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Economic Evidence on the Health Impacts of Climate Change in Europe

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ABSTRACT

BACKGROUND: In responding to the health impacts of climate change, economic evidence and tools inform decision makers of the efficiency of alternative health policies and interventions. In a time when sweeping budget cuts are affecting all tiers of government, economic evidence on health protection from climate change spending enables comparison with other public spending.

METHODS: The review included 53 countries of the World Health Organization (WHO) European Region. Literature was obtained using a Medline and Internet search of key terms in published reports and peer-reviewed literature, and from institutions working on health and climate change. Articles were included if they provided economic estimation of the health impacts of climate change or adaptation measures to protect health from climate change in the WHO European Region. Economic studies are classified under health impact cost, health adaptation cost, and health economic evaluation (comparing both costs and impacts).

RESULTS: A total of 40 relevant studies from Europe were identified, covering the health damage or adaptation costs related to the health effects of climate change and response measures to climate-sensitive diseases. No economic evaluation studies were identified of response measures specific to the impacts of climate change. Existing studies vary in terms of the economic outcomes measured and the methods for evaluation of health benefits. The lack of robust health impact data underlying economic studies significantly affects the availability and precision of economic studies.

CONCLUSIONS: Economic evidence in European countries on the costs of and response to climate-sensitive diseases is extremely limited and fragmented. Further studies are urgently needed that examine health impacts and the costs and efficiency of alternative responses to climate-sensitive health conditions, in particular extreme weather events (other than heat) and potential emerging diseases and other conditions threatening Europe.

KEYWORDS: cost, economic, climate change, policy, assessment

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Introduction

Climate change will have large and diverse impacts on European countries. Some of these impacts are already being felt.[1–3] Health effects are among some of the major effects, for example, increased frequency and intensity of heat-waves and flooding, and more extended and changed distribution of disease vectors. In addition, health is indirectly impacted by many other factors that are themselves affected by climate change, such as water quality and quantity, ecosystems, food security, agriculture, transportation, energy production, and economic growth itself. Also in Europe, some health gains from climate change are anticipated, such as reduced winter cold-related deaths, and positive health and economic benefits of increased crop productivity in some geographical areas.[1,2,4] However, in relation to climate change impacts, the 53 countries that make up the World Health Organization

(WHO) European Region should not be analyzed as a homogeneous group of nations. These countries vary enormously in relation to geography, climate, sociocultural environment, health system development, population health status, and economic level. Hence, their vulnerability and capacity to respond to the health threats of climate change are widely divergent.[5]

Mitigation measures are currently not being implemented fast enough to prevent substantial changes to the global climate over the next 100 years.[1,2] Hence, these new health threats will need adaptive responses to avert significant but as yet unpredictable health impacts with major implications for population welfare and economic indicators. In Europe, many actions are ongoing at country as well as at regional levels.[6] Between 2004 and 2014, 22 of 53 WHO European Region countries (or 15 of 28 European Union countries) adopted national adaptation plan (NAP) or strategies.[7] The majority of these include assessment of health as a vulnerable sector. The main health actions planned include strengthening health systems, early warning systems, disaster preparedness, awareness-raising of citizens, and specific legislative changes for buildings and constructions to regulate heat in the internal environment. The European Commitment to Act of the Fifth Ministerial Conference on Environment and Health has further set direction on the action to take in the health sector and beyond to avert the adverse health effects of climate change.[8] As a response, a total of 26 European countries have conducted national health vulnerability assessments between 2001 and 2012.[9]

To respond effectively to the health effects of climate change, evidence is needed to justify action as well as support the selection, planning, and budgeting of preferred actions. Additional spending in the health sector will need to demonstrate value for money through health economic studies in order to access sustained funding flows to climate change adaptation activities. Therefore, the aim of this paper is to review the economic evidence relating to the health impacts and adaptive responses to climate change in the WHO European Region, and to identify the most important evidence gaps to be filled and methodological issues to be addressed.

Methods

The geographical focus of this review is on the 53 countries in the WHO European Region.[10] Literature in the English language was obtained using a Medline search for the years 1990–2012 and an Internet search, and were included when they both (1) addressed health impacts of extreme weather events or effects of climate change on respiratory diseases and infectious diseases (vector borne, water related, and food borne) and (2) provided monetary estimation of the health impacts of climate change or the adaptation measures to protect health from climate change in Europe, or both. All costs are presented in euro (€) in the year of the study; when costs are presented in another currency, they are also converted to euro at the average exchange rate in the year of the study.

Based on the title and abstract reviewed for relevance, full articles were obtained. Once a study was found to present quantitative estimates of health impact cost, health adaptation cost, or cost-effectiveness of interventions, the key results and methodological approaches were evaluated for inclusion or exclusion.

Manuscripts were grouped into three categories, depending on which economic measures were presented. These three types of studies have different primary purposes and are classified as follows:

1. Health impact cost studies (also referred to as "damage cost" studies) estimate the societal costs (or benefits) (eg, the costs of disease treatment, the costs of lost production because of disease, value of premature mortality) of the health impacts of climate change, valuing health impacts in monetary units. The principle objective is to provide aggregated economic impact numbers, which allow assessment of importance over time (such as comparing to gross domestic product (GDP)) as well as provide a comparison of economic impacts in money metric across sectors, based on which policy makers can prioritize sectors where adaptive measures are most needed.
2. Health adaptation cost studies estimate the costs of alternative measures to reduce, or avert altogether, the health impacts of climate change. The objective of health adaptation cost studies is to identify the expenditure required for specific health actions and thus enable realistic budgeting of fund-holding decision makers.
3. Health economic evaluation studies compare the costs and benefits of health adaptation measures, estimating a return on spending in the form of a cost-effectiveness ratio (such as cost per death averted) or a cost–benefit ratio (monetary return per currency unit spent). The objective is to enable selection of efficient measures to protect the population's health, in comparison with other health protection options or uses of public resources.

These three types of studies are related, and often draw on similar health and economic data. These outputs feed into other decision-making tools, such as multi-criteria analysis or policy analysis.

