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Climate Change and Human Health: Estimating Avoidable Deaths and Disease

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Human population health has always been central in the justification for sustainable development but nearly invisible in the United Nations Framework Convention on Climate Change negotiations. Current scientific evidence indicates that climate change will contribute to the global burden of disease through increases in diarrhoeal disease, vector-borne disease, and malnutrition, and the health impacts of extreme weather and climate events. A few studies have estimated future potential health impacts of climate change but often generate little policy-relevant information. Robust estimates of future health impacts rely on robust projections of future disease patterns. The application of a standardized and established methodology has been developed to quantify the impact of climate change in relation to different greenhouse gas emission scenarios. All health risk assessments are necessarily biased toward conservative best-estimates of health effects that are easily measured. Global, regional, and national risk assessments can take no account of irreversibility, or plausible low-probability events with potentially very high burdens on human health. There is no "safe limit" of climate change with respect to health impacts as health systems in some regions do not adequately cope with the current climate variability. Current scientific methods cannot identify global threshold health effects in order for policymakers to regulate a "tolerable" amount of climate change. We argue for the need for more research to reduce the potential impacts of climate change on human health, including the development of improved methods for quantitative risk assessment. The large uncertainty about the future effects of climate change on human population health should be a reason to reduce greenhouse gas emissions, and not a reason for inaction.

KEY WORDS: Burden of disease; climate change; equity; population health; risk assessment

1. INTRODUCTION

Maintaining and improving human population health, as well as preventing morbidity and mortality, is an important justification for taking action on climate change and other environmental problems. We protect environments, water supplies, and agricultural production because of the goods and services that they supply to human populations, and implicitly the benefits they confer on well-being and health. Health is increasingly used as a justification for action

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on climate change.[1,2] Impacts on health tend to appear prominently in IPCC summaries, as well as in media coverage, and political speeches. Health, however, is not well represented in the international policy agreements that address climate change, such as the United Nations Framework Convention on Climate Change (UNFCCC).

In this article, we review current methods for the quantification of health impacts of climate change at the global or regional level, and suggest the appropriateness of applying health risk assessment frameworks (the most policy-relevant piece of our environmental health toolkit) for climate-related decision making. Health policymakers and technical professionals are comfortable with "hard" quantification on specific health endpoints. There is, therefore, an urgent need to improve methods that quantify the potential burden of disease due to climate change at global, regional, and national levels.

The causes of adverse environmental exposures, and the potential for intervention, can be ascribed to both proximal and more distal factors (driving forces).[3,4] The World Health Organization (WHO) recognizes the need to focus on long-term action directed at reducing the driving forces that generate environmental health threats, such as climate change (Fig. 1). The health sector has an important role as "advocate and guide for healthy development."[4]

Legislation and legally binding agreements at the international level now make provision for health impact assessment (HIA) in policy making. There

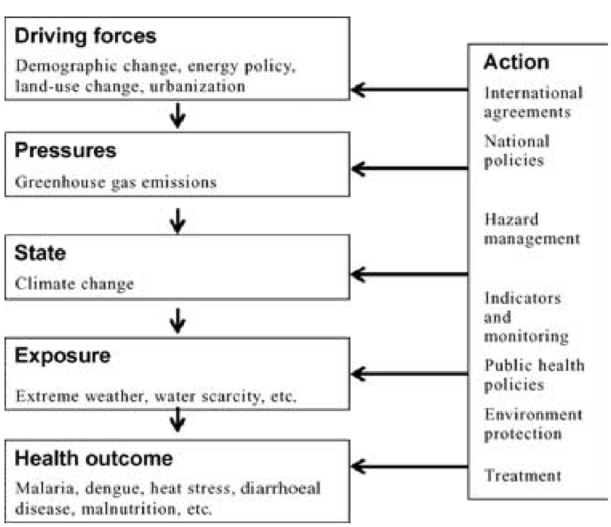

Fig. 1. The DPSEEA framework for environmental health risk assessment, applied to climate change.

