Health Impact Assessment of Global Climate Change: Expanding on Comparative Risk Assessment Approaches for Policy Making

Jonathan Patz,[1] Diarmid Campbell-Lendrum,[2] Holly Gibbs,[1] and Rosalie Woodruff[3]

[1]Center for Sustainability and the Global Environment (SAGE), Nelson Institute for Environmental Studies & Department of Population Health Sciences, University of Wisconsin, Madison, Wisconsin 53706; email: patz@wisc.edu, hkgibbs@wisc.edu

[2]Department of Public Health and Environment, World Health Organization, CH-1211 Geneva 27, Switzerland; email: campbelllendrumd@who.int

[3]National Center for Epidemiology and Population Health, Australian National University, Canberra ACT 0200, Australia; email: Rosalie.Woodruff@anu.edu.au

Annu. Rev. Public Health 2008. 29:27–39

First published online as a Review in Advance on January 3, 2008

The *Annual Review of Public Health* is online at http://publhealth.annualreviews.org

This article's doi:
10.1146/annurev.publhealth.29.020907.090750

0163-7525/08/0421-0027$20.00

Key Words

biofuels, deforestation, global warming, malaria, diarrhea, urban planning

Abstract

Climate change is projected to have adverse impacts on public health. Cobenefits may be possible from more upstream mitigation of greenhouse gases causing climate change. To help measure such cobenefits alongside averted disease-specific risks, a health impact assessment (HIA) framework can more comprehensively serve as a decision support tool. HIA also considers health equity, clearly part of the climate change problem. New choices for energy must be made carefully considering such effects as additional pressure on the world's forests through large-scale expansion of soybean and oil palm plantations, leading to forest clearing, biodiversity loss and disease emergence, expulsion of subsistence farmers, and potential increases in food prices and emissions of carbon dioxide to the atmosphere. Investigators must consider the full range of policy options, supported by more comprehensive, flexible, and transparent assessment methods.

Health impact assessment (HIA): methods and tools by which a policy's, program's, or project's potential effects, both negative or positive, on population health can be judged

GHG: greenhouse gas

INTRODUCTION

Although many health effects of climate change have been identified (16, 52), the global disease burden for only a limited number of climate-sensitive diseases has yet been quantified (8, 41). Systematically identifying and quantifying the many pathways through which climate change can affect health are major challenges for which a comprehensive health impact assessment (HIA) is required. The principal value of such an HIA approach would be to better inform preventive measures ranging from risk-specific activities such as heatwave early-warning systems and mosquito abatement programs to broader energy policies to reduce emissions of fossil fuels—the root cause of global warming. Through an HIA approach, decision makers may best achieve primary prevention of climate change disease risks, in addition to early warning and surveillance (4, 7, 35).

Jackson & Shields, in this *Annual Review of Public Health* symposium (32), argue that the health community should consider both disease-specific preventive measures and the reduction of greenhouse gases (GHGs) that cause global warming. We concur and emphasize that health policy interventions involve not only risk assessment but also benefit assessment and broader implications. Therefore, we contend here that the health impact assessment (HIA) framework provides a comprehensive and policy-relevant approach to improve decisions on climate change and health policy.

HEALTH IMPACT ASSESSMENT

HIA has been defined as "a combination of procedures, methods and tools by which a policy, program or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population" (17). Note that by shifting focus more broadly to "potential effects on health," including both positive and negative effects, interventions can be evaluated beyond simply risk or hazard reduction.

Under a more flexible framework of HIA, cobenefits can be included that provide a more comprehensive, and therefore valuable, decision support tool to policy makers. An efficiently designed urban mass transit system, for example, will not only reduce GHG emissions, but will certainly reduce local air pollution [with associated health benefits described in the paper by Walsh in this symposium (64)] and will also likely include multimodal transportation that promotes physical exercise. In the United States, where obesity is now viewed as the nation's most challenging epidemic, energy-efficient neighborhoods and urban design aimed toward GHG mitigation could thereby result in the substantial ancillary health benefit of increased opportunities for walking and bicycling.

Thus, HIA can be a useful tool to a range of stakeholders when considering multiple outcomes to be optimized to attain population-wide benefits. Also, climate change exposures do not occur in isolation from other concurrent environmental stressors, e.g., land use change, and the HIA framework encourages analysis of synergistic pressures on environmental public health. Stakeholder concerns are variable across multiple criteria but can generally be grouped into (*a*) economic, (*b*) political, (*c*) quality of life, or (*d*) moral concerns (34). Therefore, key components that are important to the multistakeholder HIA process include equity/democracy, sustainability, and ethical use of evidence (66). Human health is central to all these stakeholder interests. Health is essential to quality of life, is viewed by many as a fundamental human right, and is central to many economic impacts and political actions (34). The principles of HIA are therefore clearly suited to considering the full set of implications of any of the range of policy options that could affect health in association with climate change. However, we need to develop further the practical application of these methods to such upstream decisions and to pay increased attention to prioritization and economic implications to ensure that the assessments have true impact on the eventual outcome of decisions and that their true potential is realized (18).

ENVIRONMENTAL JUSTICE, HIA, AND CLIMATE CHANGE

Marked regional differences influence vulnerability to health effects of climate change, be they from differences in climate exposures, public infrastructure/adaptability, or baseline climate-sensitive disease rates (28, 48). These include regions that are currently most influenced by El Niño (e.g., western South America, Southeast Asia, and Africa). Also, areas undergoing concurrent environmental degradation could modify climate exposures, for example, broadly deforested regions across Indonesia or Latin America where the cutting of forests can alter local ambient conditions or—in the face of heavy rainfall events—can exacerbate flooding (53). Of course, regions bordering areas with high endemicity of climate-sensitive diseases, such as malaria in the African highlands, could be at risk if current temperatures are limiting the geographic distribution of disease. For each of these areas, society's capacity to adapt to expected changes will determine vulnerabilities to climate change–induced health risks.

Issues of inequity in GHG responsibilities have been noted by many researchers, and it is widely accepted by those studying the impacts of climate change that developed countries are responsible for the largest share of the cumulative past GHG emissions, which led to the observed rise in temperature (3, 9, 60). Yet, those countries or populations most vulnerable to global warming are ironically those least responsible for causing the problem (**Figure 1**). Africa, a continent where an estimated 70% of malaria occurs, has some of the lowest per capita emissions of GHGs. Up to this point, the United States, by comparison, has been the world's leading contributor to GHGs, and per capita, Americans rank as the world's highest energy consumers.

