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APPLYING A PUBLIC HEALTH CONTEXT TO CLIMATE CHANGE

Jonathan A. Patz and Barry S. Levy

In a small village in sub-Saharan Africa, children are increasingly undernourished because of long-lasting drought.

In a large city in Europe, hundreds of older people die during a prolonged heat wave.

In South Asia, several days after an extremely heavy rainfall, dozens of people develop waterborne disease in an outbreak similar to waterborne disease outbreaks that have occurred after heavy rainfall in developed and developing countries throughout the world.

In South America, people with chronic respiratory disorders experience more frequent exacerbations of their symptoms.

In North America, increased numbers of people develop illnesses due to West Nile virus and other vector-borne pathogens.

In rural areas of Australia, episodes of collective violence increase.

In China, after a severe cyclone, people suffer from depression and other mental health problems.

While it is difficult, if not impossible, to definitively attribute any of these groups of health problems to climate change, all of them could be directly or indirectly related to global warming, extreme weather events, and other adverse consequences of climate change.

This book summarizes what health professionals, environmental scientists, and others know about climate change and its adverse health consequences, and what can be done to mitigate its causes and to adapt to its consequences. More extensive discussion about climate change, its adverse health consequences, and mitigation and adaptation measures can be found in the most recent report of the Intergovernmental Panel on Climate Change (IPCC), the leading international body for the assessment of climate change.[1] (See Box 1-1.)

DEFINITIONS

Climate change has been defined as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable

Box 1-1 The Intergovernmental Panel on Climate Change and a Brief History of Organizational Responses to Climate Change

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The United Nations Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP). Since 1990, the IPCC has conducted international assessments, at approximately 5-year intervals, of scientific work on climate change, potential impacts of climate change, and prevention strategies and measures. IPCC members include leading scientists from various sectors and from major educational and research institutions. The evolution of organizational responses to climate change can be traced back many years.

In 1950, the WMO was established as a specialized agency of the United Nations. It has since provided a framework for international cooperation, contributing to protection against natural disasters; safeguarding the environment; enhancing the economic and social well-being of food security, water resources, and transport; promoting establishment of networks for making observations and exchanging, processing, and standardizing related data; and assisting technology transfer, training, and research. The WMO helped establish international coordination of measuring chemicals, including ozone. In the 1970s, the WMO focused on the threat of chlorofluorocarbons to the stratospheric ozone layer, acidification of lakes and forests, and the buildup of greenhouse gases (GHGs) in the atmosphere. This work facilitated development of the global response to climate change.

In 1987, the United Nations World Commission on Environment and Development published the book *Our Common Future* (the Brundtland Report), which placed environmental issues on the political agenda and envisioned environment and development as inextricably connected—creating the concept of *sustainable development*. The work of the Commission led to the creation of the IPCC and many other related developments.

The IPCC assembled an international community of experts to prepare assessments on all aspects of climate change and its impacts, with the goal of formulating realistic strategies for adaptation and mitigation. In 1989, IPCC published its First Assessment Report, stressing that climate change is a challenge requiring international cooperation. The scientific evidence in the report led to the creation of the United Nations Framework Convention on Climate Change (UNFCCC), the key international treaty to reduce global warming and cope with the impacts of climate change.

Our Common Future also led to the first United Nations Conference on Environment and Development (UNCED), which took place in Rio de Janeiro in 1992—the "Rio Earth Summit." Fulfilling the main goal of the conference, the United Nations, multilateral organizations, and national governments voted to adopt an action plan on sustainable development (Agenda 21). This plan was revised, and commitments to its implementation were made in 1997, 2002, and 2012 at subsequent Earth Summit conferences.

Since 1990, participation of the scientific community in the work of the IPCC has grown substantially. In 1995, the IPCC Assessment Report emphasized the connections between impacts of climate change and human health. This report provided vital support to the adoption, in 1997, of the Kyoto Protocol, an international treaty that set binding obligations on industrialized countries to reduce emissions of GHGs.

Since 1995, the IPCC has produced three more comprehensive scientific reports about climate change, the most recent of which was the Fifth Assessment Report in 2014. The IPCC has augmented these reports with methodology reports, technical papers, and special reports, such as the often-cited *Special Report on Emissions Scenarios (SRES)*.