is growing consensus that systematic assessments of health effects are needed to inform the development of policies in a range of sectors, such as water, food, housing, and global trade. Important recent examples include the quantification of the health impacts of traffic-related air pollution[5,6] and the estimation of health costs for different fuel cycles (such as coal, nuclear energy).[7] High-quality assessments are expensive and, in practice, few have been undertaken. The Intergovernmental Panel on Climate Change (IPCC) has facilitated several important advances in the development of approaches to evaluating complex scientific evidence.[8] These methods are now being followed in other areas, such as the Millennium Ecosystem Assessment, which addresses the impact of loss of biodiversity on human health.[9,10]

Health policy, unlike, for example, energy policy, focuses on addressing clear and urgent (disease) problems. Both decision making and research are undertaken in a compartmentalized way. There is overemphasis on the clinical side of the health sector (i.e., the treatment of disease, and the provision of health services such as hospitals and clinics). Public health and disease prevention measures are often not given the attention they deserve. Health researchers generally accept that many diseases are climate-sensitive, and therefore potentially affected by climate change. But researchers are focused on the complexity of their own area of expertise, in which climate change may only be one small influence among many complex interacting factors. In many cases, climate change is seen as distracting attention and funds from more urgent public health problems, such the HIV/AIDS pandemic. The frameworks that are used to assess climate change risks to health, and the way that the results are presented, are therefore critical for a potentially difficult dialogue between health and climate change researchers and policymakers, and the general public.

2. THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON HUMAN HEALTH

Climate change can affect human health through a wide range of mechanisms and for a range of diseases or health outcomes (Table I). Climate variability, as characterized by extreme weather events, and interannual variability, is known to affect human health.[11,12] The impacts of long-term shifts in climate conditions may lead to shifts in distribution of infectious diseases and areas suitable for food production.[13] The health chapter of the *Third Assessment Report* of the IPCC concluded that negative impacts

Table I. Summary of Known Effects of Weather and Climate on Human Health

Health Outcomes	Known Effects of Weather
Heat stress	• Deaths from cardiopulmonary disease increase with high and low temperatures • Heat-related illness and death increase during heat waves
Air-pollution-related mortality and morbidity	• Weather affects air pollutant concentrations • Weather affects distribution, seasonality, and production of aeroallergens
Health impacts of weather disasters	• Floods, landslides, and windstorms cause direct effects (deaths and injuries) and indirect effects (infectious disease, long-term psychological morbidity) • Droughts are associated with increased risk of disease and malnutrition
Mosquito-borne diseases, tick-borne diseases (e.g., malaria, dengue)	• Higher temperatures shorten the development time of pathogen in vectors and increase potential transmission to humans • Vector species have specific climate conditions (temperature, humidity) necessary to be sufficiently abundant to maintain transmission
Undernutrition	• Climate change may decrease food supplies (crop yields, fish stocks) or access to food supplies
Water-/food-borne diseases	• Survival of important bacterial pathogens is related to temperature • Water-borne diseases are most likely to occur in communities with poor water supply and sanitation • Increases in drought conditions may affect water availability • Extreme rainfall can affect transport of disease organisms into water supply

on health will outweigh the benefits, and that populations in poorer areas will be the worse affected.[14]

Research on the potential health impacts of climate change must rely on observed effects of weather and climate, primarily using epidemiological methods.[15] As climate *change* requires at least 30 years of data, the opportunities for observing directly the effects on human health are limited.[16] Good-quality empirical studies of the effects of weather or climate on health outcomes can provide the evidence base for developing risk assessment models. We suggest that good-quality studies are those that

1. measure and control confounders (such as differences in poverty levels, or age profiles between populations or individuals);
2. describe the geographical area from which the health data are derived;
3. use appropriate observed meteorological data for the population of interest (the use of reanalysis data may give spurious results for studies of local effects[17]);
4. have a plausible biological explanation for association between weather parameters and disease outcome;
5. remove any trend and seasonal patterns when using time-series data prior to assessing relationships;
6. report associations both with and without adjustments for spatial or temporal autocorrelation.

A particular problem arises from extrapolating observed weather-health relationships to risk assessment models. Time-series methods have been developed to estimate the proportion of disease in a population that is attributable to weather, that is, the short-term variation in meteorological exposures (day-to-day or week-to-week). Strong associations have been found between temperature and daily mortality, and between temperature and cases of bacterial diarrhea. It is, however, problematic to extrapolate long-term effects from a short-term association.

