Valuing human health effects from global environmental change

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1 Introduction

Purpose of the report and main take-aways

This report describes the approach for valuing human health effects from global environmental change. The rationale for valuing human health impacts is to improve comparisons of the benefits from environmental improvements with its costs. Valuation involves quantifying the extent of the human health effects, and then monetising these effects using various approaches, such as the value of a statistical life. Since estimates are typically produced on a local level, many assumptions are needed to produce global estimates. Several examples of studies that have valued human health impacts on a global scale are discussed, along with the strengths and weaknesses of each. There is strong evidence that global environmental change harms human health, though the human health effects only represent a small fraction of the total effects on human well-being.

The main take-aways from this report are that:

- Human health effects represent only a small fraction of the total effects of global environmental change on human well-being. As a result, focussing on human health alone can lead policy-makers to undervalue the environment, and lead to mistaken policy conclusions. For example, there were 739 heat-related deaths in Chicago (USA) in the heat wave of 1995. Chicago has experienced comparable temperatures since then but very few heat-related deaths, largely because of increased use of air conditioning. Solely focussing on the health effects would lead one to perhaps incorrectly conclude that heat waves are not a major concern.

- Valuing the impact of global environmental change on human health is an ambitious exercise, requiring many assumptions to provide global estimates. For this reason, studies assessing global impacts are few and far between, with many more studies focussing on a limited set of outcomes or limited set of nations, often without attempting to monetise impacts.

- Several studies seeking to assess the impact of global environmental change on human health are so general in scope that they only assess the effect of a particular change in the environment, such as removing pollution completely. As a result, such studies are less useful for understanding the health effects from alternative policies under consideration.

- While some local or regional studies take human capacity to adapt into account, using various assumptions and under a multitude of different scenarios, the global studies often fail to assume any change in human behaviour. Therefore, the results present a worst-case scenario, and are likely to overstate actual impacts.

- The benefits of global environmental change to human health are seldom taken into account in these studies. For instance, while heat waves brought about by climate change may increase mortality, a decrease in cold spells could decrease mortality. This reinforces the worst-case scenario conclusions that some of these studies reach.

- Despite these caveats, there is strong evidence that global environmental change affects human health. We must continue to fine-tune our understanding and methodologies, and extend the scope beyond human health.

More generally

Health is the cornerstone of our lives, and damages to human health represent a significant loss to well-being. Why, then, do we need to place a monetary value on health? Although many people are uncomfortable with the notion of such a concept, we do so for the simple reason of trying to improve comparisons. By measuring the health benefits from improved environmental conditions in monetary units, we can combine it with other monetised benefits and readily compare it to the costs associated with improving the environment. Valuation allows us to move away from comparing "apples to oranges" to comparing "apples to apples."

Global environmental change can affect human health in many ways. In this report, we focus on impacts where the chain of events linking environmental change to human health are most salient. Such impacts consist of both direct and indirect effects. A direct effect might be an increase in heat waves from a warmer climate, which increases human suffering. Whereas an indirect effect might be that a warmer climate leads to a change in the seasonal and geographic distribution of vectors, which affects the spread of vector borne diseases, such as malaria and Dengue fever.

By focusing on these more salient human health impacts, this report captures one important way in which global environmental changes impacts human well-being. There are several other ways in which global environmental change may affect humans. First, there may be more inconspicuous routes by which human health impacts may arise. For example, a warmer climate may lead to reductions in crop yield, which affects human nutrition through changes in food availability. Second, there are other economic damages beyond health impacts, such as changes in economic output and conflict, which pose significant effects on social welfare. Focusing solely on the most salient human health outcomes paints a partial picture of the total damages to society from global environmental change.

This paper has 3 sections. The first reviews the methodology used for valuing environmental health impacts, discussing the limitations involved in each step. The second discusses some evidence on the estimates of global environmental change on human health. The third section concludes by highlighting some of the limitations in our understanding of the human health impacts.

2 Review of methodology

Valuing the human health impacts from global environmental change involves two main steps. The first step involves estimating the effect of the environment on health. In particular, **quantifying** the number of additional cases of mortality, disease, or other outcomes of interest due to global environmental change. The second step consists of **monetising** these additional cases.

A Quantifying health effects

The first step of valuation involves the use of empirical estimates of the effects of global environmental change on human health. This involves calculating the number of cases of a particular disease arising from global environmental change, such as the number of cases of mortality, malaria, or diarrhoea disease. To obtain this, we must rely on **dose-response** estimates of the relationship between the environment and health. This evidence comes from epidemiological studies, though it is not limited to the discipline of epidemiology. For example, many economists study the link between the environment and human health. In general, the empirical estimates of the dose-response relationship are buttressed by biological models that motivate the physiological underpinnings of the relationship. For example, exposure to higher temperatures limits the body's ability to rid itself of excess heat, which leads to heat-related illnesses, such as heat exhaustion and heat stroke.

