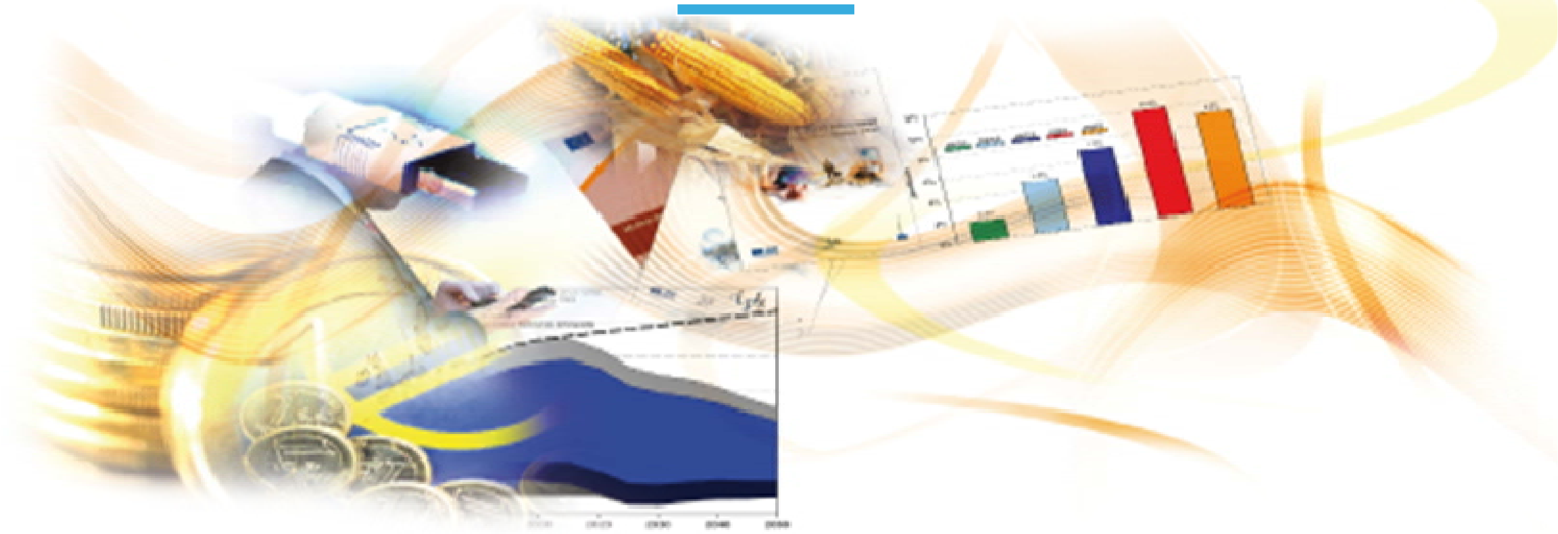
European Commission



JRC TECHNICAL REPORTS

Human Health Impacts of Climate Change in Europe

Report for the PESETA II project

Daniele Paci

2014

Report EUR 26494EN

Joint Research Centre

European Commission
Joint Research Centre
Institute for Prospective Technological Studies

Contact information
Address: Edificio Expo. c/ Inca Garcilaso, 3. E-41092 Seville (Spain)
E-mail: jrc-ipts-secretariat@ec.europa.eu
Tel.: +34 954488318
Fax: +34 954488300

http://ipts.jrc.ec.europa.eu
http://www.jrc.ec.europa.eu

JRC 86970

EUR 26494 EN

ISBN 978-92-79-35421-2 (pdf)

ISSN 1831-9424 (online)

doi:10.2791/64481

Luxembourg: Publications Office of the European Union, 2014

Printed in Spain

Table of Contents

Acknowledgments

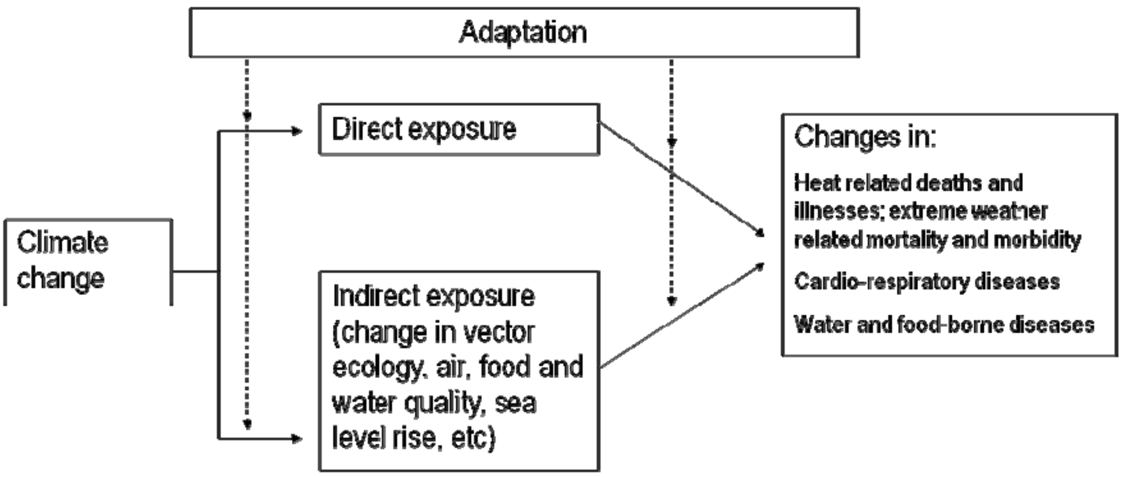
The author wishes to thank his colleague Dolores Ibarreta for her helpful suggestions and for her precious assistance in the review and revision of this Technical Report. Thanks also to Juan Carlos Ciscar and Perry Miles and the components of the PESETA II Steering Committee for their comments and suggestions. The Report relies on the valuable work of Maté Roszai, who helped with the extraction and calculation of climatic data and variables.

1. Introduction

The global average surface temperature has increased by about 0.74 °C over the last 100 years. The projected increase for Europe between the end of the 20th and 21st centuries varies from 2.3 °C to 6 °C, depending on the scenario considered. Greenhouse gas (GHG) emissions, particularly from the burning of fossil fuels, are warming the earth. GHGs have increased by 70% over the last four decades, trapping more heat in the lower atmosphere. Even if emissions were to halt immediately, temperatures would still be expected to rise by over 0.6 °C this century. Climate projections also indicate an increase in incidence of heat waves and extreme events. It is important to understand and quantify the consequences of all these factors in terms of health in the next decades.

The inter-linkages between climate change and human health have been already recognized in a growing number of recent studies (e.g. Patz et al., 2005; McMichael et al., 2001 and 2004; Markandya and Chiabai, 2009). Figure 1 shows a conceptual framework that synthesizes these linkages:

Figure 1 Linkages between Climate Change and Human Health



Adapted from McMichael et al. (2004)

The effects of climate change on health include direct impacts, such as temperature-related illness and death, and the impacts of extreme weather events. They also include more indirect impacts as those that cause water- and food-borne diseases; vector-borne diseases; or food and water shortages. While mitigation strategies can reduce climatic change by acting on its causes (GHG emissions), adaptation acts on the effects of climate change, by reducing population exposure, vulnerability and / or the consequences of exposure.

Table 1 shows some of the most important impacts of climate change on health. The factors through which climate change affects health are grouped into six categories of stressors. In turn their impact is articulated into health outcomes. Each of these endpoints deserves a specific study as they have a specific response to the stressor. However, rather than acting separately, at least some of them are likely to have mutual interaction and reinforcing effects. For instance, poor air quality (especially high ozone concentration) exacerbates the impacts of heat.

Table 1 Selected health impacts of Climate Change

Stressors	Health Effects
Heat stress	Heat related illnesses and deaths during heat waves. Temperature-related mortality and morbidity
Air pollution	Respiratory diseases; allergies
Food- and water-borne diseases	Salmonellosis; Campylobacteriosis
Vector-borne diseases	Malaria; dengue; Lyme disease
Natural disasters	Unintentional deaths and non-fatal injuries; depression; effects on diseases diffusion (e.g. malaria; salmonellosis; E.coli, etc.) , asthma
Undernutrition	Decrease food supply – increase risk of diseases

The current study relies on previous EU-wide bottom-up studies, which has provided estimates for the impact of climate change on health, notably the PESETA Project; the ClimateCost Project and the PHEWE Project.

PESETA

The PESETA project (Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis)[1] was the first attempt to make a multi-sectoral assessment of the impacts of climate change in Europe for the 2011-2100 time horizon.

In the health study (Watkiss and Hunt, 2011), exposure-response functions were combined with estimates of the future modelled climate, along with estimated changes in the population (size and age), to predict the likely consequences of climate change (2011-2100). The models show that climate change will increase average temperatures (compared to the historical climate of the 1960-1990 period), and so will lead to increased incidence of heat related mortality. The study assessed the physical and economic impact of heat and cold-related mortality, the incidence of salmonellosis and depression as a consequence of river flood events. The specific effects of heat waves are not explicitly included in the analysis, as well as cold spells, heat and cold related morbidity; and changes in the risk of accidents and wider wellbeing from extreme events (e.g. storms and floods).

