in the medium to long-term⁸. If it is assumed that case rates are reduced, the number of annual cases falls to 7,300 by the 2050s and 5,700 by the 2080s (10,800 by the 2050s and 10,400 by the 2080 for the constant rate). Mitigation is therefore estimated to reduce annual cases by 1500 by the 2050s (2041-2070) and 3610 by the 2080s (2071-2100) – and by 2100 in the 2050s (2041-2070) and 6500 in the 2080s (2071-2100) if case rates are held constant.

Table 7 presents the economic costs of these additional cases. Under the **A1B scenario** and assuming a decreasing case rate, the estimated annual costs (without adaptation, current prices, no discounting) due to climate change (alone) are €29.5 Million/year by the 2020s (2011-2040), €46.4 Million/year by the 2050s (2041-2070) and €48.1 Million/year by the 2080s (2071-2100). If the case rate is held constant, the corresponding annual costs are €36, €68.4, and €88.8 Million/year.

⁸ The climate model ensemble for E1 gives a slightly higher warming signal than A1B, see TPBN1, hence the values appear slightly higher in this first period.

Table 7. EU27 Salmonellosis cases in millions of Euros (2010 prices, undiscounted) for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario (ensemble mean) and E1 (ensemble mean) driven by climate models. No acclimatisation.

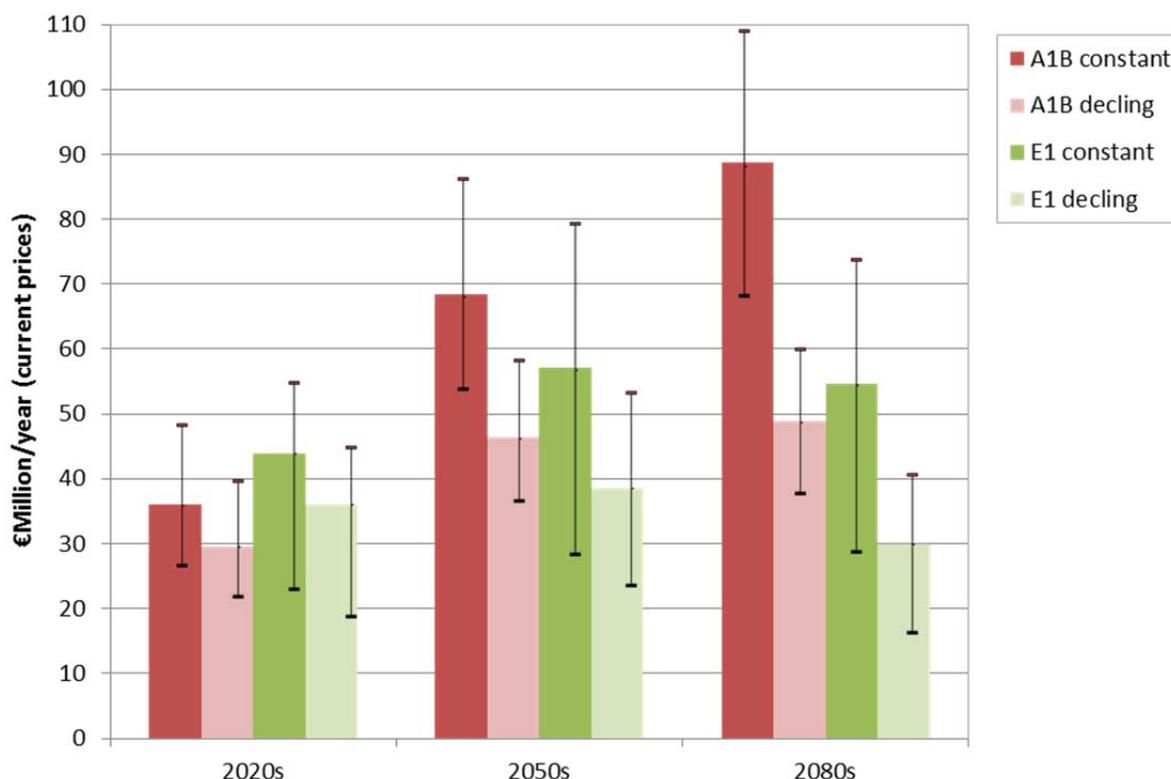
Million Euro/year for EU27, A1B scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only, constant rate			
Climate change, constant case rate	36.0	68.4	88.8
Climate change, decreasing case rate	29.5	46.4	48.9
Million Euro/year for EU27, E1 mitigation scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only, constant rate			
Climate change, constant case rate	44.0	57.1	54.6
Climate change, decreasing case rate	36.0	38.6	30.0

Notes: These values are presented as current prices without adjusting future unit economic values or discounting. No adaptation is included.