There are at least three important steps for producing reliable estimates of the relationship between the environment and human health: **measurement**, **causality**, and **generalisability**. Measurement concerns our ability to observe the degree of environmental exposure (how many heat waves are people exposed to? Which people do we consider being exposed to a heat wave?) and the health endpoints of interest. Since considerable efforts are needed to collect these data, such measures are more readily available in nations where governments have larger resource. This leads to greater data availability in wealthier countries, and less data in poorer countries. Figure 1 provides evidence of the availability of mortality data by country obtained by the Climate Impact Lab, an interdisciplinary group studying the impacts of climate change at a comprehensive level. While not an exhaustive list, it shows that such data is unavailable in much of the world.[1] This is even more true for events less salient than death, such as doctor visits and hospital admissions.

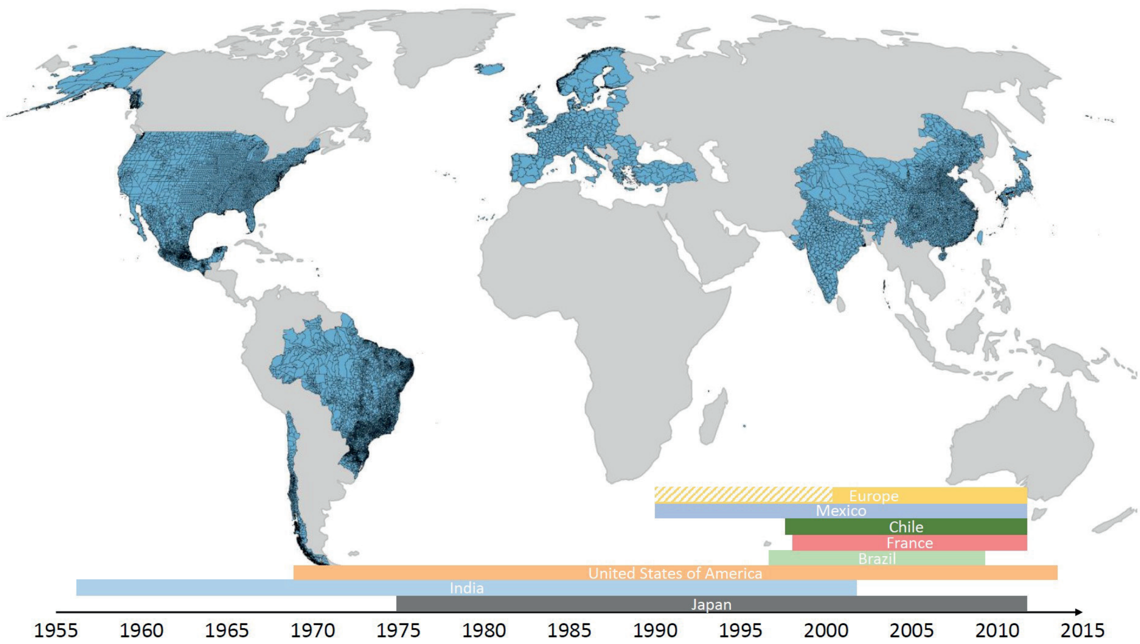

Figure 1. Mortality data coverage by country
Notes: This figure shows the availability of mortality data by country. Source: Climate Impact Lab.

Even in nations with higher levels of data collection, measurement issues arise in terms of the ability to obtain full coverage of environmental exposure and disease surveillance. Monitoring networks only provide partial measures of exposure, whereby people who live between monitors have exposure approximated using various statistical approaches. Improved disease and environmental surveillance has enhanced measurement reliability, but many holes remain.

Another important part of measurement involves projecting future exposures. Many of the impacts from global environmental change are expected to occur with greater intensity in the future, such as particularly warm temperatures at the end of the 21st century. In order to make such projections, we rely on models to produce such output. These models involve many assumptions, some of which may be more reasonable than others. The most common approach for accommodating this uncertainty is to provide a range of projections under different modelling assumptions, and assess the sensitivity of the human health impacts under the different scenarios.

The second important step for producing reliable estimates of the relationship between the environment and health involves the ability to uncover causal relationships. Statistical studies may uncover a correlation between the environment and health, but this may not tell us about the causal effect of the environment on health. For example, hotter areas may experience higher death rates, but this may be due to factor other than the heat, such as lower levels of economic development and access to health care. It is essential to uncover causal effects because this will better inform society about the potential effects from policy changes that alter the environment. Methodological tools are available to improve the ability to uncover causal effects, but their applicability may be limited to distinct settings.

