Special Communication

Climate Change
Challenges and Opportunities for Global Health

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Editorial

IMPORTANCE Health is inextricably linked to climate change. It is important for clinicians to understand this relationship in order to discuss associated health risks with their patients and to inform public policy.

OBJECTIVES To provide new US-based temperature projections from downscaled climate modeling and to review recent studies on health risks related to climate change and the cobenefits of efforts to mitigate greenhouse gas emissions.

DATA SOURCES, STUDY SELECTION, AND DATA SYNTHESIS We searched PubMed from 2009 to 2014 for articles related to climate change and health, focused on governmental reports, predictive models, and empirical epidemiological studies. Of the more than 250 abstracts reviewed, 56 articles were selected. In addition, we analyzed climate data averaged over 13 climate models and based future projections on downscaled probability distributions of the daily maximum temperature for 2046-2065. We also compared maximum daily 8-hour average with air temperature data taken from the National Oceanic and Atmospheric Administration National Climate Data Center.

RESULTS By 2050, many US cities may experience more frequent extreme heat days. For example, New York and Milwaukee may have 3 times their current average number of days hotter than 32°C (90°F). The adverse health aspects related to climate change may include heat-related disorders, such as heat stress and economic consequences of reduced work capacity; and respiratory disorders, including those exacerbated by fine particulate pollutants, such as asthma and allergic disorders; infectious diseases, including vectorborne diseases and water-borne diseases, such as childhood gastrointestinal diseases; food insecurity, including reduced crop yields and an increase in plant diseases; and mental health disorders, such as posttraumatic stress disorder and depression, that are associated with natural disasters. Substantial health and economic cobenefits could be associated with reductions in fossil fuel combustion. For example, the cost of greenhouse gas emission policies may yield net economic benefit, with health benefits from air quality improvements potentially offsetting the cost of US carbon policies.

CONCLUSIONS AND RELEVANCE Evidence over the past 20 years indicates that climate change can be associated with adverse health outcomes. Health care professionals have an important role in understanding and communicating the related potential health concerns and the cobenefits from reducing greenhouse gas emissions.

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Current science highlights serious worldwide adverse health outcomes related to climate change. Although uncertainty remains regarding the extent of climate change, this uncertainty is diminishing.[1] Consensus is substantial that human behavior contributes to climate change: 97% of climatologists maintain that climate change is caused by human activities, particularly fossil fuel combustion and tropical deforestation.[2-4] Questions remain concerning risks, vulnerabilities, and priorities for policies to promote adaptation (reducing adverse outcomes) and mitigation (reducing heat-inducing emissions).

About half of anthropogenic greenhouse gas emissions between 1750 and 2010 occurred since 1970. The increase in greenhouse gas emissions has been greatest in the last decade (2.2% per year) compared with 1.3% per year between 1970 and 2000.[5] Emissions continue to increase; 2011 emissions exceeded those in 2005 by 43%.[1] Carbon dioxide from fossil fuels and industrial processes accounted for approximately 78% of the total increase from 1970-2010. Economic and population growth contribute most to increases in emissions globally and have outpaced improvements in energy efficiency. The trend toward decarbonization (cleaner fuels) of the world's energy since the 1970s has been reversed by increased coal combustion since 2000.[5]

Climatologists calculate that to avoid heating the earth more than 2°C from preindustrial levels, anthropogenic carbon dioxide emissions must be significantly reduced. Some of the projected earth system changes—which include changes in temperature and precipitation, the rise in sea levels, and acidification of the ocean—are widely accepted as the consequences of increasing carbon dioxide concentrations in the earth's atmosphere (**Box 1**).[1] Although evidence on global trends and the extent that climate change is related to human behavior are substantial, necessary actions on emission reductions have lagged.

Box 1. Overall Trends in Temperature, Precipitation, Sea Level, and Ocean Acidification

Temperature

Overall temperatures and frequency of more than 38°C (>100°F) weather are projected to increase by 2100. Increase of global mean surface temperatures for 2081-2100 are projected to likely be in the ranges of 0.3°C to 4.8°C relative to 1986-2005.

Precipitation

In the United States, precipitation in the heaviest 1% of rains increased 20% in the past century, while total rainfall increased 7%. In dry regions mean precipitation will decrease, while El Nino–related precipitation variability will likely intensify.[6]

Sea Level Rise

Global mean sea level has risen approximately 20 cm in 100 years, far more than in the 2 previous millennia, associated with thermal expansion and melting small glaciers. Although sea level is likely to rise between 26 cm and 98 cm by 2100, "tail risk" projections give more extreme estimates (>200 cm) due to catastrophic melting events.

Ocean Acidification

Oceans have absorbed about 30% of anthropogenic carbon dioxide surface pH has become 0.1 more acidic since the beginning of the industrial era.

Framing Climate Change and Health

Climate change is happening: the relationship of heat-waves, floods, and droughts along with adverse health outcomes is evident.[7,8] Two broad approaches are needed to protect public health: *mitigation*, or major reductions in carbon emissions, corresponding to primary prevention; and *adaptation*, or steps to anticipate and reduce threats, corresponding to secondary prevention (or public health preparedness).

A wide range of solutions is available to mitigate the problem of climate change. Many of them would improve health immediately. From decreasing rates of chronic diseases to reducing motor vehicle crashes, there are many good solutions for climate disasters and health risks. Reducing greenhouse gas, deploying sustainable energy technologies, shifting transportation patterns, and improving building design—many of which yield multiple benefits—are feasible, cost-effective, and attractive to multiple parties. Health care professionals are uniquely positioned to develop policies that simultaneously serve both planet and people.[9]

Climate change, as a global disturbance, can exacerbate many environmental health risks familiar to clinicians and public health professionals.[10,11] The nature of risks and population vulnerability will vary by region; indirect consequences such as ecosystem collapse may overshadow more direct health effects, yet are more difficult to estimate.

Recent reviews on health effects of climate change have been published by the Intergovernmental Panel on Climate Change[7] and the US National Climate Assessment.[8] Our goals in this Special Communication are to provide new US-based temperature projections from downscaled climate modeling and to review recent studies on climate change health risks and the cobenefits of mitigating greenhouse gas emissions. A brief list of key findings is summarized in **Box 2**.

