Considerations for improving the relevance, use, and robustness of projections of the health risks of climate change

Kristie L Ebi, Jeremy J Hess, Rupert F Stuart-Smith, Ana M Vicedo-Cabrera, Alistair Woodward, Andy Haines

The increased interest and investment in climate change and health research and policy should be a turning point for providing policy-relevant projections of how changing weather patterns and climate trends could alter the magnitude and distribution of climate-sensitive health outcomes. Decision makers recognise that future health burdens result from interactions between exposure, sensitivity, and the capacity to adapt. Fit-for-purpose projections to inform climate risk management should be based on a range of scenarios of greenhouse gas emissions and socioeconomic development. The relevance, use, and robustness of projections would be improved by addressing the considerations outlined here.

Lancet Planet Health 2025; 9: e442–47

Center for Health and the Global Environment, Department of Global Health, School of Public Health (Prof K L Ebi PhD, J J Hess MD), **School of Medicine** (J J Hess), **University of Washington, Seattle, WA, USA; Oxford Sustainable Law Programme, University of Oxford, Oxford, UK** (R F Stuart-Smith DPhil); **Institute of Social and Preventive Medicine, Oeschger Center for Climate Change Research, Universitat Bern, Bern, Switzerland** (A M Vicedo-Cabrera PhD); **School of Population Health, University of Auckland, Auckland, New Zealand** (A Woodward MMedSci); **Centre for Climate Change and Planetary Health, London School of Hygiene & Tropical Medicine, London, UK** (A Haines FMed Sci)

Correspondence to: Professor Kristie L Ebi, Center for Health and the Global Environment, Department of Global Health, School of Public Health, University of Washington, Seattle, WA 98195, USA **krisebi@uw.edu**

Introduction

Policy makers and practitioners are increasingly seeking to understand the extent of the impacts of climate change on health, the magnitude and pattern of projected risks, and possible effective mitigation and adaptation solutions. Policy makers and practitioners hope to use this information to develop and implement effective and efficient policies at local to regional scales to protect and promote population health and wellbeing, to increase the climate resilience and sustainability of health systems, and to improve population health with salutary changes in health-determining sectors. This Personal View offers recommendations to increase the policy relevance and usefulness of projections.

Health scientists have extensive experience of modelling contributions of a range of factors, often socioeconomical, biological, or behavioural, to the current burden of injury and disease. For example, research and modelling identified the key variables driving cardiovascular diseases, which led to public health interventions to alter the drivers, including reducing smoking, lowering blood pressure, changing diets, and increasing physical activity.[1,2] Similarly, research has identified multiple linkages between climate-sensitive exposures and health outcomes. Nevertheless, comprehensive and up-to-date projections for climate-sensitive health outcomes are scarce: the WHO Quantitative Risk Assessment, which estimated risks in 2030 and 2050, continues to be highly cited although it is a decade old and includes only six health outcomes.[3] Methods and data have matured since and there is a much larger global interest in, appetite for, and apparatus for updated assessments that include a much broader range of current and projected health impacts.

Climate change is different from many other exposures because everyone is exposed to varying extents (there is no unexposed control group and there is no natural baseline without climate change), there is no theoretical minimum risk exposure level, and exposures cannot be reduced immediately. Disruption of the planet's climate is also a different class of hazard to obesity or COVID-19. Prolonged timescales, feedback loops, tipping points, impacts of other global environmental changes, long-term health impacts from an extreme event, and complex interacting risks (including those driven by policy responses),[4] all necessitate a modified approach that extends beyond classic burden of disease assessments.[5]

For example, tropical cyclones in the USA, a climate-sensitive hazard, are commonly reported to have low per-event mortality, and this response function is used in conventional burden estimates. A more comprehensive analysis of the long-term mortality impacts of 501 tropical cyclones in the contiguous USA between 1930 and 2015 illustrates the importance of including broader systemic effects and longer timeframes. Accounting for the indirect mortality effects on infrastructure, health care, and economic opportunity, the authors found an average of 7000–11 000 excess mortality after each event, with the effects persisting 15 years on average, and accounting for 3·2–5·1% of all deaths along the Atlantic coast during that period.[6] In addition, there could be life course effects. Together, these far exceed the official estimate of an average of 24 deaths per event.

Even with ambitious mitigation of greenhouse gas (GHG) emissions well beyond current targets, the feasibility of which is very much in question, exposures to many climate-related hazards will continue to increase from lagged responses in the climate system and additional warming, and from population growth in hazardous regions.[7] Recent developments undermining mitigation policy in the USA are anticipated to further slow short-term progress towards global net zero GHG emissions. In the foreseeable future, there will be considerable variability in the magnitude and pattern of change between locations and across time.[8] In the context of this need for regionally specific information, climate change projections facilitate the assessment of expected changes conditional on scenarios of future GHG emissions and socioeconomic changes.