The last important step involves generalisability, which describes how the effects estimated in one area during one time period inform us of the effects in other areas or during other time periods. Issues with measurement often lead to applying estimates from areas with high quality data to areas with low quality data, which assumes the same dose-response holds across the two areas. A temperature of 35°C may have significantly different effects on mortality in, say, London, U.K., than it does in Lagos, Nigeria, because 35°C is more common in Lagos, where people have learned to cope with such temperatures. Figure 2 provides evidence on this point, demonstrating that the effect of hotter temperatures has a smaller effect in regions with higher average temperatures.

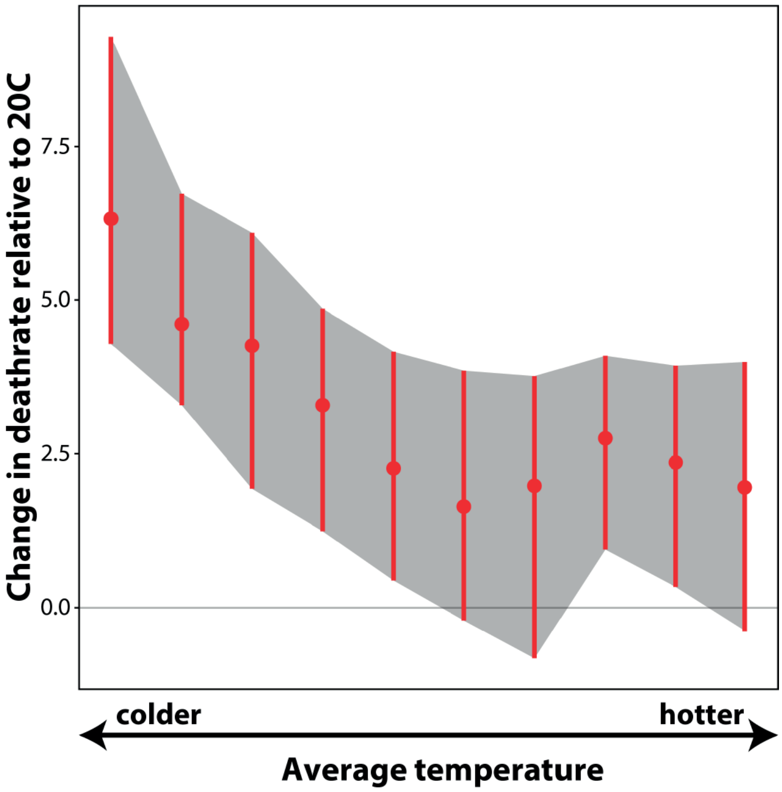

Figure 2. Change in death rate relative to 20C by average temperature
Notes: This figure shows the estimated impact from being above 20C (relative to 20C) separately by historical climate. Source: Climate Impacts Lab.

The same concern may hold true across time, as 35C temperatures used to have a much larger effect on mortality in the past than it does today. This point is particularly important because many of the damages from global environmental change are far in the future, allowing society time to adapt to these changes. As an example, figure 3 demonstrates how the death rate from higher temperatures has fallen dramatically in New York City over the past 100 years.[2]

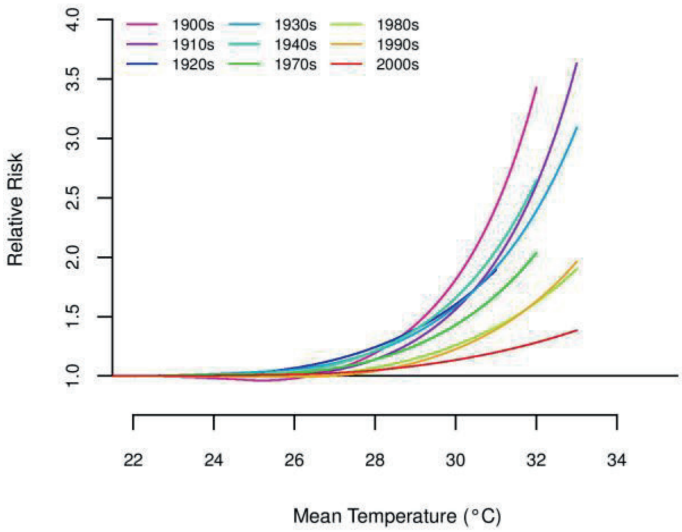

Figure 3. Temperature – mortality curves of overall cumulative relative risk of death for New York City by decade, 1900s -2000s
Notes: This figure shows the dose-response relationship between mortality and mean temperature separately by decade. Source: Petkova et al., 2014.

