

Review

The Economics of Health Damage and Adaptation to Climate Change in Europe: A Review of the Conventional and Grey Literature

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Abstract: Economic evidence is a key component of public policy responses to complex societal and health problems, including climate change. Activities to protect human health from climate change should routinely be evaluated not only in terms of their effectiveness or unintended consequences, but also in terms of the health damage cost of inaction, the cost of health adaptation, and the monetized benefits of different alternatives. In this paper we reviewed the economic evidence on the health impacts of climate change and health-relevant adaptation within the 53 Member States of the World Health Organization (WHO) European Region, including grey literature and conventional scientific literature. We found that the evidence base on the health economics of climate change is scarce, incomplete and inconsistent. Despite these shortcomings, the existing evidence clearly indicates that adaptation to avert the health impacts of climate change could provide substantial economic benefits, particularly in the poorer areas of the Region.

Keywords: climate change; climate; economics; health; health economics; Europe

1. Introduction

Climate Change Impacts on Health in Europe

Human health is sensitive to shifts in weather patterns and other climatic variability. While this association has long been known and studied by scientists, anthropogenic climate change has added a new dimension in terms of the magnitude and urgency of action. Climate change has already affected human health over the last decades, directly by changing weather patterns (temperature, precipitation, rising sea levels and more frequent extreme events); indirectly by disrupting basic determinants of health like safe drinking-water, clean air and food security and quality; and also by shifting patterns of disease vectors and other factors involved in disease transmission [1,2]. In Europe (understood in this paper as the 53 countries comprising the WHO European Region) the categories of health-relevant climate exposures that are most likely to affect this region under climate change are [1,2]: (1) Extreme temperatures; (2) Vector-borne diseases (VBDs); (3) Floods; (4) Food-borne and water-borne infections; (5) Poor air quality; and (6) Heavily human-mediated outcomes like mental health and occupational health issues.

Besides their inherent human cost, ill health and premature mortality represent significant economic costs to society. The health impacts of climate change, if not averted, will thus add a component of economic stress and loss to society. Therefore, evidence-based planning of health protection under a changing climate requires an evaluation of the economic costs and welfare losses, monetized or unmonetized, and data on the distribution in time, space and society of the economic impacts analysed. However, data on losses and costs constitute only the starting point for evaluation and action. Policy-makers need enough information to appraise the magnitude and nature of the current and projected impacts of climate change and their implications for health and to prepare and implement a variety of responses to ensure optimal adaptation. Specifically, adaptation planners should have estimates of the costs of inaction, the costs of action (health adaptation) and the costs of residual damage where relevant. In addition, health benefits should routinely be accounted for when evaluating the value for money of activities that reduce greenhouse gas emissions (mitigation), since otherwise the evaluation of their investment worthiness would be systematically biased. However, the conceptual models and considerations of the evaluation of co-benefits from mitigation have been extensively reviewed elsewhere [3–6].

Based on these considerations, this paper aims at reviewing the evidence from commercially published and grey literature on the costs of health impacts of climate change in the WHO European Region, as well as on the costs and benefits of health adaptation policies and activities.

2. Methods

2.1. Search Strategy

To identify relevant articles regarding the economics of the health impacts of climate change and health-relevant adaptation in Europe, a systematic literature search was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) methodology [7,8]. The PRISMA Statement was modified for use in this review: items pertaining to meta-analyses have been

excluded and assessment of risk of bias across studies has also been removed, as this point is of little relevance to health economic literature. The traditional methodologies based on a systematic search of peer-reviewed literature through scientific and technical databases were complemented in this review with grey literature and additional search strategies. References were searched from March to August 2014, with the last search run on 11 August 2014. The following search terms were used to search all sources: climate change, health, health economics, economic, health impacts, health damage, costs, damage costs, economic costs, health adaptation, public health adaptation, adaptation costs, adaptation savings, adaptation planning and adaptation benefits.

2.2. Eligibility Criteria and Study Selection

Studies including economic analyses of the health impacts of climate change and health-relevant adaptation within the 53 Member States of the WHO European Region were considered. The review included studies in the English language that involved economic modelling of the impacts of climate change and climate on health and of health-relevant adaptation to climate change, both within and outside health services. Studies published between January 2004 and July 2014 were included. The review was limited to studies from the past decade to ensure relevance and accuracy of the data, given the rapid development of climate change science and expansion of interest in this field over the past decade. No publication status restrictions were imposed. We selected for analysis only studies that provided quantitative economic results on: (a) health impacts (monetized costs); (b) health-relevant adaptation (monetized costs and benefits) to climate change; and/or (c) relevant methodological contributions. A key methodological difference from previous reviews is the fact that we did not include studies that did not have an explicit climate change modelling component. For instance, we excluded studies on the economics of climate-sensitive health outcomes if they did not specify the additionality due to climate change. Initially, all titles and abstracts of the retrieved articles were screened by a single reviewer using pre-defined eligibility criteria, described above. If no abstract was available for the retrieved article, then the full text was reviewed. If there was any uncertainty regarding inclusion of the reference after reading the title and abstract or full text if abstract was unavailable, two independent reviewers checked the full text for fulfilment of the eligibility criteria. Disagreements between reviewers were resolved by consensus; if consensus was not reached, the final decision on inclusion was taken by the lead author.

2.3. Information Sources

2.3.1. Scientific and Technical Journal Databases

Scientific and technical peer-reviewed books and articles were identified by searching the following electronic databases:

- PubMed (<http://www.ncbi.nlm.nih.gov/pubmed>),
- Ovid MEDLINE (<http://ovidsp.ovid.com>),
- Web of Science (<http://www.webofknowledge.com>),
- Scopus (<http://www.scopus.com/home.url>),

- EconLit (<http://www.ebscohost.com/academic/econlit>), and
- RePEc IDEAS (<http://ideas.repec.org>).