Meanwhile, the World Bank has committed to lending money to environmental groups and non-governmental organizations (NGOs) to help reduce the adverse effects of its past development policies, such as financing commercial logging projects. Following approval in 1989 of the Montreal Protocol to protect the stratospheric ozone layer, the World Bank established an agency to help stop depletion of the ozone layer by phasing out the use of 95 percent of ozone-depleting chemicals by 2015. Much of the work of the World Bank now focuses on promoting low-carbon, climate-resilient cities; "climate-smart" agriculture; energy efficiency and investment in renewable energy; development of carbon prices; and ending fossil fuel subsidies.

NGOs also play vital roles. The Climate Action Network, which consists of over 850 NGOs in more than 100 countries, works to promote government and individual action to limit human-caused climate change. Member organizations work to achieve this goal through information exchange and development of coordinated NGO strategies on climate issues. (See Chapter 15.)

The U.S. Global Change Research Program, which was established in 1989, develops and coordinates research to understand, assess, predict, and respond to global environmental changes. It provides the scientific basis to inform and enable timely decisions on adaptation and mitigation; builds sustained assessment capacity that improves ability to understand, anticipate, and respond to global change impacts and vulnerabilities; and advances communication and education to broaden public understanding of global change and to develop the scientific workforce of the future.

State and local responses have included many initiatives. For example, the C40 Cities Climate Leadership Group, established in 2005, consists of representatives of megacities who cooperate on reducing GHG emissions by promoting uptake of climate-friendly technologies, better financing of projects to address climate change, and uniform reporting of GHGs. For decades, the U.S. Conference of Mayors has adopted and promoted policies on energy and the environment. Its policies have focused on renewable energy sources, national standards for climate change, building standards and practices, and transportation options. Its Climate Protection Center provides mayors with guidance and assistance in reducing GHG emissions.

As another example, the World Mayors Summit on Climate Change in 2013, which included 50 mayors from 30 countries, initiated an advocacy process aimed at recognizing, engaging, and empowering local governments in addressing climate change.

time periods."[2] Throughout this book, we use the term *climate change* to mean both climate change and increased climate variability.

The terms *climate* and *weather* are distinct. *Climate* has been defined as "the average course or condition of the weather at a place usually over a period of years as exhibited by temperature, wind velocity, and precipitation,"[3] and as "the weather conditions prevailing in an area in general over a long period."[4] In contrast, *weather* has been defined as "the state of the air and atmosphere at a particular time and place: the temperature and other outside conditions (such as rain, cloudiness, etc.) at a particular time and place" and "the state of the atmosphere with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness."[3] It has also been defined as "the state of the atmosphere at a place in time as regards heat, dryness, sunshine, wind, rain, etc."[4] Climate scientists frequently use a period of 30 years to distinguish between *climate* and *weather*.

Public health has been defined as "what we, as a society, do collectively to assure the conditions in which people can be healthy."[5] The three major categories of public health activities are the following:

- *Assessment*: Collecting, analyzing, and disseminating data, including performing surveillance and monitoring for health effects and antecedent exposures and other risk factors
- *Policy development*: Developing, implementing, and evaluating policies, in both the health sector and other sectors, including energy, transportation, and agriculture
- *Assurance*: Developing, implementing, and evaluating broad approaches, including planning for disaster preparedness and response, building sustainable communities, and developing renewable energy.

All of these activities are relevant in applying a public health context to climate change. (See also Chapter 11.)

MECHANISMS

Climate change, whether it is caused by natural variability or human activity, depends on the balance between incoming (solar) shortwave radiation and outgoing (infrared) longwave radiation. This balance is affected by the Earth's atmosphere in much the same way as the glass of a greenhouse (or a car's windshield) allows sunlight to enter and then traps the heated air from rising and mixing with cooler air aloft. (See Figure 1-1 and the discussion on how greenhouse gases [GHGs] cause global warming in Chapter2.)

Concentrations of carbon dioxide, methane, nitrous oxide, and other GHGs have increased substantially over the past several decades—and as much as 43 percent between 2005 and 2011.[6] For example, carbon dioxide concentrations in the atmosphere have substantially increased since the beginning of the Industrial Era (Figure 1-2). The concentration of these three GHGs in the atmosphere now exceed their highest concentrations recorded over the past 800,000 years.[6] In addition, the average rates of increase of these three GHGs over the past century are higher than at any time in the past 22,000 years.[6]

An atmosphere that retains more heat because it has higher levels of GHGs leads to higher average surface temperatures. Between 1880 and 2012, average surface temperature of the Earth increased 0.85°C (1.53°F) (Figure 1-3).