These dose-response estimates are then applied to the exposed population to obtain the number of cases of the outcome of interest. For example, if the dose-response estimate indicates that each day when temperature exceeds 35C leads to a 1 percent increase in mortality for people over age 65, we would apply this 1 percent to the number of people over 65, which is the exposed population. If there are 1 million people over age 65, this estimate would imply that 1 additional day over 35C would lead to an additional 10,000 deaths. This would necessitate the collection of data on the exposed population, something that also often proves elusive in some countries.

B Monetising health effects

The second step of valuation involves applying a monetary value to the human health damages due to global environmental change. The valuation involves different calculations depending on the type of health impact. Valuation also includes costs that people incur to minimise risks. Finally, valuation accounts for the fact that outcomes occur at different time periods and must be compared in the same time unit.

i Mortality

To monetise the mortality impacts, economists apply the concept of the **value of statistical life** (VSL). The VSL is the amount of monetary compensation received by an individual for a particular increase in the risk of death.[1] Importantly, this does not represent a change from life to death with certainty, as if someone pointing a gun asks “your money or your life?” Instead, the VSL focuses on changes in the probability that death will occur. To fix ideas, imagine 100 people considering an action that has a .01 probability of death; this action results in the loss of 1 “statistical” life. People often incorrectly drop the modifier “statistical” and instead refer to it as the “value of life,” which unfortunately exacerbates misunderstandings about the concept.[2]

The VSL is typically obtained from studies in the labour markets, whereby one estimates the effect of occupational risk on the wages of workers. Workers who are exposed to higher mortality risk on the job are compensated with higher wages, and this higher compensation is used to infer the VSL. A single VSL is estimated in a study, and this VSL is then applied to a different setting in which mortality occurs. Hundreds of VSL studies have been conducted, with the vast majority of studies suggesting a VSL ranging from $3 million to $9 million.[3] The range in estimates is largely due to different contexts and methodologies, and is generally considered acceptable on statistical grounds.

As an example of applying the VSL to monetise mortality effects, continue with the temperature-mortality relationship described above where 10,000 people over age 65 die prematurely from 1 additional day over 35C. Assuming a VSL of $6 million, we would value the total loss in mortality from 1 additional day over 35C by multiplying 10,000 by $6 million to arrive at a value of $60 billion. Note that this VSL may come from labor market studies, but the mortality occurs in people over age 65, many of whom may not be working.

While there are several methodological concerns with the VSL, the two most relevant for this report centre on VSL-transfer and VSL across the lifecycle. **VSL-transfer** involves applying the VSL estimated in one location to another location. As previously mentioned, most VSL studies are based on data from the United States. These estimates may not readily apply to other countries because of differences in income levels and attitudes toward risk. For example, lower incomes in China would suggest people there are willing to pay less to avoid a certain risk. Absent country-specific estimates of the VSL, the most common, albeit imperfect, approach is: 1) to scale the US-based VSL by purchasing power parity (PPP), which divides the price of a particular “basket of goods” in a particular country by the price of that same basket in the US; and 2) to adjust the VSL by the sensitivity of VSL with respect to income, referred to as the “income elasticity.”

1 Alternatively, it could be the monetary amount paid by an individual for a particular decrease in the risk of death.
2 This misunderstanding has led to efforts to rebrand the VSL, such as the “value for mortality reduction,” but until there is widespread agreement we use the more commonly accepted term.

A second concern with the VSL centres on applying it across the lifecycle. The VSL is typically estimated using the working-age population, but that same VSL is applied to all individuals, regardless of age. Since remaining life expectancy decreases with age, the VSL is unlikely to be constant across the lifecycle. A 30 year old may be willing to pay more to reduce risk than an 80 year old because there are more years left in life. This is a potential issue because most studies that estimate the VSL focus on the working age population, but many of the impacts from global environmental change fall on the elderly where that VSL may not readily apply. One approach to this issue is to use estimates of value of statistical life-year (VSLY), which allows one to account for differences in remaining life expectancy.

ii Morbidity

For valuing the impacts from morbidity – the incidence of disease – there is much less agreement over the appropriate approach. A common approach is to measure the amount of **health care expenditures** devoted to treating a particular disease as affected by global environmental change. Health care expenses, which represent a significant portion of total expenditures in a nation, are a consistent concept across many countries. To estimate health care expenditures associated with global environmental change requires estimating expenditures associated with each disease, and then attributing a portion of expenditure on the disease to the environment. This would involve separate estimates of expenses by country, noting that not all countries provide such estimates.