Methods

We reviewed the literature of international studies on climate change and health and disease risk or the cobenefits of reducing fossil fuel emissions by searching the PubMed database and Google Scholar from January 2009 to April 2014. Priority for inclusion was based on peer-reviewed articles published within the past 3 years that focused on climate and heat-related disorders, reduced work capacity, respiratory disorders, infectious diseases, food insecurity, mental health disorders, climate change communications, and health cobenefits. We identified more than 250 abstracts, and 56 articles are the basis of this review component of this article. In addition, we included our original analysis of US-based risks from heat waves and ozone air pollution (**Figure 1** and **Figure 2**). Extreme heat data were obtained from the University of Wisconsin Probabilistic Downscaled Climate Data[12] according to methods described in Kirchmeier et al.[13] (*Downscaling* is the process of providing locally specific information based on large-scale data. We took large-scale climate data from the global climate models and made it regionally specific using a statistical method.) Data were averaged over 13 climate models, which are required by the World Climate Research Programme's coupled model intercomparison project phase 3 multimodel data set to accommodate the intercomparison nature of the program.[14] Present-day estimates of the number of hot days are based on downscaled probability distributions—used for future climate modeling to establish uncertainty ranges—of daily maximum temperature for the years 1960 through 1999 from the Climate of the 20th Century simulations. Future projections are based on downscaled probability distributions of daily maximum temperature for the years 2046-2065 from the IPCC A1B emissions scenario that assumes "business as usual" or rapid economic growth and a global average temperature increase of 2.8°C.[12-14]

For ozone and temperature analysis, we used ground-level ozone measurements from the US Environmental Protection Agency Air Quality System database. The maximum daily 8-hour average for each city—based on the number of monitoring sites within the city in operation between 1980 and 2002 during the May through October period, when ozone concentrations are highest—were calculated. If any monitor was higher than the 75 ppb threshold, selected as the current health-protective ozone limit from the EPA National Ambient Air Quality Standards, then the day was counted in the yearly total. Air temperature data were taken from the US National Oceanic Atmospheric Administration (NOAA) National Climate Data Center. In an analysis approach modeled after the Connecticut Department of Energy and Environmental Protection,[15] annual values were compared and demonstrated that relationships existed between the number of high-ozone days each year and the number of hot-temperature days each year.

Heat-Related Disorders

The most direct effect of a warming planet is heat stress and associated disorders. Heat-related deaths are routinely attributed to causes such as cardiac arrest without citing temperature as the underlying factor.[16] Thus, the actual death toll attributable to heat is greater than certified on death certificates. Annual certified heat-related deaths averaging 658 in the United States between 1999 and 2009, represent more fatalities than all other weather events combined.[17,18] More accurate risk estimates have compared observed vs expected mortality during heat events; for example, 70 000 excess deaths were estimated for the 2003 European heat wave and 15 000 for the 2010 Russian heat wave.[19,20]

Although air conditioning has reduced heat-related deaths and illness in the United States, climatic and demographic trends suggest that risks may persist.[21,22] Estimates from 7 climate models for the years 2081-2100 project that more than 2000 excess heat wave–related deaths per year may occur in Chicago, Illinois.[23] More frequent and persistent heat waves are forecast, especially in the high latitudes of North America and Europe.[24,25] Mega heat waves (as occurred in Europe and Russia) are projected to increase in frequency by 5- to 10-fold within the next 40 years.[26] Figure 1 shows projected days with temperatures exceeding 32°C (90°F) per year by midcentury for Milwaukee, Wisconsin, New York, New York, and Atlanta, Georgia, and days of temperatures exceeding 38°C (100°F) for Dallas, Texas. Data were averaged across 13 climate models for this analysis. Frequency of hot days markedly increases across all cities; for example, New York City is projected to experience 3 times the current average number of 32°C (90°F) days by the midcentury (from 13 to 39 days).

High-risk groups include elderly persons, those living in poverty or social isolation, and those with underlying mental illness.[27,28] Depression may be aggravated; suicide has long been observed to vary with weather.[29-32] Dementia is a risk for hospitalization and death during heat waves.[33,34] Psychotic illnesses such as schizophrenia,[35-43] as well as substance abuse,[44] also are associated with an increased risk of death during extremely hot weather. Increased frequency of kidney stones (likely precipitated by dehydration) also occurs during heat waves.[45]

Cities with investments in early warning and response programs have seen some success. For example, after Milwaukee implemented an extreme heat conditions plan following 91 fatalities during the 1995 heat wave, a subsequent heat wave in 1999 resulted in only 10 deaths, or 49% less than expected.[46] It is estimated that more proactive health adaptations in cities, such as enhanced tree canopies and more reflective, less heat-absorbing surfaces, could reduce heat-related mortality by 40% to 99% in Atlanta, Philadelphia, Pennsylvania, and Phoenix, Arizona.[47]

Might fewer cold-related deaths balance mortality from heat waves? This is a topic of active research and current uncertainty, with results likely differing for climate zone and infrastructure characteristics. Although relative increases in heat-related deaths may exceed relative decreases in cold-related deaths, this may not apply in absolute terms because the balance may depend on location, population structure (proportion of older residents), and amount of warming,[48,49] and the Intergovernmental Panel on Climate Change expressed low confidence that modest reductions in cold-related mortality would occur.[7] Reasons for this include the observation that

Box 2. Key Messages

Health Effects of Climate Change

Heat-related disorders, including heat stress and economic consequences of reduced work capacity

Respiratory disorders, including those exacerbated by fine particulate pollutants, such as asthma and allergic diseases

Infectious diseases, including vectorborne diseases, such as Lyme disease, and water-borne diseases, such as childhood gastrointestinal diseases

Food production, including reduced crop yields and an increase in plant diseases

Mental health disorders such as posttraumatic stress disorder and depression that are associated with natural disasters