2.3.2. Grey Literature

Several definitions of “grey literature” exist. For operational purposes, we used the one proposed by Schöpfel [9] whereby “not being published by primary publishers” is the condition that defines grey literature, and not whether it has been peer-reviewed or not. Examples of grey literature include documents published by agencies of the United Nations (UN), multilateral development banks and other international organizations, conference proceedings, working papers, web objects, and statistics [10,11]. Relevant grey literature studies were identified through the following databases: (1) OpenGrey (<http://www.opengrey.eu>); and (2) the Grey Literature Report (<http://www.greylit.org>). Publicly available databases and publications of international and European organizations were also reviewed for relevant articles, including the World Bank, the UN, WHO, the Organization for Economic Co-operation and Development, the European Union (EU), the European Investment Bank, and the European Bank for Reconstruction and Development. In addition, we identified twelve related literature reviews through our original search of the conventional and grey literature. We performed a “backward snowballing” search [12] using these literature reviews. That is, we identified from these articles relevant citations which we then searched for in the mentioned databases. This “backward snowballing” search identified 982 studies, of which 91 were duplicates. Nine studies identified by this search were included in the final qualitative assessment. Of these literature reviews, six were excluded from the final analysis as they were not specifically related to the topic of this review.

3. Literature Review

3.1. Search Results

After removing duplicates, a total of 4975 records were obtained through the combination of database searching and other sources (a combination of snowballing from other literature reviews and grey literature). Once those records were screened against the eligibility criteria described above, only 95 records remained eligible. From those, 26 had a geographical focus outside the WHO European Region, 33 studies addressed climate mitigation only, 3 did not ascertain the effect due to climate change, 2 had no original quantitative results, 1 had unclear methodology and 6 systematic reviews were not specifically related to the topic of this review and were thus discarded from further analysis. A total of 24 studies were included in the final qualitative assessment, 11 of which were peer-reviewed studies and 13 of which were grey literature reports; the flow diagram of this process is represented in Figure 1 below.

The studies collected through the search were categorized into the following categories:

- Studies on the cost of health damage of climate change;
- Studies on the cost, cost-effectiveness and/or benefits of health adaptation; and
- Studies reviewing the literature on the topic.

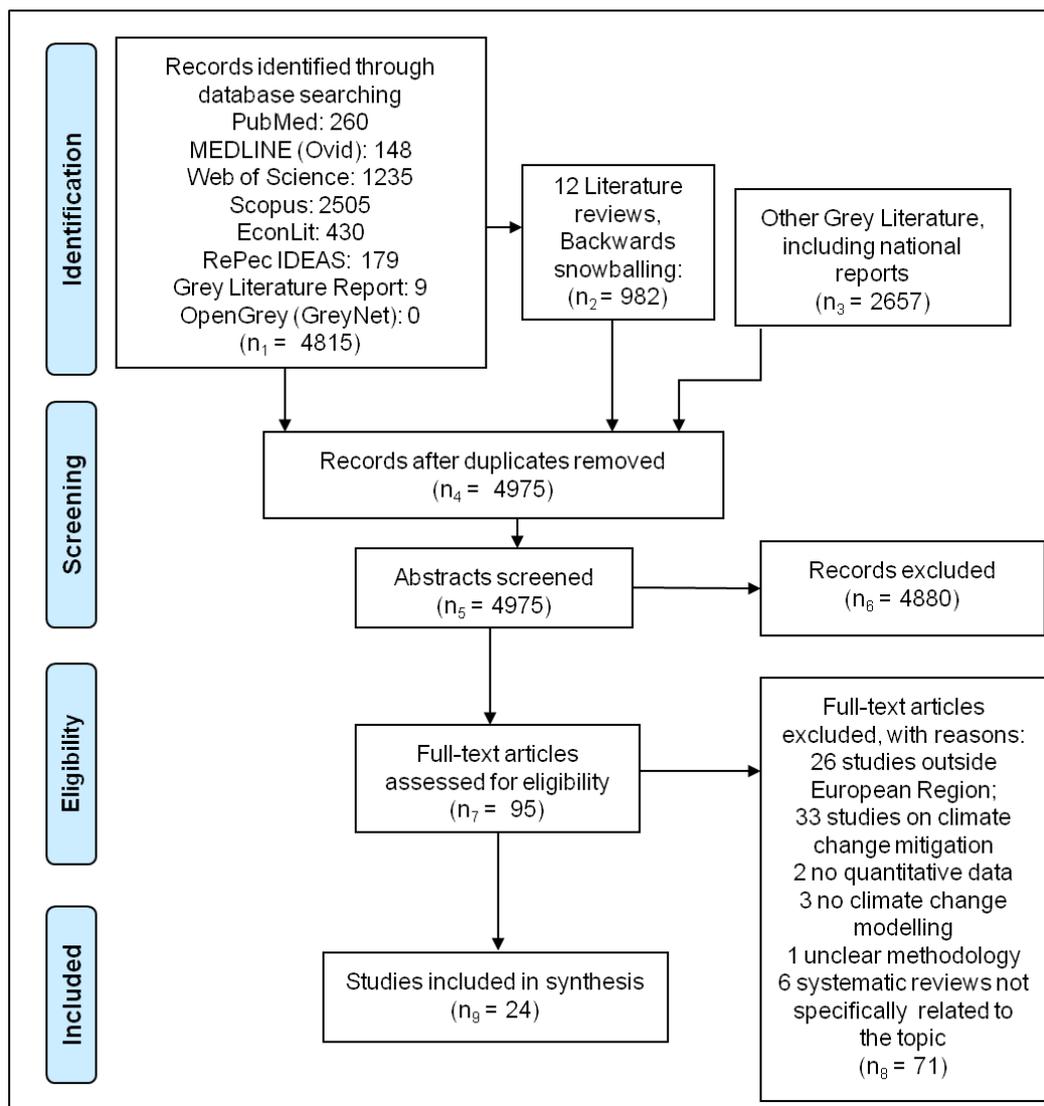


Figure 1. Flow diagram of the review, adapted from the PRISMA methodology [8]

The original studies, that is, the two first categories, are further categorized according to their methodological approach.