Results

In all, 40 relevant studies from Europe were identified, covering the health damage costs (10 studies) or adaptation costs (5 additional studies) related to the health effects of climate change, and the efficiency of response measures for climate-sensitive diseases (25 additional studies). Efficiency means an input–output metric such as cost per death averted or cost–benefit ratio. Table 1 presents data on the health impact cost studies and adaptation cost studies where projections

Table 1. Studies that estimate annual health impact costs and adaptation costs attributed to climate change in the WHO European Region.

DISEASES	COVERAGE	YEAR	ECONOMIC MODEL[a]	ANNUAL COST OR SAVINGS	REFERENCE
Health impact cost studies (attributed to climate change)					
Cardio-respiratory	EU	2050	CGE	€38 billion savings	Bosello et al.[11]
	FSU[b]			€4 billion savings	
Heat related, Salmonellosis, Flooding	EU	2080	Bottom-up	€46–147 billion cost	Kovats et al.[12]
Heat-related	EU	2080	Bottom-up	€50–118 billion	Watkiss et al.[4]
Salmonellosis		2011–40		€70–140 million	
Heat-related	Skopje, FYRM[c]	2005–10	Bottom-up	€1 million	WHO Regional Office for Europe[13]
Heat-related	Rome, Italy	2020	Bottom-up	€281 million	Alberini et al.[14]
Heat-related	Germany	2071–2100	Bottom-up	€300–€700 million (hospital admissions) €2.5–€10.3 billion (productivity)	Hübler et al.[15]
Cardio-respiratory	EU	2050	Bottom-up	€125 billion	Holland et al.[16]
Pollution[d]	OECD Europe, Eastern Europe	2100	CGE	0.02% of GDP	Nordhaus and Boyer[17]
Adaptation cost studies (attributed to climate change)					
All health-related adaptations	Europe and Central Asia	2010–2050	Bottom-up	€1.18 (CSIRO) – €4.32 billion (NCAR)[e,f]	World Bank[18]
Diarrheal cases	WHO European Region	2030	Bottom-up	€148 million[f]	Ebi[19]
Disease treatment	Western Europe	2060	Bottom-up	€0.68 billion savings	Agrawala et al.[20]
	Eastern Europe			€0.06 billion savings	

Notes: [a]"Model" describes the economic model. CGE – computable general equilibrium model, which is a computer software that includes assessment of impacts across different sectors of the economy. "Bottom-up" means different sector level economic impacts of climate change have been examined, without examining linkages of impacts in specific sectors across the broader economy, where there might be consequences for the prices of goods and services and the resulting demand.
[b]Former Soviet Union.
[c]The Former Yugoslav Republic of Macedonia.
[d]Also included tropical disease cluster, but not relevant for European countries.
[e]National Centre for Atmospheric Research model (termed the "wet" scenario); Commonwealth Scientific and Industrial Research Climate-3 model (termed the "dry" scenario).
[f]Converted from US dollars to euros in cost base year.

are available. Studies that do not estimate health impact or adaptation costs attributed to climate change (but only of climate-sensitive diseases or conditions) are described in the text but excluded from the table, as they are not comparable.

There were no economic evaluation studies identified that compared costs and benefits of response measures specific to the impacts of climate change. Nevertheless, a range of economic studies on response measures to avoid climate-sensitive health effects was identified, even though they were developed not to reduce the effects of climate change but rather reduce the disease condition (with no reference to climate change).

Health impact costs. The literature search identified three studies estimating economic damages or savings resulting from multiple diseases[4,11,12] and seven studies estimating the economic damages from single health risks associated with climate change (including heat-waves and *Salmonella*) in Europe.

Bosello et al use the general equilibrium Global Trade Analysis Project (GTAP) model to estimate, among other impacts, the health-care costs of treating climate change-attributed cases and labor productivity impacts of six disease groups for each world region.[11] For the European regions, the study included cardiovascular, respiratory, and diarrheal diseases for the year 2050. The paper does not report if it valued the future economic impacts in present values using discounting. The study predicts 176,000 net deaths avoided from higher temperatures, which are valued at a saving of €38 billion annually in the EU area, and 284,000 annual deaths avoided in former Soviet Union (FSU) countries valued at a saving of €4 billion. The significantly lower economic value in FSU countries for a higher number of deaths avoided is because the estimation of the value of life is based on GDP per capita, which is significantly lower in FSU countries. The net reductions in death in temperate regions in the Northern Hemisphere are due to the avoidance of cold-related cardiovascular death exceeding the increase in heat-related deaths. However, there is no assessment of winners and losers, by demographic or geographical group within each of the eight world regions. Using a computable general equilibrium model to assess economy-wide impact of the global health effects, the study reports that the negative impact on GDP is greater than the sum of the costs associated with the three diseases because of their impacts on other economic activities.

Kovats et al estimate the welfare costs of heat mortality and salmonellosis cases in 27 EU countries.[12] Under the Special Report on Emission Scenarios (SRES) A1B scenario (medium–high emission trajectory, leading to central estimates of global average surface temperatures of around 3–4 °C relative to pre-industrial levels), the authors use two alternative units of health impact to value the lives lost from these two risk factors: the number of life years lost because of premature mortality and the number of premature deaths. The economic value of a "life year" is derived from that of a premature death, and is a fraction of the latter. When valuing life years lost, the marginal impact of climate change alone is €0.8 billion by the 2020s, €2.8 billion by the 2050s, and €4.0 billion by the 2080s; using the numbers of deaths, the marginal impact of climate change alone is €31 billion by the 2020s, €103 billion by the 2050s, and €147 billion by the 2080s. The 30-fold difference in valuation methodologies is accounted for by the fact that the two risk factors brought forward death by an average of just a few months. Kovats et al also estimate the economic costs of additional cases of *Salmonella*.[12] Under the A1B scenario and assuming a decreasing case rate, the estimated annual costs without adaptation because of climate change are €29.5 million/year by the 2020s (2011–2040), €46.4 million/year by the 2050s (2041–2070), and €48.9 million/year by the 2080s (2071–2100). If the case rate is held constant, the corresponding annual costs are €36, €68.4, and €88.8 million/year. Additionally, the study estimates the costs of fatalities from coastal flooding, with a marginal impact of climate change costing €34 million by the 2020s (2011–2040), €122 million by the 2050s (2041–2070), and €720 million by the 2080s (2071–2100).