COMPARATIVE ASSESSMENT OF THE GLOBAL BURDEN OF DISEASE FROM CLIMATE CHANGE

Estimating the full range of effects of climate change on health, over appropriately long time scales, presents challenges to conventional epidemiological approaches. These challenges include (*a*) the absence of an appropriate comparison group, (*b*) the long time period over which human actions affect climate, (*c*) the large number of health outcomes potentially affected by climatic change, and (*d*) the numerous nonclimatic influences on each of these outcomes. Simply observing long-term trends in climate-related diseases and attributing these changes directly to anthropogenic climate change are insufficient (35, 43, 54). We have learned the most about future climate change impacts using empirically observed relationships between weather variability and subsequent health effects.

Models already provide useful quantitative measures of future risks from climate change for specific health outcomes. However, the results of these models are difficult to relate directly to inform decisions on GHG mitigation strategies, first, because many do not attempt to account for changes in nonclimatic influences such as economic development (and hence, the ability to protect against disease risk), and second, the model outcomes are often indirectly related to health, and then only to specific diseases. On aggregate, the cobenefits of GHG mitigation may substantially add to specific climate-sensitive diseases—reinforcing the need for embedding a comparative risk assessment (CRA) into a broader HIA framework.

By adopting the World Health Organization CRA approach, some of these concerns can be partly addressed by using a standard framework for comparison across risk factors and diseases (22, 23, 45, 65). The assessment generated estimates of the numbers of deaths and disability adjusted life years (DALYs) attributable to each risk factor in the year 2000,

Comparative risk assessment (CRA): uses a standardized quantitative assessment framework and a single comparative mortality and morbidity measure to compare the disease burden across health risk factors

DALY: disability adjusted life year

along with expected changes in exposures and associated relative risks of disease outcomes for several time points between 2000 and 2030.

Comparative risk assessment involves four stages: (*a*) identifying climate-sensitive health outcomes, (*b*) determining dose-response relationships for baseline climate, (*c*) selecting future climate scenarios, and (*d*) estimating the climate change–attributable burden of disease and the burden that is avoidable by plausible reductions in the risk factor (41, 42).

IDENTIFYING CLIMATE-SENSITIVE HEALTH OUTCOMES

Global climate change is already beginning to affect health states and is expected to have broad and increasingly severe health impacts. These could occur through various exposure pathways, such as the frequency or intensity of extreme heat waves, floods, and droughts (51). Warmer air temperatures could also influence local and regional air pollutants and aeroallergens. Less-direct health impacts may result from climate-related alteration of ecosystems or water and food supplies, which in turn could affect infectious disease incidence and nutritional status. Finally, sea-level rise could lead to massive population displacement and economic disruption (29). The first World Health Organization (WHO) global assessment of the disease burden caused by climate change utilized quantitative models for heat- and cold-related mortality, malaria, diarrhea, malnutrition, and fatalities from flood events.

QUANTITATIVE ESTIMATES

Population-specific quantitative models of the climatic effects for health outcomes, or sufficient reliable disease and environmental data to allow construction of such models, are required for CRA. Models are usually generated on the basis of measurements of the health effects of observed variations in climate over time, for instance the effect of unseasonably hot or cold days on disease rates (13, 30), or geographic range (31, 55), or both (e.g., 36, 57). Extrapolating short-term or geographic relationships between climate and disease to the process of long-term climate change is likely the most important source of uncertainty in the assessment; impacts from gradual climate shifts may either be less severe (e.g., because of gradual adaptation) or more severe than expected owing to long-term stresses, for example, leading to irreversible changes in food-producing ecosystems. Another challenge to assessing risk from empirical extrapolation is that some climatic events, such as heat waves, are projected to be of a duration or intensity previously unexperienced.

To accurately compare health risks attributed to climate change we must adopt a summary measure of population health, such as the DALY (44), to combine effects of mortality and morbidity. This restricts assessment to only diseases with well-characterized and quantified disease burdens (e.g., cases of diarrhea) excluding other likely outcomes of climate change that will be broad scale and relevant to health yet lacking well-defined links to disease risk, such as populations suffering increased water stress (1) (another reason to couple CRA with HIA approaches). To resolve model discrepancies for the same health outcome, selection should be made on the basis of (*a*) validation against historical data, (*b*) biological plausibility, and (*c*) applicability to other regions.

SCENARIO-BASED CLIMATE CHANGE EXPOSURE ASSESSMENT

Baseline exposure for comparison generally consists of a climate presumably unaffected by any human activities. Although not entirely unaffected by fossil fuel combustion or deforestation, the World Meteorological Office climate averages from 1961 to 1990 are considered an appropriate baseline for such analysis.

Climate change exposures are based on global climate scenarios: internally consistent representations of future climatic conditions. These are generated by applying a range of levels of anthropogenic forcings from GHG emissions to computer models representing human and natural influences on the global climate. Output data consist of grid maps of climate variables, such as temperature, precipitation, and humidity at varying spatial resolution. The global health assessment, for example, applied three scenarios of future GHG emission levels (2): The first would continue on an unmitigated trajectory approximately following the IPCC IS92a scenario; the second would stabilize CO_2 concentrations at 750 ppm [approximately double preindustrial concentrations; (10)] by the year 2210 (s750), and the third would stabilize CO_2 concentrations at 550 ppm by the year 2170 (s550), with projected changes in climate variables compared with a 0.5° spatial resolution grid of 1961–1990 climate.

ESTIMATING ATTRIBUTABLE AND AVOIDABLE BURDENS OF DISEASE

The key challenge of the CRA of climate change is the need to link the change in exposure measurement to the change in health outcome. For each degree centigrade (unit) increase in ambient temperature, the increase in diarrhea incidence in a country (or subpopulation) per year can be estimated using relationships derived from more detailed longitudinal or cross-sectional studies. A relative risk or proportional change can then be calculated under each of the various future climate scenarios. The disease burden attributable to climate change can then be estimated by multiplying this relative risk by the total burden of disease that would have been expected to occur in the absence of climate change.

Obviously, many health outcomes are multifactorial, requiring one to consider the nonclimatic factors such as economic development or demographic trends. Nonclimatic effects can be partly addressed by stratifying relative risk estimates separately for populations with clearly different baseline disease burdens and vulnerabilities, e.g., the 14 WHO subregions in the global assessment or specific cities or particularly vulnerable locales such as small island nations. Future relative risks should be applied to projections of disease burden that incorporate changes in nonclimatic influences over time that are key to determining population vulnerability, such as improved water and sanitation services. Past global and national assessments made such adjustments to relative risks of the various outcomes. The concepts of avoidable and attributable disease burdens under alternative climate change scenarios are illustrated graphically in **Figure 2**.