Health impact assessment (a measure of the absolute, rather than relative, burden of disease due to climate change) requires a robust estimate of the true health burden in terms of premature death (years of life lost). This is problematic for temperature-related deaths (both heat and cold) that are predominantly in the elderly and persons with preexisting cardiovascular disease. As with air pollution effects, it is thought that the acute environmental stress of a very hot day precipitates death in a susceptible (rather than a healthy) person. For some populations, there is good evidence that deaths are brought forward by nontrivial amounts during heat waves.[18,19] Following the very severe heat wave in Paris in 2003, no obvious mortality displacement was observed, indicating significant loss of life-years in that population.[20]

Mapping of many vector-borne diseases and/or their vectors has been rapidly advanced by improvements in computing as well as in the geo-referencing of disease and exposure data. These spatial models are able to be validated with limited data that are available, although there is great uncertainty about the edges of the distribution—precisely the areas where climate change would be expected to have an effect (both latitudinal and altitudinal). Models have also been developed that rely on universal biological relationships between temperature, vector, and parasite. These models have been shown to overemphasize the relative changes in risk, when the projected absolute risk remained small.(21) Many vector-borne diseases have complex transmission cycles involving a range of hosts that are poorly understood, e.g., diseases transmitted by ticks,(22) and temperature-sensitive models are unlikely to be developed quickly. However, there have been research developments in the mapping of vectors and disease and the quantification of a range of factors that determinate distribution, particularly land cover/land use, and these studies will improve the scientific basis for climate change assessment.(23,24)

An important but often overlooked part of the assessment process is the qualitative evaluation of the published literature to reach a scientific consensus (at least among the experts conducting the assessment). Epidemiological studies are inherently conservative and more prone to producing false negatives (type II errors).(25) However, climate and health literature, as a relatively new research area with a limited range of peer-reviewed publications, has been prone to publication biases. Publication bias occurs when studies that show a positive association are more likely to be published than those that find a negative association for a given environmental exposure.

Scientists are not in disagreement over many of the scientific details about climate change and human health. For example, there is strong agreement about the role of weather and climate in malaria transmission and distribution from field and laboratory studies of mosquito vectors and the plasmodium parasite. Differences arise, however, because of differences in world view, assumptions about future capacity to control malaria, and how the "risk" is presented in assessments such as those from the IPCC.(26,27)

3. COMPARATIVE RISK ASSESSMENT OF CLIMATE CHANGE

Linkages between different levels in the environmental and health framework can be the focus of quantitative modeling and health impact assessment, which must be policy-relevant (Fig. 1). Projections of future healthy life years lost are made based on current exposures (such as smoking) for diseases with a long latency (lung cancer takes 20–30 years to develop). Climate change impacts relate to future uncertain exposures.(28) Predictive models of the impact of climate on health have been developed for a limited range of health outcomes (malaria, dengue, diarrheal disease, temperature-related mortality). Health-related or "welfare" outcomes have also been addressed in projections of populations at risk of water stress or hunger.(29,30) These studies, as reviewed elsewhere, provide some limited, evidence for fairly monotonic increases in health impacts as climate change increases where those changes are driven by temperature. When rainfall effects are important drivers of disease risk, the results can be very inconsistent.(29,31,32) Due to the limited number of models and publications available, there has been considerable recycling of original estimates, leading to further bias in review papers.(33)

Many factors, such as physiological adaptation and individual and community wealth, will influence both the exposure of individuals and populations to climate hazards and their impacts. For some impact models, simple modifying factors (e.g., technological development of crops) are integrated into the models both for present and future impacts (e.g., people at risk of hunger). Other models incorporate the effects of existing modifiers when defining current climate-disease relationships, such as estimates of the global distribution of malaria based on current climate associations.(34) Although such models implicitly capture the *current* modifying effects of socioeconomic and other influences, they do not either (1) separately attribute climate and socioeconomic effects, or (2) attempt to model *future* changes in these modifiers. The majority of health impact models in fact make no estimate of future changes in important modifying influences: for example, models that predict future changes in areas climatically suitable for malaria transmission, and associated populations at risk.(31) The valid reason for this is the great uncertainty in future socioeconomic factors. Plausible scenarios can be developed in the near term (on extrapolation from current situations) and the longer term to generate a plausible range of future impacts.