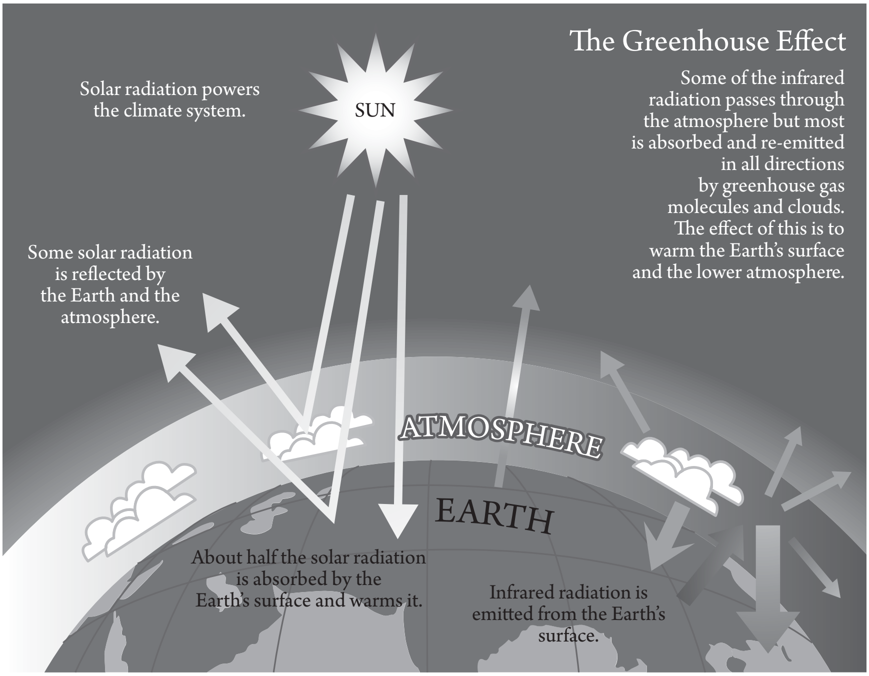

Figure 1-1 A schematic diagram of the greenhouse effect. (*Source:* Adapted from: Solomon S, Qin D, Manning M, et al. [eds.]. Climate change 2007: The physical science basis. Cambridge, UK: Cambridge University Press, 2007.)

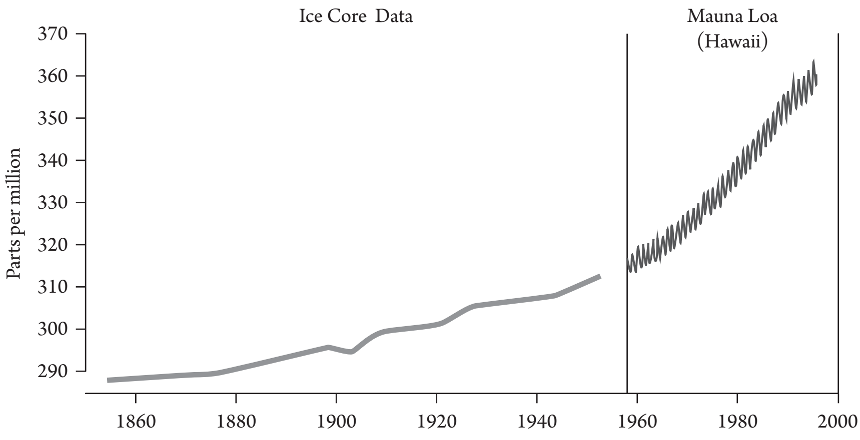

Figure 1-2 Carbon dioxide concentrations in the atmosphere (in parts per million), 1860–2000. Concentrations from 1860 to approximately 1960 are based on ice core data. Concentrations from approximately 1960 are based on continual measurements by scientists at an observatory in Mauna Loa, Hawaii, reflecting vegetation absorbing carbon dioxide each spring and releasing carbon dioxide into the atmosphere each autumn. (*Source:* White House Initiative on Global Climate Change. The greenhouse effect and historical emissions. http://clinton4.nara.gov/Initiatives/Climate/greenhouse.html. Accessed February 5, 2015.)