In addition to the analytical difficulties in quantifying health impacts of climate change, the main limitation of the CRA approach in relation to policy making is that CRA is directed at measuring the burden associated with a specific risk, rather than considering the full range of implications of a policy or an intervention (i.e., including the costs, or cobenefits, of interventions).

IPCC: Intergovernmental Panel on Climate Change

COBENEFITS FROM MITIGATING CLIMATE CHANGE

Solutions to the health risks posed by climate change have often been divided into either adaptation strategies to prevent adverse consequences or mitigation measures to reduce fossil fuel combustion as the main cause of global warming. Responses should occur at many points along the continuum from energy policy and climate warming to more proximal health risks from heat waves or climate-sensitive infectious diseases. Moreover, as with any health risk, the further upstream the intervention, the broader the potential benefit. Briefly described below are a few well-recognized cobenefits of reducing GHG emissions, and Smith & Haigler (in this symposium) (58) suggest standard scoping methods for first-level assessments of such cobenefits for energy interventions that

Table 1 Health benefits from GHG mitigation strategies or climate-health adaptation

	Reduced fossil fuel combustion	Preserving forests as CO_2 sinks	Urban heat-island reduction	Sustainable urban design	Improved mass transportation systems
Cerebrovascular disease	**		***	***	**
Respiratory diseases	***	*	**	***	**
Diseases related to obesity (e.g., diabetes and cancers)				***	**
Mental health		**		***	**
Infectious diseases		***		*	

*some evidence; **good evidence; *** very good evidence.

reduce both health-damaging and climate-changing air pollutant emissions.

Pacala & Socolow (47) have examined existing technologies that could limit emissions of CO_2. The authors have additionally outlined a portfolio of 15 potential stabilization wedges to reduce GHG emissions by 25 gigatons of carbon (GtC) by the year 2054 (**Figure 3**). Many of these GHG mitigation strategies to prevent climate change will also have immediate public health cobenefits. Three broad areas of cobenefits include reduced local air pollution, enhanced fitness from sustainable urban design, and infectious disease regulation from abating deforestation (**Table 1**).

COBENEFITS FROM REDUCED AIR POLLUTION

Probably the best-known example of cobenefits from reducing fossil fuel combustion is the reduction of local air pollution because CO_2 is emitted alongside criteria air pollutants. Cifuentes et al. (14) found that a significant number of illnesses and deaths could be avoided by implementing GHG mitigation measures available today. By achieving a 10% reduction in GHGs, the resultant reductions in ozone and particulate matter (PM) air pollution over the period from 2001 to 2020 across the cities of New York, São Paulo, Santiago, and Mexico City would prevent 64,000 premature deaths, 65,000 cases of bronchitis, and 37 million person-days of restricted activity or work loss.

GtC: gigatons of carbon

The 1996 summer Olympics that occurred in Atlanta offered a unique natural experiment of the direct respiratory health benefits of removing cars and their tailpipe emissions from an urban environment. During the Olympics, peak morning traffic decreased by 23%, and peak ozone levels dropped by 28%. As a result, childhood asthma–related emergency room visits fell by 42% (26). See Walsh in this volume (64) for a detailed analysis of transportation trends and health trade-offs.

MULTIPLE COBENEFITS FROM SUSTAINABLE URBAN DESIGN

Over the past century, urban planning in many parts of the world has become decoupled from public health. Sprawling suburbs, particularly in the United States, have translated to increased dependence on the automobile, with multiple consequences including non-point source air pollution and water pollution from run-off over impervious asphalt surfaces, the urban heat island effect, and very likely a marked decrease in personal exercise, fitness, and mental health (27).

Recent quantitative studies are reinforcing this connection between urban design and health. For example, a survey conducted from 1998 to 2000 across 448 U.S. counties showed that suburban sprawl, at the county level, was associated with higher body-mass index (BMI), hypertension, and inversely, amount of time spent walking (21). And according to a U.S. Department of Transportation National Household Survey, for respondents who indicated they used mass transit, the median time of walking to and from transit was 19 min (5). A study from Galway, Ireland, showed that highly walkable locales (e.g., the city center or mixed-use suburbs) enhanced social capital [e.g., knowing and trusting neighbors, engaging in civic groups, and generally feeling a sense of community (38)]. Certainly many socioeconomic or cultural variables can confound such analyses, but there is a growing literature addressing the ramifications that the built environment has on the physical and mental health of urban dwellers.

As a population, 60% of American adults do not meet recommended levels of physical activity, and 25% are sedentary (20). Fifteen percent of children and adolescents ages 6–19 are overweight (12), and 7% of the U.S. population has diabetes (11). Of the 10 leading causes of death in the United States, most can be attributed in part to a sedentary lifestyle. According to the Department of Transportation, 40% of trips made by car are less than two miles (19). If, for example, the proportion of commuters by bike increased from the current level of 1%–2% to a new level of ~15% or 20% (similar to the rate of bicycling commuters in Davis, California), a significant triple win could be achieved: increased personal fitness (measured as additional calories expended), improved respiratory health from improved air quality, and reduced tons of emitted greenhouse gases (M. Grabow & J. Patz, unpublished data).

REDUCING DEFORESTATION TO MAINTAIN AND ENHANCE TERRESTRIAL CARBON STORAGE

Forests sequester and store more carbon than any other terrestrial ecosystem and are an important safeguard against climate change. When forests are cleared or degraded, their stored carbon is released into the atmosphere as carbon dioxide (CO_2) and the carbon store or sink they could provide in the future is removed. Tropical deforestation alone is responsible for ~20% of annual worldwide GHG emissions (25, 39). The pace of tropical forest clearing has dramatically increased over the past three decades, and some have estimated that an area of tropical forest the size of New York (9 million hectares) was cleared each year during the 1990s alone (24). If current trends continue, the world's rainforests could vanish by the end of this century.

Reducing rates of tropical deforestation, or in some case replanting trees, would significantly increase carbon storage and could have the cobenefits of preserving valuable plant-derived pharmaceuticals and regulating several widespread infectious diseases that have resurged in the face of deforestation. At the current rates of deforestation in the tropics (62), at least 20% of species, including ~600 potential drugs, will be lost in the next 30 years (17). Livelihoods and the mental health of indigenous forest dwellers may be affected by deforestation that displaces settlements and alters traditional ways of life.