[1] The summary of the project results and methodology has been published in PNAS: Juan-Carlos Ciscar, Ana Iglesias, Luc Feyen, László Szabó, Denise Van Regemorter, Bas Amelunge, Robert Nicholls, Paul Watkiss, Ole B. Christensen, Rutger Dankers, Luis Garrote, Clare M. Goodess, Alistair Hunt, Alvaro Moreno, Julie Richards, and Antonio Soria (2011) "*Physical and economic consequences of climate change in Europe*". (Ref. Ciscar et al., 2011).

ClimateCost

ClimateCost (the Full Costs of Climate Change) is a FP7 research project, concluded in 2011, with a multi-sector bottom-up approach similar to the PESETA study. Within this project a specific study on the health impacts of climate change has been undertaken by Kovats and colleagues. It assessed the effects on climate change on three health end-point: (a) Reduced labour productivity; (b) Heat-related mortality; (c) Salmonellosis. The study included also a detailed cost assessment of adaptation measures; however no cost benefit analysis were performed. All the impacts are estimated for Europe for the 2011-2100 time horizon.

PHEWE

The aim of PHEWE project (Assessment and prevention of acute health effects of weather conditions in Europe) was to assess the health effects of extreme weather, during the winter and summer season, in 16 European cities. The study investigated the association between weather, daily mortality, and hospital admissions through city-specific and pooled analysis, using a time series approach. It also identified threshold levels above which an effect is observed, the latency time between exposure and effect, and the effect of cumulative exposures.

A significant association of mortality to both low and high temperatures in all cities was found. During summer, a J-shaped relationship between maximum apparent temperature and mortality was observed in most cities. The threshold level above which the increment of mortality was observed showed a large heterogeneity among cities (from 21.5°C to 32.7°C). The percent variation in mortality was higher for respiratory and cardiovascular mortality and the effect increased with age. The analysis of the effect of temperature on hospital admissions showed that, during summer, no effect of high temperatures was observed on cardiovascular causes, while for respiratory disease a significant positive effect of high temperatures was observed.

The primary purpose of the PESETA II project is making within JRC a detailed quantitative modelling analysis of the benefits of a low carbon economy for Europe, including an assessment of climate impacts and adaptation in Europe in the 2010-2100 horizon in the key impact areas (agriculture, human health, forestry, river floods, energy, transport, tourism, and other areas).

In this framework, the human health study aims at modelling and quantifying the most of the projected health impacts of climate change in Europe in the next 90 years.

2. Towards an Integrated Model for the Health Impacts of Climate Change

The scientific literature on the impact of climate change on human health has produced so far a relevant number of assessments of individual impacts (usually limited to one disease / health impact) but still a few studies aggregated more than one impact. Moreover, the studies which consider several health outcomes are usually structured as a collection of different specific assessments, rather than as a unified framework (Haines et al., 2006) The approach of the model developed for the PESETA II project is to put together the most important human health impacts into a new single integrated assessment model. The main features of the model are:

- Coupling climate data with demographic, socio-economic and illnesses incidence/prevalence data (spatial data – EU NUTS 2 Level)
- Relative risk exposure and impact-response functions (based on latest epidemiological studies)
- Projections under alternative emissions scenarios (A1B and E1) and different climate models
- Calculation of climate change-related mortality and morbidity
- Monetization of the health impacts
- Both acclimatization and adaptation included
- Sensitivity analysis on the main sources of uncertainty

The modelling approach is therefore similar to PESETA and ClimateCost, two important improvements including a wider set of climate change related health impacts and an all-in-one assessment tool grouping several impacts

In line with the majority of climate change health impact studies at macro level (e.g. WHO, 2003; ClimateCost), the approach used is the *comparative risk assessment approach*. A life table assessment approach would have the advantage of an endogenous population change; however it was not possible to be applied in this large-scale study mainly because of input data limitation. In the current model mortality does not affect population trends, which follow, exogenously, the scenario path. The comparative risk assessment approach allows an estimate of the impact of a change in the exposure to be estimated and it explicitly separates the effects of economic and social change from that of climate. The health estimates are provided as the annual excess attributable to climate change compared to the same socio-economic future world without climate change.

The input data and the output variables are expressed at NUTS 2 level[2]. Data in other format or at a different geographical scale have been converted as indicated in section 3.

[2] Because of data constraints the following NUTS2 regions are not included in the analysis: overseas French regions; MK subregions; Erzurum (TR); Agri (TR); Van (TR); Sanliurfa (TR); Mardin (TR); Região Autónoma dos Açores (PT); Região Autónoma da Madeira (PT); Ciudad Autónoma de Ceuta (ES); Ciudad Autónoma de Melilla (ES); Canarias (ES); Liechtenstein (LI).

2.1 Model Structure

This assessment combines daily climate data, empirical temperature-health relationships, and information on population exposure / vulnerability to estimate climate change-attributable impacts on health. The impacts considered in the current version of the model are:

- Heat-related mortality and morbidity (cardiovascular and respiratory causes)
- Heatwaves additional heat stress (mortality and morbidity)
- Food and water-borne diseases
  - Salmonellosis
  - Campylobacteriosis

The association between daily temperature and mortality have been proven and estimated by several recent studies. This observed short term association (adjusted for season and air pollution) is used to estimate annual temperature-attributable mortality in this study. Temperature-mortality relationships show significant heterogeneity (Curriero et al, 2002; Yu et al. 2010). However, for European populations pooled estimates were available from the PHEWE project (Baccini et al., 2008). The temperature indicator used in the PHEWE study, as in other similar epidemiological studies, is apparent temperature (AT)[3]. As information on future changes in humidity/dewpoint temperature were not available for this assessment and Tmax is used as a proxy of AT; this is likely to lead to an underestimate of future impacts in relatively humid regions (e.g. in southern Europe).

Temperature-related deaths were calculated using the heat mortality exposure-response functions described in Box 1 and 2. Climate change-attributable deaths were calculated as the change in temperature-attributable deaths for each climate scenario compared to a baseline (future mortality projections with the current observed climate).

Not only isolated exceptionally warm days plays a role in affecting health. Recent studies have also linked heat waves with significant impacts on human health and mortality (Naughton et al. 2002; Grize et al. 2005; Anderson and Bell 2009; D'Ippoliti et al. 2010; Ostro et al. 2009). Studies that have estimated the effects of both heat waves and single days of high temperatures have suggested that extended periods of extreme temperatures increase risk beyond that associated with single days of high temperatures (Anderson and Bell, 2009; Hajat et al., 2006).

Although explicitly considered in some relevant studies (e.g. PESETA I) an expected reduction in cold-related mortality is not included among the effects of future climate change in this work.
The choice not to include coldspells was made based on the evidence that does not suggest a significant shift in the balance of deaths between winters and summers because of lower cold-related mortality (Ebi et al 2006; Ebi and Mills 2013; Kinney et al 2012; Astrom et al 2013). The impact of cold waves seems to be negligible and it is not included either (Barneet et al 2012).

We do not include in the current version of the model the health effect of exposure to ultraviolet (UV) radiation as not sufficient evidence has been found on the linkages between climate change and solar radiation. Furthermore the climate models used to generate climate input provide data on relevant variables to calculate UV radiation hazard (e.g. daily hours of sunlight).

Other effects such as the impact of temperature and air pollution, floods, food shortage, droughts and vector-borne diseases (e.g. malaria, Lyme disease) are also excluded.

---

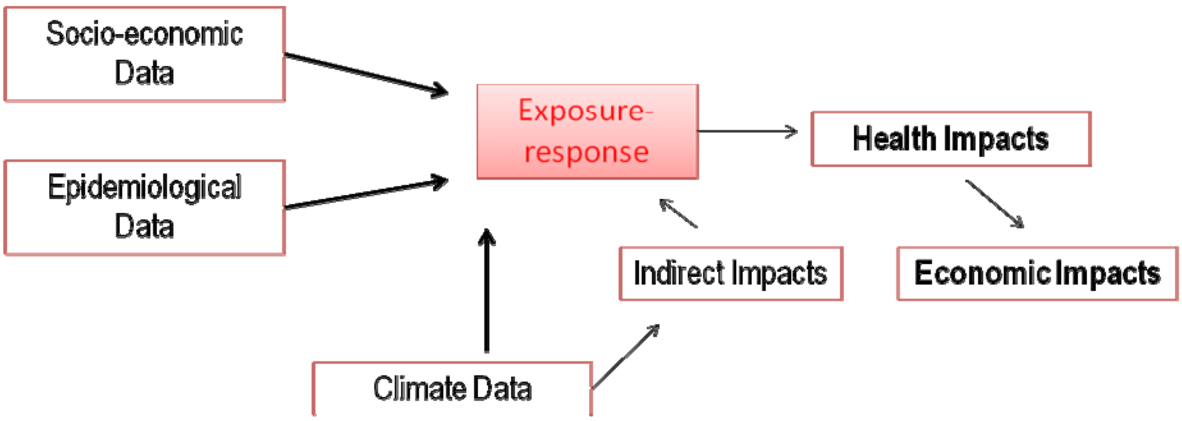
[3] AT is a combination of air temperature and humidity. AT = (-2.653)+(0.994* T_a)+(0.0153* T_a*T_d), Where AT is Apparent Temperature (deg C); T_a air temperature (deg C); T_d dewpoint temperature (deg C).

In line with the PESETA II overall objective, and following PESETA and ClimateCost methodology, the human health study uses a detailed bottom-up impact assessment approach. A set of impact functions (exposure-response functions), derived from epidemiological studies in the literature, form the core of the assessment model. They link climate variables (in this case temperature-related measures, aggregated on yearly basis) with the health endpoints of mortality and morbidity. The application of the temperature-health functions is carried out in each NUTS 2 of EU27.