Despite the appeal from using health care expenses to measure disease impacts, unlike VSL it is an incomplete measure of willingness to pay to lower risk. In particular, it misses three important components of the total costs to humans. One, it only measures the costs to treat an individual with an illness, and does not capture the pain and suffering that individual feels. Second, it does not capture the lost productivity for an individual forced to miss time at work because of the illness. Third, it only includes formal health care encounters, thereby omitting changes in health that do not result in more formal care, either because such care is unavailable or because any changes in health are subtle enough that they do not necessitate formal care. These more subtle effects, such as fatigue and diminished focus, may be more widespread, affecting not only the most vulnerable segments of the population but also healthy, working-age adults.

iii Avoidance behaviour

In addition to direct impacts on mortality and morbidity, an additional impact consists of the actions people engage in to reduce the risk from exposure. These actions range from minor adjustments in daily activities, such as spending time indoors on a hot day, to major adjustments, such as purchasing capital equipment and relocating to a new city or even country.

Accounting for avoidance behaviour plays two important roles. First, these behaviours have costs associated with them. While a purchase of an air conditioner has clear out of pocket expenses, these behaviours can also have non-pecuniary effects as well. A person may forgo a particular outdoor activity on a hot day and choose instead to spend that time inside, and this reduces the well-being of that person. These costs can often be a significant portion of the total costs to society.[4]

Second, avoidance behaviour can affect the estimated dose-response relationship between the environment and health. This is particularly important in the context of climate change because the effects are far into the future, allowing people time to adapt to the changing climate. Through the advent of air conditioning, for example, we have seen the dose-response relationship between temperature and mortality decline markedly over the past century.[5] This provides a specific explanation behind the complications involved in generalising dose-response estimates from one setting to another.

iv Discounting

Many of the health effects that we experience from the environment occur at different time periods. This is particularly relevant in the case of climate change, where steps taken today may not lead to climate and thus health improvements until 50-100 years from now. Furthermore, many of the costs that we incur from policy changes to improve the environment are experienced immediately. In order to compare dollar values at different points in time, economists use an approach called discounting. Discounting takes the amount of all future values, and discounts them to the present term. This step is necessary because the resources used to improve the environment could be used in some other way, and we must account for this other possible use. For many projects where the costs and benefits occur within a person's lifetime, there is less contention over the choice of the discount rate. When projects cross generations, however, there is a strong and yet unresolved debate over the choice of the discount rate. Unfortunately, small changes in discount rates can have large effects of the merit of a policy, making the choice of a discount rate a pivotal step.

3 Example applications

In this section, we describe some example applications from studies that have attempted to value the human health impacts from global environmental change. Many studies explore the first component of the above steps (i.e., quantifying the mortality impacts), or perform a full valuation but only at a regional or local level. For example, several studies performed at a national level estimate the mortality impacts from climate change.[6] However, very few provide a full valuation at the global level. Given this paucity of evidence, we also include some studies that provides estimates of global disease counts but do not explicitly value them, as this valuation may be performed after the fact.

A Air pollution

Air pollution concerns stem from both local issues as well as global ones, such as higher temperatures increasing ozone concentrations and more droughts contributing to forest fires. The recent Lancet-commissioned report on the human health impacts from air pollution ("The Lancet Commission on pollution and health"), although it did not distinguish between local versus global impacts, provides a useful, state-of-the-art application of valuation.[37] For dose-response estimates, the authors relied on the Global Burden of Disease (GBD) estimates provided by the 2015 WHO report, which used various methodologies to produce estimates of the amount of disease attributable to the environment. In the Lancet report, they value these changes and provide two relevant tables: VSL damages by region and the percent of total health expenditures by disease category by country.

For VSL damages by region, the report used GBD reports of the number of deaths due to ambient particulate pollution. To value these changes in mortality, the report transfers the OECD base VSL of $3.83 million ($2015) to other countries using the ratio of their PPP Gross National Income (GNI) to the OECD GNI ($40,002) and the income elasticity of the VSL by income-tiers as suggested by the World Bank. Results are shown in Table 1. To interpret numbers, there are 0.6 million estimated deaths due to ambient particulate pollution in the African Region, and the VSL damages per person is $47.[4]

WHO Region	Estimated deaths (millions)	Value per capita ($2015)
African Region	0.6	47
Eastern Mediterranean Region	0.2	168
European Region	0.1	1,168
Region of the Americas	0.1	715
South-East Asia Region	1.3	96
Western Pacific Region	0.7	659

Table 1. Ambient Particulate Pollution Effects by WHO Region
Notes: This table provides the estimated number of deaths in each WHO region attributable to air pollution, and the per capita value of these deaths. Source: Landrigan et al., 2017.