The study "Projection of economic impacts of climate change in sectors of the European Union based on bottom-up analysis" (PESETA) predicts almost 107,000 extra heat-related deaths 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.[4] In 2080, the value of excess deaths is estimated at €50 billion annually (when valuing each excess death) and €118 billion (when valuing the loss of a year of life). The greatest impact is in central southern Europe. These impacts are, however, likely to be balanced out by reduced cold-related deaths, with the greatest gains in northern Europe and the United Kingdom. For food-borne diseases, the PESETA study estimates that the average annual number of temperature-related cases of *Salmonella* may have increased by a total of almost 20,000 as a result of climate change in Europe, leading to annual costs of €70–€140 million between the years 2011 and 2040, based on a cost per case of €3,500 and €7,000, respectively.[4] These unit costs were based on a review of studies that ask potential beneficiaries what they would be willing to pay to avoid food-borne disease. Under climate scenario A2, these cases and costs are predicted to double for the period 2071–2100.

Other studies estimate the climate change-attributable impact on single diseases in specific countries. For example, the application in the former Yugoslav Republic of Macedonia of a WHO Toolkit for the estimation of health and adaptation costs related to climate change focused on morbidity and mortality from heat-waves in the capital city, Skopje.[13] Over a 5-year period from 2006 to 2010, the study estimated an annual average of 316 additional cases of cardiovascular disease and 344 additional cases of respiratory disease attributable to climate change, with 13 and 1 deaths resulting, respectively. The estimated average cost resulting over the 5-year period was €1.03 million per year or €2.5 per inhabitant of Skopje. Similarly in Germany, Hübler et al estimated the costs of heat-induced health effects in terms of hospital admissions; but the greater impact is the impact of heat on work performance resulting in an estimated output loss of 0.1–0.5% of GDP.[15]

Within the project "Climate change and adaptation strategies for human health in Europe" (cCASh), a contingent valuation survey was carried out to estimate the benefits of reducing the risk of dying during heat-waves. In contingent valuation, a survey questionnaire builds theoretical scenarios to enable values to be obtained for situations that do not commonly arise in real-life, or cannot easily be observed. The survey was administered to adults aged from 30 to 75 years in the Czech Republic and Italy. For the city of Rome, the monetized mortality damages of the heat-waves in the absence of planned adaptation programs was estimated to be €281 million for the year 2020 (in 2004 values).[14]

Other studies estimate the costs of excess deaths from heat-waves, but do not estimate attributed costs to climate change, such as the 2003 heat-wave in the United Kingdom that led to 2,157 excess deaths at a cost of £2.6 billion (€3.6 billion) using valuation of a death at £1.2 million (€1.7 million), or £32 million (€45 million) using valuation of a saved year of life of £15,000 (€21,000).[21] In all, 1,650 excess hospital admissions were estimated to cost £15 million (€21 million), at an upper threshold of £9,120 (€12,770) per admission. Likewise, the 2003 heat-wave in France was estimated to have caused 14,800 excess deaths from August 1 to 20, 2003, costing society more than €500 million using a value per life saved of €37,500.[22] Both studies assume an average of 1 year of life lost per deceased person given that the majority of excess deaths were of people 75 years and over. Furthermore, the absence of a surge in health insurance expenses for the year 2003 in France led the authors to conclude that the increased hospitalizations from excess cases balanced out with hospitalizations averted because of excess deaths in the same year.[22]

For air pollution-related deaths, the attributed cost of acute and chronic mortality to climate change was estimated by the Climate Cost project at €125 billion per annum in 2050 for the 27 European Union countries.[16] These costs are dominated by premature death (€86 billion), with the majority of the remaining accounted for by the cost of chronic bronchitis (€17 billion), restricted activity days (lost productivity at €14 billion), and suffering from disease symptoms (at €9 billion). One-third (€42 billion) of the overall economic impacts can be reduced by mitigation measures.

Health adaptation costs. Three studies have been conducted that estimate health adaptation costs in Europe – two global multi-sectoral cost studies, by the World Bank[18] and the United Nations Framework Convention on Climate Change (UNFCCC)[23] – and one global cost study focusing on the health service response alone.[19] The multi-sectoral cost studies estimate costs of adapting to health impacts of climate change as part of other sector activities such as agriculture and water resources, as well as the health sector. The UNFCCC study, whose estimates are based on the methodology of the another cost study,[19] is not presented here, as the study does not provide a cost breakdown for the European Region.

In the World Bank's Economics of Adaptation to Climate Change study,[18] the "health sector" costs include only the costs of treating and preventing diarrhea cases for Europe and central Asia from 2010 to 2050 at 2005 prices. The results are presented with future costs in present values using an annual discount rate of 5% and 0%. The underlying health models do not predict increase in malaria cases for this region. However, investments in several other sectors have important implications for health, such as the water sector and extreme events, and hence these are added to the health sector costs below to give "health-related" costs. Two alternative global circulation models are used to predict future disease cases: the National Centre for Atmospheric Research (NCAR) Community Climate System Model (CCSM)-3 model (termed the "wet" scenario) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO)-3 model (termed the "dry" scenario). Infrastructure investment (estimated as the cost of health education, water supply, and sewers) is estimated to cost between US$300 (€250) (CSIRO) and US$800 (€670) (NCAR) million annually. The adaptation cost for agriculture and fisheries (estimated as the cost to prevent climate change-attributed cases of malnutrition) is estimated at between US$470 (€390) (CSIRO) and US$1,320 (€1,100) (NCAR) million annually. Water storage and flood protection cost between US$300 million (€250) (CSIRO) and US$2,600 (€2,170) (NCAR) million annually. Preparing for extreme events – involving education and training schemes for target populations – is estimated to cost between US$500 (€415) (CSIRO) and US$1,000 (€830) (NCAR) million annually. The overall health-related costs for Europe and central Asia are estimated at between US$1.57 billion (€1.3 billion) (CSIRO) and US$5.72 billion (€4.8 billion) (NCAR).