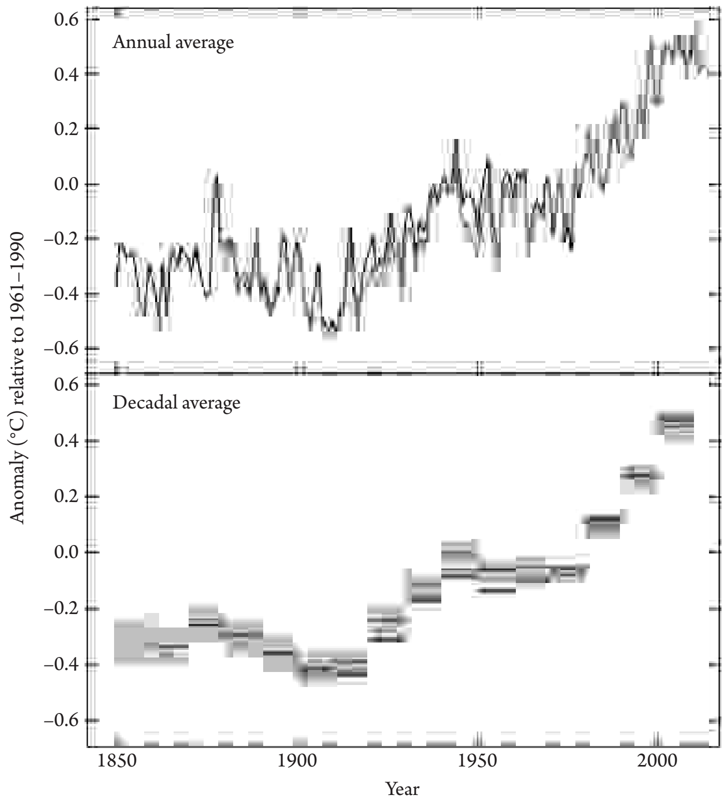

Figure 1-3 Observed global mean combined land and ocean surface temperature anomalies, 1850–2012. Top panel: Annual mean values from three data sets. Bottom panel: Decadal mean values from three data sets, including estimates of uncertainty for one dataset. Anomalies are relative to the mean of 1961–1990. (*Source:* Stocker TF, Qin D, Plattner GK, et al. [eds.]. Summary for policymakers. In: Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press, 2013, p. 6.)

ENVIRONMENTAL CONSEQUENCES OF CLIMATE CHANGE

Environmental phenomena likely related to climate change include the following:

- Increased temperature and increased frequency and/or duration of heat waves
- Increased heavy precipitation events
- Increased intensity and/or duration of drought
- Increased intense tropical cyclone activity
- Increased sea level.[1]

Additional environmental phenomena possibly related to climate change include shrinking of glaciers and the polar ice caps, increases in chemical pollutants and aeroallergens in ambient air, and ecosystem changes that reduce biodiversity. The

Table 1-1 Assessment that Various Changes Have Occurred and Assessment of a Human Contribution to Observed Changes

Phenomenon and Direction of Trend	*Assessment that Changes Occurred (Typically Since 1950 Unless Otherwise Indicated)*	*Assessment of a Human Contribution to Observed Changes*
Warmer and/or fewer cold days and nights over most land areas	Very likely	Very likely
Warmer and/or more frequent hot days and nights over most land areas	Very likely	Very likely
Warm spells/heat waves: Frequency and/or duration increases over most land areas	Medium confidence on a global scale Likely in large parts of Europe, Asia, and Australia	Likely
Heavy precipitation events: Increase in frequency, intensity, and/or amount of heavy precipitation	Likely more land areas with increases than decreases	Medium confidence
Increases in intensity and/or duration of drought	Low confidence on a global scale Likely changes in some regions	Low confidence
Increases in intense tropical cyclone activity	Low confidence in long-term (centennial) changes Virtually certain in North Atlantic since 1970	Low confidence
Increased incidence and/or magnitude of extreme high sea level	Likely, since 1970	Likely

Source: Intergovernmental Panel on Climate Change. Climate change 2013: The physical science basis. Cambridge, United Kingdom: Cambridge University Press, 2013. https://lackofenvironment.files.wordpress.com/2013/11/ar5-table-spm-1.jpg. Accessed February 5, 2015.

IPCC has performed comprehensive assessment of (a) changes that have occurred and the human contribution to these changes (Table 1-1) and (b) the likelihood of further changes (Table 1-2).