3 The report also focused on other environmental concerns, such as toxins and indoor pollution, but we have chosen to omit those since they are generally not considered global environmental issues.
4 The report also estimates the loss in worker productivity due to premature death. We omit this from this paper because it represents an incomplete picture of the full mortality costs.

The largest number of deaths occur in the South-East Asia region, which is due in part to higher pollution levels but also higher population levels. The higher value in Europe reflects the higher VSL for that region.

For measuring morbidity damages, the report used GBD estimates of **disability adjusted life years** (DALYs), which measures the number of years a person lives with a disability plus the years of life lost. The years with disability are weighted to account for the fact the some disabilities are worse than others. The authors estimated the percent of total health care expenses due to 3 disease categories: cancer, cardiovascular disease, and respiratory diseases. To approximate the average healthcare costs for each disease, the authors multiplied the ratio of total healthcare expenses to total number of DALYs by the ratio of the percent of total healthcare expenses due to a disease to the percent of DALYS due to that same disease. Only a handful of countries had consistently reported measures of healthcare expenditures, and only one from a Low and Middle Income Country (Sri Lanka). The report found that 3.5% of total healthcare expenditures in high income countries were spent on diseases caused by air pollution, and 7.4% of total health care expenditures were spent on disease in Sri Lanka. As previously noted, the healthcare expenses only represent a partial picture of the total morbidity damages.

This study provides a useful benchmark for understanding the magnitude of health effects from air pollution. As with all studies, there are important limitations that must be noted. These limitations are not due to research error but due to the natural uncertainty and need for assumptions when conducting research. The most significant limitation of this study is that it measures the burden of disease due to all pollution. As such, it is only useful for understanding the effect from removing pollution completely, and cannot be used for understanding the effect of various policy changes that might lower pollution by a particular amount. A second limitation is that DALYs, while a useful metric of disease burden, do not provide a measure of economic value. As such, the procedure used to approximate healthcare expenses is a crude approximation for converting DALYs into prices. Furthermore, since DALYs include both morbidity and mortality, it cannot be used to separately identify morbidity impacts. Nonetheless, this report provides a useful global picture of the extent of the health damages from air pollution.

B Climate change and mortality

As evidence of the mortality impacts from a warmer planet, we turn to an OECD report ("The Economic Consequences of Climate Change").[8] This report provides estimates of the number and value of deaths due to warming in 3 future years: 2030, 2050, and 2080. It combines the estimated dose-response between temperature and mortality with the baseline levels of mortality and daily temperature data. It uses estimates of future temperature based on projections from the Hadley Centre's HadGEM climate model. The losses in mortality are then multiplied by the VSL to provide the total costs associated with the mortality.[5] Table 2 presents the results from this exercise.

	2030		2050		2080	
	Deaths (1000s)	Value ($2010B)	Deaths (1000s)	Value ($2010B)	Deaths (1000s)	Value ($2010B)
Canada	3	9.9	8	23.4	19	55.6
Chile	1	1.5	1	3.5	3	7.5
Mexico	7	20.3	12	35.6	25	74.3
USA	27	7.5	63	27.4	137	132.5
EU large 4	31	92.3	66	197.2	131	392.3
Other OECD EU	22	49.6	44	104.4	75	182.7
Other OECD	5	16	13	39.4	25	75.2
Australia/N Zeal.	2	5.7	3	9	7	20.3
Japan	7	21.8	10	30.3	16	49.4
Korea	3	7.5	6	17	13	38.7

Table 2. Heat Stress Mortality and Valuation by Region
Notes: This table shows the number of deaths (in thousands) for each region in each of 3 time periods (2030, 2050, and 2080) based on projected temperatures under climate change. The deaths are valued using the VSL, and are measured in $2010 billions. EU large 4 is France, Germany, Italy and the United Kingdom. Source: OECD (2015).

This paper provides a useful measure of the potential monetised mortality impacts from climate change around the globe. The large effects in the EU region reflect both higher effects from warming and a larger VSL.

There are two major caveats to this report. First, as previously mentioned, there is large scope for adaptation over time. The studies referenced within the report have estimates under various scenarios about adaptation, but it is unclear which scenario this report used. Second, while heat waves increase mortality, a decrease in cold spells may decrease mortality. There is some ambiguity as to the extent of the benefit from less cold spells, and this report did not include any potential effects from it.