Approaches to Climate Change Adaptation

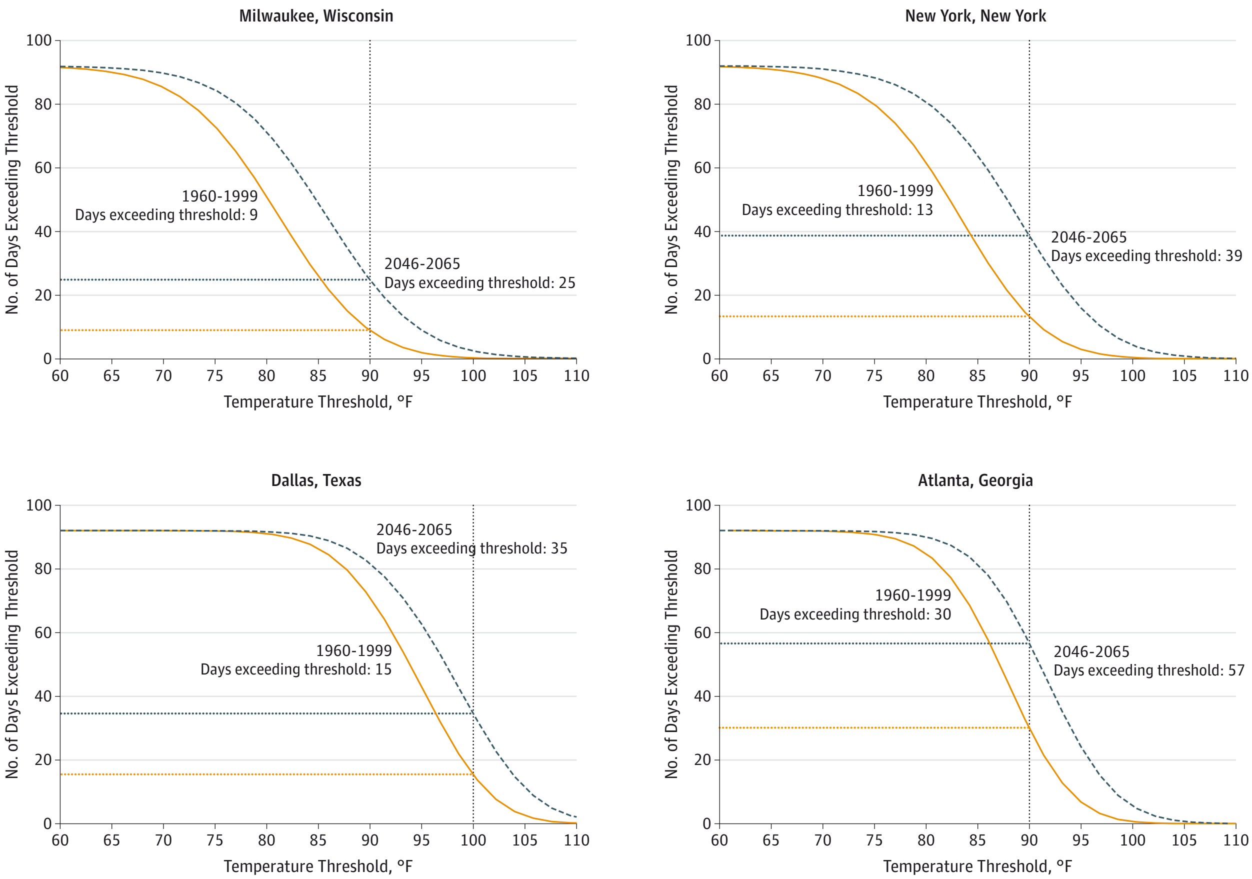
Infrastructure improvements, including more green spaces, building replacement, and white roofs

Health Cobenefits From Mitigating Climate Change

Economic advantages of reducing fossil fuel combustion and improving air quality, including a reduction in chronic diseases and their associated health care costs, and economic opportunities associated with development of alternative forms of energy

Infrastructure improvements that reduce greenhouse emissions could also lead to increased physical activity that would be associated with a reduction in various chronic diseases

Figure 1. Cumulative Distribution of Days in June Through August of Daytime Maximum Temperatures Exceeding a Given Threshold, 1960-1999 and 2046-2065



The dotted line indicates the temperature thresholds for each city: 90°F (32°C) in Milwaukee, Atlanta, and New York and 100° (38°C) in Dallas. The estimates predict temperatures based on "business as usual" emissions scenario. The curves represent the average of an analysis conducted by the University of Wisconsin, Center for Climatic Research of more than 13 models.

many deaths related to cold temperatures do not occur during coldest times and that there is a lag between exposure to cold temperatures and increased risk of death typically much longer than 1 or 2 days.[50]

Occupational Health

Outdoor workers are affected by heat, so economic consequences on work capacity can be substantial.[51] Modeling by Kjellstrom et al[52] projected that by the 2050s workdays lost due to heat could reach 15% to 18% in South-East Asia, West and Central Africa, and Central America.

Using industrial and military guidelines, Dunne et al[53] estimated that ambient heat stress has reduced global population-weighted labor capacity by 10% in summer's peak over the past few decades. Projected reduction may double by 2050 and may be even larger in the latter half of the 21st century. Locations already with hot ambient conditions are particularly susceptible to heat stress losses in labor capacity, a potential liability for fragile economies.

Respiratory Disorders

The majority of research on the climate change–pollution connections has focused on ground-level ozone and particulate matter,[54] both of which vary with the weather.[55] Even in the face of improving emissions, a climate penalty or temperature-related worsening of pollution may be anticipated.[56]

We compared ground-level ozone measurements from the US EPA Air Quality System with temperature data from NOAA's National Climate Data Center. The analysis displayed in Figure 2 suggests a direct relationship between temperature and ozone. The summers with the highest number of hot days (>32°C) in Chicago, for example, strongly correlated (R^2=0.57) with summers with the highest number of days when ozone levels exceeded 75 parts per billion by volume (ppbv), the US threshold level for ozone.

Models demonstrate increased ground-level ozone concentrations by the midcentury across the eastern United States,[57-60] suggesting that further reductions in ozone precursors would be needed to offset the effect of climate change on ground-level ozone.

Fine particulate matter less than 2.5 μm is a pollutant posing health risks and is influenced by weather. Fine particulate matter is formed as part of diesel exhaust, forest fire smoke, windblown dust, and chemical products of gaseous release from power plants, vehicles, and industry. Forty-three million people in the United States inhabit areas that exceed EPA health-based standards for fine particulate matter,[61] and nearly a third of the earth's population inhabit areas that fail World Health Organization standards.[62] Fine particulate matter exposure is highest in low-income countries, where regulations to limit particulate emissions are lacking or unenforced.