A methodological note is thus in order before synthesizing the results. The cost of health damage from climate change, and indeed any health economic impact, can be estimated in various ways. A key question to determine what approach to use is whether the health economic impact is to be measured on society as a whole or only on some part(s) of it (e.g., households) [13]. The latter frequently entails in the practice aggregating partial estimates of the cost of increased morbidity and its consequences, and of the cost of increased premature mortality risk. The economic valuation of mortality risk is extensively explored elsewhere [14,15] but for the purposes of our review it is worth noting that the choice of valuation technique and metric greatly affects the final estimates. For the estimation of the costs associated to morbidity, a commonly used approach is the “Cost of illness” (COI) which usually considers three categories of costs [16]: (1) direct costs, including health care costs and other costs directly caused by illness like the cost of a caregiver time or direct economic losses; (2) Indirect costs, mainly resulting from the loss of productivity or impaired ability to work, or premature death; and

(3) Intangible costs reflecting the value associated to the avoidance of pain and suffering, and their limiting effects. The main current alternative analytical approach to the aforementioned is to assess, for a whole economic system, the aggregate impact of climate-related disease and injury across different economic agents. The diversity and complexity of methods derived from this approach is considerable, but the most common categories found in the literature are [13]: (1) Regression-based estimation models, which try to derive empirical relations between health indicators and growth or GDP; (2) Simulation-based calibration models, which include intermediate factors such as labour supply or savings rates in the relationship between health and economic growth; and (3) Computable general equilibrium models, which attempt to simulate the impact of health “shocks” across all sectors of the market economy.

All of the results found in this review utilize one or more of the mentioned categories of methodologies and models; these are mentioned in the synthesis only insofar as they provide context for the economic interpretation of the study results. An in-depth methodological discussion of current practices is beyond the scope of this review. The search results are summarized in the following section.

3.2. Synthesis of Results

3.2.1. Studies on the Cost of Health Damage of Climate Change

The literature review identified a number of studies that calculated either the economic cost of multiple health impacts, or those of a specific set of outcomes linked to climate change in the WHO European Region. Some of these studies feature a partial focus “microeconomic” approach as mentioned above (*i.e.*, aggregating the cost of individual cases of attributable mortality, morbidity and consequences), whereas others estimate economy-wide impacts of the health outcomes. Key results from these studies are summarized below.

Studies Aggregating Selected Costs of Health Outcomes Attributed to Climate Change

This group of studies address selected outcomes and economic impacts under climate change, reporting annualized aggregated costs in future timeframes. While the specific health outcomes included vary, the partial focus approach is a common denominator. For instance, the project “Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis” (PESETA), a key seminal reference in the European evidence base on the cost of the health impacts of climate change, looked at exposure-specific single outcomes, specifically temperature (heat and cold) related mortality as well as Salmonella infections and mild depression due to flooding. PESETA researchers projected about 27,000 annual heat-related additional deaths in the 2020s and 106,000 additional ones per year in 2071–2100 for 27 EU member states under a global mean temperature increase of 3.9 °C, compared to the baseline period 1961–1990. For the 2020s without acclimatization, heat-related effects are valued at either €13 billion annually, using the “value of a life year lost” (VOLY) method, or €30 billion applying the “value of a statistical life” (VSL) approach (assuming that on average, eight years of life is lost per case). These costs drop to between €2 billion and €4 billion when acclimatization is included. In 2080, the annual cost of excess deaths is estimated at €50 billion annually (when valuing each excess death) and €120 billion (when valuing the loss of a year of life), dropping with acclimatization to €8 billion and €19 billion respectively. By 2100 under an A2 emissions scenario

(for more information on emissions scenarios see [17]) the values range from €50 billion to €180 billion without acclimatization, and €8 billion to €80 billion a year with acclimatization. The greatest impact is in central southern Europe. Conversely, the decrease in cold-related mortality brings about annual savings of between €24 billion and €56 billion by the 2020s and between €41 billion and €96 billion by the 2080s (3.9 °C scenario) without acclimatization (in this case, resulting in a decline in sensitivity of mortality to cold). The greatest gains in cold-related mortality reduction are in northern Europe and the British Isles [18,19]. For food-borne diseases, the PESETA study [20] estimates an average increase in the annual number of temperature-related cases of Salmonella of almost 20,000 by the 2020s and 40,000 by the 2080s (Scenario A2) as a result of climate change in the EU 27. That would lead to an increase in the valuation of the average annual number of temperature related cases of Salmonella of between €70 billion and €140 million, by the 2020s. By the 2080s (Scenario A2) the increase in the valuation could be between €142 million and €284 million. These values are based on a cost per case of €3,500 and €7,000 respectively, in turn based on a review of studies in the literature on willingness to pay (WTP) to avoid food-borne disease. With regard to mild depression following coastal flooding, PESETA predicts 13,000 additional cases by the 2020s and up to 5 million additional cases by the 2080s (A2 scenario, high sea level rise). This could lead to potential costs of €1 billion to €1.4 billion a year. With many similarities to the PESETA methodologies, the final ClimateCost project report [21] disaggregates effects by type of exposure. Without acclimatization, the economic costs of heat-health effects can be summarized as: (1) €2.8 billion per year (using VOLY metrics) in the 2050s for the EU 25 (A1B, no adaptation) rising to €4 billion per year in the 2080s, falling to €2.4 billion and €2.3 billion per year respectively under an E1 scenario; and (2) using VSL metrics, under the A1B scenario, the economic costs rise to €102 billion per year (2050s) and €146 billion per year (2080s). The economic costs of additional food-borne illnesses (in this case Salmonella) for the 2050s are estimated at €45 million per year for the EU for the A1B scenario under current baseline assumptions, falling to €30 million per year if a baseline decline in incidence is assumed. The estimated welfare costs associated with premature mortality due to coastal flooding are €700 million per year for the EU by the 2080s under the A1B scenario. These fall significantly under a mitigation scenario to €180 million under E1 for Europe in the 2080s. Lastly, the estimated welfare costs associated with productivity losses in the 2080s, under the A1B scenario, are equivalent to around €750 million per year, though these fall to around €300 million if the workforce is assumed to move towards less intense occupations over time. These impacts are significantly reduced under the E1 scenario, to around €150 million per year (2080s, baseline).