In 2002, climate change was one of the environmental risk factors analyzed in the World Health Organization's Comparative Risk Assessment (CRA) of the factors contributing to the global burden of disease (GBD).(35) WHO developed the CRA to quantify the burden of disease from specific risk factors and to estimate the benefit of realistic interventions that remove or reduce these risk factors (Fig. 2). Estimates

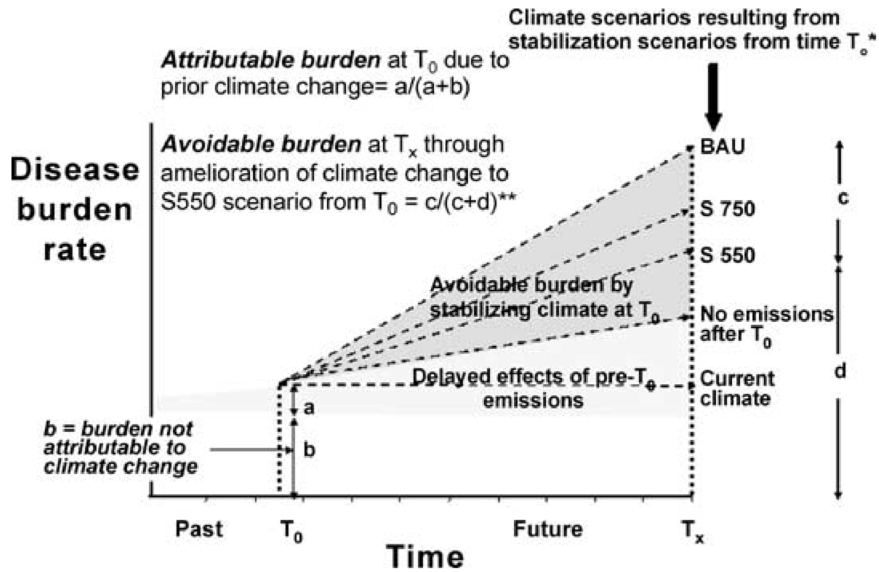

Fig. 2. Illustration of comparative risk assessment in relation to climate change.

Notes: BaU-business as usual scenario; s550-scenario with stabilization of atmospheric CO_2 at 550 ppmv; s750-scenario with stabilization of atmospheric CO_2 at 750 ppmv.
Source: D. Campbell-Lendrum.

were derived as relative risks for each climate scenario compared to the baseline climatology (i.e., average climate 1961–1990). In order to estimate the number of deaths avoided by the stabilization of greenhouse gas emissions, the relative risks can potentially be applied to projections of population- and disease-specific incidence. The framework used the disability-adjusted life-year (DALY), which quantifies both mortality and morbidity impacts in a single unit to allow aggregation of the various health impacts caused by each risk factor.[36,37]

All risk factors were assessed by the WHO using similar epidemiological criteria. The method, as applied during the global risk assessment, makes conservative assumptions, which may lead toward a more complete representation of risk factors with more direct causal pathways and a longer history of epidemiological investigation (e.g., smoking). In the case of climate change, this leads to completely excluding some impacts that are likely but difficult to quantify (such as drought-related mortality, or the diverse health effects on populations displaced due to sea level rise), or impacts that are plausible but with low probability (health impacts of acute regional failures in crop production or health impacts of a major flood disaster in Europe). The approach, as currently applied, also does not adequately deal with the increased uncertainty about the future frequency or intensity of extreme weather events, as opposed to more gradual and predictable changes in mean conditions, particularly temperature.

The "avoidable burden" at future points in time was estimated by defining alternative plausible distributions of the risk factor in the study population, and comparing relative risks under each scenario. In the case of climate change, the relative risks and associated impact fractions are applied to WHO estimates of future disease burdens, which attempt to take account of the most probable future changes due to climate-independent factors, such as improving socioeconomic and disease control conditions. The analysis therefore attempted to estimate the proportional change that climate change would exert on the disease burden that would otherwise have occurred if the climate had not been affected by human actions. This is different from most published studies of future health impacts, which assume that there will be no changes in disease patterns other than those caused by climate change.