Deforestation and land use change have also resulted in the spread of infectious diseases as well as a rise of emerging and reemerging diseases (49, 50). Deforestation, along with associated land use changes and human resettlement, has contributed to changes in malaria and/or its vectors throughout the tropics (6, 15, 59). In the East African Highlands *Anopheles gambiae* larvae survivorship in small pools was 55%–57% in open habitats exposed to direct sunlight, compared with 1%–2% in fully and partially forested habitats (61). The expansion of malaria is also occurring in Amazonia, where deforestation has provided suitable breeding sites for *Anopheles darlingi*. In deforested areas, breeding sites yield more than a 100-fold increase in *An. darlingi* biting rates, even after controlling for human population density (63).

The rapid rush to switch energy sources away from oil and increase reliance on crop-derived ethanol or biodiesel could also have devastating effects on the fate of the world's forests. In fact, the impacts of expanding prominent biofuel crops instead of food production are already evident in South America and insular Southeast Asia as large-scale fields of soybean and oil palm, respectively, expand in these regions, leading to forest clearing, expulsion of subsistence farmers, and large emissions of CO_2 to the atmosphere (25). Furthermore, recent research shows that the vast majority of newly expanding oil palm fields have replaced closed forest in parts of Malaysia and Indonesia and that increases in soybean production in Brazil coincide with more forest conversion (H. Gibbs, unpublished data). Some biofuel crops will be accompanied by increased use of agrotoxins or routine burning that may harm human health beyond increases in infectious diseases from forest clearing (46). Although reducing our reliance on fossil fuel energy is immediately and obviously necessary, an unregulated biofuels boom could affect world food supplies and price (62) and could easily have the opposite effect on the conservation of tropical forest if energy demand continues to rise without thoughtful planning (H. Gibbs, unpublished data).

HEALTH AND ENVIRONMENT: OPPORTUNITIES IN THE INTERNATIONAL FRAMEWORK CONVENTIONS

The growing confluence of health and global environmental change creates a unique opportunity for the international community. Growing evidence of the acute impacts of global environmental change is making clear the need to act quickly to protect the planet's ecological and climatic systems. Without such action, millions of people in all countries are likely to face significantly greater health risks. Existing health disparities are being exacerbated by climate change and the loss of ecosystem services required to support and maintain health and well-being for many people already struggling with poverty, malnutrition, and the effects of natural disasters.

In this context, new emphasis on the human health dimensions of global environmental change offers a strong motivation for concerted global action to address challenges such as climate change, biodiversity loss, and land degradation. Health has long been a major component of environmental concern in many countries, and a new focus on health may help shore up public support for progress toward new, more ambitious global environmental policies.

The emerging UNFCCC discussion on reducing emissions from deforestation and degradation (REDD) could have major benefits for regulating human disease and general welfare by mitigating local climate change and natural disasters, while providing financial incentives to developing countries to conserve forests (56). A group of developing countries, led by Papua New Guinea and Costa Rica, have formed the Coalition for Rainforest Nations and are calling for financial incentives via the international carbon market to help curb rates of tropical deforestation and the associated carbon emissions (37). This initiative was formally negotiated at the UNFCCC Conference of the Parties (COP)-13 meeting in December 2007. These key international policy measures may represent key moments for health and climate scientists and policy makers to work together.

CONCLUSION

Quantifying the health risks linked to climate change and comparing these figures to those from other risk factors will assist in public health planning. However, to the extent that many cobenefits will arise from reducing fossil fuel emissions that cause global warming, and that other actions either to mitigate or to adapt to climate change (e.g., utilizing increased amounts of biofuels) could have significant trade-offs and potential negative health implications, assessment approaches that extend beyond conventional risk assessment—such as health impact assessment—are required. Under this broader assessment strategy, the grand challenge of climate change could present enormous health opportunities. Redesigning cities to be sustainable, thus encouraging less automobile dependence and more biking and walking, is but one example of why reducing fossil fuel combustion can be so health promoting. To realize some of these multi-wins, new concerted and highly interdisciplinary partnerships must be forged, nurtured, and maintained.

SUMMARY POINTS

1. Poor nations and communities are disproportionately vulnerable to the consequences of climate change. Whereas industrialized nations contribute the bulk of carbon emissions, mostly through fossil fuel burning, developing nations suffer far higher relative economic and human losses from increased vulnerability to infectious diseases and other health concerns associated with climate change.
2. The IPCC Fourth Assessment report has further strengthened the overwhelming body of evidence showing that human activity, primarily from fossil fuel burning, is the dominant cause of the observed rise in average global temperatures. The report further warns that adverse health effects will likely outweigh health benefits.
3. Fossil fuel combustion is also the main source of conventional air pollution and air toxics. Additionally, gasoline-based transportation and subsequent automobile dependence in many urban centers may decrease opportunities for population-wide physical fitness, as well as opportunities for building social capital and enhancing health equity. Therefore, major health cobenefits are possible from greenhouse gas mitigation policies.
4. In adapting or mitigating climate change and associated risks, we must carefully plan (under a comprehensive health impact assessment framework) for potential trade-offs or side effects of new energy options (e.g., potential destruction of rainforests in the quest to expand biofuels to replace fossil fuel sources).

FUTURE ISSUES

1. Future research should explore the health effects of biofuels and other renewable energy sources.
2. It is important to identify potential health and ecological impacts caused by the shift from fossil fuels to biofuels.
3. We must weigh the pros and cons of adaptation strategies (e.g., over-reliance on air conditioning with potential risk of electrical blackouts).
4. Investigators should conduct full health impact assessments to optimize the multiple health benefits through decarbonizing our energy economy.

DISCLOSURE STATEMENT

The authors are not aware of any biases that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

The authors thank Sarah Olson from the Center for Sustainability and the Global Environment of the University of Wisconsin for constructing the GIS map of per-country climate-sensitive diseases, and the World Health Organization (WHO) for providing the data. The views of this paper are those of the authors and not necessarily of the WHO.