Under an E1 mitigation scenario these fall in line with the number of cases in Table 6, with a reduction in the mid and long-term. The net benefits of mitigation are estimated €7.8 Million/year by the 2050s (2041-2070) and by €18.9 Million/year by the 2080s (2071-2100) assuming decreasing rates, an €11.3 Million/year and a €34.2 Million/year (2050s and 2080s) for constant rates.

As highlighted above, these values present the ensemble mean results. The effect of climate model uncertainty – as represented by the low and high climate model projections – are shown below.

Figure 5: EU27 Salmonellosis cases in millions of Euros (2010 prices, undiscounted) for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B and E1 scenario (ensemble mean and low and high values across the climate models)



As a result of climate change, the expected annual EU costs of additional salmonella cases are €46 million by the 2050s and €49 million by the 2080s (A1B, undiscounted, declining rates, climate change only). Under a mitigation (E1) scenario, these fall to €30 billion by the 2080s

4.3 Coastal Flooding

The results of the coastal assessment in ClimateCost (Brown et al, TPBN 2) estimates the number of people affected by coastal flooding. These estimates have been used here to assess the associated direct risks as fatalities. This includes an analysis for a range of sea level projections, associated with the A1B and E1 scenarios, with and without adaptation.

The results in the table below are reported without adaptation, as additional deaths due to (i) population changes (no sea level rise), (ii) the impact of climate change and population changes together, and (iii) the marginal impact of climate change (estimated by deducting (i) from (ii)).

The analysis shows that under **the A1B scenario without adaptation**, the total number of additional deaths from coastal flooding is projected to be 54 additional fatalities per year by the 2020s (2011-2040), 130 by the 2050s (2041-2070) and 647 by the 2080s (2071-2100), as a result of climate and socio-economic change (without acclimatisation or adaptation). The marginal impact of climate change alone is 29 additional fatalities per year by the 2020s (2011-2040), 105 by the 2050s (2041-2070) and 621 by the 2080s (2071-2100).

Under an E1 mitigation scenario without adaptation, the impacts are significantly reduced to 51 additional deaths/year by the 2020s (2011-2040), 101 by the 2050s (2041-2070) and 185 by the 2080s (2071-2100), as a result of climate and socio-economic change. The marginal impact of climate change alone is 27 additional fatalities per year by the 2020s (2011-2040), 75 by the 2050s (2041-2070) and 158 by the 2080s (2071-2100). The marginal benefit of the E1 scenario is therefore 463 fatalities per year by the 2080s.