To generate consistent estimates, the analysis incorporated:

1. Geographic variation in vulnerability to climate, where not already incorporated into the predictive models.
2. Future changes in disease rates due to other factors (e.g., decreasing rates of infectious disease due to technological advances/improving

socioeconomic status), and for changes in population size and age structure (e.g., potentially greater proportion of older people, at higher risk of cardiovascular disease mortality caused by temperature extremes). The estimates of relative risks under alternative climate change scenarios have been applied to the WHO projections of disease rates and population size and age structure.
3. Assumptions of improvements in a country's ability to control an infectious disease, such as malaria, dengue, or diarrheal disease. It was also assumed that populations would gradually acclimatize to exposure to higher temperatures by both physiological acclimatization and behavioral changes.
4. Uncertainty estimates describe uncertainties around current exposure-response relationships and around the degree to which these are likely to be maintained in the future.

The modest climate change that has occurred since the mid-1970s was estimated to have caused the loss of over 150,000 lives and 5,500,000 DALYs in the year 2000.[38] The climate-change-attributable impacts (as defined under a single unmitigated climate scenario) were projected to approximately double by 2020. The majority of this increased burden of disease was estimated to be due to increases in diarrheal disease and malnutrition. This is due to the high underlying (baseline) incidence of these diseases at the global level. Table II summarizes the relative risks for the three climate scenarios in selected WHO world regions. Results are presented as relative risks compared to the baseline climate, and uncertainty bands (high and low estimates) around the central estimate. Absolute burdens are dependent on assumptions of population growth and future disease incidence. Estimates were not generated beyond the 2000–2030 time period as this was outside the decision-making framework of the World Health Organization.

The requirement that decision making or climate policy be based on good scientific evidence requires a piecemeal approach. The CRA approach goes one step toward addressing this problem for a complex issue such as global climate change in that it provides a standardized framework that can take account of diverse health impacts (see Appendix). However, even the aggregation of a range of individual health impacts does not necessarily give a complete assessment of climate change risks to health. Many suggested effects of climate change are not disease-specific but relate to broader threats to health that are not readily quantified, such as the risk of collapse of ecological systems (e.g., fisheries, agricultural systems) that underpin human health.[39]

Table II. Estimated Relative Risks[a] of Various Health Outcomes in Year 2030 due to Climate Change (with High and Low Estimates in Brackets), Compared to the Situation if Climate had Remained at 1961–1990 Conditions

		Diarrhea Deaths	Coastal Floods Death (Drowning)	Malaria Deaths	Dengue Deaths
West Africa	Unmitigated scenario	1.08 (0.99, 1.16)	1.64 (1.32, 2.29)	1.02 (1.02, 1.05)	1.28 (1, 1.57)
	Stabilization at 750 ppm CO_2	1.06 (0.99, 1.13)	1.48 (1.24, 1.96)	1.01 (1.01, 1.03)	1.2 (1, 1.41)
	Stabilization at 550 ppm CO_2	1.05 (0.99, 1.1)	1.44 (1.22, 1.89)	1.01 (1.01, 1.02)	1.19 (1, 1.37)
North America	Unmitigated scenario	1 (0.93, 1.08)	1.19 (1.09, 1.38)	1.51[b] (1.51, 2.03)	1.46 (1, 1.92)
	Stabilization at 750 ppm CO_2	1 (0.94, 1.06)	1.14 (1.07, 1.27)	1.33 (1.33, 1.65)	1.33 (1, 1.66)
	Stabilization at 550 ppm CO_2	1 (0.95, 1.06)	1.13 (1.06, 1.25)	1.27 (1.27, 1.53)	1.3 (1, 1.61)
Central, S. America	Unmitigated scenario	1.02 (0.95, 1.1)	4.64 (2.82, 8.28)	1.08 (1.08, 1.17)	1.3 (1, 1.59)
	Stabilization at 750 ppm CO_2	1.02 (0.96, 1.08)	3.76 (2.38, 6.52)	1.05 (1.05, 1.1)	1.22 (1, 1.43)
	Stabilization at 550 ppm CO_2	1.02 (0.96, 1.07)	3.58 (2.29, 6.17)	1.04 (1.04, 1.09)	1.2 (1, 1.4)
Southeast Asia	Unmitigated scenario	1.09 (1, 1.19)	1.04 (1.02, 1.07)	1.01 (1.01, 1.02)	1.17 (1, 1.34)
	Stabilization at 750 ppm CO_2	1.07 (1, 1.15)	1.03 (1.01, 1.05)	1.01 (1.01, 1.01)	1.12 (1, 1.25)
	Stabilization at 550 ppm CO_2	1.06 (1, 1.13)	1.03 (1.01, 1.05)	1 (1, 1.01)	1.11 (1, 1.23)