The annual figures for temperature-related changes are combined, within the impact functions, with exposure/vulnerability measures to provide the average number of additional cases (deaths, hospital admissions or cases) NUTS2 for each year. The responses provide an average annual percentage change in mortality (or numbers of hospital admissions or disease cases) within each NUTS2, for each year of the study period. Climate variables are also used as input to calculate climate change indirect health impacts. Selected output of these models will be used as input in specific exposure-response functions to calculate the effects on health endpoints.

These projections are then compared with a baseline scenario, constructed applying current epidemiological data (mortality and incidence of specific conditions) to future exposed population. The difference between these two values provides the additional deaths, hospital admissions and cases attributable to climate change alone. Results are provided in at NUTS2 level. Figure 2 illustrates the raw model structure.

Figure 2 Model Structure



The last step of the model converts health outcomes into monetary values, using standard evaluation methodologies and values retrieved from the literature. Total resource cost (cost of healthcare services), the economic value of working days lost, and evaluation of the years of life lost are calculated.

3. Input Data

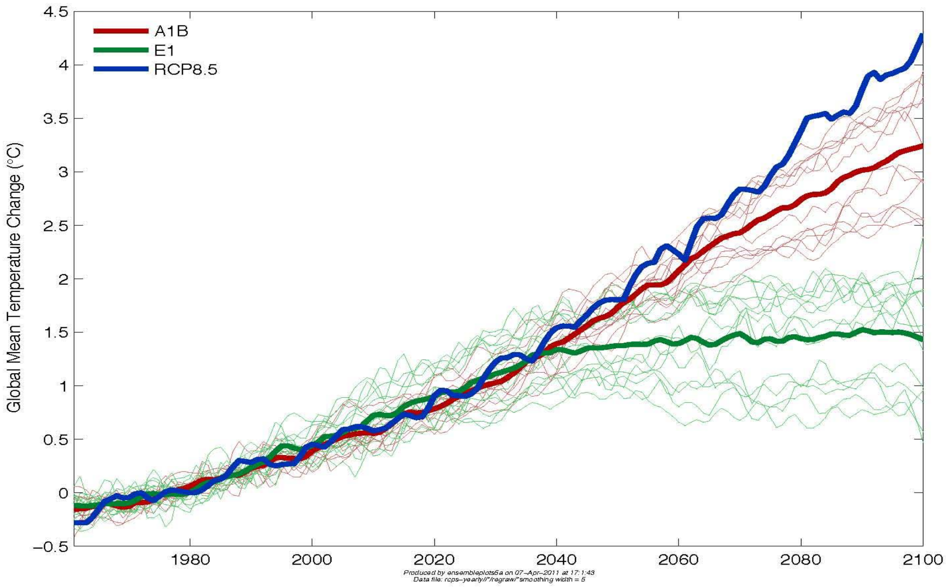
The model uses different sources of data as input to calculate future projections of health outcomes. These input data can be grouped in four main categories:

- Climate projections
- Population and socio-economic projections
- Mortality and morbidity projections
- Indirect impacts

3.1 Climate Projections

A rang0e of climate scenarios and EU climate model data have been provided by JRC-IES. The model provides results for each climate scenario, and summary tables were also generated (based on the ensemble mean).

Table 2 Global mean temperature change under the three alternative emissions scenarios



The climate scenarios used in this assessment (A1B and E1) show little variability in the 2020s; in some regions climate warming is greater under E1 than A1B in 2020s, because of lower emissions and less aerosols (which have a cooling effect) under E1 emissions profile. The climate models used so far are summarized in table 3:

Table 3 Emission scenarios and climate models used to generate climate projections

Scenario	Climate Model
A1B	KNMI-RACMO2-ECHAM5
	METO-HC-HadRM3Q0-HadCM3Q0
	DMI-HIRHAM5-ECHAM5
E1	MPI-REMO-E4

Data were extracted by the climate models and the gridded data (25x25 km resolution) have been aggregated at NUTS 2 Level. To do that, the data retrieved from climate models are overlaid with EUROSTAT-GISCO database. From the database GISCO_ NUTS 2006 features were used[4]. Domains are classified according the INSPIRE Classification of spatial data services. The coordinate reference system is the European Terrestrial Reference System 1989 (ETRS89), LAEA.

[4] http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/introduction

On the basis of the climate projections generated by climate models, the following data and indexes have been extracted /calculated:

(A) Distribution of daily summer (June-July-August) temperatures for all simulations and grid points / NUTS 2 Region. This is based on local percentiles of temperature distributions and is conducted for daily minimum and maximum temperatures, as well as the diurnal temperature range.

(B) Multi-day heat wave indexes

There is no standard definition for heat waves, but most studies have used a combination of temperature (intensity) and duration to define them. Heat wave is defined here as a spell of at least five consecutive days with maximum temperatures exceeding the local 90th percentile of the 0control period (1961-1990). To account for the seasonal cycle, the 90th percentile is calculated for each calendar day, each model and at each grid point using a centered 15-day-long time window[5]. On the basis of this definition, the following extreme summer temperature index have been derived:

- HWF90 (heat wave day frequency): the frequency of days meeting the heat wave criterion.

We used Max daily temperature (TMax) as an approximation of daily Max apparent temperature..

Given the nature of the exposure-response functions used in the assessment several thresholds have been set and for each threshold, two indices have been calculated from the results of the climate models:

- Number of days where TMax > T Threshold
- Average yearly difference between TMax and T Threshold, in case TMax > T Threshold

Either daily or weekly TMax temperatures have been considered, depending on the impact functions.

3.2 Population and Socio-Economic Projections

Determining the exposure and vulnerability of current and future population is a key aspect of the assessment. The model accounts for some of the relevant variables that affect vulnerability of the population (Basu and Samet, 2002):

- Changes in the number of people and their geographical location.
- Changes in the age structure of the population.

Other socio-economic aspects are likely to influence vulnerability and exposure to health risks, including, among others, wealth, education, technological and medical advances, and inequalities in wealth allocation. However, the socio-economic scenarios used in this study do not include quantitative indicators of these elements.

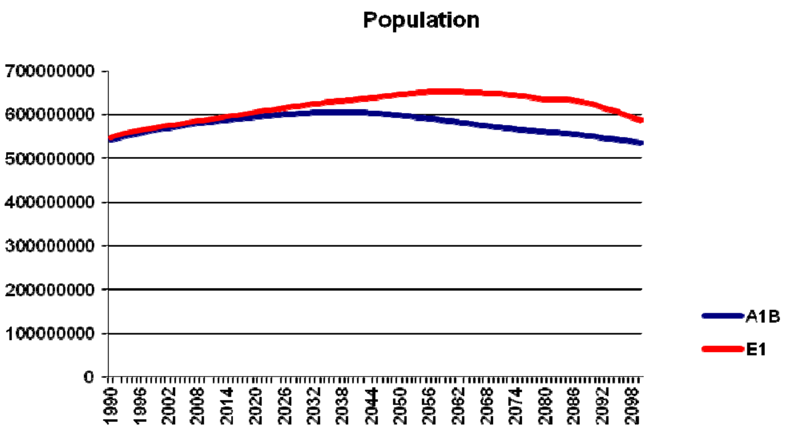
[5] This is the definition used in Frich et al. (2002). For a discussion on the definition of heat wave, see Robinson (2001)

Population

Projected country population totals are the same as in ClimateCost, based on IPCC Special Report on Emissions Scenarios (SRES) scenario A1B. Data had been supplied by IIASA[6]. Country-level population estimates have been provided on a 5 yearly interval basis, intermediate years and NUTS 2-level estimates have been interpolated. To allocate national population to each NUTS2 region, a simple linear downscaling method has been used. Each region annual growth rate for population, at any year, is set equal to the growth rate of the country within which each region resides. This is mathematically equivalent to keeping the fractional share of each NUTS 2 region population relative to the country-level population constant, at the base year value, for the duration of the forecast period (Smith et al., 2001).

To be consistent with the climate scenario used, population estimates are calculated also for the E1 scenario[7]. The E1 scenario population data were provided by the ENSAMBLE project and have been downscaled, with the same technique and assumptions used for the A1B. Figure 3 illustrates the total population trend in Europe under A1B and E1 socio-economic scenarios.

Figure 3 Total EU Population Projection (A1B and E1 scenarios)



Both A1B and E1 scenario population estimates are split into three age bands, which are the most relevant in terms of calculating the health impacts (0-64; 65-74; 75+). Age-specific population dynamics are based on EUROSTAT country-level projections (on 10 years intervals, up to 2080). Intermediate years are interpolated. To estimate future NUTS2 shares of population in each age group, the current share of the population in each NUTS2, provided by the latest EUROSTAT regional data (2010) is assumed to remain constant over time, in the absence of justifications to assume alternative paths (e.g. concentration in core regions).