Increased Temperature

The IPCC has determined that warming of the Earth, since the 1950s, has been "unequivocal" and "unprecedented." With 95 percent certainty, it has attributed this warming to human activity. The IPCC has projected that, by 2081–2100, the temperature on the surface of the Earth will increase between an average of 1.0° and

Table 1-2 Assessment of the Likelihood of Further Changes in the Early and Late 21st Century

	Likelihood of Further Changes	
Phenomenon and Direction of Trend	*Early 21st Century*	*Late 21st Century*
Warmer and/or fewer cold days and nights over most land areas	Likely	Virtually certain
Warmer and/or more frequent hot days and nights over most land areas	Likely	Virtually certain
Warm spells/heat waves: Frequency and/or duration increases over most land areas	Not formally assessed	Very likely
Heavy precipitation events: Increase in the frequency, intensity, and/or amount of heavy precipitation	Likely over many land areas	Very likely over most of the mid-latitude land masses and over wet tropical regions
Increases in intensity and/or duration of drought	Low confidence	Likely (medium confidence) on a regional to global scale
Increases in intense tropical cyclone activity	Low confidence	More likely than not in the Western North Pacific and North Atlantic
Increased incidence and/or magnitude of extreme high sea level	Likely	Very likely

Source: Intergovernmental Panel on Climate Change. Climate change 2013: The physical science basis. Cambridge, United Kingdom: Cambridge University Press, 2013. https://lackofenvironment.files.wordpress.com/2013/11/ar5-table-spm-1.jpg. Accessed February 5, 2015.

3.7°C (1.8° and 6.7°F) (Table 1-3). In the United States, the frequency of daily temperatures over 38°C (100°F) is expected to increase substantially; temperature levels that now occur once in 20 years could, in the future, occur every 2 years.[7] Extreme heat events are projected to become longer, more severe, and more frequent (Chapter 4B).[8,9] In some areas, prolonged periods of record high temperatures associated with droughts contribute to dry conditions, which increase the risk of wildfires.

Changes in Precipitation

Globally, El Niño–related variability of precipitation will likely intensify; in many dry regions, mean precipitation will decrease.[6,10] In the United States, precipitation is expected to become less frequent, but more intense.[11] (During the past century

Table 1-3 Ranges of Likely Global Mean Temperature Change (Expressed as Anomalies with Respect to 1986–2005), Average for Different Representative Concentration Pathways (RCPs)

Periods	*RCP2.6*	*RCP4.5*	*RCP6.0*	*RCP8.5*
2046–2065	0.4–1.6°C	0.9–2.0°C	0.8–1.8°C	1.4–2.6°C
2081–2100	0.3–1.7°C	1.1–2.6°C	1.4–3.1°C	2.6–4.8°C

Source: Adapted from Smith KR, Woodward A, Campbell-Lendrum D, et al. Human health: Impacts, adaptation and co-benefits. In Field CB, Barros V, Dokken D, et al. (eds.), Climate change 2014: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom: Cambridge University Press, 2014, Table 12.2.

in the United States, total rainfall has increased 7 percent, and precipitation in the heaviest 1 percent of rains has increased 20 percent.[7]) Episodes of heavy rainfall are projected to occur more frequently because warmer air holds more water vapor.[12–14] Since 1991, precipitation in episodes of heavy rainfall has been above average everywhere in the United States, except in Hawaii.[7]

Heavy rainfall events are most likely to cause health impacts through flooding, directly injuring people and indirectly causing gastrointestinal illness due to sewage contamination of drinking water (Chapter 7), and mental health impacts (Chapter 9). The frequency of river floods has been increasing.[15] At least 2.8 billion people were adversely affected by floods between 1980 and 2009, and more than 500,000 people died due to floods during this period.[16] Floods are expected to increase globally, especially in Asia, Africa, Central America, and South America.[1]

Extreme Weather Events

There is uncertainty regarding whether the frequency of hurricanes and cyclones might increase, but evidence suggests that the frequency of more extreme (Category 4 and Category 5) hurricanes has already increased, posing serious adverse health consequences. (See Box 9-1 in Chapter 9.) Hurricanes are likely to become more intense because of warmer surface temperatures of the ocean.[17,18] The most powerful hurricanes are likely to become more frequent; one study projects a near doubling in the frequency of Category 4 and Category 5 hurricanes by 2100.[19] (See Figure 1-4.)

Decreased Rainfall and Drought

Some regions of the world, such as the southwestern United States, the Mediterranean, and parts of Africa, are already dry and are expected to become drier.[7,11] Inadequate rainfall in combination with extreme heat events is likely to result in droughts of increasing frequency, severity, and duration, threatening food

Figure 1-4 House destroyed by Superstorm Sandy. (*Source*: Copyright Associated Press.)

security and causing adverse consequences for health, nutrition, and economic well-being. (See Chapter 8.)