[a]Relative risks (a relative risk of 1 implies no effect of climate change in 2030, but taking into account changes in disease trends driven by changes in socioeconomic status and technology, for example).
[b]Relative risks are applied to estimates of actual and future prevalence. For example, actual reported cases of malaria in North America are very rare, and so the number of cases due to climate change is estimated to be extremely low.

4. CRITICAL THRESHOLDS AND TOLERANCE THRESHOLDS

Thresholds in biophysical systems, such as the collapse of the West Antarctic Ice Sheet, have been identified as indicators of risk and danger for climate change (see other articles in this issue). At the global aggregate level, thresholds in health are predominantly "type 1,"(44) where climate change will cause continuous changes in numbers of deaths/ DALYs upon which a threshold (or acceptable limit) must be imposed. The impacts of climate change will not be equally distributed but will mostly affect the poorest populations.(45) Low- and middle-income countries in particular have difficulties coping with current climate variability. Countries in Africa still experience a considerable burden of malnutrition and malaria due to climate variability.(46) The scientific evidence so far is consistent with a 2°C limit for "dangerous" climate change that has been proposed by the German Advisory Council on Global Change(47) and others.(48) There is strong evidence that the impact on health would be greater with warming in excess of 2°C of global mean temperature before the end of this century than warming that remains below this value. Further, we have some idea of the implications of 2°C warming for human population health, but the implications of 6°C warming are much harder to assess.

At a local level, there are likely to be important thresholds for public health that would be passed before 2°C of global mean warming, such as shifts in the climate envelop for an important vector-borne disease, or the sustainability of a rural or coastal population triggered by a major flood or drought. Some thresholds in natural ecosystems, such as coral reefs or freshwater lenses, may cause threshold health effects in local communities. Thus, type 2 thresholds in relation to health, dramatic and irreversible changes that would be considered unacceptable by most policymakers, represent plausible worst-case scenarios. Weather disasters are generally associated with property damage and high economic losses, which may represent a considerable proportion of the GDP in a low-income country. Low-income countries cannot recover economically from a disaster without some external aid, thus leading to stagnation and increased poverty and disease.(49)

In the policy arena, few attempts in the health and environment policy sectors have been made to formally define the criteria for the regulation of environmental threats to health. Indeed, there is considerable confusion about what qualifies as dangerous under Article 2 of the United Nations Framework Convention on Climate Change.(50) The UK Health and Safety Executive, for example, have made an attempt to make explicit their decision making regarding the regulation of occupational hazards and, in particular, to define risks in this context that are "acceptable," "tolerable," or "unacceptable."(51) People are generally less tolerant of inequities in health risks than in some other aspects of life that may be affected by climate change (such as tourism or agro-industry impacts). In the health sector, people are less tolerant of health risks where they are caused by other people, rather than the affected individual's actions.(52)

The current (baseline) situation with regard to human health is not good. There is a large global burden of disease, and many of the most important determinants (malnutrition, diarrheal disease due to lack of sanitation and safe water) are readily avoidable with available technology. There is also a considerable current burden due to climate variability and extreme weather. Health policy debates therefore focus more on prioritization in tackling current problems, than on avoiding future risks, unless they can be shown to be very large and/or very likely. The practical application of a "tolerable" health risk varies widely, and unacceptably, among countries.