In many regions, future temperatures most likely will increase wildfire risk by causing increased drought.[63] A study on worldwide mortality estimated that 339 000 premature deaths per year (range, 260 000-600 000) were attributable to pollution from forest fires, especially particulates.[64]

In some cases, health adaptations to one hazard, eg, air conditioning for heat stress, may exacerbate another risk, such as air pollution. For example, electricity demands during more frequent heat waves, and associated power plant emissions may compound direct temperature effects on atmospheric chemistry.[54,65]

Allergies and Pollen

Climate change may exacerbate allergies by enhancing pollen production and other allergens from nature. Fifty-five percent of the US population tests positive for allergens,[66] and more than 34 million have asthma.[67] Climate shifts alter abundance and seasonality of aeroallergens, eg, earlier flowering of oaks over the past 50 years,[68] and increased pollen production by ragweed (*Ambrosia*) with warmer temperatures and higher ambient carbon dioxide.[69,70] Data along a 2560-km (1600-mile) north-south sampling of monitoring stations through mid–North America indicate that the ragweed season has been lengthening by as much as 13 to 27 days north of the 44th parallel since 1995.[71]

Infectious Diseases

Vectorborne Diseases

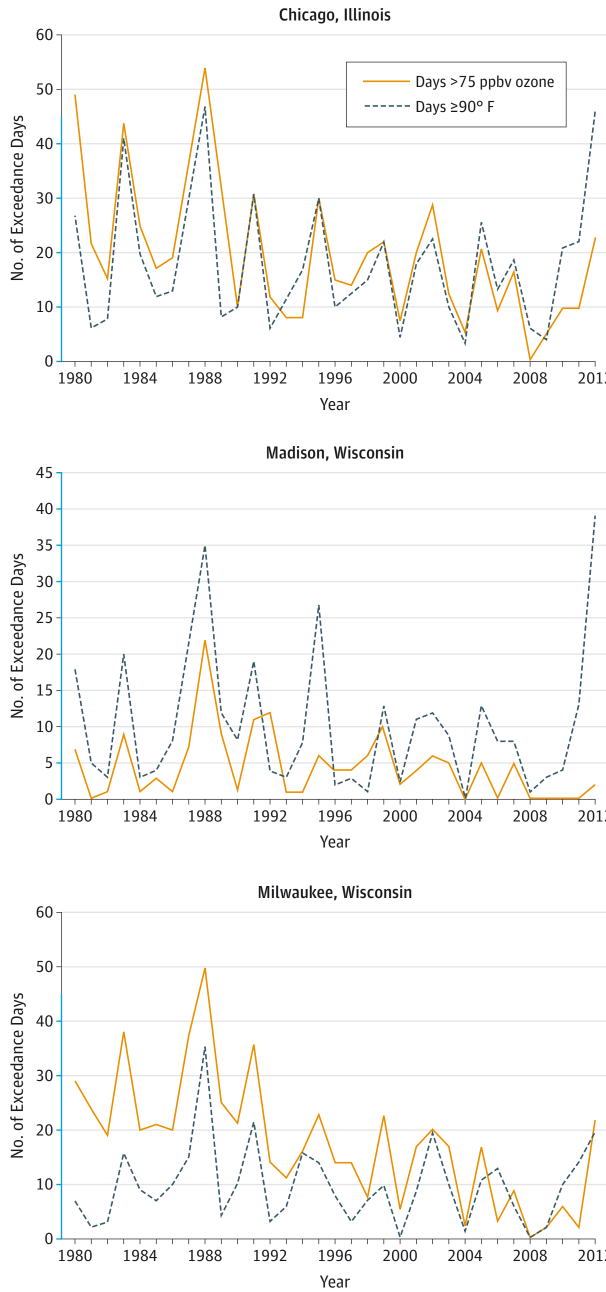
Vectorborne diseases are sensitive to climate through multiple mechanisms: first, through geographic shifts of vectors or reservoirs; second, through changes in rates of development, survival, and reproduction of vectors, reservoirs, and pathogens; and third, through increased biting by vectors and prevalence of infection in reservoirs or vectors.[72,73] All affect transmission to humans,[74-77] such that exposure to vectorborne disease will likely worsen in a warmer world.

Demographic trends influence the risk of vectorborne diseases. Warmer ambient temperatures in both the Ethiopian and Colombian highlands are projected to increase malaria in densely populated locations.[78] Similar results occur in North America: warmer temperatures increase the development rate of the Lyme disease vector, *Ixodes scapularis*[79]; and climate models predict expansion of Lyme disease into Canada.[80] Modeling shows northern and central Europe at risk for the Chikungunya virus due to warmer, wetter weather.[81] Policy responses can yield major health benefits, and the Intergovernmental Panel on Climate Change[7] found overall malaria declining in East Africa due to improved control programs, such as use of bed nets.

Waterborne Diseases

Waterborne diseases are expected to worsen, especially due to heavier precipitation events (>90% ile) projected to occur with climate changes.[74] Childhood gastrointestinal illness in the United States[82] and India[83] have been linked to heavy rainfall. In the Netherlands, a 33% increase in gastrointestinal illness was associated with sewage overflow following heavy rain. Flood waters contained

Figure 2. Relationship Between Days of High Temperatures and Ozone Levels



Number of days in Chicago, Madison, and Milwaukee for each year (1980-2012) in which temperature exceeded 32°C (90° F) and ozone exceeded 75 ppbv (parts per billion by volume). The y-axis scale shown in blue indicates range of 0 through 45 days.

Campylobacter, *Giardia*, *Cryptosporidium*, noroviruses, and enteroviruses.[84] In the United States, by 2100, Great Lakes climate modeling projects a 50% to 120% increase in overflow events.[85] A meta-analysis of 87 waterborne communicable disease outbreaks occurring worldwide from 1910 to 2010 showed that communicable disease is associated with heavy rainfall and flooding; *Vibrio* and *Leptospira* were most often cited.[86]

Waterborne diseases can be reduced with improved management infrastructure to better handle heavy rainfalls and through urban design by reducing impermeable surface areas. Improved monitoring can also help reduce many climate-sensitive infectious disease risks. The National ArboNET surveillance system tracks 8 mosquito-borne diseases, eg, West Nile virus in humans, birds, mosquitoes, and other animals.[87]

Food Security

Undernutrition is one of the most important health concerns related to climate change. Three mechanisms affect food security: reduced crop yields, increased losses, and decreased nutrient content. On average, climate change is projected to reduce global food production by 2% per decade, even as demand increases by 14%.[88] More than 800 million people currently experience chronic hunger,[89] concentrated where productivity could likely be most affected.[90] Climate change is projected to reduce wheat, maize, sorghum, and millet yields by approximately 8% across Africa and South Asia by 2050.[88] One estimate suggests that globally, by 2050 approximately 25 million more children might be undernourished through climate change,[91] and rates of growth stunting[92,93] could increase substantially. Climate change–related rapid increases in food prices, especially for staples such as corn and rice, could more than double by midcentury, placing impoverished populations at further risk.[94]

Plant diseases caused by fungi, bacteria, viruses, and oomycetes, already responsible for a 16% crop loss, may substantially increase with climate change.[95] Moreover, the nutrient value of some crops may diminish. Whereas carbon dioxide fertilization can enhance growth, protein content can decline in wheat and rice, as can iron and zinc content in crops such as rice, soybeans, wheat, and peas.[96]

Preventive measures range from drought or salt-resistant crops to improved technology such as drip irrigation and hoop houses (inexpensive greenhouses). Other potential adaptation strategies include changing planting dates, increasing crop diversity, and combining different strategies.