5 The report does not mention the specific VSL-transfer that is used.

C Climate change and morbidity

One study ("Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors") focuses more on the morbidity impacts from climate change, focusing on 4 significant diseases and pathways: diarrhoea, malaria, floods, and malnutrition.[9] The health outcome of interest is DALYs. One can potentially use the procedure performed in the Lancet-commissioned study on pollution and health to value these impacts, though this would be complicated by the fact that most of these diseases occur in nations where health care expenditure data is less available and/or reliable. Nonetheless, the results from this paper provide a useful point for discourse.

Region	Diarrhea	Malaria	Floods	Malnutrition
AFR-D	154	178	1	293
AFR-E	260	682	3	323
AMR-A	0	0	4	0
AMR-B	0	3	67	0
AMR-D	17	0	5	0
EMR-B	14	0	6	0
EMR-D	277	112	46	313
EUR-A	0	0	3	0
EUR-B	6	0	4	0
EUR-C	3	0	1	0
SEAR-B	28	0	6	0
SEAR-D	612	0	8	1,918
WPR-A	0	0	1	0
WPR-B	89	43	37	0

Table 3. Global burden on climate-change-attributable disease
Notes: Each column measures the incidence of disease by region. Disease measured in thousands of DALYs attributable to climate change in 2000. The list of country in each region are defined in the footnote.[6] Source: McMichael, et al. 2004.

This paper provides a useful elucidation of the global variation in disease attributable to climate change. Many of the diseases fall disproportionately on poorer countries. An important limitation in this study is that these impacts are not monetised. This is in part due to the focus on DALYs, which measure disease burden but not monetisable outcomes like health care expenses. Furthermore, as previously discussed in the discussion of the Lancet report,

6 Regions are defined as follows. AFR-D: Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guines-Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Togo. AFR-E: Botswana, Burundi, Central African Republic, Congo, Coˆte d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, Zimbabwe. AMR-A: Cuba, Canada, United States of America. AMR-B: Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Honduras, Jamaica, Mexico, Panama, Paraguay, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela. AMR-D: Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, Peru. EMR-B: Bahrain, Cyprus, Iran, Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates. EMR-D: Afghanistan, Djibouti, Egypt, Iraq, Morocco, Pakistan, Somalia, Sudan, Yemen. EUR-A: Andorra, Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, the Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom. EUR-B: Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgystan, Poland, Romania, Slovakia, Tajikistan, Macedonia, Turkey, Turkmenistan, Uzbekistan, Yugoslavia. EUR-C: Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Moldova, Russian Federation, Ukraine. SEAR-B: Indonesia, Sri Lanka, Thailand. SEAR-D: Bangladesh, Bhutan (Democratic People's Republic of), Korea, India, Maldives, Myanmar, Nepal. WPR-A: Australia, Brunei, Darussalam, Japan, New Zealand, Singapore. WPR-B: Cambodia, China, Cook Islands, Fiji, Kiribati, Lao, Malaysia, Marshall Islands, Micronesia, Mongolia, Nauru, Niue, Palau, Papua New Guinea, Philippines, Republic of Korea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Vietnam.

DALYs measure both morbidity and mortality, and cannot be readily monetised. A second limitation is that strong assumptions are made in generalising the dose-response estimates between climate and each disease. For example, the estimates for diarrhoea are based on dose-response estimates from only 2 countries (Peru and Fiji). A final limitation is that health impacts are estimated for the year 2000 to highlight the current effects of climate, so this report does not project the future health impacts. These steps are necessary for obtaining global estimates, and are merely being highlighted to illustrate some of the challenges needed to obtain global estimates.

D Ozone depletion and skin cancer

The increased use of chlorofluorocarbons (CFCs) has led to depletion in the ozone layer, which has increased the amount of ultraviolet (UV) radiation that reaches the Earth's surface. This increased UV radiation is linked with increase in the incidence of skin cancer. One study attempts to quantify the increase in skin cancer incidence under a scenario where no actions are taken to reduce the use of CFCs[7] and a scenario under the Montreal Protocol (agreed upon in 1987) where various restrictions were put in place to reduce the use of CFCs by 50% by 1999 ("Estimates of ozone depletion and skin cancer incidence to examine the Vienna Convention achievements").[10] The authors simulate the change in UV exposure and the incidence of skin cancer over the next century under the two scenarios. Calculations are performed for the United States and Northwest Europe. The results are shown in Table 4.

	USA		NW Europe	
Year	BAU	MP	BAU	MP
2000	36	36	17	17
2030	233	192	121	103
2050	705	420	348	231
2070	1890	758	1017	424
2100	6530	1958	3468	1051

Table 4. Excess cases of skin cancer per million per year for the USA and Northwest Europe

Notes: BAU = business as usual, MP = Montreal protocol. This table provides estimates of the excess cases of skin cancer for the USA and NW Europe under 2 scenarios. Source: Slaper et al., 1996.