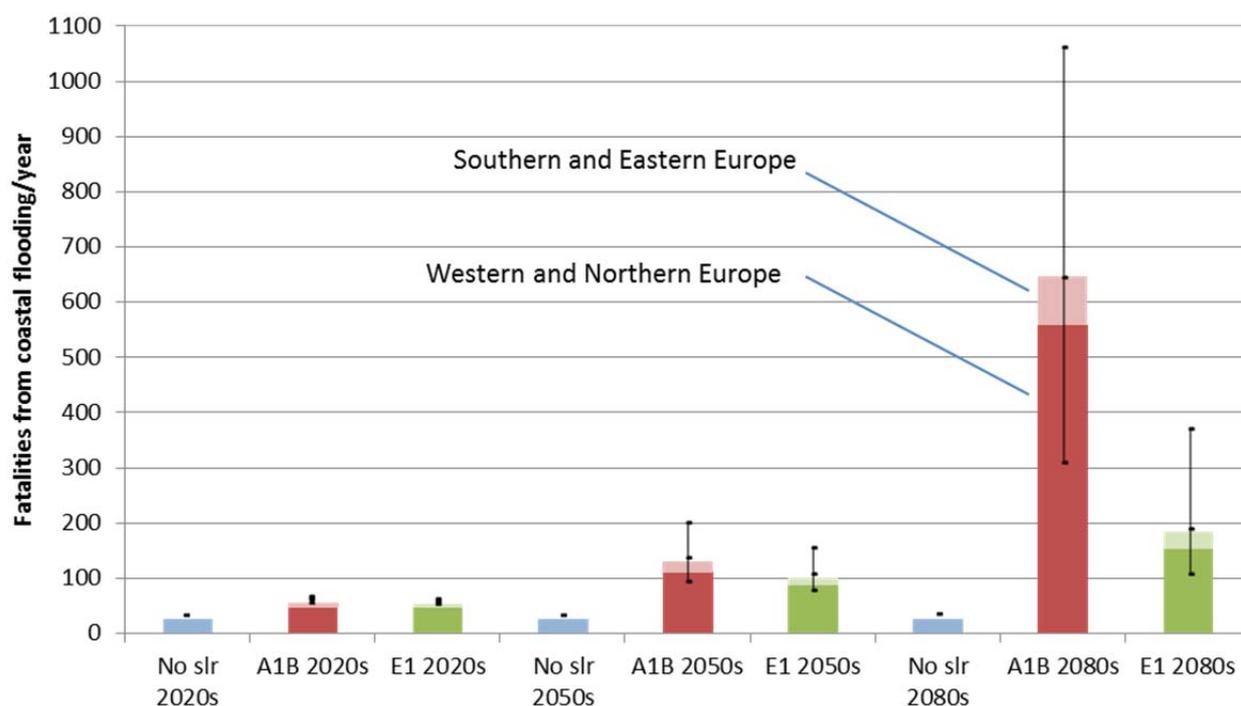
It is stressed that there is a considerable variation across the sea level rise projections: the values in the table are for the mid values only.

Table 8. EU27 Additional deaths from coastal flooding compared with 1990 levels, for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario and E1. Mid estimate. No adaptation.

Additional Fatalities from coastal flooding/year for EU27, A1B scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate)	25.2	25.2	26
Climate and population change	54.4	130.3	646.8
Marginal climate change impact	29.2	105.1	620.8
Additional Fatalities from coastal flooding/year for EU27, E1 mitigation scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate)	24.1	25.5	26.8
Climate and population change	51.2	100.5	184.6
Marginal climate change impact	27.1	75	157.8

The impacts without adaptation are shown in the figure below, along with the broad geographical split for regions of Europe, and the uncertainty ranges from the DIVA model output. Note that this uncertainty relates to the uncertainty around ice melt response to a single temperature profile over time, it does not include consideration of the full multi-model ensemble temperature range.

Figure 6. Additional deaths from coastal flooding compared with 1990 levels, for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario and E1. Mid Estimate. No acclimatisation or adaptation. Estimates are the combined effects of climate and population together.



The uncertainty range (5 to 95%) shown in the figure is associated with the sea level rise, specifically the ice melt response to a single temperature profile over time. Note that a multi-model climate analysis with a range of temperature profiles (as used in other sectors in ClimateCost) would expand the range of estimated sea-level rise from that shown.

The greatest absolute impacts are seen Western and to a lesser extent, Northern Europe. The impacts in Eastern and Southern Europe are low.

These values have then been monetised using a Value of Statistical Life. The results are shown below.

Table 9. EU27 Economic Costs (Million Euro, (2010 prices, undiscounted)) from coastal flooding fatalities compared with 1990 levels, for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario and E1. Mid estimate. No acclimatisation or adaptation.

Economic Costs (Million Euro) from additional coastal fatalities/year for EU27, A1B scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate)	29.2	29.2	30.2
Climate and socio-economic change	63.1	151.1	750.3
Marginal climate change impact	33.9	121.9	720.1
Economic Costs (Million Euro) from additional coastal fatalities, for EU 27E1 mitigation scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate)	28.0	29.6	31.1
Climate and socio-economic change	59.4	116.6	214.1
Marginal climate change impact	31.4	87.0	183.0

Under the **A1B scenario**, the estimated costs of coastal flooding related mortality are projected to be 63 million Euro/year by the 2020s (2011-2040), €151 Million by the 2050s (2041-2070) and €750 Million by the 2080s (2071-2100), as a result of climate and population change (without

acclimatisation or adaptation, current prices, no discounting). The marginal impact of climate change alone is €34 million by the 2020s (2011-2040), €122 million by the 2050s (2041-2070) and €720 million by the 2080s (2071-2100).