Mental Health

Depression, anxiety, and related disorders cause major morbidity worldwide.[97,98] Besides vulnerability to adverse effects from heat exposure, climate change may threaten mental health in other ways.[99-102]

Climate-Related Disasters

Posttraumatic stress disorder, anxiety, and depression are common following disasters, sometimes a major part of the health burden.[103-107] Several months after Hurricane Katrina, 49.1% of those surveyed in New Orleans and 26.4% in other affected areas developed a *Diagnostic and Statistical Manual of Mental Disorders* (Fourth Edition) (*DSM-IV*) anxiety mood disorder; 1 in 6 had posttraumatic stress disorder (PTSD) (with considerable overlap between the 2 diagnoses).[108] Similar outcomes have been documented following other disasters likely to increase with climate change, including floods,[109,110] dam collapses,[111] heat waves,[34,112] and wildfires.[113] Psychopathology typically declines over time following disasters,[114] but may persist for years,[115] especially among vulnerable groups.[116] Risk factors include little social capital (networks of relationships that build trust within a community) or support,[112] physical injury,[103] property loss,[103] witnessing others with illness or injury while they were in pain or were dying during the disaster, loss of family, displacement, and history of psychiatric illness.[98,113] Children may be at special risk.[114] These findings suggest a variety of protective strategies,[115] including strengthening social support networks,[116] providing postdisaster mental health services, and prompt insurance compensation for loss.

Slow-moving disasters may also threaten mental health. Research in Australia during the recent decade-long drought revealed increases in anxiety, depression, and possibly suicidality among rural populations.[34,117,118] Strategies to reduce this burden included raising mental health literacy, building community resilience through social events, and disseminating drought-related information.[107]

Climate-Related Displacement

Displacement may mean degradation of a familiar environment; the resulting distress has been documented among Alaskan natives in villages endangered by climate-related changes.[117] More typically, displacement means relocation forced by disaster or resource scarcity,[118] creating considerable mental health effects.[119] An important protective strategy is keeping families, even entire communities, united.[120]

Anxiety and Despair Related to Climate Change

Researchers have noted that climate change may engender despair, anxiety, and hopelessness, although few empirical data are available.[100,101] Although social circumstances and political views help determine cognitive and emotional processing of climate change information, there is an essential role for communication—presenting the problem and solutions in ways that engender engagement rather than despair.[121] Climate adaptation and mitigation can therefore be considered, in part, a psychological task,[122] one that includes effective communication.

Other Climate Health and Societal Impacts

Variation in precipitation, including increased severe rainfall events and increased frequency of droughts could create major risks or could have major consequences. Too little rainfall creates "dust bowl" conditions and worsens particulate matter exposure. Too much rainfall can overwhelm sewage systems, leading to increased waterborne diseases. Too much or too little can destroy crops.[123]

From 2003 to 2012, an average of 115 000 people died each year due to natural disasters.[124] For every person killed by natural disaster, an estimated 1000 people are affected physically, mentally, or materially, through loss of property or livelihood.[125] Floods are the most common severe weather event worldwide, and the frequency of river floods has been increasing.[126] Conservative estimates report 2.8 billion people were affected by floods between 1980 and 2009, with 500 000 cumulative deaths estimated, even as death rates declined.[127]

Uncertainty exists over whether hurricane frequency might increase, but evidence suggests that extreme hurricanes (categories

4 and 5) may occur more frequently.[1,128-130] Sea level rise will exacerbate storm surges, worsen coastal erosion, and inundate low-lying areas. Salinization of aquifers most likely will augment challenges to coastal settlements.

Health Effects of Social Disruption and Civil Conflict

In developing regions, climate-related disasters may trigger broad dislocations, often to places ill prepared for refugees who are overwhelmed by undernutrition and stress. Displaced groups commonly experience violence, sexual abuse, and mental illness.[131]

Increasing, but still inconclusive, evidence links climate change and violence,[132] from self-inflicted and interpersonal harm to armed conflict. A 2013 meta-analysis found that each standard deviation of increased rainfall or warmer temperatures increases likelihood of intergroup conflict by 14% on average.[133] The Centers for Naval Analyses Military Advisory Board, comprising retired generals, warned that climate change could catalyze instability and conflict.[134]

Communicating Climate Change and Health

Public Belief in Climate Change

Views on climate change range widely. Two decades of polling suggest that about two-thirds of US residents believe that climate change is occurring; of these about two-thirds (or about 40% of the total) believe humans cause it. About half (or about 1 in 3 overall) believe it will pose a serious threat in their lifetimes.[135-137] Compared with other wealthy nations,[138,139] US residents generally see the issue as remote in time and space (eg, affecting the next generation and in developing countries) and of low priority, well behind such concerns as jobs, health care, and even other environmental issues.[140]

Researchers have segmented the US population along a spectrum ranging from "alarmed" (≈ 16%) to "dismissive" (≈ 10%), according to climate change belief, concern, and motivation.[141] Many factors shape views of climate change: economic trends,[142] cultural norms,[143] beliefs of family and friends,[144] and values and political ideology,[145-147] often exercised through cognitive shortcuts called *heuristics* that bypass evidence.[148,149] Media coverage matters.[150-156] Deliberate, well-funded attempts to deceive the public and sow confusion have succeeded.[152,157-160] Despite robust scientific consensus on climate change,[2,3,161] there is widespread perception that scientists disagree, which in turn fuels public disbelief.[162] In addition, many people are unduly influenced by personal experience, such as short-term weather perturbations. A heat wave may strengthen belief in climate change, a snowy winter may undermine it. Interpretation of weather rests heavily on prior beliefs and social cues.[163-167]

Communicating Climate Change and Health

Effective communication may shift knowledge, attitudes, and behavior toward reducing the risks of climate change.[168,169] Research indicates several principles of effective climate communication that closely resemble those used in health.[170,171] Themes include 2-way communication,[149] gearing messages to the audience,[172,173] limiting use of fear-based messages,[174,175] issuing simple lucid messages repeated often from trusted sources,[169] and making health-promoting choices easy and appealing.[168]

Health may be a compelling frame for communication about climate change,[176,177] reflecting views that change threatens health.[178] Although further research is needed to define the role of health in climate communication, practical communication resources are becoming available,[179] implying an important role for health care professionals.[180]

Approach to Climate Change Adaptation

Persistent elevated atmospheric carbon dioxide will continue to warm the planet for decades even after implementation of mitigation strategies. A full range of adaptation options is reviewed elsewhere.[181-183] The following section discusses health implications of some alternatives.