Two other global studies of health adaptation costs are based on economic integrated assessment models. De Bruin used the Adapted Regional Integrated model of Climate and the Economy (AD-RICE) model and estimated that health would be a very small total of adaptation costs for Europe up to 2050.[24] Agrawala et al used the WITCH model (A World Induced Technical Change Hybrid Model) and estimated that there will be net cost savings in disease treatment of €0.74 billion with a doubling of CO_2 concentrations for western and eastern Europe combined.[20] Watkiss and Taylor conclude that the estimates from both studies can only be considered illustrative because of the highly theoretical nature of these models, and their treatment of adaptation.

In terms of water-borne diseases, as many as 17.5 million additional diarrhea cases have been estimated as attributed to climate change by Ebi for the year 2030 for the WHO European Region.[19] Based on emission reductions resulting in stabilization at 750 ppm carbon dioxide equivalent by 2210, and applying the unit costs of providing preventive services (immunization, and water and sanitation improvements) to avert these cases, the costs are estimated at US$217 million per year.

Heat-health action plans have been strengthened in recent years. In France, the cost of preparing the heat-wave and health alert system (Système d'alerte canicule et santé [SACS]) in 2005 was calculated at €287,000 and the operating cost between June 1 and August 31 was calculated at €454,000, summing to a first year cost of €741,000.[22] These costs cover mainly the additional human resource costs. Compared to the estimated health costs of more than €500 million, including loss of human life at the value of €37,500 per year of lost life, this intervention cost is relatively small.

For newly emerging infectious diseases in Europe, vaccination campaigns will be feasible where an efficacious vaccine exists. However, few actual vaccines are available on the market for vector-borne diseases. No available studies have estimated the costs of vaccinating the at-risk or high-risk populations in Europe.

Health economic evaluation studies. Health economic studies not only assess adaptation costs (above) but also compare these costs to health impacts and other outcomes in cost-effectiveness analysis (CEA) or cost–benefit analysis (CBA).[25] Ideally, economic evaluation includes a comparative economic assessment of alternative policy options. The literature search revealed no studies that have specifically examined the costs and health effects of interventions specifically related to addressing the additional disease burden associated with climate change. However, several studies were found that assessed cost-effectiveness or cost–benefit of health interventions targeting climate-sensitive diseases. These are most available in the areas of preventing food-borne diseases, preventing diarrhea through rotavirus vaccination and preventing or treating air quality-related conditions. However, as these studies were non-specific to climate change, they fell outside the initial systematic search criteria. Therefore, the studies presented below illustrate the types of studies available, but they do not represent the entire published economic literature. These were included in this assessment as they provide indications for future research.

In the area of heat-health early warning systems, while many European countries have heat-health plans,[26] no studies were found from Europe that compare the costs and health impacts of such systems. A study from Philadelphia, United States of America, indicates the potential value for money of such systems. The Philadelphia heat-health early warning system, initiated in 1995, was considered unique at the time because of its coordination between different public and private agencies, including mass media campaigns and community mobilization. At a value of US$4 million (€5.4 million) per life saved, the gross benefits of the Philadelphia heat-health warning system were in the order of US$468 million (€626 million) over 4 years, or US$117 million (€157 million) per year. Additional non-valued benefit is from avoided morbidity. The annual marginal costs of the system were estimated at US$115,000 (€154,000), in addition to the costs of developing the system of US$60,000 (€80,000).[27,28] Hence, the cost per life saved is very low at less than US$4,000 (€5,350), indicating an efficient use of public funds. However, these costs are only marginal costs, and do not consider the redeployment of resources already paid for by public authorities, such as salaries and vehicles.

In the area of food-borne disease prevention, quite a number of farm-level economic studies have been performed, focusing mainly on *Salmonella* prevention. These studies generally find that disease prevention is cost-effective or economically viable (ie, benefits greater than costs). For example:

- Dutch studies found hygiene interventions with relatively favorable cost–utility ratio for *Salmonella* reduction[29,30] and *Campylobacter* control.[29,30]
- Danish studies compare the economic performance of decontamination technologies at pork abattoirs in Danish farms. One study estimates that the technologies might reduce *Salmonella* from the present level of 2.2% to between 0.18% and 0.89%.[31] A second study compares alternative approaches to *Salmonella* reduction, and finds hot-water decontamination to be the only intervention with positive net present value.[32]
- In Finland, the benefits of the Finnish Salmonella Control Program were estimated to be four times the costs of the program.[33]
- In the United Kingdom, surveillance and early withdrawal of products contaminated with *Salmonella* had benefits to the public sector of 3.5 times the cost, and benefits to society of 23 times the cost.[34,35]

Economic studies on end-use food preparation studies are fewer. One study evaluated the potential cost-effectiveness of a disinfection program that targets high-risk food preparation activities in household kitchens in the United States of America, Canada, and United Kingdom.[36] The average cost–utility ratio in United Kingdom was £86,341 (€124,770) per quality-adjusted life-year (QALY) gained. A QALY is a positive measure of health, and is the equivalent of a year of life lived in full health. When targeting households with high-risk members (those less than 5 years of age, greater than 65 years of age, or immune compromised), the cost per QALY reduced to £28,158 (€40,700).