LITERATURE CITED

1. Arnell NW. 1999. Climate change and global water resources. *Glob. Environ. Change* 9:S31–51
2. Arnell NW, Cannell MGR, Hulme M, Mitchell JFB, Kovats RS, et al. 2002. The consequences of CO_2 stabilization for the impacts of climate change. *Clim. Change* 53:413–46
3. Baer P, Harte J, Haya B, Herzog AV, Holdren J, et al. 2000. Climate change—equity and greenhouse gas responsibility. *Science* 289:2287
4. Somers J. 2002. *City of Madison climate protection plan*. **http://www.ci.madison.wi.us/environment/ccp_2002.pdf**
5. Besser LM, Dannenberg AL. 2005. Walking to public transit: steps to help meet physical activity recommendations. *Am. J. Prev. Med.* 29:273–80
6. Bunnag T, Sornmani S, Pinithpongse S, Harinasuta C. 1979. Surveillance of water-borne parasitic infections and studies on the impact of ecological changes on vector mosquitoes of malaria after dam construction. *Southeast Asian J. Trop. Med. Public Health* 10:656–60
7. Campbell-Lendrum D, Woodruff R. 2006. Comparative risk assessment of the burden of disease from climate change. *Environ. Health Perspect.* 114:1935–41
8. Campbell-Lendrum DH, Pruss-Ustun A, Corvalán C. 2003. How much disease could climate change cause? In *Climate Change and Health: Risks and Responses*, ed. AJ McMichael, DH Campbell-Lendrum, C Corvalán, K Ebi, A Githeko, et al. Geneva: WHO
9. Cazorala M, Toman M. 2000. *International Equity and Climate Change Policy*. Washington, DC: Resour. Futur.
10. CDIAC. 2003. *Trends online: a compendium of data on global change*. **http://cdiac.esd.ornl.gov/trends/trends.htm**
11. Cent. Dis. Control Prev. (CDC). 2005. National diabetes fact sheet: general information and national estimates on diabetes in the United States, 2005. **http://www.cdc.gov/diabetes/pubs/pdf/ndfs_2005.pdf**
12. Cent. Dis. Control Prev. (CDC). National Center for Health Statistics (NCHS). 2007. *National Health and Nutrition Examination Survey*. Hyattsville, MD: US Dep. Health Hum. Serv., Cent. Dis. Control Prev.
13. Checkley W, Epstein LD, Gilman RH, Figueroa D, Cama RI, et al. 2000. Effects of El Nino and ambient temperature on hospital admissions for diarrhoeal diseases in Peruvian children. *Lancet* 355:442–50
14. Cifuentes L, Borja-Aburto VH, Gouveia N, Thurston G, Davis DL. 2001. Climate change. Hidden health benefits of greenhouse gas mitigation. *Science* 293:1257–59
15. Coluzzi M. 1994. Malaria and the Afrotropical ecosystems: impact of man-made environmental changes. *Parassitologia* 36:223–27
16. Confalonieri U, Menne B, Akhtar R, Ebi KL, Hauengue M, et al, 2007. *Human health. Climate Change 2007: Impacts, Adaptation and Vulnerability*, ed. ML Parry, OF Canziani, JP Palutikof, PJ van der Linden, CE Hanson, pp. 391–431. Cambridge, UK: Cambridge Univ. Press

17. Confalonieri UEC. 2000. Environmental change and human health in the Brazilian Amazon. *Glob. Change Hum. Health* 1:174–83
18. Davenport C, Mathers J, Parry J. 2006. Use of health impact assessment in incorporating health considerations in decision making. *J. Epidemiol. Community Health* 60:196–201
19. Dep. Transport. (DOT). 2001. *Summary statistics on demographic characteristics and total travel, 1969, 1977, 1983, 1990, 1995 NPTS and 2001 NHTS*. **http://www.fhwa.dot.gov/policy/ohim/hs05/pdf/nt1.pdf**
20. Dep. Health Hum. Serv (DHHS). 1996. *Physical Activity and Health: A Report of the Surgeon General*. Hyattsville, MD: Natl. Cent. Chron. Dis. Prev. Health Promot., Cent. Dis. Control Prev.
21. Ewing R, Schmid T, Killingsworth R, Zlot A, Raudenbush S. 2003. Relationship between urban sprawl and physical activity, obesity, and morbidity. *Am. J. Health Promot.* 18:47–57
22. Ezzati M, Lopez A, Rodgers A, Murray C, eds. 2004. *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors*. Geneva: WHO
23. Ezzati M, Lopez AD, Rodgers A, Vander Hoorn S, Murray CJ. 2002. Selected major risk factors and global and regional burden of disease. *Lancet* 360:1347–60
24. FAO. 2001. Global forest resources assessment 2000. *Rep. 140*. Rome **http://www.fao.org/forestry/site/fra2000report/en/**
25. Fearnside PM, Laurance WF. 2003. Comment on "Determination of deforestation rates of the world's humid tropical forests." *Science* 299:1015
26. Friedman MS, Powell KE, Hutwagner L, Graham LM, Teague WG. 2001. Impact of changes in transportation and commuting behaviors during the 1996 Summer Olympic Games in Atlanta on air quality and childhood asthma. *JAMA* 285:897–905
27. Frumkin H, Frank L, Jackson RJ. 2004. *Urban Sprawl and Public Health: Designing, Planning and Building for Healthy Communities*. Washington, DC: Island. 288 pp.
28. Gross J. 2002. The severe impact of climate change on developing countries. *Med. Glob. Surviv.* 7:96–100
29. Haines A, Patz JA. 2004. Health effects of climate change. *JAMA* 291:99–103
30. Hajat S, Armstrong BG, Gouveia N, Wilkinson P. 2005. Mortality displacement of heat-related deaths: a comparison of Delhi, Sao Paulo, and London. *Epidemiology* 16:613–20
31. Hales S, de Wet N, Maindonald J, Woodward A. 2002. Potential effect of population and climate changes on global distribution of dengue fever: an empirical model. *Lancet* 360:830–34
32. Jackson RJ, Shields K. 2008. Preparing the U.S. health community for climate change. *Annu. Rev. Public Health* 29:57–73
33. Kay D, Prüss A, Corvalan C. 2000. Methodology for assessment of environmental burden of disease: report on the ISEE session on environmental burden of disease. *Rep. WHO/SDE/WSH/00.*7, Buffalo, NY
34. Kjellstrom T, van Kerkhoff L, Bammer G, McMichael T. 2003. Comparative assessment of transport risks—how it can contribute to health impact assessment of transport policies. *Bull. World Health Organ.* 81:451–57
35. Kovats RS, Campbell-Lendrum DH, McMichael AJ, Woodward A, Cox JS. 2001. Early effects of climate change: Do they include changes in vector-borne disease? *Phil. Trans. R. Soc. Ser. B* 356:1057–68
36. Kuhn KG, Campbell-Lendrum DH, Armstrong B, Davies CR. 2003. Malaria in Britain: past, present, and future. *Proc. Natl. Acad. Sci. USA* 100:9997–10,001
37. Laurance WF. 2007. A new initiative to use carbon trading for tropical forest conservation. *Biotropica* 39:20–24