In 2008, for the first time, more people worldwide resided in urban than in rural environments.[184] Increasing urbanization, especially in low- and middle-income countries, presents opportunities to redesign habitats that promote public health, climate resiliency, and sustainability.

Essential infrastructure improvement could help adaptation to climate change. For example, vegetation, building placement, white roofs, and architectural design can reduce the urban heat island effect and therefore electricity demands for air conditioning. A recent study found that waste heat from air conditioning can warm outdoor air more than 1°C, so limiting the need for air conditioning use has a direct influence on urban heat islands.[185]

In most US cities, infrastructure for potable water and wastewater management is more than 50 years old; in some cases more than a century. These systems, which serve 80% of the population, received an average near-failing grade of D+ on the 2013 Infrastructure Report Card of the American Society of Civil Engineers.[186] Under projected increases in extreme weather, cities face a daunting but timely opportunity to establish healthier, environmentally sustainable infrastructure.

Optimal adaptation strategies achieve multiple objectives. Green spaces—forests and parks—not only reduce heat islands; they also are linked to stress reduction,[187-189] neighborhood social cohesion,[190] and reductions in crime and violence.[191-193] A recent cross-sectional study of 2427 Wisconsin individuals found that neighborhood green space and tree canopy percentage had strong inverse correlation with objective measures of depression, anxiety, and stress.[194] The magnitude of this influence was comparable with other contributors to depression, including socioeconomic status and health insurance. Tree species composition of the canopy presents another strategy; red maples, for example, emit 70% fewer biogenic volatile organic compounds than do oaks, an opportunity to develop green space while minimizing ozone-forming compounds.[195]

Multiple benefits and cost savings may be gained through an ecological approach rather than by engineering single solutions.[196] As sea level rises, seawalls have frequently served to stabilize shorelines. But in Vietnam, planting mangroves for storm surge protection incurs one-seventh the cost of building and maintaining seawalls or dikes for this purpose.[197] This coastal ecosystem also preserves wetlands and marine food chains that support local fisheries.

Preparing for Tail Risks

The uncertainty regarding effects of climate change can be expressed in probability distributions. Tails of such distributions contain catastrophes—rare high-consequence events.[198,199] Economists and risk managers have focused on tail risk in climate change, asking how much society should spend to reduce these risks.[200] This question is familiar to homeowners who insure against the small but devastating possibility of a house fire and to physicians who treat patients when withholding treatment entails even a small risk of catastrophic outcome. Although some issues in public health decision making require a trade-off among risk management options, many existing climate mitigation measures have no adverse consequences to health or the economy (eg, energy conservation, cropland management, waste recycling).[201] This thinking asserts that the possibility of catastrophic outcomes not only justifies but compels preventive action now.

Health Cobenefits From Mitigating Climate Change

There are many social, economic, and political barriers to realizing reductions in global greenhouse gas emissions. These include difficulties of behavior changes; costs of implementing energy and industrial policies; opposition of vested interests, especially fossil fuel industries; and challenges of coordinating a worldwide solution among countries at different economic stages.

Thus, it is essential to design carbon reduction policies with ancillary benefits, often referred to as *cobenefits*, such as improved air quality or fitness-promoting urban design. These may be viewed as more near-term and politically attractive strategies than climate mitigation alone.[202] Articulating multidimensional aspects of carbon reduction strategies also helps avoid poorly designed policies that may have adverse effects on public health. For example, biofuels that compete with crop production may contribute to increased food costs and insecurity.[203]

Economic Advantages of Reducing Fossil Fuel Combustion

Concern remains over the cost of policies to shift to renewable energy and reconfigure transportation systems. However, a 2014 US-based full life-cycle analysis—consideration of full supply chains for energy, eg, from processes associated with production to transportation—shows the contrary. For example, monetized human health benefits stemming from air quality improvements are estimated to potentially offset the cost of US carbon policies by 26% to 1050%.[204]

Global average monetized health cobenefits from avoided mortality are projected to range from $50 to $380 per ton of carbon dioxide removed and exceed abatement costs in 2030 and 2050.[205] Estimated cobenefits are $30 to $600 for the United States and Western Europe, $70 to $840 for China, and $20 to $400 for India. For East Asia, air quality–related health benefits are projected to be 10 to 70 times the abatement costs in 2030.[205] These large benefits are not surprising, given EPA estimates of a return of $30 for every dollar spent on reducing air pollution through the Clean Air Act.[206]

Further economic benefits likely will accrue from enhanced opportunities for physical fitness. If active transport scenarios reached the levels of those in Copenhagen, costs averted for the England and Wales National Health Service would approximate $25 billion over a 20-year period[207]; also for just 1 region of the United States, $3.8 billion per year (95% CI, $2.7-$5.0 billion) would be saved through physical fitness benefits stemming from increased biking.[208]

Energy Sector

Increasing use of wind, solar, wave, and geothermal energy can yield benefits for both health and climate. A Wisconsin study found that increased efficiency and renewable generation in electrical power, designed to reduce carbon at low cost, could reduce statewide emissions of nitrogen oxides by 55% and sulfur dioxide by 59%.[209] Regarding biofuels, if sugar cane, fast-growing tree species, and *Miscanthus* are used instead of corn, competition for food production could be eliminated, thus avoiding food price shocks especially affecting the poor.[5]

Strategies to address short-lived climate pollutants, especially tropospheric ozone and black carbon, complement those that address carbon dioxide. Shindell et al[210] screened 400 potential control measures and identified 14 that both mitigate warming and improve air quality, such as reducing emissions from coal mining, oil and gas production, and municipal landfills. The measures are estimated to reduce global mean warming by approximately 0.5°C by 2050. Health cobenefits include prevention of between 0.7 million and 4.7 million premature deaths annually, while crop yields would benefit from reduced ozone damage.