Cardiovascular and respiratory diseases result from air pollution, which are exacerbated with higher temperatures. While the pathways of effects are indirect and complex, the purpose of this presentation is to explore studies that assess the damage costs of overall air pollution and the economics of various response measures. The economic literature on air quality-related disease burden includes a range of studies examining different interventions applied at different levels, from sector-specific studies to national studies to Europe-wide studies.[37,38] Most studies value economic gains by aggregating the value of reduced premature deaths, lower health-care costs, and work days gained because of lower morbidity. Few studies include other economic benefits, such as avoided damage to agriculture and ecosystems or avoided damage to infrastructure and public buildings from corrosive pollutants. Six studies identified including health impact measurement and presenting benefit–cost ratios were as follows:

- The Clean Air for Europe (CAFE) Program estimates a benefit–cost ratio of between 6 and 19 for achieving air quality targets for Europe.[39]
- The United Kingdom Air Quality Strategy review estimates a benefit–cost ratio of meeting EU standards of between 1.5 and 3.8 for "low-intensity" interventions and 0.9 and 2.3 for "high-intensity" interventions.[40]
- The benefit–cost ratio of air pollution control measures in various sectors in Hungary varies from 3 in agriculture, to 5 in industry, to 6 in transportation and energy, to 16 in household interventions, and to 17 in the service sector.[41]
- Pollution emission reduction in the oil extraction industry in Kazakhstan is estimated to have a benefit–cost ratio of 5.7.[42]
- The economic returns on investing in cycle networks in three cities of Norway are between 3 and 14 times greater than the costs.[43]
- Reducing greenhouse gas emissions in Europe by 20% in 2020 would improve life expectancy by 3.3 months and reduce health damage costs by €12–€29 billion.[44]

For curative or palliative care, several cost-effectiveness studies have been conducted on respiratory conditions, such as asthma interventions,[45,46] allergic rhinitis testing methods,[47] immunotherapy,[48] and drugs.[49,50] For example, the cost per QALY of treating grass allergen with GRAZAX® ranged between €12,930 and €18,263 in seven northern European countries.[49]

For waterborne diseases, rotavirus vaccination has been the subject of several economic evaluation studies across Europe. The cost per QALY gained ranges from €21,900 to €35,076 in Dutch children from 0 to 4 years old, using Rotarix™.[51] In

France, a routine universal rotavirus immunization program was estimated to cost €138,000 per QALY saved and avoid annually 89,000 cases of diarrhea, 10,500 hospitalizations, and 8 deaths.[52] In Finland, the cost per QALY gained was €25,218 for Rotarix and €45,199 for RotaTeq, preventing annually 2,000 hospitalized cases and over 10,000 outpatient visits.[53] The costs and benefits of improved provision of water supply and sanitation services were estimated by the WHO in WHO epidemiological strata B and C (mainly, non-EU and non-OECD countries) – finding that the economic benefits (including health and time savings) were worth 20 times the costs of these services[54] and costing US$9,500 (€6,940) per disability-adjusted life-year (DALY) averted.[55] A DALY is a negative measure of health, the other side of the coin to a QALY (where a health intervention leads to a DALY being avoided while a QALY is gained), and with its own estimation approach.

Limited economic studies on vector-borne disease have been conducted in Europe. A hypothetical tick-borne encephalitis (TBE) vaccine for French troops stationed in the Balkans was estimated to avert 121 cases of TBE at a program cost of €10.05 million, thus costing €83,000 per case prevented.[56] Based on estimated economic benefits of €4.37 million, the net costs were €5.68 million – and hence not justifiable on the grounds of providing economic returns. For Lyme disease, an economic study from the USA estimates the average cost per case averted to be US$4,466 (€4,190).[57] However, cost-effectiveness is highly variable, depending on the vaccine price, incidence, and probability of early detection and referral. Hence, cross-border extrapolations should be made with care, adjusting for differences in key determinants.

Discussion

The presentation of the available economic evidence-base on health costs and health intervention efficiency related to climate change in Europe shows major gaps in evidence, as well as limitations in the quality and usefulness of the existing studies.

First, the few studies presented in this paper indicate that the economic evidence-base is incomplete and fragmented. There are few Europe-wide economic studies that provide a comprehensive overview of the economics of climate change health impacts and response measures. Likewise, there are even fewer peer-reviewed country or city-level studies that provide an adequate economic evidence-base to inform policy decisions. Economic evidence from non-EU European countries is particularly weak.

Second, the lack of standardization of economic outcome measures is a serious constraint to the use of evidence by decision makers. As the literature review reveals, a range of economic outcomes are used, such as cost per DALY averted, cost per QALY gained, cost per case averted, cost per death averted, net cost or net present value, and economic benefits per unit of money invested. Few studies present all of these outcomes together. The outcome presented depends primarily on the study aim. Indeed, the choice of different outcome measures is justified by the fact that different decision-making contexts require expression of efficiency in different units. Interventions requiring public health funds tend to favor the use of cost per QALY gained or cost per DALY averted. Interventions requiring private investment or cost recovery from households, such as food-borne disease prevention or water and sanitation services, tend to show net present value or benefit–cost ratio. However, the reviewed economic studies do not analyze the mix of financing sources that might be required to successfully implement the evaluated interventions. This is a particular gap given that the analysis of financing options provides a concrete link from academic studies to policy makers.

Third, widely varying climate models and economic methods and impacts were used in the studies reviewed, making it difficult to compare results between studies. There are a large number of climate models that vary in their specifications and precision. Economic models include various types of general equilibrium model (where linkages between impacts in different sectors are quantitatively assessed), sector-specific estimates (with no linkage assessed between sectors), and also a mixture of the two such as the WITCH model.[20] Most studies only examine health service costs and savings, while other studies such as the World Bank adaptation cost study broadened the intervention beyond health services.[18] Health effects included in health impact models vary – some focus on only the negative effects such as heat-related health impacts or salmonellosis, while others present net effects by including the positive health effects associated with climate change in the European Region such as fewer cold-related deaths.