[6] Data for SRES A1B Scenario available at: http://sres.ciesin.org/final_data.html
Downscaled data: http://www.ciesin.columbia.edu/datasets/downscaled/

[7] Tol R. (2006) "A new Scenario for Global Carbon Dioxide Emissions in the 21st Century", Ensembles Report http://ensembles.eu.metoffice.com/project_reporting/year3reporting/publicly_completed_deliverables/D7.1c_newscen.pdf
The socioeconomic data for the E1 scenario were developed using the CHIMP model and FUND Model
Fisher B.S. et al. (2006) "CHIMP: A simple population model for use in integrated assessment of global environmental change", The Integrated Assessment Journal, 6(3), pp. 1-33

Urban/Rural typology

Heat tends to impact more severely population living in urban areas rather than population in rural areas (Kilbourne, 1997; Rooney et al., 1998; Sheridan, 2003; Gabriel and Endlicher, 2011). This relationship has been incorporated in this assessment through the impact-response functions. As a proxy of the share of population living in urban areas we used the latest urban/rural typology developed by the European Commission to classify regions (NUTS 3) as 'predominantly rural', 'intermediate' or 'predominantly urban' based on the share of population living in rural or grid cells[8]. More than 50 % of the total population in rural grid cells = predominantly rural, between 20 % and 50 % in rural grid cells = intermediate, and less than 20 % = predominantly urban. The NUTS 3 typologies have been aggregated at NUTS 2 level, on the basis of the prevalent typology.

3.3 Mortality and Morbidity Projections

Current mortality data have been obtained by WHO Global Burden of Disease (2004). This source allowed us to use age-specific mortality rates by cause of death. For the purpose of the study only cardiovascular diseases and respiratory diseases are considered among the causes of death. Mortality and disease incidence data have been interpolated at national and NUTS2 level, starting from available regional average rates, supposing that the sub-national areas have all the same epidemiological profile as the national average.

The projections are built on the simplifying assumption that these rates do not change over time. This assumption may be challenged in future developments of the model. For example, following the WHO Global Burden of Disease study, one could reasonably assume reduced future mortality due to economic development (Mathers and Loncar, 2005), even if this effect is most likely to be observed in developing countries.

Morbidity data used in this assessment refer to two different health outcome variables: total number of hospital admissions by cause and number of cases (reported).

There is sufficient evidence of increased hospital admissions due to high ambient temperature for two main causes: respiratory and renal disease. Both are considered in the current assessment. The incidence of the episodes on population (based on hospital admissions data from "The Hospital Morbidity Database (HMDB)", 2011) is used to calculate the baseline projection, assuming no future change in incidence.
The epidemiological literature shows evidence of a positive relationship between temperature and the cases of food and water-borne diseases. In particular, salmonellosis and campylobacteriosis have been proven to increase in its incidence as temperature rise. To calculate the incidence of salmonellosis and campylobacteriosis we used the reported cases in the Annual epidemiological report 2011 by the European Centre for Disease Control and Prevention.

Table 4 Incidence (n of reported cases/total population) of Salmonellosis and Campylobacteriosis

	Salmonellosis*	**Campylobacteriosis***
EU average	0,0002975	0,0004397

Rather than using country-specific rates, we calculated a Europe-wide average incidence rates. This is still likely to underestimate the actual rates of salmonellosis infection in Europe, as a result of under-reporting. The use of a single value hides heterogeneity across medical practice, age structure, background prevalence, etc, but it seems acceptable for this analysis to scope the potential importance of these effects.

We assume that both the salmonellosis and campylobacteriosis rates remain constant over time in all the scenarios as we have no data on which to base alternative numbers. However declining incidence could be a reasonable assumption also for developed countries as highlighted in the previous PESETA Health Report. This may be considered for further model improvements.

3.4 Indirect Impacts

The model aims at including not only direct climate-health interactions but also indirect climate change health impacts. Among indirect effects that are considered especially important are food and water-borne diseases, air quality-related pathologies (respiratory diseases, allergies), and mortality and morbidity related to weather-related extreme events (river floods; coastal flooding; storm surge; tornados; etc.).

This study focuses on food and water-borne diseases such as salmonellosis and campylobacetrosis. These climate change impacts, *strictu sensu*, should be considered “indirect”. We do not model bacteria’s ecology, which is the channel through which temperature change affects the incidence of these diseases in the population. We consider instead food and water born pathologies within the same framework of heat-related morbidity projections (see sub-section 3.3).

4. Exposure-Response Functions

According to the majority of epidemiological studies, the shape of the temperature-mortality association is approximately U-shaped or V-shaped, with mortality increasing at both low and high temperatures. However, though the relationship between heat and mortality is clear, the evidence on cold-related mortality is still contradictory and we consider it insufficient to be included in our estimates at this stage. Following a similar approach of PESETA and ClimateCost, a linear relationship is assumed above a threshold temperature, to quantify the effect of heat on mortality. Estimates for the thresholds and slopes describing the relationships were derived from epidemiological models that take into account the seasonal and other long-term patterns in the outcome measure, in order to reveal any short-term effects of temperature. In Box 1 are summarized the key parameters of the exposure- response functions for the assessment of temperature-related mortality. The data used are pooled estimates[9] calculated within the PHEWE Project (Michelozzi et al, 2007); some of them are also used in the ClimateCost health assessment.

[9] The PHEWE project estimated country-specific functions.

Box 1 Exposure- response functions for temperature-related mortality (excluding heatwave impact)

Temperature-related mortality *Number of premature deaths*

Thresholds ºC

North Continental	**Urban** **Rural**	**23,3** **24,1**
Mediterranean	**Urban** **Rural**	**29,4** **29,9**

% Change for 1C increase above threshold %Change

North Continental	**0-64**	**Cardiovascular**	**1,04**
		Respiratory	**3,02**
	65-74	**Cardiovascular**	**1,5**
		Respiratory	**3,9**
	75+	**Cardiovascular**	**2,55**
		Respiratory	**6,62**
Mediterranean	**0-64**	**Cardiovascular**	**0,57**
		Respiratory	**1,54**
	65-74	**Cardiovascular**	**1,92**
		Respiratory	**3,37**
	75+	**Cardiovascular**	**4,66**
		Respiratory	**8,1**

Box 2 summarizes the key parameters of exposure-response functions for temperature-related morbidity

Box 2 Exposure-response functions for temperature-related morbidity

Temperature-related morbidity *Hospital admissions*

Thresholds ºC

North Continental	**Urban** **Rural**	**26,4** **27,1**
Mediterranean	**Urban** **Rural**	**33,4** **34,4**

% Change for 1C increase above threshold %Change

North Continental	**0-64**	**Respiratory**	**3,02**
	65-74	**Respiratory**	**3,9**
	75+	**Respiratory**	**6,62**
Mediterranean	**0-64**	**Respiratory**	**1,54**
	65-74	**Respiratory**	**3,37**
	75+	**Respiratory**	**8,1**

The values used for the exposure-response functions to calculate temperature-related morbidity are based on the works of Michelozzi et al. (2008) (data from the PHEWE Project). The authors did not find evidence of a relationship between temperature and hospital admissions for other causes than respiratory disease. This confirmed previous studies (Kovats et al, 2004).

Box 3 Heat waves impact on mortality and morbidity

Heat waves mortality *Number of premature deaths*

% Change for additional day with heatwave effect % Change

North Continental	**0-64**	**Cardiovascular**	**5,03**
		Respiratory	**3,02**
	65-74	**Cardiovascular**	**9,55**
		Respiratory	**3,9**
	75+	**Cardiovascular**	**13,38**
		Respiratory	**6,62**
Mediterranean	**0-64***	**Cardiovascular**	**13,87**
		Respiratory	**1,54**
	65-74	**Cardiovascular**	**26,35**
		Respiratory	**3,37**
	75+	**Cardiovascular**	**33,7**
		Respiratory	**8,1**

Heat waves morbidity *Hospital admissions*

% Change

North Continental	**0-64***	**Renal Failure**	**5,03**
		Respiratory	**3,02**
	65-74	**Renal Failure**	**9,55**
		Respiratory	**3,9**
	75+	**Renal Failure**	**13,38**
		Respiratory	**6,62**
Mediterranean	**0-64***	**Renal Failure**	**13,87**
		Respiratory	**1,54**
	65-74	**Renal Failure**	**26,35**
		Respiratory	**3,37**
	75+	**Renal Failure**	**33,7**
		Respiratory	**8,1**

The values used for the exposure-response functions for heat waves mortality and morbidity (box 3) are based on the study by Mastrangelo et al. (2007). Lower estimates have also been reported (e.g. D'Ippoliti et al., 2010), buy they are based on a specific local case study, which is may not be extrapolated to the whole EU population.

Box 4 Exposure-response functions for food and water-borne diseases

Food and water-borne diseases *Additional number of cases*

Salmonellosis

Threshold	**6**	ºC	(Average weekly T)
%Change*	**7,02%**	N. of cases	

* increase per degree above threshold

Campylobacteriosis

Threshold	**10**	ºC	(Average weekly T)
%Change*	**0,80%**	N. of cases	

* increase per degree above threshold

The exposure-response function for salmonellosis used in this assessment was derived from (Kovats et al., 2004). In the original study the authors estimated country-specific functions. Here, we will use the pooled estimate calculated for the assessment in the ClimateCost project and apply a unique function to the all population. For campylobacteriosis the function has been parameterised on the basis of Allard et al (2011) estimates. The same numbers are applied homogeneously to all countries and population.

5. Adaptation

Adaptation includes a wide range of actions in response to climate change. In general terms, it is useful to distinguish between (1) *autonomous adaptation* or *acclimatisation* and (2) *planned adaptation*; the first occurs as a physiological and behavioural process of acclimatisation to the changing climate among populations while the latter refers to collective and policy interventions to reduce the impact of expected (*ex-ante adaptation*) or experienced (*ex-post adaptation*) climate change. The model is structured to include both types of adaptation:

Regarding (1) the model assumes that populations acclimatise to a warmer climate and it includes acclimatisation by applying shifts to the threshold temperatures to reflect physiological, behavioural and cultural changes that can take place over decades.