Under an E1 mitigation scenario, these are significantly reduced to €59 million by the 2020s (2011-2040), €116 million by the 2050s (2041-2070) and €214 million by the 2080s (2071-2100), as a result of climate and population change, with marginal impact of climate change alone is €31 million by the 2020s (2011-2040), €87 million by the 2050s (2041-2070) and €183 million by the 2080s (2071-2100). The marginal benefit of the E1 scenario is therefore is €511 million per year by the 2080s.

The number of additional deaths from coastal flooding in Europe is estimated to rise to 650/year in the 2080s under the A1B mid-range value, with a welfare cost of €0.75 billion/year, falling to 185 deaths/year and €0.2 billion/year under a mitigation (E1) scenario.

As well as direct effects above, flood events affect wider well bring (mental health, stress and depression). These effects have not been considered here but would increase the impacts reported above.

High sea level rise scenario.

The values above relate to the IPCC literature reported by Meehl et al., (2007). There is however, the emergence of literature (post IPCC AR4) that suggests greater increases could be possible. To investigate this, the DIVA analysis (Brown et al, 2011) has considered a trajectory from Rahmstorf (2007) that gives 1.4 metres of change by 2100. This high sea-level rise scenario has undertaken as a sensitivity study, but makes a very material difference to the results.

Under this extreme scenario, the increase in sea level leads to a very large increase (a factor of five) in the fatalities from coastal flooding (assuming no adaptation), with an estimated number of annual fatalities (EU27, no adaptation) of 645/year by the 2050s and 3070/year by the 2080s. The equivalent costs (current prices, no discounting) are €0.75 billion by the 2050s (2041-2070) and €3.5 billion by the 2080s (2071-2100). It is assumed that the risks of these high end scenarios are avoided in the E1 mitigation scenario, i.e. the reduced risk and impacts of extreme sea-level rise is an additional factor in the relative costs and benefits between the A1B and E1 (stabilisation) scenario.

4.4 Labour Productivity

The study has estimated impacts of climate change on future labour productivity – as working days lost due to heat. The results are based on the whole GTAP European region, rather than the EU27 alone. The study first assessed the impacts of current climate on labour productivity in Europe. Under the current climate, there the only impacts are in Southern Europe, where losses were estimated to be 0.14% days lost. Under the future climate scenarios, future productivity losses remained close to zero in Western and Northern Europe. These regions have milder climates and the majority of the workforce are in low labour intensity jobs (service sector) which limits their exposure to temperature extremes.

Higher impacts are projected for Mediterranean countries with climate change. Under the A1B scenario, if labour distributions are held at current baseline levels, the impacts in Southern and Eastern Europe are high. For Southern Europe they are forecast to increase to a 0.9% loss in productive days (an increase of 0.76% over current levels) by the 2080s (A1B), with an increase of 0.5% in Eastern Europe – though mitigation reduces these effects significantly – to 0.5% for Southern Europe and 0.1% for Eastern Europe. It is stressed there is an uncertainty range around these numbers. Based on the multi-model ensemble, the highest values for both Southern and Eastern Europe are in excess of 1%.

However, socio-economic change is also important. The analysis has been repeated with the assumptions about future labour force changes in these regions, i.e. with Southern and Eastern Europe becoming more similar in their structure and labour force to Western and Northern Europe.

Under these scenarios, the impacts of climate change are lower. Southern Europe is estimated to incur a mean loss of productivity (days lost) of 0.42% by the 2080s (compared to 0.9% without labour changes). The net increase (from current levels) under this scenario is therefore 0.28%. Under the E1 mitigation scenario, this is expected to reduce to 0.16% (with the marginal change almost zero).