Future risks will arise from the interactions of hazards, degrees of exposure, susceptibility of individuals and health systems infrastructure, and the capacity of health systems to manage change, whatever the source.[9] The metrics of the capacity of health systems include measures of the degree of adaptation, resilience, and environmental sustainability, and how capacity could change over time. Modelling then becomes more complex, looking well beyond projecting how hazards could change with climate change; projections need to consider indicators of exposure, susceptibility, and capacity, and how they could change over spatial and temporal scales, both because of climate change and responses to it, including industrial and migration policy. Moreover, climate change entails some exposures and dynamics that are unprecedented for modern humans, particularly sea-level rise, and for which limited data exist for empirically estimating exposure–outcome associations and the impacts on demographics, differential migration, and population health. In addition, population ageing, urbanisation, changes in equity, governance, the extent to which the world achieves the Sustainable Development Goals and the post-2030 agenda, conflict, the potential disruptive and beneficial effects of artificial intelligence, and many other changes (including disruptions to multiple Earth systems boundaries that will alter the interactions among exposure, susceptibility, and capacity), could affect future health burdens.[7,10]

Anthropogenic influences, including burning of oil, coal, and gas and deforestation, will continue to cause climate change that will persist for centuries unless emissions are permanently removed and land sinks restored.[11] The extent of change will depend on individual and collective choices made over the next few decades and on the sensitivity of the climate system to the emissions.[8] Therefore, there are fundamental uncertainties about how climate-related hazards will change over time. These uncertainties need to be incorporated into impact modelling so that projections span the range of plausible futures, and so that decision makers can effectively incorporate uncertainties into adaptation processes.

Unfortunately, because of pre-existing incentive structures, inequitable data availability, and other biases, current projections often do not address the questions posed by policy makers.[2] Health researchers often focus on well understood and elaborated pathways with sufficient evidence for parameterisation, prioritising robust analyses that reduce uncertainties from scarce data and limited understanding. There is great value in emphasising validity in scientific research, and the burden of proof should be satisfied to minimise misestimation of known risks, but could omit the potential effects of causal pathways where evidence is emerging. Projecting future burdens also necessitates identifying important emerging dynamics and using the best available evidence, along with policy principles of precautionary approaches and minimising regret. These principles can be used in: (1) the construction of projections to ensure that a comprehensive range of eventualities are accounted for (eg, high climate sensitivity with limited adaptation), and (2) the interpretation of projections to ensure that appropriate interventions are implemented to protect lower probability, high impact eventualities.

Decision makers routinely take decisions under uncertainty and understand that socioeconomic changes, for instance, will interact with climate change in complex ways that might only be apparent in hindsight.[12] Decision makers might prefer integrated assessments that include a broad range of possible risks, even if assessments are semi-quantitative, instead of what scientists would consider to be more precise estimates of a restricted number of exposures. Climate modelling might also provide insight that falls short of the needs of private sector and public sector decision makers, for instance, due to the coarse spatial scale of climate model outputs and underrepresentation of extremes that limit their usefulness for adaptation and risk assessment.[13]

Modelling is often constrained by data limitations, both health and weather and climate. In the most vulnerable regions, health data might only be reported monthly, for example, with limitations in the comprehensiveness of data in low-resource settings. It can be challenging to specify when outbreaks of diarrhoeal disease start and end from monthly data. Weather data might not be collected at the same scale as health data, or even at the same elevation in mountainous regions, but there are data sources including reanalysis (eg, ERA5[14] or ERA5-Land)[15] and gridded observations that integrate in situ and satellite observations (in some cases with reanalysis, eg Multi-Source Weather),[16] and methods that can generate useful and usable information. There are biases in where and when data are collected, further marginalising some at-risk populations. Integration of Indigenous and local knowledge into quantitative data would provide new insights about impacts. Digitising health records in low-income and middle-income countries would offer opportunities for more robust modelling in currently underserved regions.

Furthermore, climate change health impacts have begun to accrue, with attribution science establishing causal relationships between anthropogenic climate change and exposure to heatwaves and infectious diseases, such as dengue fever and Lyme disease, distinguishing the effect of anthropogenic climate change from natural climate variability, in line with the Bradford Hill criteria.[17,18] These analyses face similar methodological questions of how to establish counterfactuals when the exposure is included in the baseline, particularly when the baseline does not extend sufficiently far into the past to capture potentially relevant climate dynamics.