Thus far only a few studies have attempted to incorporate acclimatisation into future projections of temperature-related mortality, but all of them indicate that acclimatisation would reduce potential increases in heat-related mortality. Dessai (2003) assumed acclimatisation to a 1 °C warming would occur every three decades. McMichael et al. (2004) indicate that acclimatisation rates should be region and scenario-specific to reflect the rate of warming experienced, and could thus be proportional to projected changes in average temperatures. The temperature-mortality relationships remain unchanged, assuming that populations acclimatise to their new average temperatures, but remain equally vulnerable to departures from average conditions, even if the shape or gradient of the slope might also change, as populations become less sensitive to temperature, perhaps through improved healthcare or living conditions.

PESETA Health study followed Dessai (2003) assuming a shift of the thresholds by a fixed rate of 1.67 °C to apply to the period 2011–40, and by 3.67 °C to apply to the period 2071–2100.
More conservative estimates have been used in the ClimateCost study, which applied a change in the heat threshold of 0.5 °C per 30 years. The PESETA II model assumes an intermediate estimate of a 0.75 °C change in threshold temperatures for the impacts caused by heat stress.

Regarding (2), recent studies (e.g. Menne and Ebi, 2006; cCASHh project) have already identified adaptation strategies to future health impacts of climate change. They include:

- Strengthening of effective surveillance and prevention programmes including early-warning systems (heatwave / floodwatch warnings) Emergency planning / disaster preparedness schemes, Health education and training),
- Sharing information and lessons learned across countries and sectors (e.g. on behavioural strategies such as clothing, drink, food; scheduling daily work; seasonal migration; Food safety and water quality);
- Introducing new prevention measures or increasing existing measures(e.g. Urban / spatial planning, Building design, natural cooling systems)

However, Kovats (2009) has already highlighted the lack of evidence on the assessment of specific adaptation options. More recent work as part of the ClimateCost study confirmed this lack of information in peer-reviewed literature. This was because there was such limited information about modifiers of the temperature-heath functions.

The present study includes only the implementation of Heat-Health Warning Systems (HHWS), as it is the only adaptation option for which reliable estimates of both costs and specific health benefits have been provided (see, for example, the extensive literature review provided by the ClimateCost study).

In particular, following the findings of Ebi et al. (2004) in their study of the Philadelphia hot weather–health watch/warning system, we assume in this assessment that a HHWS has the potential to prevent 117 fatalities, over a three-year period (1995-1998 in the Ebi et al. study) over an exposed population of about 6 million people.

This measure of the "efficacy" of HHWS has been applied to the current EU assessment projections to simulate the potential impact of the application of this system in all EU regions. Alternative hypotheses can be tested (e.g. partial coverage of HHWS, only on the 50% of EU regions or HHWS only in urban areas). The reduction in mortality (and the associated economic benefit) is then compared with the cost of this adaptation measure.

6. Economic Evaluation

In health economics evaluations, three main elements need to be considered in estimating the total impact on society's welfare. These are:

1. Resource costs (i.e. medical and healthcare costs). These costs could be paid by the health service or covered by insurance, or any other personal out-of-pocket expenses made by the individual (or family).
2. Opportunity costs (i.e. the cost in terms of lost labour and leisure time);
3. Disutility

Estimates of point 2 include both the cost in terms of lost productivity (work time loss, or performing at less than full capacity) and the opportunity cost of leisure (leisure time loss) including non-paid work. The welfare changes represented by components 1 and 2 can be proxied using market prices.

Point 3 comprises other social and economic costs including any reduction of desired leisure activities, discomfort (pain or suffering), anxiety, and concern and inconvenience to family members and others. Estimates of point 3 rely on the use of non-market valuation techniques (with imply a high degree of uncertainty). Two metrics are currently used to measure this end-point: the value of a prevented fatality (VPF), also known as the Value of a Statistical Life (VSL)[10] and the value of a life year (VOLY), the latter providing a means of explicitly accommodating differing lengths of remaining life expectancy.

Following the approach of PESETA and Climate Cost, the physical metric (health impacts) is converted to a monetary value by multiplying the health outcomes by a relevant unit value. Thus:

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

The respective monetary values are derived, as described in the following paragraphs.

Even though there is some risk in applying values estimated in context different from the one under study, empirical estimates of the value of the key parameters in each of the elements above is beyond the scope of this assessment exercise. Therefore, we relied on existing literature to parameterise the model. The following parameters have been used to monetise health outcomes[11]:

6.1 Resource Costs

1.1. Hospital Costs			
Average cost per stay	4200	Euros	OECD (2011)
Average length of stay	3,4	Days	OECD (2011)
1.2 Healthcare costs associated to specific diseases			
Salmonellosis and Campylobacteriosis (per case)	5250	Euros	Buzby et al. (1996); Kovats et al. (ClimateCost)

The average length of hospital stay and costs are taken by the latest version of the OECD heath indicators. They are average values since specific values for disease and/or country were not available.

The cost per case of salmonellosis is the one suggested in ClimateCost study. After summing the cost component estimates, the range of unit values, weighted by the incidence of a range of severities, was assumed to be €5,250 (on average). This value is also similar to the one estimated by Buzby et al. (1996).

[10] The VSL is estimated by dividing the WTP for a given annual risk change, by the risk change.

6.2 Productivity loss

2.1 Lost working days due to morbidity (respiratory diseases and renal failure)		
*Average length of hospital stay * n of cases in population (0-64)* average labour participation rate (0-64)*		
Average labour participation rate (0-64)	56%	EUROSTAT (2010)
2.2 Lost working days due to morbidity (salmonellosis and campylobacteriosis)		
*Average Lost working days * n of cases in population (0-64)*average labour participation rate (0-64)*		
Av0erage Lost working days (per case)	2,8	Bambrick et al (2008)
2.3 Lost working days due to mortality		
*Years of Life Lost (0-64)*participation rate (0-64) * Effective working days per year*		
*Years of life lost = (Reference age - Average Death Age)*N of deaths*		
Reference age (years)	75	WHO (2004)
Effective working days (per year)	215	Bambrick et al (2008)

6.3 Evaluation of mortality losses

Value of Prevented Fatality	1,16	M Euros	Kovats et al. (ClimateCost)
Value of a Year of Life	63000	Euros	Kovats et al. (ClimateCost)

Mortality risks in the health analysis above are expressed in terms of number of premature fatalities (heat) and number of life years (heat-related), the latter metric being used to reflect the fact that the majority of premature deaths occur in the elderly population who might be expected to have less life-time remaining. As considerable uncertainty exists in estimating the value of both metrics we adopt the central values suggested for use in environmental impact assessment by the European Commission and used also recently in ClimateCost study.

Value of a Prevented Fatality: 1,16 M Euros (2010 prices)
Value of a Life Year: 63000 Euros (2010 prices)

The assessment of adaptation measures (HHWS) will use the parameters above to monetise the benefits from avoided deaths. Avoided deaths are calculated using as a benchmark the rate of avoided fatalities the study by Ebi et al. (2004). These benefits will be compared to the costs of HHWS, calculated using the following estimates.

6.4 Cost of Adaptation

	low	high		
Yearly cost of HHWS	9760266	34769389	Euros	Kovats et al. (ClimateCost)
	200000	6000000	Euros	Euroheat (2007)

Kovats et al. estimated yearly cost of HHWS based the London HHWS in-depth case study. Also in this case different hypotheses can be tested, using higher or lower adaptation cost. We consider the figures of Kovats et al. the most comprehensive and updated, and we will apply their estimated cost range (low and high values) in our cost-benefit exercise.

However, before performing a EU-wide assessment, further analysis is needed to understand if and how these estimates can be applied to other regions with different characteristics (less populated, rural areas, etc.).

7. Results

We present in this section some the results as pooled estimates of the climate models considered. The outcomes are presented as averages over 30 year periods, as country and/or European average (or total). The results presented here refer to EU 27.

7.1 Health impacts

The model estimated that climate change-attributable deaths will increase significantly over the next 90 years. At European level, on average, the climate change-attributable deaths are expected to increase from 41556 additional annual deaths in the period between 2010 and 2040 to more than 140000 in the latest 30 years of the century.