Few studies have investigated lay and professional views of the *societal* risk due to climate change.(44) Traditional hazards, such as urban air pollution and toxic waste are given highest priority as *individual* risks to health. As seen with the nuclear threat, the potential for very severe consequences leads to feelings of powerlessness. With climate change and current media reporting, people report a high degree of complexity and confusion in belief patterns and a sense of leaving action to others.(53)

5. CONCLUSIONS

Prevention is nearly always better than cure. There is an urgent need to develop improved methods and tools of climate impact assessment (such as the use of probabilities and Bayesian analysis) within a precautionary framework.(54,55) There is, however, potential for climate change to affect health in ways that are completely unexpected, and therefore not subject to risk assessment.(56) The first risk assessments for chlorofluorocarbons were for their direct human toxicity, rather than for causing cancer via changes in stratospheric chemistry. Even when scientists had discovered this unintended consequence, effective international action was not undertaken to restrict emissions until the ozone hole was discovered.[57]

There is no "safe limit" of climate change with respect to health impacts, as current health systems often do not adequately cope with current climate variability. The impact of El Niño on human health, in terms of disasters and mosquito-borne diseases, and the 2003 heat wave in Europe clearly illustrate this. "Health" can and should be included in the discussion on global climate change and dangerous climate change. Although health (and other nonmarket impacts) are being addressed, robust assessments are still missing and appropriate policy decisions in terms of public health adaptation are not being made.

Climate change should be addressed as part of the larger challenge of sustainable development.[25,45] We argue that scientists should not be entering arguments of acceptable risks (and definitions of "dangerous" climate change) but should be providing evidence to support policy alternatives. Current scientific methods cannot identify threshold health effects in order for policymakers to regulate a "tolerable" amount of climate change. The protection and improvement of population health must be recognized as a central goal of environmentally sustainable development.

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APPENDIX: COMPARATIVE RISK ASSESSMENT

Starting in the late 1990s,[40] the World Health Organization has produced estimates of the "global burden of disease"—the total amount of mortality and morbidity resulting from each of over 135 causes of diseases and injuries, from malaria, to cardiovascular disease, to road traffic accidents.[41] A major innovation in this work was the development of summary measures of population health, which combine data on mortality and nonfatal health outcomes into a single number. The most commonly used measure is the disability-adjusted life-year (DALY), which takes into account premature mortality, along with the time lived with disability and the severity of the disability.[42] This allows meaningful comparisons between diseases with very different health consequences, giving appropriate weight to diseases that disproportionately cause death at a young age (such as infectious diarrhea), or that cause long-term morbidity (such as some neuropsychiatric disorders).

As a further elaboration of this work, the organization later defined a framework for comparative risk assessment (CRA) in order to provide quantitative estimates of the contribution that different public health risk factors make to this burden of disease. The CRA is based on the following data for each risk factor:

1. the current or predicted future distribution of risk factor exposure within the study population;
2. the exposure-response relationship to all associated diseases (e.g., the relative risk of each disease for individuals exposed vs. unexposed to the risk factor, or a continuous dose-response function);
3. the total burden of disease (e.g., number of DALYs) lost to the various diseases associated with the risk factor.

The distribution of the risk factor exposure in the population (1), and the exposure-response information (2), are combined into an "impact fraction," or "attributable fraction"—the proportion of the total burden of that disease that is attributable to the risk factor:[43]

$$IF = \frac{\Sigma P_i RR_i - \Sigma P_i' RR_i}{\Sigma P_i RR_i},$$

where IF = Impact fraction, P_i = Proportion of the population in exposure category, P_i' = Proportion of the population in exposure category i after an intervention or other change, and RR_i = Relative risk at exposure category i compared to the reference level.

Impact fractions for each associated disease are then in turn multiplied by the total burden of that disease and summed to give the overall attributable burden. These relative risks are usually assessed compared to one or more "counterfactual scenarios," for example, a theoretical minimum (often zero) exposure to identify the total attributable burden, or a plausible reduction in the risk factor to measure the burden that would be avoidable by a policy intervention. Where appropriate, assessments can be carried out separately by region, sex, and age group, to provide more policy-relevant estimates.

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