Valuation approaches vary between studies. For example, premature mortality is valued in terms of both a saved life and a saved life year. Valuing a saved life year usually leads to lower economic values than saved lives, especially for the elderly population. Furthermore, some studies only measure morbidity costs (mainly health-care costs) or some measure only mortality costs, while others include both morbidity and mortality costs. In general, when they are both included, mortality costs outweigh morbidity costs by several times. Given that mortality valuations are based on value of statistical life, and not actual financial transactions to reduce health risks, the major share of overall welfare gain from health protection measures is of a non-financial nature. Cost comparisons between studies are further impeded by the fact that the baseline year is often different, the years covered by the study are different, and some studies estimate future impacts in current values using discounting, while others do not. Good practice is to present results under different scenarios to show sensitivity of results to different assumptions or study scope and to support comparison.

Fourth, the number of studies that assess the health effects of climate change is very few. While general relationships and trends are predicted with increasing confidence as models are refined and data quality improves (eg, on changes in temperature and precipitation), the health impact numbers are still not known. The only EU-wide health economic estimates are on selected temperature-related disease burdens – on *Salmonella* and diarrheal disease cases. Given the variation in climate models and impact assessment frameworks used, combined with uncertainty in economic values, the resulting economic outcomes would have very wide confidence intervals or ranges if sensitivity analysis was conducted using alternative data inputs. However, this is rarely done in studies. This makes it extremely difficult to understand the range of likely economic impact or intervention efficiency, and thus reduces the strength of policy recommendation possible. Further, current available health vulnerability assessments have not been used to assess the economic costs.

Fifth, the long-time horizons involved in climate change make it important to clarify what is the baseline scenario. For example, should the costs of future measures take into account future expected health sector developments that affect underlying disease vulnerability and hence adaptation responses? This point is particularly relevant for the lower income countries of Europe where there is a greater adaptation deficit. Whether future health investments are labeled as development investments or adaptation investments will affect the calculation of adaptation costs. Given that investments in climate change adaptation will increasingly become part and parcel of a country's development process, especially for lower income countries, the "development baseline" approach adopted by the World Bank study, for example, will underestimate the actual costs of adapting to climate change.[18]

Conclusions

Based on this review, methodological guidelines specific to the economics of health and climate changes are needed to stimulate more economic research and provide standardization of approaches. More recently, the WHO Regional Office for Europe developed detailed methods on how to assess impacts and adaptation costs, which hopefully will be helpful to further shape this agenda.[13] Further, more information and data are necessary on the health impacts of climate change, potential future developments, adaptation options, and the monetary requirements in the health sector and beyond. At the moment, the few studies available indicate simply that more resources need to be allocated in countries with the highest health impacts and with the least resilience to withstand climate change. Despite the evidence gaps, investing in health protection measures will pay economic dividends in terms of saved treatment costs, gained workforce productivity, as well as the very large social and welfare value associated with saved lives. Current approaches focus mainly on a near-term perspective with a lower risk "no regrets" policies, rather than a longer term perspective. A monitoring and surveillance system targeted to detect the health effects of climate change would help to identify emerging health risks so that timely action can be taken, as well as would generate data to be used in assessments and economic analysis.

Evidence plays a more important role than it currently does in guiding health and policies that cut across different sectors. This fact is generally recognized across EU member states, for example, where health systems regulate what health interventions are applied through strict Health Technology Assessment procedures and other evidence-to-policy initiatives.[58] However, preventive policies – environmental health policies more specifically – have a significantly weaker evidence-base than curative and drug-related procedures in the health community. More evidence is required to show the health-protecting effect of safe environments (eg, urban areas, homes, workplaces) as well as the intangible health and non-health impacts. To support the generation of this evidence, methodological guidelines specific to the economics of health and climate change are needed to stimulate more economic research and provide standardization of approach. The first step has been done by the recent economic tool developed by the WHO Regional Office for Europe to guide health damage and adaptation studies.[13] This will help to stimulate health and scientific authorities to consider approaches to utilizing existing health economic studies based on recalculating results from common methods using local input values, and adjusting to current prices. Access to the underlying data and tools remains a challenge, in particular when health effects estimations are not available or detailed health service utilization costs are required.

Significant health gains can be achieved through interventions that are not primarily under the control of the health sector, but are embedded in action at, for example, the urban or regional level. Health gains from investments in other sectors are an opportunity rather than a threat. Economic analyses in areas such as air pollution, nutrition, and transport policy generally show the importance of health outcomes. The new Health 2020 aims at promoting health in all policies.[59–61] Collaboration with other ministries and public agencies, in order to ensure that health is not overlooked in any policy that can potentially harm or benefit health, is embedded in the Expo Convention and the strategic impact assessment, however not always carried out. Economics can be used as a common language to make the case for intervention and hence bring others on board. To achieve this, a standardized approach, increased transparency of methods and interests, and a more common presentation from economic studies are needed.

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Author Contributions

Conceived and designed the experiments: GH, BM. Analyzed the data: GH. Wrote the first draft and follow-up drafts of the manuscript: GH. Contributed to the writing of the manuscript, from the European and public health angle: BM. Agree with manuscript results and conclusions: GH, BM. Jointly developed the structure and arguments for the paper: GH. Made several critical revisions and approved final version: GH. Both authors reviewed and approved of the final manuscript.