Figure 4 EU total climate change-attributable mortality (all causes, per year)

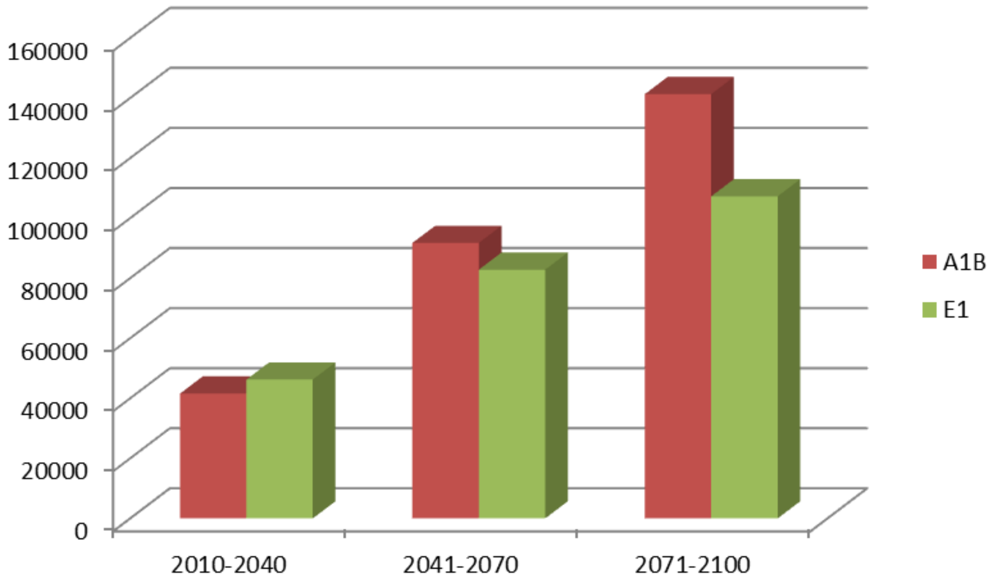
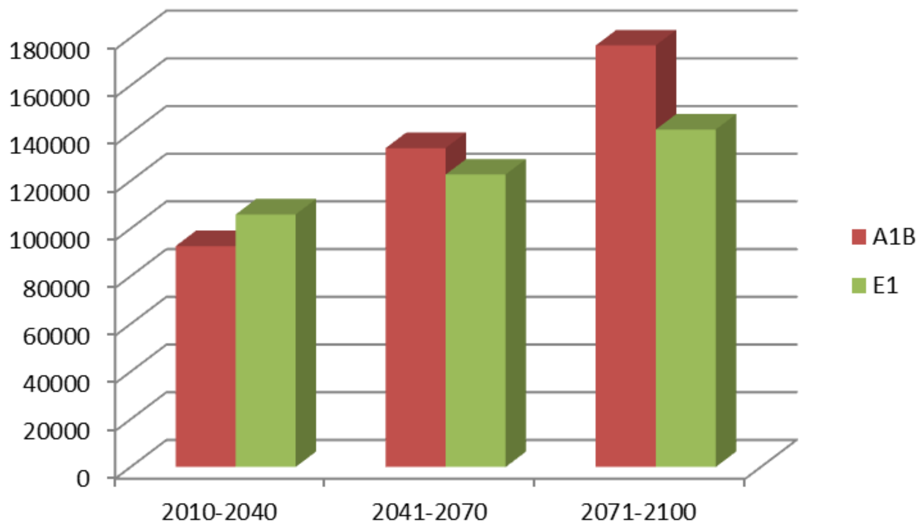


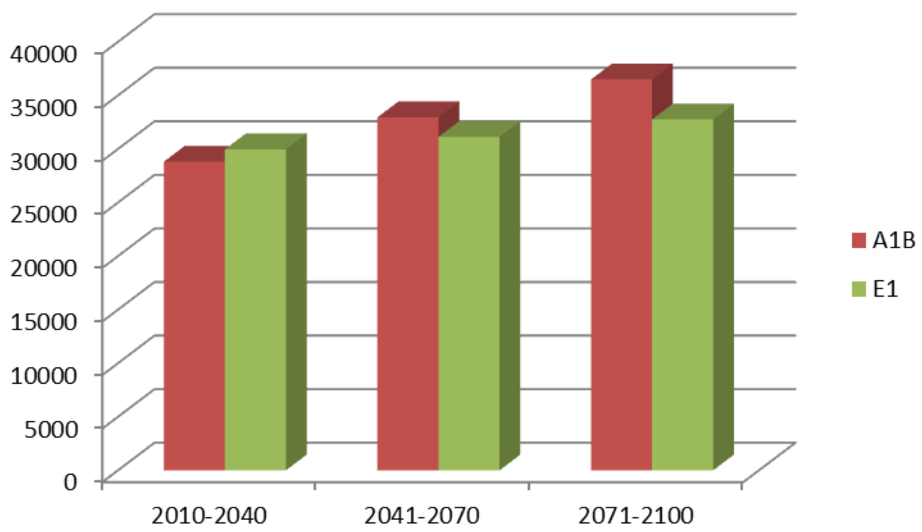
Figure 5 EU total climate change-attributable hospital admissions (all causes, per year)



Also hospital admissions are found to increase over time, even if less than mortality. It is estimated that in 2071-2100 period in Europe more than 170000 hospital admissions per year will be caused by higher temperatures (figure 5) under the A1B scenario. This increase is mainly caused by respiratory diseases in the oldest age group.
In the E1 scenario the increase is estimated to be less pronounced. In the first period the expected extra morbidity is higher than in the A1B scenario (100000 yearly hospital admissions in the 2010-2040 period), but it will be significantly lower in the last period considered.

The cases of salmonellosis and campylobacteriosis (only climate change-attributable ones) are projected to increase from 28438 per year in 2010-2040, to 32501 in 2041-2070, to 35989 in 2071-2100 (EU total, Figure 6). At country level, the number of cases is expected to increase up to 1091 additional cases per year, due to higher temperatures in the A1B scenario.
Lower figures are found in the E1 scenario simulations in the last two periods.

Figure 6 EU total climate change-attributable yearly cases of food and water-borne diseases

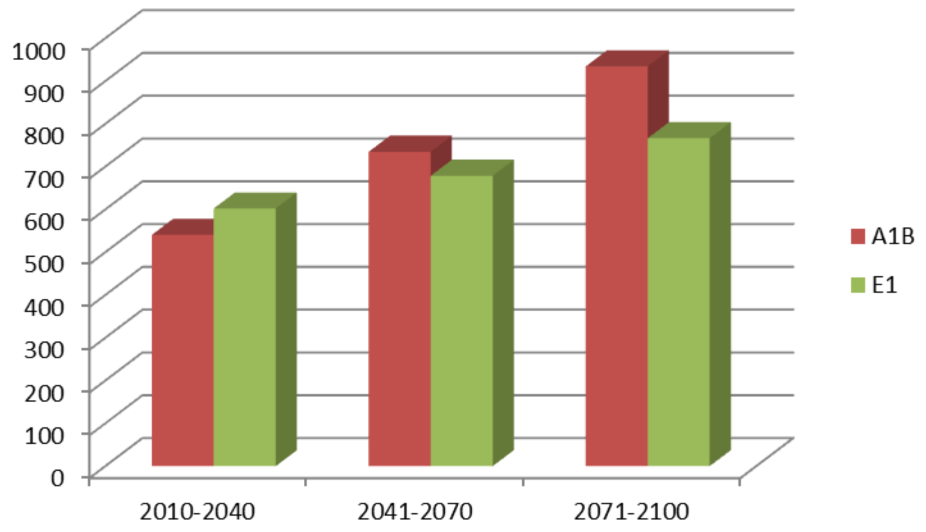


7.2 Economic impacts

The impacts calculated for the economic assessment are grouped as in section 6. All impacts are reported at 2010 prices. No discount rate is applied on future cost.

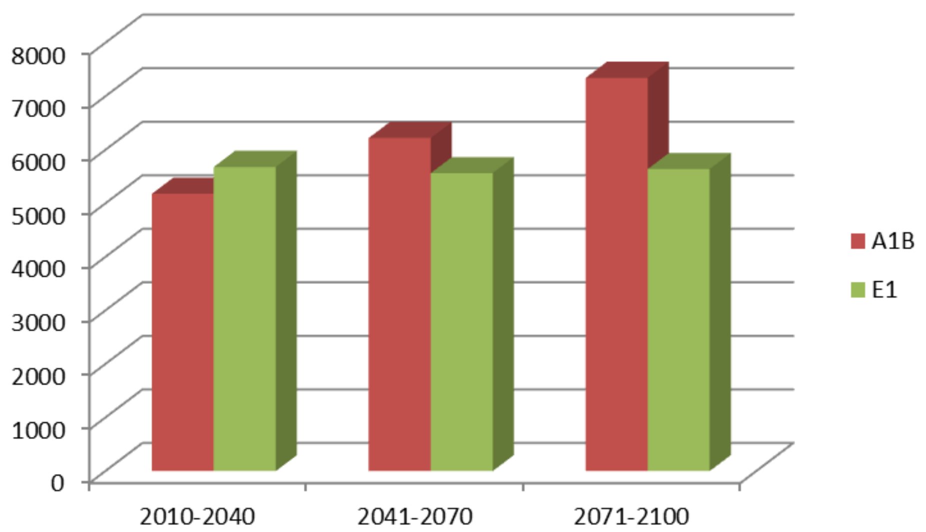
Resource costs are calculated for both additional hospital admissions and additional cases of salmonellosis and campylobacteriosis. These costs, for each country, can grow up to 28,23 M Euros (on average) at the end of the century. For the whole Europe, the direct resource healthcare resource costs (annual) attributable to climate change are calculated to be around 932 M Euros in 2071-2100 period in A1B scenario and around 766 M Euros in the E1 scenario (figure 7).

Figure 7 Total resource costs (Total EU, M Euros)



In terms of productivity loss due to climate change, model's projections, reported in figure 8, results indicate that in the last 30 year period, EU countries may expect to have a reduction in labour productivity quantified as 7M fewer working days per year in the A1B scenario and 5M fewer in the E1 scenario.

Figure 8 Climate change-attributable productivity loss (n. of working days lost, thousands)



The evaluation of mortality loss is the most uncertain and controversial one. One of the issues is that it strongly depends on the index used to measure it. Usually the YLL is considered more adequate as it allows differentiating the impacts according to the estimated death age, thus being is less sensitive to the mortality displacement bias.