Based on the corpus of literature projecting health risks[7] and our knowledge in the field, including long interaction with policy makers in the climate change and global health spaces, we offer recommendations to increase the policy relevance and usefulness of projections, which are offered as suggestions that could be revisited in the light of changing availability of data and methodological advances.

Systems-based approaches

The use of systems-based approaches, including via establishing transdisciplinary teams with collaborations across institutions and ongoing opportunities for input from other sectors relevant to health, is recommended to improve the usefulness of projections. Projections of how health burdens could change in the future are more robust when informed by deep collaborations between health scientists, climatologists, demographers, and experts on future socioeconomic development. Projections that explicitly consider various futures are more policy relevant for assessing health risks than projections only considering temperature or precipitation, for example. Descriptions and modelling of possible futures should include ranges of plausible pathways of GHG emissions, climate sensitivities, changes in demographic structures, and socioeconomic development. Projections can also incorporate climate-sensitive upstream drivers of health, such as migration or access to safe water and improved sanitation. Understanding the characteristics of climate models is needed, including their strengths and limitations, as is close familiarity with the geographical region of interest, to decide, for example, which models best represent the range of uncertainties.

Identify and consult with interest holders

Interest holders should be identified and consulted with before finalising the research question to ensure that their needs are met. This step involves developing explicit criteria for identifying key interest holders to engage throughout the research, implementing a deliberative process for engaging with representatives of the interest holders, and then acting on their input. Given the numbers of people currently affected by and dying from climate change, modelling is not an academic exercise but is crucial for informing interventions and investments in health and other sectors. For example, projecting when disease vectors could become established in a region is important for proactively modifying vector control programmes.[19] Understanding demand for health services and supporting the development of appropriate infrastructure requires insight into population movements, age structure, and health status, and into projected shifts in hazards, such as droughts, hurricanes, and flooding.[10] Decision makers need to know how changing weather patterns, demographic change, urbanisation, and economic change interact to affect future disease patterns and how these patterns might necessitate changes to health protection and health-care delivery. Urban infrastructure is being modified to prepare for higher temperatures and more heatwaves; decision makers want to ensure their plans account for changes in at-risk groups and locations and population ageing. Capacity building is required to help interest holders understand the strengths and limitations associated with projections, and how to work with the modelling outputs. Resources devoted to modelling are often public goods and should be responsive to public needs and priorities.

Modellers should consider the context for the projections. Where projections show that States' actions fall short of legal obligations, for instance to protect human rights, projections might provide a basis for climate targets to be challenged in court.[20] This context could affect decisions about the framing and inputs into the projections.

Plausible mechanisms

Plausible mechanisms should be described because climate and development pathways could affect the health outcomes of interest now and in the coming decades, with explicit discussion of assumptions and sensitivity to changes in principal drivers of ill health, potential confounders, and mitigation and adaptation policies and their funding and implementation. Such descriptions should include detailed coverage of empirical evidence and statistical and process-based modelling choices and parameters. Alternatives to the theoretical minimum risk exposure level of climate change need to be advanced. Exposure–response relationships used in such modelling efforts need to follow best practices based on decades of epidemiological research, such as considering possible non-linear and lagged effects, seasonality, long-term trends, and mortality displacement when attributing health risks to changes in temperature or the magnitude and frequency of other climate-related environmental hazards.[21] Projections should increasingly include a broader range of health outcomes to address the knowledge gaps of current projections—eg, only about 15% of potential climate-sensitive communicable diseases have been included in projections in low-income and middle-income countries and many non-communicable diseases also are unrepresented.[22]

Projections should incorporate the relevant range of and interactions among exposure variables, moving beyond temperature in heat-related mortality, for example, to consider the interplay of temperature, humidity, greenness, and air pollution. Modelling approaches should also account for the specific characteristics of the populations that affect their susceptibility to climate-related drivers. For example, assuming the same heat-related risks across cities of the same country or region would represent an over-simplification and potentially lead to biases that do not provide the information needed by decision makers. Extrapolation of risks in time and space should be justified, and assumptions, uncertainties, and derived biases should be clearly stated and discussed. Pathways by which effects could materialise and timing of their emergence can be used to design adaptation options to reduce or prevent projected risks, including early warning or flood protection systems.