Wildfires

Climate change is expected to increase the occurrence of wildfires, due to the combination of increased temperatures and decreased rainfall (Figure 1-5).[20] Wildfires adversely affect health, not only directly, but also by increasing air pollution; one study estimated that globally there have been between 260,000 and 600,000 premature deaths annually due to air pollution from forest fires.[21]

Additive Effects of Climate Change and Changes in Land Use

Additive, and possibly synergistic, effects can occur as a result of climate change combined with changes in land use, as illustrated by the following examples:

- As human populations extend into flood plains and vulnerable coastal areas, the consequences of floods and coastal storm surges will likely increase.
- In areas where there has been deforestation, heavy rainfall is more likely to increase landslides. For example, in 1998, Hurricane Mitch caused 11,000 deaths in Central America, many of which were due to mudslides from deforested hillsides.[22]
- In 2005, Hurricane Katrina and resultant flooding killed more than 1,800 people (mainly in Louisiana), injured many more, and displaced thousands. The severity of its consequences was probably increased by receding coastal wetlands, which offered less buffering from storm surges.[23]

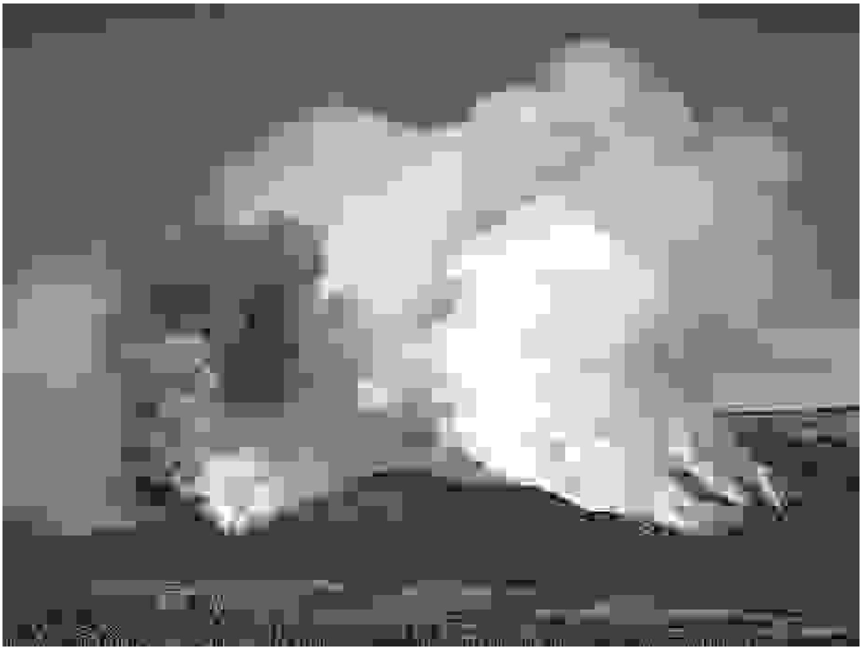

Figure 1-5 Smoke from a wildfire. (*Source*: Copyright Associated Press.)

- Increased frequency, intensity, and/or duration of heat waves in combination with black-asphalt roads and other dark surfaces, buildings, and industrial activities in cities can create an *urban heat island effect* (Chapter 4B). In addition, since urban areas are relatively lacking in trees, they receive less of the cooling effect associated with evapotranspiration.

SEA LEVEL RISE

Global mean sea level has increased approximately 20 cm (8 inches) during the past century—far more than in the previous 2,000 years.[1] By 2100, sea level is projected to rise, mainly due to thermal expansion and melting of glaciers, by 26 to 63 cm (about 10.1 to 24.6 inches).[6] (Some projections provide more extreme estimates of sea level rise, greater than 100 cm [39 inches], due to catastrophic melting events.) Sea level rise will exacerbate storm surges, worsen coastal erosion, and inundate low-lying areas. It will also cause salinization of aquifers, presenting problems for people living in coastal areas. In addition, sea level rise threatens to inundate low-lying coastal nations as well as small, low-lying island nations in the Pacific Ocean.

Ocean Acidification

Since the start of the Industrial Era, acidification of oceans has been occurring due to absorption of increasing atmospheric levels of carbon dioxide.[6] Acidification of oceans may threaten shell-forming organisms, such as corals and species that feed on them.