Retrofitting buildings with improved insulation, ventilation, efficient appliances, and renewable sources for electricity and heating could improve health and reduce greenhouse gas emissions.[211] Health care is among the most energy-intensive commercial sectors. It represents nearly one-fifth of the US gross domestic product. Health care facilities that reduce energy use can therefore contribute to climate mitigation, reduce operating costs, and demonstrate leadership. More than 6700 health care facilities have shifted to environmentally sustainable practices and formed "Hospitals for a Healthy Environment."[212]

Transportation and Community Design

Major health cobenefits accrue from increased urban walking and cycling, so-called active travel. This approach may offer the most direct benefits by reducing health-damaging pollution emissions and enhancing personal fitness simultaneously. Physical inactivity is a risk factor for many noncommunicable diseases and may be responsible for 3.2 million deaths annually.[213] An increasing number of studies show significant global health benefits from shifting to environmentally sustainable practices (key findings are summarized in the **Table**). For example, active commuting in Shanghai, China, was associated with a reduction of colon cancer by 48% in men and 44% in women,[223] and across sample populations from Europe and Asia, active transport led to an 11% reduction in cardiovascular risk.[217] For the United States, comparing cities with highest vs lowest levels of active transport, obesity rates were 20% lower and diabetes rates were 23% lower,[222] and 1295 lives could be saved annually in the upper Midwest of the United States by replacing short (<4 km) car trips with bike transport.[208]

Developed countries, including the United States, could benefit from greater levels of exercise,[208,215,216,222,229] whereas low-

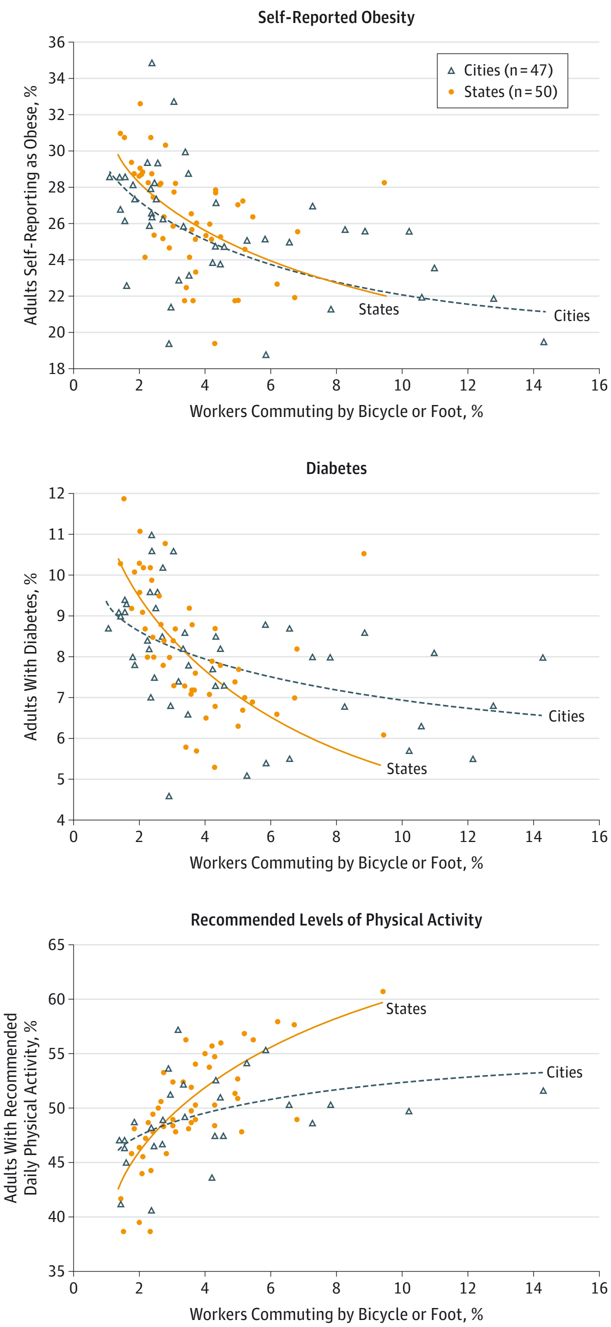
Table. Health, Environmental, and Economic Benefits of Active Commuting[a]

Source	Location	Study Population	Key Findings
Cardiovascular Diseases			
Woodcock et al,[214] 2013	England (outside London) and Wales	All age groups living in urban areas outside London	Reductions in IHD disease from increased physical activity, with a reduction in the total population disease burden of ≤4.1%
Maizlish et al,[215] 2013	San Francisco Bay area	All age groups	14% Decrease in cardiovascular disease (32 466 DALYs), increased traffic injury burden by 39% (5907 DALYs), and decreased greenhouse gas emissions by 14% with 20 min/d of active transportation
Hankey et al,[216] 2012	Southern California	30 007 Residents	Lower IHD mortality rates in high- vs low-walkability neighborhoods (24.9% vs 12.5%) and 7 fewer IHD deaths/100 000/y
Hamer et al,[217] 2008	8 Countries in Europe and Asia	173 146 Participants	Active commuting was associated with an overall 11% reduction in cardiovascular risk, especially among women
Hu et al,[218] 2007	Finland	47 840 Finnish participants aged 25-64 y	Active commuting in Finland reduces 10-y risk of chronic heart disease events
Forrest et al[219] 2001	Benin, Nigeria	799 Civil servants	Commuting to work vs leisure activities contributed more to reported physical activity time and was associated with reduced coronary heart disease risk
Chronic Diseases			
Jarrett et al,[207] 2012	England and Wales	Urban populations across the United Kingdom	Reductions in prevalence of 7 chronic diseases associated with physical inactivity; would save US $26 billion within 20 y
Rabl and de Nazelle,[220] 2012	Europe	Large cities across the European Union	For every driver who switches to bicycling for a commute of 5 km (1 way) 5 d/wk 46 wk/y, the annual benefit would be €1300 from improved physical fitness and €30 from improved air quality
MacDonald et al,[221] 2010	Charlotte, North Carolina	Individuals before and after light rail system construction	Light rail transit for commuting was associated with a 1.18 reduction in BMI and an 81% reduced odds of becoming obese over time
Pucher et al,[222] 2010	47 Large US cities	Adults ≥18 y	US cities with highest active transport have 20% diabetes rate vs 23% in lowest active transport
Hou et al,[223] 2004	Shanghai, China	931 Colon cancer cases vs 1552 controls	High levels of daily active commuting result in reduced risk of colon cancer by 48% in men and 44% in women
Mortality and/or Economic Benefits			
Macmillan et al,[224] 2014	New Zealand	Urban population of Auckland, New Zealand (1.5 million)	System dynamic modeling shows transforming urban roads using best practice of physical separation and bicycle friendly speed reduction would yield benefits 10-25 times greater than costs, over next 40 y
Rojas-Rueda et al,[225] 2012	Metropolitan Barcelona, Spain	All age groups	Shifting 40% of car trips to cycling and public transportation would avoid approximately 99 deaths and reduce carbon dioxide emissions by 251 tons per year
Grabow et al,[208] 2012	Upper midwestern United States	All age groups, 11 metropolitan areas	1295 Avoided annual deaths from automobile emissions reduction and fitness benefit from bicycling
Lindsay et al,[226] 2011	Auckland, New Zealand	Residents of urban Auckland	Shifting 5% of vehicle kilometers to cycling would save 22 million L of fuel, avoid 122 deaths annually, and save New Zealand $200 million per y
de Hartog et al,[227] 2010	The Netherlands and England	500 000 Dutch	Fitness benefits of cycling were 9 times more in life-years than losses due to increased inhaled air pollution doses and traffic crashes
Andersen et al,[228] 2000	Copenhagen, Denmark	Men and women in all age groups	Commuter cyclists have 39% lower mortality rate