Adaptation

Adaptation should be incorporated by developing agreed-upon indicators of adaptation activities for a wide range of climate-sensitive exposures, characterising the effectiveness of these activities in reducing the burden of injury and disease associated with climate change, supporting surveillance of implemented adaptation options, and incorporating estimates of adaptation coverage in health and other sectors in modelling efforts. Adaptation indicators will vary by health outcome. For example, assumptions about the extent of acclimatisation, including physiological limits, are important for projecting heat-related mortality.[23]

Researchers should avoid the assumption that adaptation co-varies with development and is adequately captured in the proxy of gross domestic product. Instead, health protection against climate-sensitive exposures should be addressed similar to other health protection interventions—eg, countermeasures against malaria and HIV and investments in water, sanitation, and health infrastructure. The health community should develop and track robust indicators for surveillance of climate change health protections at subnational levels. Policy makers also need to know if adaptation in other sectors could affect human health and wellbeing.

Adaptation assumptions should consider possible advances in new medical technologies and health system resilience, including in timely and effective diagnosis and treatment of climate-sensitive health outcomes, more successful prevention programmes (including effective primary health care),[24] positive use of artificial intelligence, and many other potential advancements in the coming decades. New technologies also will arise in the upstream drivers of health and wellbeing. Assumptions should be well documented so they can be considered and tested by other researchers.

Climate model scenarios

Climate model scenarios that represent a range of possible futures of relevance for the research question, including different emissions pathways, should be selected. When possible, using an ensemble of models provides more robust analyses than only using a single model.[25] The criteria used to select the models should be explained and justified so that analyses can be replicated by other research groups. Individual models have varying levels of skill in different regions; consultation with climatologists can inform selection of models that are best suited to answering the question being investigated and can inform on appropriate approaches for downscaling projections to the scales of decision making.

Non-temperature variables

The effect of climate change in the context of non-temperature variables should be considered. Projecting health risks considering only temperature ignores: (1) the fact that underlying health burdens will change because of various development choices that could be as or more important than climate change in the next 25 years, such as investments in water, sanitation, and hygiene in low-resource settings, (2) the effect of non-temperature climate variables, such as precipitation, that drive a range of climate change impacts on health; (3) the role of sea-level rise and its increasing effect on migration and infrastructure loss in specific regions and of ocean acidification, warming, and deoxygenation and their effects on both nutrition and livelihoods; (4) trends in other Earth systems that might influence health (eg, freshwater availability, land use change, and biodiversity loss); and (5) feedback on the social determinants of health that interact substantially with development pathways. Environmental information included in modelling should reflect the appropriate parameterisation of the hazard, considering the aetiology of the health outcome. This information should consider how the transgression of other Earth system boundaries could influence projections.

Baselines and counterfactuals

Baselines and counterfactuals for climate and health, including the rationale for choices, should be constructed and incorporated into modelling sensitivity analyses. Baselines and counterfactuals are needed to provide estimates of the magnitude and pattern of future changes in climate and development. Ideally, projections are conducted separately for climate and development and then integrated to inform investments. For example, Byers and colleagues[26] used 14 impact metrics, including one for health, to project the numbers of people exposed and vulnerable to the multisector risks of climate change in 2050. Holding the development pathway constant (eg, Byers and colleagues[26] used Shared Socioeconomic Pathway [SSP] 2; a world with moderate challenges to adaptation and mitigation) to show that temperature increase is the dominant driver ahead of population increase. However, assuming the global mean temperature increase would not exceed 2°C by mid-century, the numbers of exposed and vulnerable people are projected to increase 8-fold to 32-fold in a world with high challenges to adaptation and mitigation (SSP3) compared with a world aiming for sustainable development, with risks concentrated in African and Asian regions.

Socioenvironmental pathways

Multiple socioenvironmental pathways should be selected to reflect a range of possible future scenarios of demographic change, socioeconomic development, and other environmental factors. It is not just climate that is changing, populations are ageing, urbanisation is taking place in most regions, the size of economies changes with time, and adaptation will take place.

SSPs are the standard scenarios used by other sectors to inform robust projections of changes in risk; the five pathways describe (in narrative and quantitative terms) possible futures with different combinations of challenges to adaptation and to mitigation, including changes during this century in demographics, economics, equity, urbanisation, investments in science and technology, and other factors.[27] The thousands of publications using SSPs highlight how possible interactions between climate and development could alter poverty, ecosystem services, food and water security, health of ocean ecosystems, economics, and other domains. The SSPs were extended for several sectors, such as agriculture and oceans, and have been downscaled to national and subnational regions.[28]

Efforts are under way to develop explicit adaptation pathways within the SSPs. Extending these pathways for health systems should strengthen health projections and provide consistency with other sectors to more easily generate comparable results. These developments would facilitate research that explores the effects of different adaptation choices, supporting governments to identify high-impact interventions that maximise health benefits. Projections that assess the effect of mitigation actions should also include the health co-benefits of mitigation actions—eg, from reduced fossil fuel-related air pollution.[29,30] Otherwise, they will seriously underestimate the total health benefits of the mitigation action.