A few of the studies found featured national-level examples. A national assessment carried out in the United Kingdom [22] estimated the cost of climate change-induced heat mortality at between £13,015 million and £37,040 million by the 2080s. Another study [23] analysed climate induced health risks for Germany, forecasting the number of days with heat load and cold stress for the period 2071 to 2100. The researchers estimated an average increase in the number of heat induced casualties by a factor of more than 3, a 6-fold increase in heat related hospitalization costs, not including the cost of ambulant treatment, and a heat-related reduction in work performance resulting in an estimated output loss of between 0.1% and 0.5% of GDP. Other national-level examples were found, but their methodologies and assumptions were too unclear to be included in this review.

Table 1. Studies aggregating costs of health outcomes attributed to climate change.

Study Author; Date [Reference]	Timeframe, Population and Scenarios	Exposure; Health Outcome	Health Cost Components and Valuation
Ciscar <i>et al.</i> ; 2009 [18]	2011–2040 and 2071–2100; EU27; IPCC SRES	Temperature change; Heat-related mortality	Mortality: VSL, VOLY Morbidity: N/A Others: N/A
Watkiss <i>et al.</i> ; 2009 [20]	2011–2040 and 2071–2100; EU27; IPCC SRES	Temperature and precipitation change; Salmonella infections and depression following coastal flooding	Mortality: VSL, VOLY Morbidity: cost of treatment; opportunity costs (lost work days); intangible costs (Disutility) Others: N/A
Kovats <i>et al.</i> ; 2011 [21]	2020–2100; EU25 ; IPCC SRES	Temperature change; Heat-related mortality and productivity losses, salmonella infection, premature mortality due to coastal flooding	Mortality: VSL, VOLY Morbidity: cost of treatment; opportunity costs (lost work days) Others: cost of decrease in labour productivity due to heat
Richter <i>et al.</i> ; 2013 [24]	2011–2050; Austria and Southern Germany (Bavaria); IPCC SRES	Temperature and precipitation; Increase in concentrations of invasive ragweed pollen; Allergy-related morbidity and loss of productivity	Mortality: N/A Morbidity: allergy treatment costs and work days lost to allergy symptoms Others: N/A
Kovats <i>et al.</i> ; 2006 [22]	2000–2100; United Kingdom; IPCC SRES	Temperature change; Costs of temperature related premature mortality	Mortality: VSL, VOLY Morbidity: cost of treatment; opportunity costs (lost work days) Others: cost of decrease in labour productivity due to heat
Hubler <i>et al.</i> ; 2008 [23]	2071–2100; Germany; IPCC SRES	Temperature change; heat-related mortality, cold-related mortality, heat-related decrease in productivity	Mortality: N/A Morbidity: costs of medical treatment (hospitalization) Others: heat-induced productivity loss (performance reduction)

Also at the national level, on the health economics of climate-aggravated pollen exposure (assumed to increase the prevalence of allergic diseases), Richter *et al.* [24] model the climate change related spread of invasive ragweed (whose pollen is highly allergenic), the related increased in pollen exposure and the associated costs of treating allergic conditions triggered by the pollen, as well as lost work days. The authors estimated allergy-related costs of €291 million a year for the period 2011–2050. The proposed adaptation measures (ragweed survey and eradication) would cost €15 million a year at an effort level of 50 management effort units (MEUs) defined by researchers. This adaptation would in turn reduce allergy costs to €82 million a year. Of additional interest in this study is the exploration of the diminishing returns of adaptation: researchers found that effort beyond 75 MEUs did not further reduce allergy costs.

Regarding evidence on current costs and benefits of interventions against allergenic pollen, the clinical and treatment aspect is substantially better researched than environmental interventions, making the cost-effectiveness of the latter difficult to assess.

An overview of the cost components considered in each study is listed in Table 1. Despite their overall similarities in focus, these studies are barely comparable in terms of economic methods and inputs. The PESETA [18,20] and ClimateCost [21] studies represent a partial exception, with a comparable structure of costs estimates in mortality (*i.e.*, VSL and VOLY) and some morbidity outcomes (*i.e.*, Salmonella infection). However, the cost of other outcomes, as well as indirect costs and intangible costs are treated differently.