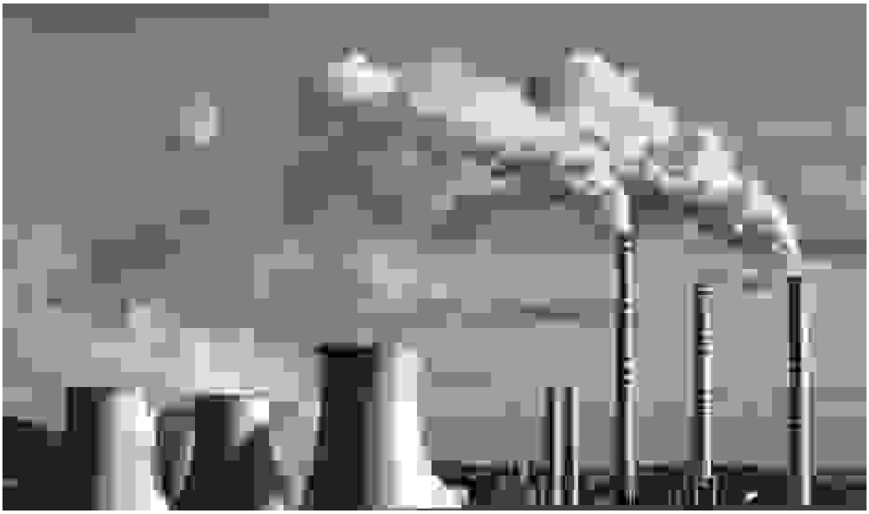

Figure 1-6 Coal-fired power plant. (*Source*: Copyright Associated Press.)

CAUSES OF CLIMATE CHANGE

Virtually all climate scientists are convinced that climate change is caused by human activity, primarily from the combustion of fossil fuels (Figure 1-6), deforestation, and cement production.[24–26] However, although there is strong consensus on this issue, there are many remaining questions concerning (a) the risks and consequences of climate change; (b) vulnerabilities due to socioeconomic, demographic, geographic, and other factors; and (c) the effectiveness and feasibility of various measures to mitigate and adapt to climate change.

ADVERSE HEALTH CONSEQUENCES

As described in detail in Part II of this book, there is a wide range of adverse health consequences—both direct and indirect—that can occur as a result of climate change. These adverse health consequences include heat impacts on work, human performance, and daily life (Chapter 4A); morbidity and mortality due to heat waves (Chapter 4B); respiratory and allergic disorders (Chapter 5); vector-borne disease (Chapter 6); waterborne and foodborne disease (Chapter 7); health impacts related to food and nutrition insecurity (Chapter 8); mental health impacts (Chapter 9); and collective violence (Chapter 10).

VULNERABLE POPULATIONS

Vulnerability is determined by the level of exposure to a risk factor, sensitivity to that risk, and capacity to adapt to it. Socioeconomic, demographic, health-related, geographic, and other risk factors make specific populations vulnerable to the health consequences of climate change.[27,28] These risk factors include residing in:

- Areas with a high baseline prevalence of climate-sensitive diseases, such as malaria
- Areas where epidemic disease is associated with climate patterns, such as cholera and other diseases linked to the El Niño Southern Oscillation
- Areas with reduced access to food or water as a result of drought or other impacts of climate change
- Areas of increased risk of waterborne or vector-borne disease.

In addition, poverty, minority health status, female gender, young or old age, and the presence of disease or disability may place people at higher risk of the health consequences of climate change. Geography influences vulnerability to the consequences of climate change; for example, Arctic peoples, such as the Inuit, are experiencing significant consequences due to exceptional warming in the Arctic (Box 1-2).[29] Workers in many occupations are also at increased risk (Box 1-3).

Climate change increases the health risks of marginalized populations, including low-income people, indigenous communities, and other disadvantaged groups. These populations generally have few resources to adapt to climate change and limited input into decision-making that affects their lives. As a result, climate change threatens to exacerbate health and socioeconomic inequalities within and among communities.

On a global scale, there are great inequalities among countries with respect to both (a) amounts of GHG emissions and (b) magnitude and severity of the health risks due to climate change. In general, those countries that contribute the least to global GHG emissions face the greatest health risks due to climate change (Figure 1-7).

EFFECTS ON BIOLOGICAL SYSTEMS

In addition to its impacts on human life, climate change is already having profound impacts on biological systems around the world. These impacts include the following:

- Changes in the lifecycles of vectors, reservoirs, and pathogens
- Impacts on diseases of wildlife and plants
- Disruptions of the interactions among species
- Destruction of habitats.

These widespread impacts make it important for experts in medicine, veterinary medicine, public health, ecology, environmental science, and other fields to work together to increase knowledge about climate change and to develop and implement preventive measures.