38. Leyden KM. 2003. Social capital and the built environment: the importance of walkable neighborhoods. *Am. J. Public Health* 93:1546–51
39. Malhi Y, Grace J. 2000. Tropical forests and atmospheric carbon dioxide. *Trends Ecol. Evol.* 15:332–37
40. Marland G, Boden TA, Andres RJ. 2007. Global, regional, and national CO_2 emissions. In *Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center*. Oak Ridge, TN: Oak Ridge Natl. Lab. US Dep. Energy
41. McMichael A, Campbell-Lendrum D, Kovats R, Edwards S, Wilkinson P, et al. 2004. Climate change. In *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors*, ed. M Ezzati, A Lopez, A Rodgers, C Murray. Geneva: WHO
42. McMichael A, Woodruff R, Whetton P, Hennessy P, Nicholls N, et al. 2003. *Human Health and Climate Change in Oceania: A Risk Assessment*. Canberra: Commonw. Aust.
43. McMichael AJ, Githeko A. 2001. Human health. In *Climate Change 2001: Impacts, Adaptation and Vulnerability*, ed. JJ McCathy, OF Canziani, NA Leary, DJ Dokken, KS White, pp. 451–85. Cambridge, UK: Cambridge Univ. Press
44. Murray CJL. 1994. Quantifying the burden of disease—the technical basis for disability-adjusted life years. *Bull. World Health Organ.* 72:429–45
45. Murray CJL, Lopez AD. 1997. The utility of DALYs for public health policy and research: a reply. *Bull. World Health Organ.* 75:377–81
46. Nepstad DC, Stickler CM, Almeida OT. 2006. Globalization of the Amazon soy and beef industries: opportunities for conservation. *Conserv Biol.* 20:1595–603
47. Pacala S, Socolow R. 2004. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science* 305:968–72
48. Patz JA, Campbell-Lendrum D, Holloway T, Foley JA. 2005. Impact of regional climate change on human health. *Nature* 438:310–17
49. Patz JA, Confalonieri UEC. 2005. *Health Health: Ecosystem Regulation of Infectious Diseases*. Washington, DC: Island. **http://www.maweb.org/en/Global.aspx**
50. Patz JA, Daszak P, Tabor GM, Aguirre AA, Pearl M, et al. 2004. Unhealthy landscapes: policy recommendations on land use change and infectious disease emergence. *Environ. Health Perspect.* 112:1092–98
51. Patz JA, Engelberg D, Last J. 2000. The effects of changing weather on public health. *Annu. Rev. Public Health* 21:271–307
52. Patz JA, Epstein PR, Burke TA, Balbus JM. 1996. Global climate change and emerging infectious diseases. *JAMA* 275:217–23
53. Patz JA, Kovats RS. 2002. Hotspots in climate change and human health. *BMJ* 325:1094–98
54. Reiter P. 2001. Climate change and mosquito-borne disease. *Environ. Health Perspect.* 109(Suppl. 1):141–61
55. Rogers DJ, Randolph SE. 2000. The global spread of malaria in a future, warmer world. *Science* 289:1763–66
56. Santilli M, Moutinho P, Schwartzman S, Nepstad D, Curran L, Nobre C. 2005. Tropical deforestation and the Kyoto Protocol. *Clim. Change* 71:267–76
57. Singh RB, Hales S, de Wet N, Raj R, Hearnden M, Weinstein P. 2001. The influence of climate variation and change on diarrheal disease in the Pacific Islands. *Environ. Health Perspect.* 109:155–59
58. Smith KR, Haigler E. 2008. Cobenefits of climate mitigation and health protection in energy systems: scoping methods. *Annu. Rev. Public Health* 29:11–25

59. Tadei WP, Thatcher BD, Santos JMH, Scarpassa VM, Rodrigues IB, Rafael MS. 1998. Ecologic observations on anopheline vectors of malaria in the Brazilian Amazon. *Am. J. Trop. Med. Hyg.* 59:325–35
60. Thomas DSG, Twyman C. 2005. Equity and justice in climate change adaptation amongst natural-resource-dependent societies. *Glob. Environ. Change Hum. Policy Dimens.* 15:115–24
61. Tuno N, Okeka W, Minakawa N, Takagi M, Yan G. 2005. Survivorship of Anopheles gambiae sensu stricto (Diptera: Culicidae) larvae in western Kenya highland forest. *J. Med. Entomol.* 42:270–77
62. UN-Energy. 2007. *Sustainable bioenergy: a framework for decision makers*. **http://esa.un.org/un-energy/pdf/susdev.Biofuels.FAO.pdf**
63. Vittor AY, Gilman RH, Tielsch J, Glass G, Shields T, et al. 2006. The effect of deforestation on the human-biting rate of Anopheles darlingi, the primary vector of falciparum malaria in the Peruvian Amazon. *Am. J. Trop. Med. Hyg.* 74:3–11
64. Walsh M. 2008. Ancillary benefits for climate change mitigation and air pollution control in the world's motor vehicle fleets. *Annu. Rev. Public Health* 29:1–9
65. WHO. 2002. *The World Health Report 2002*. Geneva: WHO
66. WHO Eur. Cent. Health Policy. 1999. *Health impact assessment: main concepts and suggested approach. Gothenburg concensus paper*. Presented at Gothenburg Conf., Brussels **http://www.euro.who.int/document/PAE/Gothenburgpaper.pdf**

RELATED RESOURCES

Aron JL, Patz JA, eds. 2001. *Ecosystem Change and Public Health: a Global Perspective*. Baltimore, MD: Johns Hopkins Univ. Press

Frumkin H, ed. 2005. *Environmental Health: From Global to Local*. Hoboken, NJ: Jossey-Bass

McMichael T. 2001. *Human Frontiers, Environments and Disease*. Cambridge, UK: Cambridge Press