The treatment of uncertainty varies across studies as well. The results of all six studies bear the compounded uncertainty of the successive modelling of climate projections, socio-economic scenarios, choice of health impacts, quantification methods (including impacts and acclimatisation) and the economic valuation. In that regard, the reporting of central estimates is regarded as highly misleading, as the studies within the PESETA [18,20] and ClimateCost [21] projects explicitly acknowledge. Furthermore, the choice of mortality valuation metric (VOLY or VSL) leads to large differences, with higher estimates when applying VSL values. In the practice, as discussed later on, VOLY is frequently used for sensitivity analysis. The choice of discount rate is another theoretical source of uncertainty; however, none of the studies discounted future costs, so this uncertainty factor is common to them all.

Studies Estimating Economy-wide Impacts of Health Damage from Climate Change

Rather than aggregating the costs of attributable health outcomes, some studies utilize a combination of models to estimate the overall impacts of climate change health effects on the economy. These studies feature a variety of regional and sectoral scopes and techniques. For instance, applying a General Equilibrium Model (GEM), Bosello *et al.* [25] estimate health economic impacts within the economy-wide impacts of climate change globally and by region. The time horizon is 2050 and the types of outcomes considered are cardiovascular and respiratory disorders, diarrhoea, malaria, dengue fever and schistosomiasis. In the model, mortality and morbidity are translated into changes in labour productivity and health care expenses, which in turn disturb the overall economy, as modelled in the “Global Trade Analysis Project” GTAP-E computable general equilibrium model. For the European region, which in this model comprises the EU plus Eastern Europe and the Former Soviet Union (EEFSU), a sub-region defined in the original study, no cases of malaria, dengue or schistosomiasis are predicted, but around 176,000 net deaths are predicted from higher temperatures, of which the avoidance is valued at €38 billion annually in the EU area, and the approximately 284,000 avoided annual deaths in the EEFSU are valued at €4 billion. The considerably lower economic value of morbidity and mortality in the EEFSU is explained by the use of GDP per capita (significantly lower than in the EU) to value mortality risk reductions. An effect of reduction in cold-related cardiovascular deaths exceeding the increase in heat-related deaths is reported, but there is no intra-region distributional analysis to evaluate the true meaning of this “compensation”.

Selin *et al.* [26] estimated the population-weighted exposure to tropospheric ozone under the Intergovernmental Panel on Climate Change (IPCC) A1B scenario in 2000 to 2050, and the associated health and health economic consequences thereof. Health impact was calculated using the Massachusetts Institute of Technology Emissions Prediction and Policy Analysis—Health Effects (EPPA-HE) model,

in combination with results from the Goddard Earth Observing System (GEOS) GEOS-Chem global tropospheric model. Health costs are based on cost of illness (COI) (direct and WTP) and mortality (VSL) of respiratory diseases attributable to climate change. By their estimates, health costs due to global ozone pollution above pre-industrial levels by 2050 will be US\$580 billion annually (year 2000 US dollars) and mortalities from acute exposure will exceed 2 million. The welfare loss associated with ozone concentrations over 10 parts per billion (ppb) in western Europe by 2050 was calculated at US\$96 billion (year 2000 US dollars) annually, in eastern Europe at US\$14 billion, and in the former Soviet Union at US\$33 billion.

Focusing on the European Union, the health assessment in the PESETA II [27] project roughly confirmed those of the first PESETA, with slightly higher results: over 200,000 additional heat-related deaths under the reference scenario, and about 180,000 with a 2 °C scenario, with strongest impacts in central and southern Europe. Cold-related deaths were not included in the assessment. However, from the economic standpoint, the modelling of PESETA II is quite different from PESETA: mortality is included as an overall loss of societal welfare, morbidity as increased consumption without welfare benefits, and knock-on consequences are included as a decrease in productivity and in leisure and working hours. Importantly, from the overall calculated Gross Domestic Product (GDP) impact of the eight sectors considered (around 1.8% net loss under the reference scenario, about 1.2% under a 2 °C scenario) about two thirds are related to health.

Regarding vector-borne diseases, Tol [28] applied the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model and projected no increase in morbidity and mortality related to climate change influence on malaria and no negative effect in growth in western Europe, eastern Europe, or central Asia (definitions of these subregions were determined by the model and explained in the original study). This result is roughly confirmed in a subsequent application of the same model for both the 20th and 21st centuries [29].

An overview of their characteristics is available in Table 2. Aside from the overall economy-wide approach, few methodological elements are common to these studies. A common thread can be seen in the effect of additional healthcare expenditure, as well as reduction in consumption and investment. While Selin *et al.* [26] analyse the uncertainty of both impacts and economic evaluation via Monte Carlo sampling, the rest of the studies only discuss explicitly uncertainties associated with climate modelling.

3.2.2. Studies on the Cost, Cost–Effectiveness and/or Benefits of Health Adaptation

A subset of the studies addressed the health economics of adaptation (*i.e.*, measures to reduce or avert health damage from climate change). Like the studies on health damage cost, these studies follow two main methodological approaches: the aggregation of selected health-related costs (in this case, of adaptation) or the estimation of the economy-wide implications of adaptation or its absence. The main results are synthesized below.

Table 2. Studies estimating economy-wide impacts of health damage from climate change.