Table 7 Economic evaluation of climate change-attributable mortality loss (M Euros – EU total)

		2010-2040	2041-2070	2071-2100
VPF	**A1B**	47876.01	105876.9	163250.4
	E1	53632.4	96067.93	124405.7
YLL	**A1B**	7263.492	9708.379	12040.55
	E1	7927.856	8647.749	9108.204

According to our model, the cost of additional mortality caused by climate change for the whole Europe, will be around 12000 M Euros per year at the end of the century, when mortality loss are calculated in terms of years of life lost (A1B scenario). However, if the value of prevented fatalities approach is used, the economic impact results more than 10 times higher (nearly 160000 M Euros), as indicated in Table 8.

8. Discussion

The model has been successful in updating and integrating currently available assessments performed at EU level (i.e. PESETA and ClimateCost). It also set up a flexible framework that can be easily adapted, updated, modified and changed according to users' needs or to reflect new developments in the understanding of climate change-human health interactions

The results confirm to a large extent the predictions of earlier models, we found slightly higher impacts (both in physical and economic terms) compared to ClimateCost and PESETA studies. However, comparisons have to be considered carefully. Though we used the same methodology and a similar parameterisation, some important differences must be noted:

- some impacts have been added (Heat waves stress, campylobacteriosis, renal diseases).
- we consider more articulated exposure-response functions which are both place and age specific
- we have not considered floods or air pollution in our mortality risk, yet.
- we did not account for mortality displacement[12] in calculating YLL.
- the current model applied exposure-response functions at the most disaggregated possible level (NUTS2) for each year. The resulting effects (both physical and economic) can be aggregated afterward, as presented in this report. In ClimateCost, for example, country averages were instead used for the climate input data and impact functions were applied at country level.

These differences might affect our estimates downward or/and upward with respect to previous EU-wide bottom-up studies.

[12] In ClimateCost, mortality displacement was included accounting each climate attributable death as 0,5*YLL. However, the literature has not provided any robust and coherent estimates of this effect, yet.

Limitations:

- Alternative exposure-response functions can be considered, in particular, country-specific functions, in order to account for the heterogeneity in the observed effects of extreme heat, though the distinctions considered in this study (urban *vs* rural, Mediterranean *vs* North-Continental) goes in this direction. Also non-linear exposure-response functions should be tested, to reflect better the J-shaped curve of heat-mortality relationship found in many epidemiological studies.

- Assumptions on future population trends and incidence of diseases in the long run might not be appropriate. Alternative paths could be considered.

- The health impact of extreme events (natural disasters) needs to be estimated. The lack of this section is likely to lead to significantly underestimated results.

- TMax may be a weak approximation of the relevant climate variable (AT).

- Because of data limitations a full analysis on the effects of heat stress on labour productivity (as assessed in ClimateCost) could not be performed. It could have a significant impact when this change in labour productivity is introduced into a General Equilibrium Model, even if the change is relatively small. The calculated lost working days only capture part of this change, not the absence (without hospital admission) and lower working performance due to heat-related physical discomfort.
  Moreover, the assessment of working days lost is affected by the simplifying choice of applying the same EU27 average value to the productivity loss in all countries and the same figures to all countries (e.g. the same labour participation rate).

Several important sources of uncertainty affect the results:

- uncertainties in predicting the climate in future periods,
- uncertainties related to the projections of future population size and age distribution,
- uncertainties exist over the exact relationship between climate and mortality and how this vary with geographical conditions,
- uncertainties on the economic values used to monetise health impacts.

Performing a sensitivity analysis on the key parameters is necessary to have more robust estimates, which do not depend strongly on specific point values used in the model.

Next Steps

Though the model can already provide relevant insights on the magnitude of the health impacts of climate change, to successfully finalise the assessment and to have more comprehensive and robust estimates the following steps have to be completed:

1. Using more climate models / scenarios
2. Including impacts of extreme events (at least river floods)
3. Including impacts of air quality
4. Sensitivity analysis

References

Agrawala, S. and Fankhauser, S. (Eds.) (2008) Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments. Published by the OECD.ISBN-978-92-64-04603-0.

Ahern, M., Kovats, R. S., Wilkinson, P., Few, R. &Matthies, F (2005) Global health impacts of floods:epidemiologic evidence.Epidemiol Rev, 27, 36-46.

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

Allard R., Plante C., Garnier C. (2011), The reported incidence of campylobacteriosis modelled as a function of earlier temperatures and number of cases, Montreal Canada, 1990-2006, Int.j Biometereol 55:353-60

Armstrong B G, Chalabi Z, Fenn B, Hajat S, Kovats S, Milojevic A, WilkinsonP (2011) Association of mortality with high temperatures in a temperate climate: England and Wales.*J Epidemiol Community Health*;65:340-345.

Aström D, Forsberg B, Ebi KL, Rocklöv J. (2013) Attributing mortality from extreme temperatures to climate change in Stockholm, Sweden. Nature Climate Change 2013. doi:10.1038/nclimate2022

Baccini, M., Biggeri, A., Accetta, G., Kosatsky, T., Katsouyanni, K., Analitis, A., Anderson, H. R., Bisanti, L., D'Ippoliti, D., Danova, J., Forsberg, B., Medina, S., Paldy, A., Rabczenko, D., Schindler, C. , Michelozzi, P. 2008. Heat effects on mortality in 15 European cities. Epidemiology, 19, 711-719.

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/03AThreehealthoutcomes/$File/03-A%20Three%20health%20outcomes.pdf

Barnett AG, Hajat S, Gasparrini A, Rocklov J. Cold and heat waves in the United States. *Environ Res* 2012, 112:218–224.

Basu R, Samet J 2002 Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. Epidemiol Rev, 24:190-202

Bower, P., Byford, S., Sibbald, B., Ward, E., King, M., M. Lloyd and M. Gabbay (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*, Vol 321, pp1389-1393.

Braga ALF, Zanobetti A, Schwartz J. 2002 The effect of weather on respiratory and cardiovascular deaths in 12 U.S. cities. Environ Health Perspect, 110:859-863.

Ciscar J-C, Iglesias A., Feyen L. , et al. (2011) "Physical and economic consequences of climate change in Europe", Proc Natl Acad Sci U S A 2011 108: 2678 48

CRED. 2011. Emergency Events Database (EM-DAT) [Online]. Louvain. Available: http://www.emdat.be/ [Accessed 11 May 2011].

Curriero F, K. S. Heiner, J. Samet, S. Zeger, L. Strug, and J. A. Patz, 2002, Temperature and mortality in 11 cities of the Eastern United States: American Journal of Epidemiology, v. 155, no. 1, p. 80-87.

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

Department of Health, 2008, Heatwave Plan for England - Protecting health and reducing harm from extreme heat and heatwaves, Department of Health,

Department of Health and Health Protection Agency (2008) 'Health Effects of Climate Change in the UK 2008 – An update of the Department of Health Report 2001/2002'.Edited by Sari Kovats.

www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_080702

Dessai, S., 2003: Heat stress and mortality in Lisbon. Part II. An assessment of the potential impacts of climate change. Int. J. Biometeorol., 48, 37-44.

Desjeux, G., L. Galoisy-Guibal and C. Colin (2005) "Cost-Benefit Analysis of Vaccination against Tick-Borne Encephalitis among French Troops" Pharmacoeconomics 23(9) pp913-926.

Desaigues B, Ami D, Bartczak A, Braun-Kohlová, M., et al. (2011) Economic valuation of air pollution mortality: A 9-country contingent valuation survey of value of a life year (VOLY) Ecological Indicators, 11(3): 902-910

Ebi KL, Teisberg TJ, Kalkstein LS, Robinson L, Weiher RF. 2004. Heat watch/warning systems save lives: estimated costs and benefits for Philadelphia 1995–1998. Bull Am Meteorol Soc 85(8):1067–1073.

Ebi, K. L., and Meehl, G. A., (2007). Heatwaves and Global Climate Change. The Heat is On: Climate Change and Heatwaves in the Midwest. In. Regional Impacts of Climate Change: Four Case Studies in the United States. Ebi, K. L., et al. 2007. Prepared for the PewCenter on Global Climate Change. December 2007. Available at http://www.pewclimate.org/docUploads/Regional-Impacts-Midwest.pdf

Ebi, K. L., Mills, D., Smith, J. B. & Grambsch, A. (2006). Climate change and human health impacts in the United States: An update on the results of the US national assessment. Environ. Health Perspect. 114, 1318_1324.

Ebi, K.L. (2008) 'Adaptation costs for climate change-related cases of diarrhoeal disease, malnutrition, and malaria in 2030', Globalization and Health, vol. 4, no. 9.

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, FerránBallester and Rogelio López-Vélez.

Floyd, P., George, C., Tunstall, S., Tapsell, S., Green, C., Jones-Lee, M., and H. Metcalfe (2003). The Appraisal of Human-Related Intangible Impacts of Flooding. Defra, London.

Frich, A.; L.V. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A.M.G. Klein Tank, and T. Peterson (January 2002). Observed coherent changes in climatic extremes during the second half of the twentieth century. Climate Research 19: 193–212.

Gabriel, K., Endlicher, W. (2011): Urban and rural mortality during heat waves in Berlin and Brandenburg, Germany. Environmental Pollution 159:2044-2050

Hacker, J., Belcher, SE., and Connell, RK (2005). Beating the Heat; keepings UK buildings cool in a warming climate. UKCIP Briefing report, UKCIP Oxford.