This paper provides a useful estimate of how important the ozone layer is for protecting humans against skin cancer. It projects that skin cancer rates will increase by over 100-fold over the coming century. The most obvious limitation from this study is that it only gives the number of cases, and does not explicitly value them. Post hoc procedures can nonetheless be performed to value these effects using information on mortality rates from skin cancer and healthcare treatment costs. Another limitation is these results rely solely on model simulations rather than estimated relationships. Finally, the study assumes no change in human behaviour with regard to sun exposure. The more likely scenario is that people reduce their exposure as the effects from exposure worsen. Therefore, these results present a worst-case scenario, and are likely to overstate the actual impacts.

7 A "no action" scenario is often referred to as a "business-as-usual" scenario.

4 Conclusion

Over time we have seen a broader acceptance of valuation approaches to human health, with these methods gaining acceptance amongst policy makers around the world. Despite this growing acceptance, providing global estimates requires many assumptions, some more plausible than others. Researchers are continually working on improving the approaches, and there are places with reasonable convergence on the most acceptable approaches. But this also leads to clear limitations in the methodology that must be recognised, and one must assess how sensitive the results are to alternative assumptions. Despite these limitations, there is strong evidence that global environmental change harms human health.

Thinking more broadly, the above studies, by focusing solely on valuing the human health impacts from global environmental change, only capture part of the worldwide impacts. There are many more studies that investigate local environmental issues, but only a limited number on truly global issues. Even the existing studies on global issues focus on impacts for part of the globe, or do not focus on valuation. Many of the methodologies also have important weaknesses, often relying on correlational analyses or strong assumptions about generalisability. Much work needs to be done to produce more reliable estimates of the human health impacts from global environmental change.

Perhaps most importantly, even with more reliable estimates of the human health impacts, they likely only represent a small fraction of the total economic impacts from global environmental change. Global environmental change affects human well-being in numerous ways, such as mass migrations and city relocations. While these changes may have important health effects, they are more obscure and difficult to convincingly link with the environment. Furthermore, given that many impacts may be far into the future, our ability to adapt to these changes may significantly limit some of the health impacts, but this does not minimise the gravity of the problem. Therefore, a broader perspective that includes more than just the human health impacts but considers the impacts on human well-being more generally will provide a more detailed account of the total damages from global environmental change.

Endnotes

1 Climate Impact Lab, http://www.impactlab.org/ (accessed 30 October 2017).

2 Petkova, Elisaveta P. Antonio Gasparrini, and Patrick L. Kinney. “Heat and mortality in New York City since the beginning of the 20th century.” Epidemiology 25, no. 4 (2014): 554–560.

3 Viscusi, W Kip and Joseph E Aldy. “The Value of a Statistical Life: A Critical Review of Market Estimates throughout the World.” Journal of Risk and Uncertainty 27, no. 1 (2003): 5-76.

4 Deschênes, Olivier and Michael Greenstone. “Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US.” American Economic Journal: Applied Economics, American Economic Association 3, no. 4 (2011): 152-85.

5 Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S. Shapiro. “Adapting to Climate Change: The Remarkable Decline in the US Temperature-Mortality Relationship over the Twentieth Century.” Journal of Political Economy 124, no. 1 (2016): 105-159.

6 Ibid and Todd, Nicolas and Alain-Jacques Valleron. “Space–Time Covariation of Mortality with Temperature: A Systematic Study of Deaths in France, 1968–2009.” Environ Health Perspect 123, no. 7 (2017): 659-664.

7 Landrigan, Philip J, Richard Fuller, Nereus J R Acosta, Olusoji Adeyi, Robert Arnold, Niladri Basu, et al. “The Lancet Commission on pollution and health.” Lancet. S0140-6736, no. 17 (2017): Epub ahead of print.

8 OECD. “The Economic Consequences of Climate Change.” OECD Publishing, Paris (2015).

9 McMichael, A. J. et al. in Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors (eds Ezzati, M., Lopez, A. D., Rodgers, A. & Murray, C. J. L.) Ch. 20, 1543–-1649 (World Health Organization, Geneva, 2004).

10 Slaper, Harry, Guus J.M. Velders, John S. Daniel, Frank R. De Gruijl, Jan C. Van der Leun. “Estimates of ozone depletion and skin cancer incidence to examine the Vienna Convention achievements.” Nature 384, no. 21 (1996): 256 – 258.

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