Describe uncertainties

The sources and magnitude of uncertainties across the suite of scenario combinations should be described. The often implicit assumption that uncertainties in climate models are the dominant source of uncertainty in impact might be incorrect and, regardless, are one of several frequently encountered sources of uncertainty that need to be explicitly discussed.[31]

Metrics

Various metrics should be used and those that are particularly relevant to the interest holders should be highlighted. No single metric is adequate for monitoring the complex and dynamic health risks of climate change; therefore, projections of health risks should not be collapsed into a single measure, such as excess mortality, although mortality estimates might have value when communicating findings to policy makers and the public. Disability-adjusted life-years are often a useful metric for capturing a fuller if not complete burden of health impacts, because the metric captures years of life lost due to premature mortality and years of life lost due to time lived in states of less than full health,[32] but the proportion of morbidity and mortality caused by climate change might be difficult to assess. Other metrics might be informative when accounting for impacts on at-risk populations, such as hospital admissions that incur costs of potential relevance for policy makers. Impacts on health-care systems might also be relevant for decision making.

Conclusion

The field of climate change and health is at an inflection point, with rapidly expanding research and implementation of improved methods providing new insights and increasing global demand for insights to guide practice going forward. The considerations raised in this Personal View are offered to increase the robustness of projections of health risks under a range of climate and development scenarios and to help inform effective and efficient adaptation decision making even as the climate continues to change. We recognise data availability and accessibility, and other limitations could constrain the extent to which the considerations can be implemented in each analysis.

Our proposals for undertaking projections of the health risks of climate change are coherent with those of other researchers.[33,34] Improved understanding of the health impacts of future emissions pathways will provide further impetus for climate change mitigation, highlighting the humanitarian consequences of failing to cut emissions rapidly and providing an evidence base to motivate policy action. Our recommendations support the increasing attention to climate change and health in the negotiations under the UN Framework Convention on Climate Change, including loss and damage.

Projections of the health impacts of climate change need to move beyond mortality to incorporate a greater range of health risks, including wellbeing, and beyond a narrow focus on climate to further understanding of the connections between the stability and resilience of Earth systems and the drivers of population health.[10] Filling knowledge gaps with policy-relevant insights is urgent to protect health and wellbeing, particularly of vulnerable populations and regions.

Contributors

KLE, AH, JJH, RFS-S, and AW discussed the motivation and general topics to be included in this Personal View. KLE wrote the initial draft and all authors contributed to the writing, editing, and finalising of the manuscript.

Declaration of interests

KLE received grants from the National Institutes of Health (NIH), the Wellcome Trust, and the World Meteorological Organization; consulting fees from the Green Climate Fund, Global Fund, and the UN Development Programme; honoraria and support from the University of Georgia and Penn State University; participates on data safety monitoring boards or advisory boards for START; and is a co-chair for the Future Earth Assembly. JJH received grants from the NIH, the Wellcome Trust, National Institute of Standards and Technology, University College London, the Council of State and Territorial Epidemiologists, and the New Frontiers in Research Fund; honoraria from Columbia University, the University of Massachusetts, and Harvard University; and is a board member of the Seattle Parks Foundation. RFS-S received grant support from the Wellcome Trust. AMV-C received grant support from the Swiss National Foundation. AW received grant support from the Health Research Council of New

Zealand; and support for attending meetings from the Wellcome Trust, the City of Incheon, and Shandong University. AH received grants from the Wellcome Trust and the Oak Foundation; royalties from Cambridge University Press; travel support from WHO and the human Frontiers Science Program; is on the Cool Roofs trial steering committee of the Nouna Research Centre, Burkina Faso and University of Heidelberg, and the US National Academy of Medicine Climate Grand Challenge steering committee; has been co-chair for the International Advisory Committee, the National Institute for Health and Care Research Clean-Air (Africa) Global Health Research Unit, InterAcademy Partnership, and Climate Change and Health Working Group; was a member of the Independent Advisory Group; is a member of the Collaboration for the Establishment of an African Population Cohort Consortium advisory group; is chair of the Standards for Official Statistics on Climate-Health Interactions expert advisory group; and is the co-director of WHO Collaborating Centre on Climate Change, Health and Sustainable Development.

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