Hansen et al. (2008). The effect of heat waves on hospital admissions for renal disease in a temperate city of Australia, *Int. J. Epidemiol.* (2008) 37 (6): 1359-1365.

Katharine Hayhoe, Daniel Cayan, Christopher B. Field, Peter C. Frumhoff, Edwin P. Maurer, Norman L. Miller, Susanne C. Moser, Stephen H. Schneider, Kimberly Nicholas Cahill, Elsa E. Cleland, Larry Dale, Ray Drapek, R. Michael Hanemann, Laurence S. Kalkstein, James Lenihan, Claire K. Lunch, Ronald P. Neilson, Scott C. Sheridan, and Julia H. Verville (2004). Emissions pathways, climate change, and impacts on California.12422–12427.PNAS.August 24, 2004, vol. 101, no. 34.

Kilbourne, E.M. (1997). *Heatwaves*, in Noji, E. (ed.), *The Public Health Consequences of Disasters*, Oxford University Press, Oxford, United Kingdom and New York, NY, USA, pp. 51-61.

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

Kinney P.L., Pascal M., Vautard R., Laaidi K., 2012. Winter mortality in a changing climate: will it go down? Bull. Epidemiol. Hebdo., n° 12-13, 5-7

Kirshen, P.H., Ruth, M., Anderson, W., Lakshmanan, T.R., 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 (CLIMB).Office of Research and Development, Washington, DC.

Kjellstrom, T., R. S. Kovats, S. Lloyd, T. Holt, and R. S. Tol, (2009), The direct impact of climate change on regional labour productivity: Archives of Occupational and Environmental Health, v. 64, no. 4, p. 217-227.

Kovats, R. S., S. Edwards, S. Hajat, B. Armstrong, K. L. Ebi, and B. Menne, 2004, The effect of temperature on food poisoning: time series analysis in 10 European countries: Epidemiology and Infection, v. 132, no. 3, p. 443-453.

Kovats RS, Hajat S, Wilkinson P. 2004. Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK. Occup Environ Med, 61:893-898

Kovats, S. (2009), Adaptation costs for human health. Chapter 4 in Parry, M., Arnell, N., Berry, P., Dodman, D., Fankhauser, S., Hope, C., Kovats, S., Nicholls, R., Satterthwaite, D., R. Tiffin and T. Wheeler (2009) Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and other recent estimates. IIED and Grantham Institute for Climate Change, London.Available online at http://www.iied.org/pubs/pdfs/11501IIED.pdf.

Lake, I., I. A. Gillespie, G. Bentham, G. Nichols, C. Lane, G. Adak, and E. J. Threlfall, 2009, A re-evaluation of the impact of temperature and climate change on foodborne illness: Epidemiology and Infection, v. 137, p. 1538-1547.

LCCP 2009. Economic Incentive Schemes for Retrofitting London's Existing Homes for Climate Change Impacts. London Climate Change Partnership.Published by Greater London Authority.

Markandya, A. and A. Chiabai, Valuing Climate Change Impacts on Human Health: Empirical Evidence from the Literature. Int. J. Environ. Res. Public Health, 2009. 6(2): p. 759-786.

Mastrangelo G, Fedeli U, Visentin C, Milan G, Fadda E, Spolaore P. (2007). Pattern and determinants of hospitalization during heat waves: an ecologic study. *BMC Public Health*. Aug 9; 7, p. 200.

Mathers, C. D., and D. Loncar, 2005, Updated projections of global mortality and burden of disease, 2002-2030: data sources, methods and results: Geneva, Evidence and Information for Policy, World Health Organization.

McMichael A, Githeko A, Akhtar R, Carcavallo R, Gubler F, Haines A, et al. (2001). Human health. In: Climate Change 2001. Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS, eds). Cambridge, UK:Cambridge University Press, 451–485

Meehl, GA.; Tebaldi C. (2004), More Intense, More Frequent, and Longer Lasting Heat Waves in the 21st Century. *Science*, 305 (5686): 994.

Michelon, T., Magne, P. and Simon-Delaville, F., 2005 'Lessons of the 2003 heat wave in France and action taken to limit the effects of future heat waves,' in W. Kirch, B. Menne and R. Bertollini (eds) Extreme Weather Events and Public Health Responses. Springer-Verlag, pp. 131–140.

Michelozzi P et al. 2007. Assessment and prevention of acute health effects of weather conditions in Europe, the PHEWE project: background, objectives, design, Environmental Health 2007, 6-12.

Michelozzi P et al. 2008. High temperature and hospitalizations for cardiovascular and respiratory causes in 12 European cities. American Journal of Respiratory and Critical Care.

NCDC. 2008, NCDC Climate Data Online: Global Summary of the Day.

Nicholls, R. J. 2004. Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios. Global Environmental Change, 14, 69-86.

O'Neill M, Zanobetti A, Schwartz J. 2003. Modifiers of the temperature and mortality association. Am J Epidemiol 157: 1074–1082.

Ostro B, Rauch S, Green R, Malig B, Basu R. 2010 The effects of temperature and use of air conditioning on hospitalizations.Am J Epidemiol. 172(9):1053-61.

Patz JA, Campbell-Lendrum D, Holloway T, Foley JA. 2005. Impact of regional climate change on human health. Nature 438:310–317.

Peng RD, Bobb JF, Tebaldi C, McDaniel L, Bell ML, et al. 2010 Toward a Quantitative Estimate of Future Heat Wave Mortality under Global Climate Change. Environ Health Perspect 119(5): doi:10.1289/ehp.1002430

Robinson, PJ, 2001 On the Definition of a Heat Wave. J. Appl. Meteor., 40, 762–775.

Rooney, C., A.J. McMichael, R.S. Kovats, and M. Coleman, (1998). Excess mortality in England and Wales, and in Greater London, during the 1995 heatwave. *Journal of Epidemiology and Community Health*, 52, 482-486.

Sheridan, S. (2003). Heat, mortality, and level of urbanisation, *Climate Research*, 24:255-265.

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

Tol RSJ, 2002 Estimates of the Damage Costs of Climate Change. Part I: Benchmark Estimates.*Environmental and Resource Economics* 21: pp. 47-73

UNISDR, 2009. Global assessment report on disaster risk reduction: risk and poverty in a changing climate, Geneva, United Nations.

UNISDR 2011. GAR 2011: Revealing Risk, Redefining Development. Geneva: United Nations International Strategy for Disaster Reduction.

Vafeidis, A. T., Nicholls, R. J., McFadden, L., Tol, R. S. J., Spencer, T., P.S., G., Boot, G. & Klein, R. J. T. 2008. A new global coastal database for impact and vulnerability analysis to sea-level rise. Journal of Coastal Research, 24, 917-924.

E.C. van Ierland, K. de Bruin, R.B. Dellink and A. Ruijs, 2006. A qualitative assessment of climate change adaptation options and some estimates of adaptation costs. Routeplannernaareenklimaatbestendig Nederland Adaptatiestrategiën. Study performed within the framework of the Netherlands Policy Programme ARK as Routeplanner projects 3, 4 & 5.

World Bank, 2011 World Bank Development Indicators (WDI) & Global Development Finance (GDF),Available from: http://databank.worldbank.org/ddp/home.do , accessed February 9th, 2011. New York, World Bank.

WHO, 2003. Climate change and human health - risks and responses.

WHO, 2004. The Global Burden of Diseases: 2004 update

Watkiss, P. and Hunt, A., 2011. Projection of economic impacts of climate change in sectors of Europe based on bottom up analysis: human health. Climatic Change (forthcoming).

European Commission
EUR 26494– Joint Research Centre – Institute for Prospective Technological Studies

Title: Human Health Impacts of Climate Change in Europe. Report for the PESETA II project

Author: Daniele Paci

Luxembourg: Publications Office of the European Union

2014 – 33 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424 (online)

ISBN 978-92-79-35421-2 (pdf)

doi:10.2791/64481

Abstract
The PESETA II project of the European Commission – Joint Research Centre, started in 2011 aims at assessing these effects for EU 27 both in physical and economic terms, using quantitative modelling and literature review, in several fields (including health) following a bottom-up approach.
Long term climatic forecasts (up to 2100) from four different climate models referred to two alternative scenarios (A1B, with high emissions and E1, with low emissions) are used as input in the health model. Age-specific population projections are elaborated from EUROSTAT data. Data and projections are available at NUTS2 level for EU 27. The model assesses the impacts of both heat and heat waves on mortality and morbidity (respiratory diseases, salmonellosis and campylobacteriosis) and calculates the effects of temperature and temperature-related indicators using exposure-response functions calibrated on the basis of epidemiologic literature. At European level, on average, the climate change-attributable deaths will increase significantly over the next 90 years: from 40,000 additional annual deaths between 2010 and 2040 to more than 140,000 in the latest 30 years of the century. First model results show that by 2100 the impact in terms of years of life lost, for the whole Europe, will be around 12000 M Euros per year with sensitive regional differences. Much lower impacts are found under the E1 scenario and when some level of adaptation is assumed. The effects on food- and water-borne diseases are limited. Climate change is estimated to cause additional 7550 cases of salmonellosis per year if incidence remains at current levels.
Alternative health economic evaluations have been proposed to quantify mortality and morbidity impacts.

LF-NA-26494-EN-N

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new standards, methods and tools, and sharing and transferring its know-how to the Member States and international community.

Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.

Publications Office

ISBN: 978-92-79-35421-2