With labour productivity changes factored in, the losses in Eastern Europe are much lower, estimated at just under 0.2% by the 2080s (A1B) rather than 0.5%.

These impacts can be valued using average productivity cost values. Using this approach, the total productivity losses (whole European area) are estimated at €120 - 320 million/ in the 2050s (A1B), rising to €300 - 740 million/ in the 2080s (A1B), with the range reflecting the assumptions about future labour structure. These are significantly reduced under the E1 mitigation scenario to €60 - 150 million per year in the 2050s and 2080s. The full multi-model ensemble results do give a wide range around these mid results, but with the higher warming in some models indicating costs in excess of , the highest values for both Southern and Eastern Europe are in excess of €1 billion/year in later time periods (for current structure).

Table 10. Productivity losses (days lost, whole European region) in Million Euro (2010 prices, undiscounted) from climate change for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario and E1. Mid-estimate. No acclimatisation or adaptation. Analysis presented with and without labour changes.

Economic Costs (Million Euro/year) from productivity losses for Europe, A1B scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
With current structure	76	323	743
Including future labour changes	37	119	297
Economic Costs (Million Euro/year) from productivity losses for Europe, E1 mitigation scenario			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
With current structure	111	143	145
Including future labour changes	55	61	61

Under the A1B scenario, Southern Europe is estimated to incur a mean loss of productivity – measured here as days lost - of 0.4% to 0.9% by the 2080s, depending on future labour changes. The equivalent productivity losses for Europe are estimated at Euro 300 to 740 million per year in 2080s. These are significantly reduced under the E1 mitigation scenario.

It is stressed that these values do not include the full effects of building overheating on productivity in Europe. Some studies indicate these effects could be large – at least in the absence of autonomous adaptation (cooling). As the temperature limits to productivity are defined by physiology, higher temperatures will need to be reduce by adaptation measures so that businesses will incur these costs or bear the costs of decreases productivity.

5. Adaptation

Adaptation includes all activities or interventions that reduce or prevent *additional* health effects of climate change. Adaptation can therefore include actions to reduce the health impacts assessed in the previous sections, i.e. for heat, food borne disease, flooding and labour productivity, and can cover the response to changes in trends and extreme events.

Kovats and Chalabi (2009) outlines the some of the potential costs of health adaptation as the:

- Costs of improving or modifying health protection systems to address climate change, for example, expanding health or vector surveillance systems. This includes the costs associated with building new infrastructure, training new health care workers, increasing laboratory and other capacities, etc.
- Costs of introducing novel health interventions (e.g. heat wave warning systems).
- Additional costs for meeting environmental and health regulatory standards (e.g. air quality standards, water quality standards).
- Costs of improving or modifying health systems infrastructure, for example, adapting hospitals to hotter summers.
- Occupational health costs, for example, measures to prevent the adverse impacts of increased heat load on the health and productivity of workers.
- Costs of health research to address to reduce the impact of climate change, for example, evaluation studies.
- Costs of preventing the additional cases of disease due to climate change as estimated by scenario-driven impact models – though this can also be considered as ‘damage’ or impact costs, rather than adaptation costs.

There remains a lack of detailed studies on the potential costs and benefits of these types of options. This was confirmed by the recent reviews (Kovats, 2009; Kovats and Lloyd, forthcoming), the latter finding that adaption was not considered quantitatively in any of the recent literature on the health effects and climate change. The estimation of adaptation costs (and benefits) is particularly challenging for the health sector, because of the limited information about modifiers of the health functions, i.e. the effectiveness of adaptation in reducing risks and impacts.

5.1. Adaptation to Coastal Flood Risks

The results of the coastal assessment in ClimateCost (Brown et al, TPBN 2) estimates the numbers of people affected by coastal flooding, with and without adaptation. Here, adaptation specifically refers to improved and affordable (based on projected GDP/capita growth) sea-based measures (e.g. sea dikes).

These values have been used to assess the potential benefit of adaptation (coastal protection) in reducing coastal mortality risks, as estimated in section 4.3 above. Note that other potential adaptation measures are not considered (such as building codes and/or land use regulations)⁹.

Adaptation significantly reduces the impacts and economic costs of coastal flooding on health. The estimates are reported in tables 11 and 12.