REFERENCES

1. IPCC. Impacts, Adaptation and Vulnerability. Working Group II Report. Intergovernmental Panel on Climate Change, Fourth Assessment Report; Geneva: IPCC; 2007.
2. IPCC. Mitigation of Climate Change. Working Group III Report. Intergovernmental Panel on Climate Change, Fourth Assessment Report; Geneva: IPCC; 2007.
3. Amman M, Bentham G, Dalbokova B, et al. *Climate and Health Impact Assessment*. Technical background paper for the Climate, Environment and Health Action Plan and Information System (CEHAPIS) project. Copenhagen: World Health Organization Regional Office for Europe; 2010.
4. Watkiss P, Horrocks L, Pye S, Searl A, Hunt A. *Impacts of Climate Change in Human Health in Europe. PESETA-Human Health Study*, Luxembourg: European Commission Joint Research Centre and Institute for Prospective Technological Studies; 2009.
5. Menne B, Ebi K, eds. *Climate Change and Adaptation Strategies for Human Health*. WHO Regional Office for Europe. Darmstadt: Steinkopff; 2006.
6. Swart R, Biesbroek R, Binnerup S, et al. *Europe Adapts to Climate Change. Comparing National Adaptation Strategies*, PEER Report No 1. Helsinki: Partnership for European Environmental Research; 2009.
7. European Environment Agency. Europe Climate Adaptation Platform. European Environment Agency and the European Commission; 2013. Available at http://climate-adapt.eea.europa.eu/web/guest/countries. Accessed October 9, 2014.
8. WHO Regional Office for Europe (2010): Protecting health in an environment challenged by climate change: European Regional Framework for Action. Copenhagen, Denmark. http://www.euro.who.int/__data/assets/pdf_file/0005/95882/Parma_EH_Conf_edoc06rev1.pdf?ua=1.pages10.
9. WHO Regional Office for Europe. *Country Work*; 2013. Available from: http://www.euro.who.int/en/what-we-do/health-topics/environment-and-health/Climate-change/country-work. Accessed April 30, 2013.
10. WHO Regional Office for Europe. *Where We Work*; 2013. Available from: http://www.euro.who.int/en/where-we-work. Accessed April 30, 2013.
11. Bosello F, Roson, Tol RSJ. Economy-wide estimates of the implications of climate change: human health. *Ecol Econ*. 2006;58:579–81.
12. Kovats S, Lloyd S, Hunt A, Watkiss P. The impacts and economic costs on health in Europe and the costs and benefits of adaptation. Technical Policy Briefing Note 5. Results of the EC RTD ClimateCost Project. In Watkiss, P ed., *The ClimateCost Project*. Final Report. Volume 1: Europe. Sweden: Stockholm Environment Institute; 2011.
13. WHO Regional Office for Europe. *Climate Change and Health: A Tool to Estimate Health and Adaptation Costs*; 2013. Available from: http://www.euro.who.int/en/health-topics/environment-and-health/Climate-change/publications/2013/climate-change-and-health-a-tool-to-estimate-health-and-adaptation-costs.
14. Alberini A, Chiabai A, Nocella G. Valuing the mortality effects of heat-waves. In: Menne B, Ebi K, eds. *Climate Change Adaptation Strategies for Human Health*. Germany: Springer; 2006.
15. Hübler M, Klepper G, Peterson S. Costs of climate change: the effects of rising temperatures on health and productivity in Germany. *Ecol Econ*. 2008;68(1–2):381–93.
16. Holland M, Amann M, Heyes C, et al. The reduction in air quality impacts and associated economic benefits of mitigation policy. Technical Policy Briefing Note 6. Summary of results from the EC RTD ClimateCost project. In: Watkiss, P ed., *The ClimateCost Project*. Final Report. Volume 1: Europe. Sweden: Stockholm Environment Institute; 2011.
17. Nordhaus W, Boyer J. *Warming the World: Economic Models of Global Warming*. Cambridge, MA: MIT Press; 2000.
18. World Bank. The Cost to Developing Countries of Adapting to Climate Change. New Methods and Estimates. The Global Report of the Economics of Adaptation to Climate Change Study. Washington, DC: World Bank; 2010.
19. Ebi K. Adaptation costs for climate change-related cases of diarrhoeal disease, malnutrition, and malaria in 2030. *Global Health*. 2008;4:1.
20. Agrawala S, Bosello F, Carraro C, De Cian E. *Adaptation, Mitigation and Innovation: A Comprehensive Approach to Climate Policy*. Working Paper No. 25/WP/2009. Venice: Department of Economics, University of Venice; 2009.
21. Hunt A, Boyd R, Taylor T, et al. Report on costs of the hot summer of 2003. Project E – Quantify the cost of impacts and adaptation, UK Climate Change Impacts and Adaptation: Cross-Regional Research Programme, UK Department for Food Research and Agriculture; 2007.
22. ONERC. Climate Change: Costs of Impacts and Lines of Adaptation, Observatoire National sur les Effets du Réchauffement Climatique (National Observatory for the Impacts of Global Warming). Report to the Prime Minister and Parliament; 2009.
23. United Nations Framework Convention on Climate Change. *Investment and Financial Flows to Address Climate Change*. Bonn: UNFCCC; 2008.
24. de Bruin K, Dellinkm R, Agrawala S. Economic aspects of adaptation to climate change: integrated assessment modelling of adaptation costs and benefits, Organisation for Economic Cooperation and Development. Environment Working Papers 6. Paris: OECD Publishing; 2009.
25. Drummond MF, O'Brien B, O'Brien B, et al. *Methods for the Economic Evaluation of Health Care Programmes*. 2nd ed. Oxford: Oxford University Press; 1997.
26. United Kingdom National Health Service. Heatwave Plan for England. Protecting Health and Reducing Harm from Extreme Heat and Heatwaves. London: Public Health England; 2010.
27. Kalkstein LS, Jamason PF, Greene JS, Libby J, Robinson L. The Philadelphia hot weather-health watch/warning system: development and application, summer 1995. *Bull Am Meteorol Soc*. 1996;77(7):1519–28.
28. WHO Regional Office for Europe. *Heat-Waves: Risks and Responses*. Copenhagen: WHO Regional Office for Europe, Health and Global Environmental Change Series No. 2; 2004.
29. Mangen MJJ, de Wit GA, Havelaar AH. Economic analysis of *Campylobacter* control in the Dutch broiler meat chain. *Agribusiness*. 2007;2007(23):2.
30. Mangen MJ, Havelaar AH, Poppe KP, de Wit GA, CARMA Project Team. Cost-utility analysis to control *Campylobacter* on chicken meat: dealing with data limitations. *Risk Anal*. 2007;2007(27):4.
31. Lawson LG, Jensen JD, Christiansen P, Lund M. Cost-effectiveness of *Salmonella* reduction in Danish abattoirs. *Int J Food Microbiol*. 2009;134:126–32.
32. Goldbach S, Alban L. A cost–benefit analysis of *Salmonella*-control strategies in Danish pork production. *Prev Vet Med*. 2006;77:1–14.
33. Kangas S, Lyytikäinen T, Peltola J, Ranta J, Maijala R. Costs of two alternative *Salmonella* control policies in Finnish broiler production. *Acta Vet Scand*. 2007;49(1):35.
34. Roberts JA, Sockett PN, Gill ON. Economic impact of a nationwide outbreak of salmonellosis: cost benefit of early intervention. *Br Med J*. 1989;298:1227–30.
35. Roberts J. Economic aspects of food-borne outbreaks and their control. *Br Med Bull*. 2000;56(1):133–41.
36. Duff SB, Scott EA, Mafilios MS, et al. Cost-effectiveness of a targeted disinfection program in household kitchens to prevent foodborne illnesses in the United States, Canada, and the United Kingdom. *J Food Prot*. 2003;66(11):2103–15.
37. Hutton G. Economic evaluation of environmental health interventions to support decision making. *Environ Health Insights*. 2008;2:137–55.
38. Larsen B, Hutton G, Khanna N. *Air Pollution*. Copenhagen Consensus 2008 Challenge Paper, Copenhagen Business School; 2008.
39. Holland M, Watkiss P, Pye S, de Oliveira A, Van Regemorter D. Cost–benefit analysis of the thematic strategy on air pollution, European Commission DG Environment. AEAT/ED48763001/Thematic Strategy. 2005;Issue 1.
40. United Kingdom Department for Environment Food and Rural Affairs. Economic Analysis to Inform the Air Quality Strategy Review Consultation: Third Report of the Interdepartmental Group on Costs and Benefits. London: Department for Environment, Food and Rural Affairs (DEFRA); April 2006.
41. Aunan K, Pátzay G, Asbjørn Aaheim H, Martin Seip H. Health and environmental benefits from air pollution reductions in Hungary. *Sci Total Environ*. 1998;212:245–68.
42. Netalieva I, Wesseler J, Heijman W. Health costs caused by oil extraction emissions and the benefits from abatement: the case of Kazakhstan. *Energy Policy*. 2005;33:1169–77.
43. Sælensminde K. Cost–benefit analyses of walking and cycling track networks taking into account insecurity, health effects and external costs of motorized traffic. *Transp Res Part A Policy Pract*. 2004;38:593–606.
44. European Commission. Impact assessment, SEC(2007) 1374. Commission of the European Communities; 2007.
45. Mudarri D, Fisk W. Public health and economic impact of dampness and mold. *Indoor Air*. 2007;17(3):226–35.
46. Campbell JD, Spackman DE, Sullivan SD. Health economics of asthma: assessing the value of asthma interventions. *Allergy*. 2008;63(12):1581–92.
47. Lewis AF, Franzese C, Stringer SP. Diagnostic evaluation of inhalant allergies: a cost-effectiveness analysis. *Am J Rhinol*. 2008;22(3):246–52.
48. Pokladnikova J, Krcmova I, Vlcek J. Economic evaluation of sublingual vs subcutaneous allergen immunotherapy. *Ann Allergy Asthma Immunol*. 2008;100(5):482–89.