Study Author; Date [Reference]	Timeframe, Population and Scenarios	Exposure; Health Outcome	Health Cost Components and Valuation
Ciscar <i>et al.</i> ; 2014 [27]	2071–2100; EU27; IPCC SRES	Temperature change; Heat-related mortality and morbidity	Mortality: VSL, as damage to the total societal welfare in the model Morbidity: cost of treatment, as increased consumption not increasing welfare Others: cost of decrease in labour productivity due to heat and decrease in available working and leisure time due to mortality and morbidity
Bosello <i>et al.</i> ; 2006 [25]	2050; Global and regions; IPCC SRES	Temperature change; Mortality and morbidity related to cardiovascular and respiratory disorders, diarrhoea, malaria, dengue fever and schistosomiasis	Mortality: reduction of working hours, equivalent to a change in the regional stock of labour force Morbidity: variation in the expenditure for health services by public sector and private households. Others: N/A
Selin <i>et al.</i> ; 2009 [26]	2000–2050; Global and regions; IPCC SRES	Tropospheric ozone; Mortality and morbidity of respiratory diseases	Mortality: VOLY as damage to the total societal welfare in the model Morbidity: cost of treatment and WTP, as increased consumption not increasing welfare and cost of lost labour, services, and leisure time Others: N/A
Tol; 2008 [28]	1950–2200; Developing countries (global and regions); IPCC SRES	Temperature and precipitation; Malaria and knock-on effects;	Mortality and morbidity: reduction in consumption and investment, resulting in long-term reduction of economic growth Others: cost of CO2 emission abatement.
Tol <i>et al.</i> ; 2013 [29]	1900–2000; Global; IPCC SRES	Temperature change; Diarrhoeal disease, cardiovascular and respiratory diseases and malaria	Mortality and morbidity: cost from reduction in consumption and investment, resulting in long-term reduction of economic growth Others: N/A

Studies Estimating Selected Aggregate Costs of Health Adaptation

The studies under this category are characterized by the aggregation of partial adaptation costs (mainly medical treatment) for a selected group of outcomes at either the global or regional level. Some of the studies addressing the cost of health adaptation in Europe are in fact global, with Europe being one region in a general worldwide model.

For instance, Ebi [30] looked at projected cases of diarrhoea, malnutrition and malaria by WHO subregions, proposing a methodology subsequently used by the World Bank and the United Nations (WHO subregions are defined by child and adult mortality rates, from A: very low child, very low adult mortality to E: High child, very high adult mortality. The WHO European Region includes three subregions, namely Eur A, Eur B, and Eur C) [31]. Three climate models are considered: an “unmitigated emissions” scenario, one where carbon dioxide concentrations stabilize globally at 750 ppm, and one where carbon dioxide concentrations stabilize globally at 550 ppm. Neither malnutrition nor malaria were projected to increase on account of climate change by 2030 in any European sub-region (Eur A, Eur B, Eur C), although diarrhoea was projected to increase. The reported global total investment needs in 2030 for combating diarrhoeal disease was US\$67 billion, malnutrition US\$2 billion, and malaria US\$36 billion to US\$50 billion. By applying the unit costs of providing preventive services (immunization and improvements to water and sanitation), the costs are estimated at US\$217 million per year.

A global study inspired by the Ebi [30] methodology was conducted by the United Nations Framework Convention on Climate Change (UNFCCC) [32] but it does not provide a regional breakdown of costs. By contrast, in the “Economics of Adaptation to Climate Change study” conducted by the World Bank [33], Europe is represented by the World Bank’s Europe and Central Asia (ECA) subdivision. The health sector is one of eight considered, along with infrastructure, coastal zones, water and river flood protection, agriculture, fisheries, forestry and extreme weather events. The outputs of two alternative global circulation models are used to predict conditions leading to future disease cases: the National Center for Atmospheric Research Community Climate System Model Version 3 (NCAR CCSM-3) and the Commonwealth Scientific and Industrial Research Organization (CSIRO) -3 model. The only two categories of outcomes considered are diarrhoea and malaria, and adaptation includes only the costs of averting treatment of these outcomes. Average annual adaptation costs in the health sector for diarrhoea and malaria prevention and treatment are globally in the range of US\$1.3 billion to US\$1.6 billion over the 40-year period 2010–2050. However, for the ECA region the only costs are for the NCAR scenario, US\$100 million a year from 2010–2019: there are no costs for the CSIRO scenario. A follow-up publication [34] slightly modifies the health sector adaptation cost estimates to between US\$1.45 billion (CSIRO) and US\$1.97 billion (NCAR) globally, but does not disaggregate by region.

The costing of health adaptation in these studies is minimalistic (only cost of treatment, current prices—see Table 3) and with no discounting. While this provides some consistency, the narrow selection of health outcomes limits their relevance in the European context, where incidence rates of these specific diseases are extremely low or negligible. In addition, differences in regional scope and scenarios preclude further comparison (see “Discussion” section). Regarding uncertainty, in this studies it concerns mainly the climate models, since treatment costs are market-based and estimated through retrospective data.

Studies Estimating Economy-Wide Impacts of Inaction or Health Adaptation

Three of the studies found feature analyses of the overall impacts of health adaptation in the economy (see Table 4). Bosello *et al.* [35] used the Adaptation in World Induced Technical Change Hybrid model (AD-WITCH) model, a macroeconomic climate-economy interaction simulation, and estimated disease

treatment costs would be US\$2.4 billion with a doubling of carbon dioxide concentrations for western Europe (from a total of US\$84 billion, itself equivalent to only 0.2% of GDP). Similarly, de Bruin *et al.* [36], using the Adaptation in Dynamic Integrated model of Climate and the Economy (AD-DICE) model for reference scenarios and the Adaptation in Regional Integrated Model of Climate and the Economy (AD-RICE) model for regional differences, report on adaptation costs for various sectors and while they do not report on specific health adaptation costs for Europe, they suggest that these would be a very small proportion of the total.

Table 3. Studies estimating aggregated costs of health adaptation.