Table 11 suggests that, in a future under the A1B scenario, adaptation to climate change (i.e. compared to no adaptation, as shown in table 8) is projected to reduce additional deaths by 44 per year in the 2020s, 124 per year in the 2050s, and 642 per year in the 2080s. If both mitigation (i.e. E1 scenario) and adaptation measures are implemented, annual marginal (i.e. climate attributable) deaths are projected to be reduced (compared to climate attributable deaths under the A1B scenario without adaptation, as shown in table 8) by 27.6 in the 2020s, 104.6 in the 2050s, and 620.8 in the 2080s.

⁹ This assumes that the mortality rate amongst people flooded remains constant; this is in line with current patterns in Europe, that suggest the mortality rate has plateaued in recent years (UNISDR, 2011).

Table 11. EU27 Additional deaths from coastal flooding compared with 1990 levels, for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario and E1. Mid estimate. **With Adaptation.**

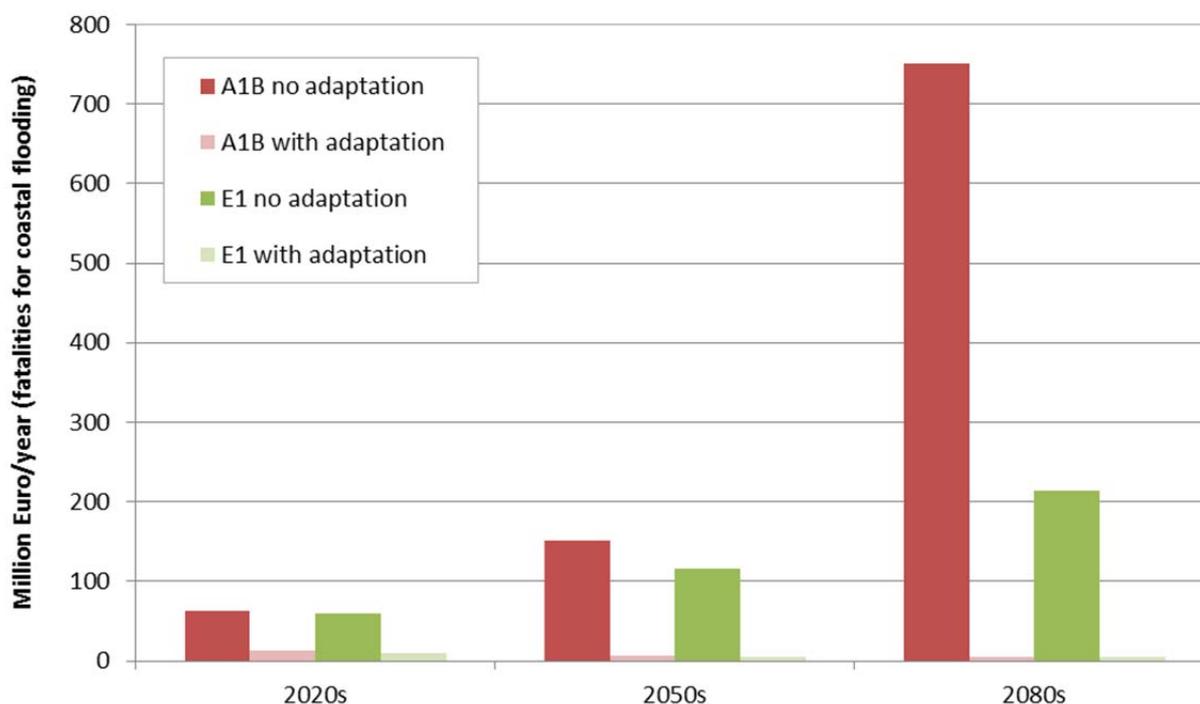
Fatalities from coastal flooding/year for EU27, A1B scenario – with Adaptation			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate)	8.1	4.5	3.9
Climate and population change	10.8	6.1	4.6
Marginal climate change impact	2.7	1.6	0.7
Fatalities from coastal flooding/year for EU27, E1 mitigation scenario – with Adaptation			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate)	7.0	4.4	4.0
Climate and population change	8.6	4.9	4.4
Marginal climate change impact	1.6	0.5	0.4