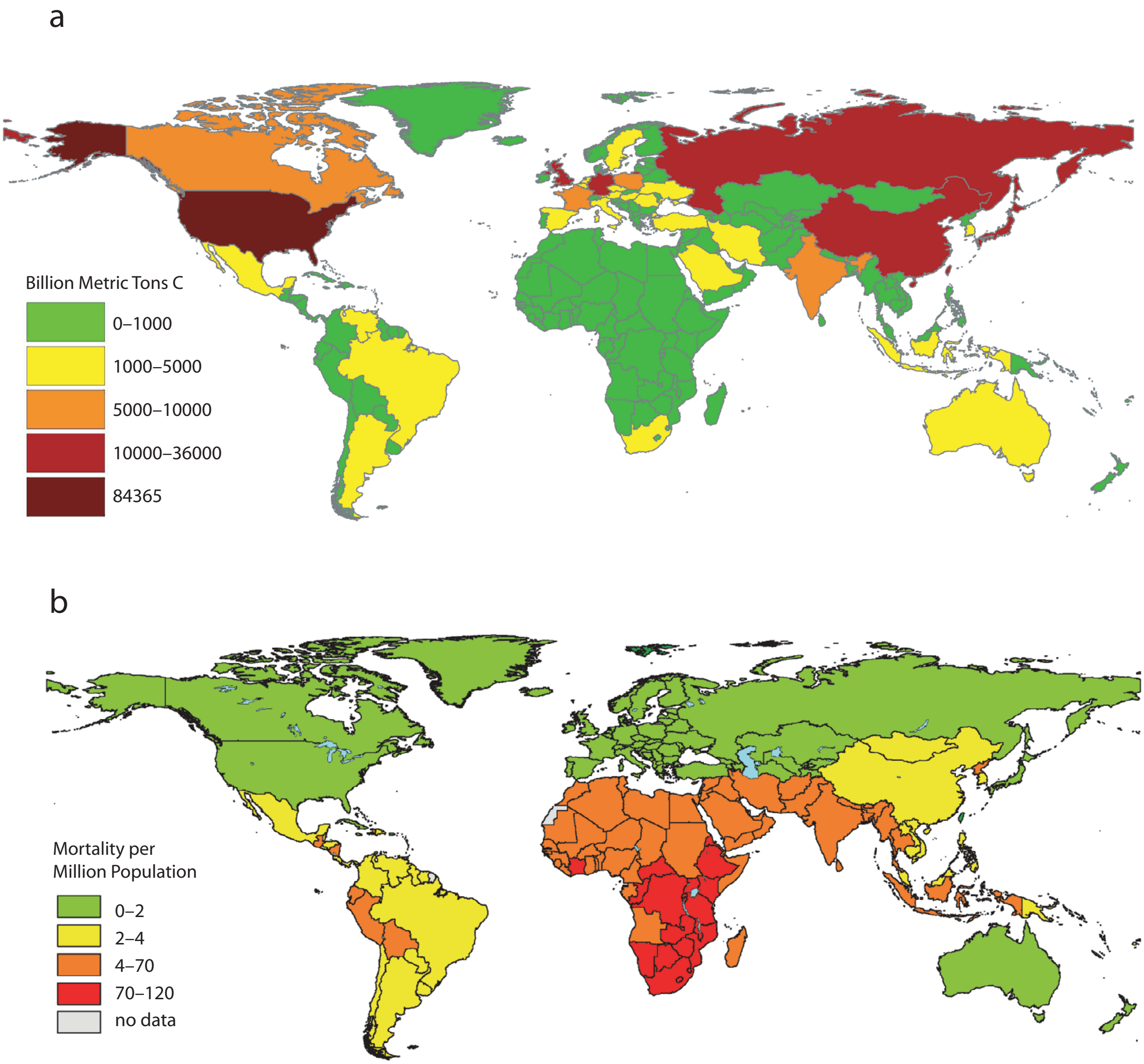

Figure 1

Comparison of year 2000 distribution of carbon dioxide (CO_2) emissions (by country) vs. the regional distribution of four climate-sensitive health effects. (*a*) CO_2 emissions (data from Reference 40). (*b*) The Intergovernmental Panel on Climate Change (IPCC) "business as usual" greenhouse gas (GHG) emissions scenario, "IS92a," and the HadCM2 general circulation model (GCM) of the U.K. Hadley Center were used to estimate climate changes relative to baseline 1961–1990 levels of GHGs and associated climate conditions. Existing quantitative studies of climate-health relationships were used to estimate relative changes in diarrhea, malaria, inland and coastal flooding, and malnutrition from 2000 to 2030. This is only a partial list of potential health outcomes, and significant uncertainties exist in all the underlying models. These estimates should therefore be considered a conservative, approximate estimate of the health burden of climate change.