Study Author; Date [Reference]	Timeframe, Population and Scenarios	Exposure; Health Outcome	Health Cost Components and Valuation
Ebi <i>et al.</i> ; 2008 [30]	2000–2030; Global and WHO subregions ; IPCC IS92/HadCM2 model	Temperature change; Malaria, malnutrition and diarrhoeal disease	Mortality: N/A Morbidity: current (2008) costs of treatment and prevention of malaria, malnutrition and diarrhoeal disease Others: N/A
UNFCCC; 2008 [32]	2000–2030; Developing countries (global and regions); IPCC IS92	Temperature change; Malaria, malnutrition and diarrhoeal disease	Mortality: N/A Morbidity: current (2008) costs of treatment for malaria, malnutrition and diarrhoeal disease Others: N/A
World Bank; 2010 [33]	2010–2050; Global and World Bank regions; based on NCAR and CSIRO models	Temperature change; Malaria, and diarrhoeal disease	Mortality: N/A Morbidity: current (2005) costs of treatment and prevention of malaria and diarrhoeal disease Others: N/A
Narain <i>et al.</i> ; 2011 [34]	2010–2050; Developing countries (regions), based on NCAR and CSIRO models	Temperature change; Adaptation costs of malaria and diarrhoeal disease	Mortality: N/A Morbidity: current (2005) costs of treatment for malaria and diarrhoeal disease Others: N/A

Lastly, in an uncommon study on the links between social determinants of health and vulnerability to climate impacts, Blankespoor *et al.* [37] suggest a direct link between flood mortality and female education in developing countries and propose “climate-neutralizing female education” as an adaptive additional value to the human capital gains. They calculate an additional need for primary and secondary education with costs of between US\$500 million and US\$1.5 billion by 2050 in the Eastern Europe and central Asia region.

While none of these studies explicitly discusses the uncertainty of their results in quantitative terms, they acknowledge it as potentially large and stemming mainly from climate change scenarios, rather than economic components.

Table 4. Studies estimating economy-wide impacts of inaction or health adaptation

Study Author; Date [Reference]	Timeframe, Population and Scenarios	Exposure; Health Outcome	Health Cost Components and Valuation
de Bruin <i>et al.</i> ; 2009 [36]	2005–2085; Global; based on AD-RICE and AD-DICE models, IPCC SRES for calibration	Temperature and precipitation change; malaria, dengue, air pollution-related and heat-related morbidity and mortality	Mortality and morbidity result in reduced inputs to consumption, investment and savings Others: N/A
Bosello <i>et al.</i> ; 2009 [35]	2010–2100; Global and regions; IPCC SRES	Temperature and precipitation change; Heat-related morbidity, vector-borne diseases, cardiovascular and respiratory diseases	Mortality: supply-side effect is impact on labour quantity Morbidity: supply-side effect is impact on labour productivity; demand-side effect are impacts on health care expenditure Others: N/A
Blankespoor <i>et al.</i> ; 2010 [37]	2000–2050; Developing countries (global and regions); based on NCAR and CSIRO models	Extreme weather events; mortality and morbidity, and knock-on effects	Mortality and morbidity: N/A Others: effect of education in reducing fatal and nonfatal outcomes, cost of provision of education

3.2.3. Studies Reviewing the Literature on the Topic

Besides having been used to identify additional sources, the literature reviews on the health economics of climate change provided interesting information on their own. Regarding methodology, Fankhauser [38] notes the high uncertainty of the economic estimates of both health damage and adaptation, albeit acknowledging improvement from the first generation of assessments to the second. In the macroeconomic literature, Bosello and Shechter [39] note the overall low vulnerability in terms of GDP loss from all impacts, including health, in European countries, a notion confirmed by our own review of the literature regarding generalized equilibrium models. On the other hand, Hutton [40] highlights the comparatively high costs of health damage (including mortality) when those are counted in overall economic evaluations of climate change impacts. He also notes that the omission of important causes of health costs (omitted health outcomes, omitted economic impacts, and the costs of health actions in other sectors) is likely to result in a severe underestimation of the health economic impact of climate change. A recent review led by the same author [41] also found the economic evidence in European countries on the costs of and response to climate-sensitive diseases to be extremely limited and fragmented. UNFCCC [42] reviewed the literature on climate change adaptation economics by sectors, including health. This and other reviews [43] insist on the need to engage in further research to narrow the estimates for the cost of adaptation.

3.3. Discussion

The evidence base on the health economics of climate change remains scarce. In fact, many of the references found through this literature search that were tagged as related to climate change (*i.e.*, including “climate change” as a key term) actually dealt with past or current economics of climate-sensitive health outcomes and exposures, or with the economic implications of factors that are related to climate change, but are not a major direct consequence thereof (e.g., air quality). In neither case was the influence of climate change taken into account. Whereas these studies are valuable in their own right and to establish baselines for the ascertainment of climate change influences, they cannot be considered to deal with climate change – and that is why they were not included in the results in Section 3.2. We acknowledge, however, that the adequacy of their inclusion is a matter of perspective.

The weak knowledge on the association of climate and climate change with several health outcomes partly explains the scarcity of economic evidence on the topic. While general trends are confidently predicted by increasingly accurate climate models, the evolution of several exposures and outcome-specific causal pathways in a context of high uncertainty still proves too challenging for current modelling capabilities. This explains the major gaps of evidence with regard to water-borne diseases, VBDs, and health outcomes from flooding and storms. It also partly explains the rarity of proper sensitivity analysis in health damage cost studies, where the compounded uncertainty of climate models, health impact models and economic estimates would provide unacceptably wide confidence intervals. On the other hand, the association between high temperatures and health, and the economic consequences thereof, are comparatively well represented in the literature, partly as a result of EU-funded research projects.