Table 12. EU27 Economic Costs (Million Euro (2010 prices, undiscounted)) from coastal flooding compared with 1990 levels, for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario and E1. Mid estimate. **With Adaptation**

Economic Costs (Million Euro/year) for EU27, A1B scenario, With Adaptation			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate)	9.4	5.2	4.5
Climate and socio-economic change	12.5	7.1	5.3
Marginal climate change impact	3.1	1.9	0.8
Economic Costs (Million Euro/year), for EU 27E1 mitigation with Adaptation			
	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Population change only (no climate)	8.1	5.1	4.6
Climate and socio-economic change	10.0	5.7	5.1
Marginal climate change impact	1.9	0.6	0.5

Table 12 suggests that in a future under A1B scenario, adaptation to climate change, adaptation (i.e. compared to no adaptation, as shown in table 9) is projected to reduce costs by €50.6 in the 2020s, €144 Million in the 2050s, and €745 Million in the 2080s. If both mitigation (i.e. E1 scenario) and adaptation measures are implemented, annual marginal (i.e. climate attributable) costs are projected to be reduced (compared to climate attributable costs under the A1B scenario without adaptation, as shown in table 9) by €32 Million in the 2020s, €121.3 Million in the 2050s, and €719.6 Million in the 2080s.

Figure 7. EU27 Economic Costs (Million Euro, 2010 prices, undiscounted) from coastal flooding and fatalities, mid estimate, with and without adaptation. Values show combined effects of population change and climate change from baseline.



This mirrors the analysis in the coastal analysis, and shows that adaptation has very high benefits in reducing coastal impacts. The benefits above are additional to the damage costs identified in the coastal analysis, and therefore provide additional justification for adaptation (and potentially the optimal level of adaptation). Indeed, the level of benefits for avoided deaths (in terms of welfare costs) are almost enough to justify the costs of adaptation reported in TPBN2 on their own.

The health and associated economic benefits of coastal adaptation are large – adaptation is estimated to reduce these from €750 Million to €5 Million (A1B, 2080s).

5.2 Adaptation to Labour Productivity losses

Our results do not account for adaptation. It is likely that many sites will autonomously adapt; for example, in the service sector, air-conditioning of workplaces could reduce the impacts of warming. However, quantifications of likely adaptations and benefits are not available (as far as we are aware). In this assessment, the majority of the losses are in the agricultural sector where there are fewer adaptation options. Thus the affect of omitting adaption is likely to be relatively small.

Additionally, while accounting for possible adaption may lower our estimates, we note that when projecting future climates, we shifted baseline WBGT distributions to the right according to the projected change in mean temperature. This method does not account for the likely greater variation in daily temperatures leading to more 'hot' days. The productivity impact model is a threshold model and is particularly sensitive around the thresholds. Hence, a relatively small increase in the number of hot days (which is likely) would have a disproportionate impact on days lost; this means it is likely our results are downwards biased.

6. Notes and limitations on the results (including uncertainty)

- This assessment deals with only limited health outcomes. The primary limitation was the lack of well-established quantified relationships between health outcomes and climate factors.
-
- Only looking at health outcomes 'internal' to Europe (i.e. as an isolated 'unit'). Impacts associated with 'external' effects, (e.g. incoming migration, costs of intervening in low income countries to prevent/deal with climate impacts etc.) are not included. Given the increasingly strong links beyond national/regional boundaries, and the moral responsibility to assist, these cost may be high and exceed those considered in this assessment.
- Climate uncertainty is dealt with via multiple climate models, but uncertainty in the quantitative relationships between the relevant climate parameters and the outcome of interest was not formally quantified.
- The mitigation future is optimistic (e.g. GDP continues to grow at same rate as in A1, yet, emissions are significantly reduced); to achieve the possible benefits, serious efforts must begin imminently.

7. Conclusions

- Even assessing just four health impacts, the costs of unmitigated climate change without adaptations are estimated to be 100,000s of lives lost and billions of EURO each year.
- Adaptation has the potential to significantly reduce impacts within Europe, and given the commitment to minimal levels of climate change should be implemented.
- Mitigation is also expected to reduce impacts within Europe, but has the critical additional benefits of reducing impacts in the rest of the world (many of which will indirectly impact on Europe) and, in the long run, maintaining climate within the range of stability and averting what are likely to be grave impacts on health and well-being.