Abbreviations: BMI, body mass index; DALY, daily activities of living; IHD, ischemic heart disease.

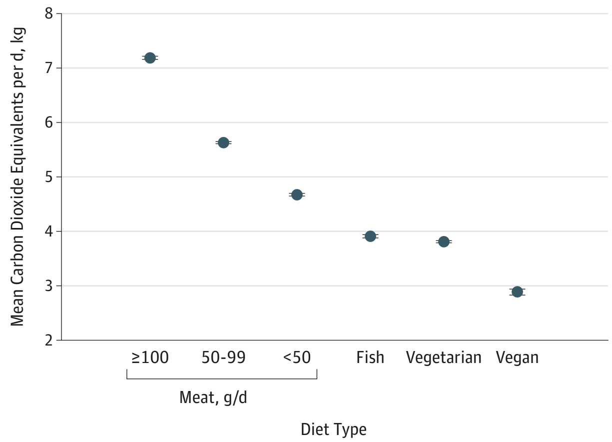
[a] Active commuting: walking or biking to work.

Figure 3. Relationship Between Active Commuting Transportation and Obesity, Diabetes, and Physical Activity Recommendations



Data are for all 50 US states and 47 of the largest US cities in 2007. Data are derived from Centers for Disease Control and Prevention's Behavioral Risk Factor Surveillance System and the US Census. Data for these graphs were provided by Pucher et al 2010.[222]

Figure 4. Estimated Greenhouse Gas Emissions From Diet Types



Mean greenhouse gas emissions (in kilograms of carbon dioxide equivalents per day) comparing diet types from 55 504 individuals in the EPIC-Oxford cohort study. Data are for a 2000 kcal diet adjusted for sex and age. Data from Scarborough et al.[233]

income countries with air quality problems may benefit more from reduced pollution.[229] Commuting to work by biking or walking reduces prevalence of obesity and diabetes in the United States, with states showing more variability in levels of active transport than cites (Figure 3).[222]

Agricultural Sector and Food Systems

Health cobenefits also emerge from decreased meat consumption in high-consuming populations. Emissions from agriculture, livestock production, and forestry constitute approximately 24% of global greenhouse gas emissions,[5] resulting principally from animal products. A review of 25 studies[230] using the life-cycle analysis concluded that beef (14-32 kg of carbon dioxide emission equivalents per kilogram of meat produced) had the highest carbon footprint, followed by pork (3.9-10 kg of carbon dioxide emission equivalents per kg), then chicken (3.7-6.9 kg of carbon dioxide emission equivalents per kg). If consumption of meat, dairy products, and eggs were halved, nitrogen and greenhouse gas emissions could be reduced by 25% to 40% and intake of saturated fat may decrease by 40%.[231] A 30% reduction in livestock production could lead to a reduction in ischemic heart disease of 15% in the United Kingdom and 16% in Sao Paulo, Brazil.[232] **Figure 4** compares greenhouse gas emissions from various diets.[233] Greenhouse gas emissions to support a high–red meat diet (>100 g/d) are nearly twice that of vegetarian diets.

Household Energy

Improved cook stoves in the developing world offer another opportunity for significant health cobenefits. In India, a program to introduce 150 million improved stoves over 10 years may prevent 2 million premature deaths.[211] Additionally, rural electrification, for example, through microgrid systems (from solar, wind, small hydropower, or biogas) could provide lighting that may enhance childhood reading and learning, and improve food and medicine cold storage.

Access to contraception can address unmet reproductive health needs and improve the health of both mother and child by increasing birth spacing.[234] Historical trends demonstrate a close relationship between carbon dioxide emissions from energy use and country-specific population size. Comparison of a United Nations low population growth scenario (7.4 billion) with a high population growth (10.6 billion) suggests a difference in global carbon dioxide emissions of 32% by 2050.[174]

Future Challenges

The relationship between climate change and health has been based on laboratory studies, observational data, and modeling studies. Traditional experimental designs to assess the effects of climate change are not possible. This often contributes to a political and scientific atmosphere of debate. Because climate change may have important implications for the health of the world's population, high-quality research must be conducted, and responsible, informed debate needs to continue. However, given that evidence over the past 20 years suggests that climate change can be associated with adverse health outcomes, strategies to reduce climate change and avert the related adverse effects are necessary.

Development of effective future policies will require understanding the relationship between climate change and health and developing approaches to ensure a sustainable future while protecting health. Accounting for cobenefits may document that reducing greenhouse emission yields net economic benefits,[205,235] that labor productivity increases,[236] and that health system costs are reduced.[207] Cobenefits can provide policymakers with additional incentives, beyond those of curtailing climate change, to reduce the emissions of both carbon dioxide and short-lived climate pollutants.

Any policy to reduce greenhouse gas emissions should include an assessment to ensure that potential benefits or risks are included in cost estimates and that unintended harm is avoided. Herein lies a special role for health professionals in policy decisions involving energy, housing, transportation, urban planning, agriculture, food systems, and more.

Conclusions

Evidence over the past 20 years indicates that climate change can be associated with adverse health outcomes. Health professionals have an important role in understanding and communicating potential health concerns related to climate change, as well as the cobenefits from burning less fossil fuels.

ARTICLE INFORMATION

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