Even for better explored sets of health outcomes, the lack of homogeneity or standardization makes proper comparisons, such as meta-analyses, all but impossible. Such lack of homogeneity applies to virtually all steps of the research modelling steps, from the specific exposure indicators, health outcomes, climate change models, timeframes, and economic outcome measures. Importantly, economic methods are also different, with crucial implications for result interpretation. Valuation approaches vary with regard to mortality; the choice of mortality valuation metric (VOLY or VSL) leads to large differences, with higher estimates when applying VSL values. This is a major and far from resolved source of uncertainty in economic terms. Treating all individuals as equivalent for valuation purposes (as is usually the case with VSL) is a frequently contested notion, given the potentially large difference in life-years lost between elderly and younger individuals due to environmental risk factors. On the other hand, the epidemiological basis on years of life lost, and particularly of their valuation in terms of willingness to pay, is much thinner. This has led to a predominance in the practice of VSL as the norm in regulatory impact assessment with VOLY used for sensitivity analysis [15]. Another theoretical source of uncertainty stems from the choice of discount rate, since it has a large effect on any climate change economic analysis, given the long timeframes involved. Opinions vary sharply in this matter [44], but the practice in climate change adaptation tends towards low or no discount. In fact, no study in this review discounted future costs or benefits, at least explicitly.

Within the small pool of studies properly accounting for climate change scenarios, some patterns arise from the available evidence:

- Studies on the cost of health damage of climate change tend to show significant costs due to mortality and morbidity attributable to climate change. Those costs, measured on a yearly basis, tend to increase with longer timeframes and under more severe climate change scenarios.
- Studies on the cost, cost-effectiveness and/or benefits of health adaptation tend to show moderate costs and substantial benefits of adaptation in the short term with a marked increase in the long term.
- The reviews of the literature commonly reflect the paucity of existing evidence, lack of comparability and gaps, but tend to confirm the general conclusions in the mentioned types of studies.

Other implications are also clear from the review. The scope of most studies tends to be partial (with only a few health outcomes considered) and the results plagued by uncertainty, particularly for outcomes in which a solid dose-response function has not been ascertained. However, the issue of discerning what outcomes are due to climate change and which ones would be expected under a no-change scenario, is in general solidly addressed and embedded in the modelling from inception. The low predicted overall impact of diarrhea, malnutrition and vector-borne diseases in the WHO European Region (at least in comparison with other world regions) has likely limited the attention of researchers with regard to the economic evaluation of its health impacts and related adaptation. It also explains the comparatively low vulnerability of the European region in models accounting for projected global economic impacts from these types of health outcomes under climate change. In the studies evaluating adaptation, evaluations frequently stop short of full cost-benefit analyses on account of adaptation costing difficulties: specifically, some of the adaptation costs in other sectors (notably water and extreme weather events) could be considered health adaptation, but frequently are not, despite their purported goal of protecting human life and welfare. Without a full adaptation costing, the all-society scope of a social cost-benefit evaluation is not attainable. This is a discussion left frequently unaddressed in published studies. Lastly, the literature reviews acknowledge that the omission of health outcomes and of important causes of health costs is likely to result in a severe underestimation of the health economic impact of climate change.

Despite these general patterns, comparisons among these references are extremely difficult, since most useful reference parameters vary across studies. Differences in geographical scope, outcomes considered, timeframes, evaluation metrics, population dynamics, and other parameters make generalizations highly challenging, if at all feasible. Even in studies that are clearly conceptually linked, like large EU-funded research studies, cross-comparisons are complex.

The value added by this review stems mainly from methodological considerations: firstly, we adopted a systematic approach to finding and analysing the existing literature; secondly, we included grey literature and acknowledged it as such for clarity and possible caveats; thirdly and most crucially, we included in our review only studies with clear methodology, quantitative results and a clear determination of the additionality brought about by climate change. While these criteria do not constitute a formal evaluation of the quality of the evidence presented in the studies, the strictness in selection adds an element of clarity often absent in previous reviews.

Regarding the limitations of this review, while we have tried to maximize the retrieval of information through the combination of search techniques, it is likely that a proportion of relevant studies have not been captured. Moreover, the boundaries of the topic (the health economics of climate change) are far from clear. It could be argued that the health economics of climate-sensitive health outcomes under

current or past climate variability are relevant to this discussion, since they constitute the baseline against which models and projections can be compared. However, we have adopted a conceptually conservative approach by including only research that explicitly modelled climate change effects, thus acknowledging the key issue of additionality both in health damage and response. A certain risk of reporting bias cannot be ruled out; almost all studies on the health damage of climate change report positive results, that is to say significant economic costs, as do a majority of cost-effectiveness and cost-benefit studies.

4. Conclusions

The literature retrieved in this review suggests that the evidence base on the health economics of climate change is scarce, incomplete and inconsistent. This is the case not only at national and local levels, but also at the EU level and especially at the pan-European level when including EEFSU. A substantial proportion of potentially relevant evidence is available in “grey literature” outlets, some of which suffer from transparency, quality and/or comparability issues. However, given the scarcity of peer-reviewed scientific journals and books on the matter, researchers, practitioners and policy-makers would miss important information if grey literature studies and reports were to be systematically excluded from the relevant evidence base.

Despite its shortcomings, the existing evidence clearly indicates that more resources need to be allocated to averting the health impacts of climate change, particularly in the poorer countries of the region, both featuring the highest vulnerability and the least climate resilience. Next steps in this research area should include the establishment of consensus with regard to basic prerequisites for comparability of results, as well as increased effort regarding the projection under climate change scenarios of the health economics of climate-sensitive exposures and outcomes. In addition, future studies using combinations of global physical and macroeconomic models addressing this issue should lay out model-specific assumptions more clearly in order to facilitate comparability of results.

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Author Contributions

This research and the resulting paper was coordinated, designed and written up by Gerardo Sanchez Martinez. The literature search, screening, peer review management and related revisions were conducted by Eloise Williams. Additional screening, formatting and revisions were made by Shwe Sin Yu.

Conflicts of Interest

The authors declare no conflict of interest.

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