49. Bachert C, Vestenbaek U, Christensen J, Griffiths UK, Poulsen PB. Cost-effectiveness of grass allergen tablet (GRAZAX) for the prevention of seasonal grass pollen induced rhinoconjunctivitis – a Northern European perspective. *Clin Exp Allergy*. 2007;37(5):772–9.
50. Canonica GW, Poulsen PB, Vestenbaek U. Cost-effectiveness of GRAZAXs for prevention of grass pollen induced rhinoconjunctivitis in Southern Europe. *Respir Med*. 2007;101:1885–94.
51. Goossens LM, Standaert B, Hartwig N, Hövels AM, Al MJ. The cost-utility of rotavirus vaccination with Rotarix™ (RIX4414) in the Netherlands. *Vaccine*. 2008;26:1118–27.
52. Melliez H, Levybruhl D, Boelle PY, Dervaux B, Baron S, Yazdanpanah Y. Cost and cost-effectiveness of childhood vaccination against rotavirus in France. *Vaccine*. 2008;26:706–15.
53. Nohynek H, Salo H, Renko M, Leino T. Finland introduces rotavirus vaccine into the national vaccination programme in September 2009. *Euro Surveill*. 2009;14(35):ii:19322.
54. Hutton G, Haller L, Bartram J. Global cost–benefit analysis of water supply and sanitation interventions. *J Water Health*. 2007;5(4):481–502.
55. Haller L, Hutton G, Bartram J. Estimating the costs and health benefits of water and sanitation improvements at global level. *J Water Health*. 2007;5(4):467–80.
56. Desjeux G, Lemardeley P, Colin C, Pascal B, Labarère J. Cost–benefit ratio of tick-borne encephalitis vaccination of French troops based in Kosovo. *Revue d'Epidémiol Santé Publique*. 2001;49(3):249–57.
57. Meltzer MI, Dennis DT, Orloski KA. The cost effectiveness of vaccinating against Lyme disease. *Emerg Infect Dis*. 1999;5(3):321–8.
58. Garrido MV, Kristensen FB, Nielsen CP, Busse R. *Health Technology Assessment and Health Policy-Making in Europe*. Current Status, Challenges and Potential, World Health Organization, on behalf of the European Observatory on Health Systems and Policies, Copenhagen; 2008.
59. European Commission. Council Conclusions on Health in All Policies (HiAP), 2767th Employment, Social Policy, Health and Consumer Affairs Council Meeting; Brussels; 30 November and 1 December 2006.
60. Ståhl T, Wismar M, Ollila E, Lahtinen E, Leppo K, eds. *Health in all Policies: Prospects and Potentials*. Helsinki: Ministry of Social Affairs and Health Finland; European Observatory on Health Systems and Policies; 2006.
61. WHO. Protecting Health from Climate Change: Vulnerability and Adaptation Assessment. Geneva, Switzerland, World Health Organization; 2011.