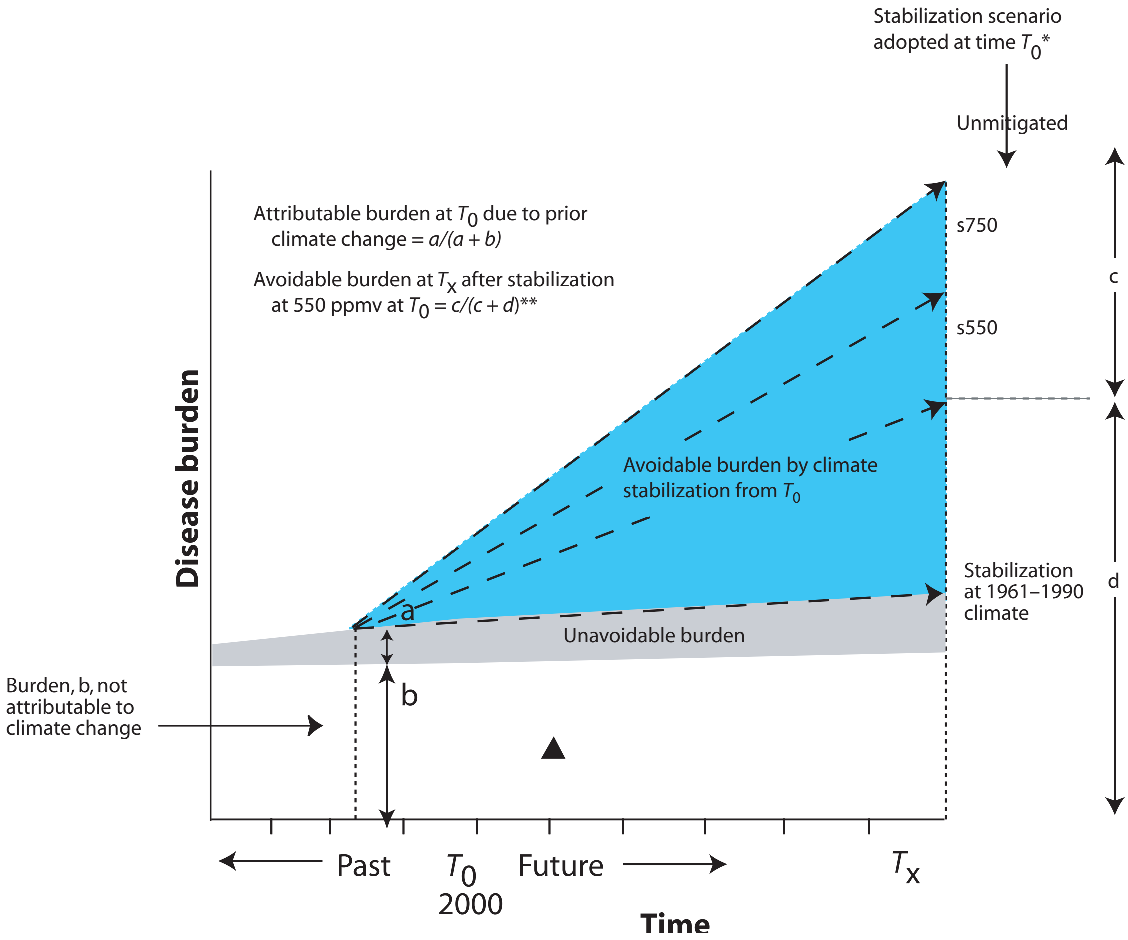

Figure 2

Comparative risk assessment definitions of attributable and avoidable disease burden in the context of climate change. GHG, greenhouse gases; ppmv, parts per million by volume; *T*, time. Adapted from (33). *a* = amount of disease as T_0 attributable to prior anthropogenic climate change; *b* = amount of disease at T_0 not attributable to prior anthropogenic climate change; *c* = amount of disease avoidable at T_x with GHG stabilization at 550 ppmv at T_0; *d* = amount of disease predicted at T_x despite GHG stabilization at 550 ppmv at T_0; *Dashed arrows represent total of burden after a given shift in risk distributions at T_0; **Avoidable burden by T_x would be given by ratio of different shaded areas.

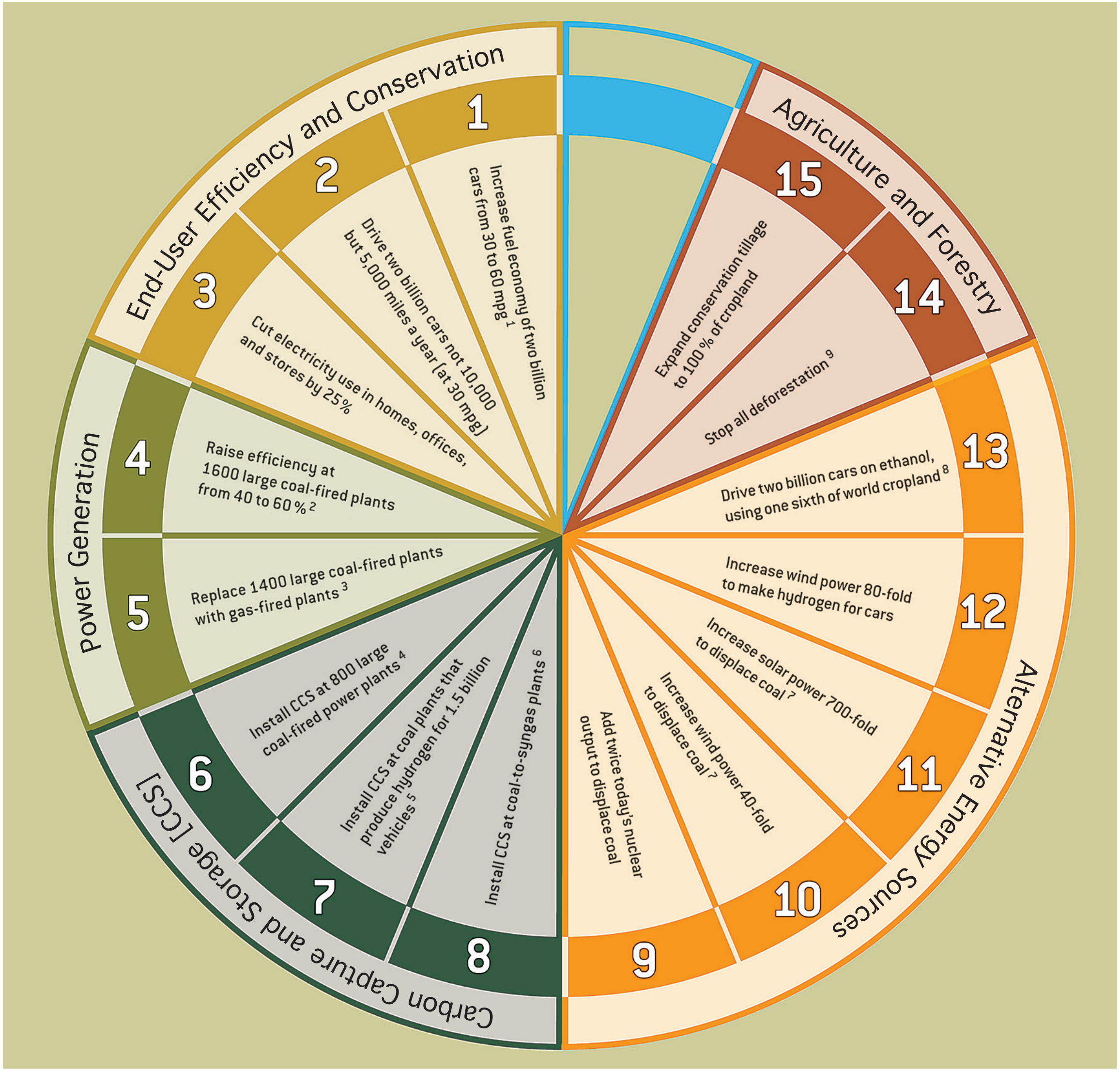

Figure 3

Potential wedges: strategies available to reduce the carbon emission rates in 2054 by 1 GtC/year or to reduce carbon emissions from 2004 to 2054 by 25 GtC. Figure created by J. Chao and reprinted with permission from *Scientific American*. See Reference 47.

Annual Review of Public Health

Volume 29, 2008

Contents

Social Environment and Behavior

The Effectiveness of Mass Communication to Change Public Behavior
Lorien C. Abroms and Edward W. Maibach 219

U.S. Disparities in Health: Descriptions, Causes, and Mechanisms
Nancy E. Adler and David H. Rehkopf 235

Health Services

A Critical Review of Theory in Breast Cancer Screening Promotion across Cultures
Rena J. Pasick and Nancy J. Burke 351

Indexes

Errata

An online log of corrections to *Annual Review of Public Health* articles may be found at http://publhealth.annualreviews.org/