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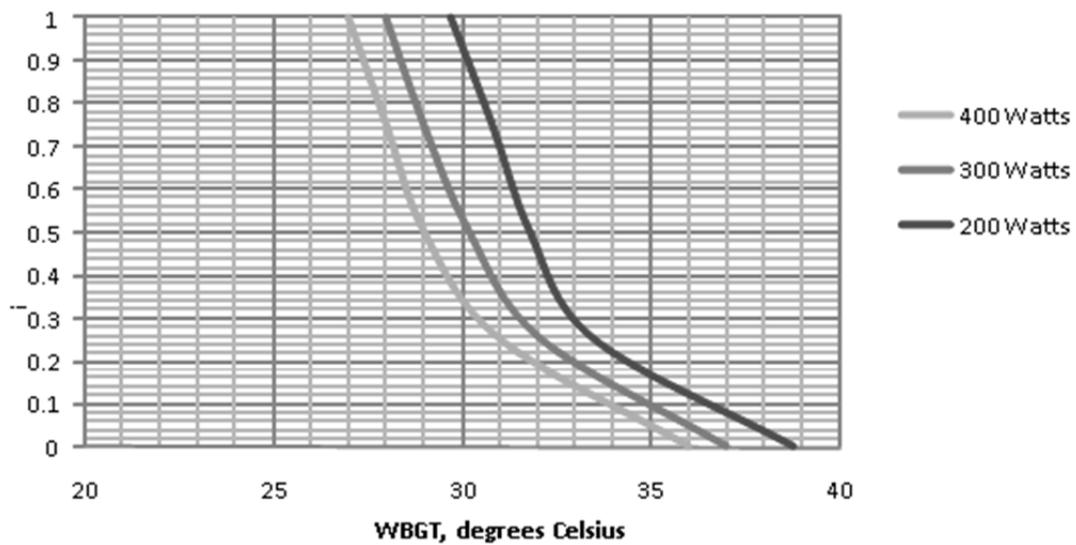
Appendix 1. Additional information

Table A1. Pooled exposure-response functions: for heat effects on mortality by age group. Heat: % change in mortality per degree (AT°C) above the heat threshold (95% confidence intervals).

	Mediterranean	North-continental
Heat threshold	29.4	23.3
0-64	0.92 (-1.92, 3.13)	1.31 (-0.94, 3.72)
65-74	2.13 (-0.42, 4.74)	1.65 (-0.5, 3.87)
75+	4.22 (1.33, 7.20)	2.07 (0.24, 3.89)
All ages	3.12 (0.60, 5.72)	1.84 (0.06, 3.64)

Source: Baccini et al., 2008

Figure A1. Work ability (%) as a function of WBGT (degrees Celsius) at 3 work intensities (Watts), acclimatized. The y-axis is proportion of time that is productive



Source: Kjellstrom et al, 2009

Further information

To find out more about ClimateCost, please visit: www.climatecost.eu

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The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 212774. The views expressed in this publication are the sole responsibility of the author(s) and do not necessarily reflect the views of the European Commission. The European Community is not liable for any use made of this information.

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First published December 2011

The ClimateCost project involved 22 partners, the lead organisation being the Stockholm Environment Institute (Oxford).

Citation. Kovats, S, Lloyd, S, Hunt, A and Watkiss, P. (2011). Technical Policy Briefing Note 5: The Impacts and Economic Costs on Health in Europe and the Costs and Benefits of Adaptation, Results of the EC RTD ClimateCost Project. In Watkiss, P (Editor), 2011. The ClimateCost Project. Final Report. Volume 1: Europe. Published by the Stockholm Environment Institute, Sweden, 2011. ISBN 978-91-86125-35-6.

The ENSEMBLES data used in this work was funded by the EU FP6 Integrated Project ENSEMBLES (Contract number 505539) whose support is gratefully acknowledged. We also thank the Max-Planck Institute for Meteorology, the Danish Meteorological Institute and the Centre National de Recherches Météorologiques for making their simulation data available for the project.