EFFECTS ON SOCIAL SYSTEMS

In many ways, climate change is having, and will continue to have, adverse consequences on social systems. For example, droughts, floods, and sea level rise often

Box 1-2 Health Effects of Climate Change in Arctic Indigenous Communities

Aaron Wernham

The climate is warming approximately twice as fast in the Arctic as at lower latitudes, with the greatest warming occurring in winter and spring—about 1°C per decade since the 1980s.[1] (See Box 2-4 in Chapter 2.) The Arctic is home to approximately 4 million people and about 40 ethnic groups, including the Inuit and Inupiat in North America and Greenland, the Yup'ik in Alaska and Russia, the Sami in northern Scandinavia and the Kola Peninsula (in northern Russia), the Athabascan in Alaska and Canada, and more than 25 different ethnic groups in Russia. In some regions, such as northern Canada and parts of Alaska, indigenous peoples comprise most of the population.[2] For these peoples, the warming climate is creating many rapid changes in environmental, social, and economic conditions, with profound implications for their health.

Thinner and less predictable ice makes winter travel more dangerous. For example, three whaling crews recently needed to be rescued when an ice floe broke away from shore. In northwest Alaska, a fire department has distributed personal locator beacons to hunters to facilitate rapid emergency response in case of ice-related accidents.[3]

Subsistence fishing, hunting, and whaling form the foundation of culture, family and community relationships, and health and well-being. These activities make a substantial contribution to the diet and food security of many remote Arctic communities. The high cost of store-bought foods in these communities, when fish and game harvests are inadequate, can contribute to food insecurity. Greater consumption of store-bought foods can also increase the occurrence of diabetes, cardiovascular disease, and dental decay.[1]

Climate change has affected subsistence activities in these communities in several ways. Whaling crews have reported not being able to "land" whales because of thinner ice and needing to travel farther on open water to encounter whales. In some regions, indigenous peoples report less success in harvesting caribou because of declining caribou populations and changes in their range and migration routes.[1] Reindeer herders have reported that climate-related changes have contributed to decreased herding ranges; some question whether they will be able to continue their way of life.[4] Not all subsistence impacts have been harmful: Some communities have harvested species, such as salmon, from rivers where they had never been seen before.[5]

Warmer temperatures have also led to thawing of ice cellars (underground rooms dug in permanently frozen earth [permafrost], in which food is cooled by ice), making it difficult to safely store harvested food. Communities that use food-preservation techniques adapted for historically stable climate conditions (such as open-air drying) have reported that climate and moisture changes are leading to increased food spoilage.[1,6]

Warming temperatures are extending the range of disease vectors and pathogens, such as ticks that transmit encephalitis in Russia and Canada, *Vibrio parahaemolyticus* in Alaska, and harmful algal blooms in several Arctic locations.[1] (See Chapters 6 and 7.) Climate-related habitat changes that bring wild animals and humans into closer contact may increase the risk of zoonotic diseases, such as toxoplasmosis, and increase the viability of temperature-sensitive pathogens, such as *Clostridium botulinum* and *Giardia lamblia*.[1]

Climate change in the Arctic causes thawing of permafrost and accelerates erosion, leading to immediate and difficult challenges. More frequent and intense storms and less sea ice are causing higher storm surges and severe erosion in many Arctic communities. In 2007, a storm surge necessitated the emergency evacuation of approximately 250 people from a low-lying coastal village in Alaska. Several Alaskan villages that are facing severe erosion have since developed facilities that allow for emergency evacuation.[7] Flooding and erosion in coastal communities increase risks of fatal injuries and epidemic illnesses and threaten the infrastructure, including homes, public buildings, and water and sewer systems.[8] Several villages in Alaska have been planning to relocate, but they have been thwarted by high costs and complex political, permitting, and engineering issues. Erosion and thawing of permafrost have interrupted water and sewer service, sometimes for many months.[8]

Tundra lakes, atop permafrost layers, may disappear rapidly when these frozen layers thaw and become more permeable. The rapid disappearance of these lakes and increased water turbidity, related to higher winds and higher temperatures, threaten village water supplies. In Point Hope, Alaska, high summer temperatures have increased algae and mosquito larvae in the lake that supplies village water, requiring the operators of the water plant to increase the frequency of filter cleaning from 4 to 50 times per day.[3]

These and other climate-related changes in the Arctic are causing stress and uncertainty for many communities. A landscape that had been mostly frozen and resilient is now thawing and fragile.[3] However, climate change is only one of many challenges to which Arctic communities have successfully adapted. Despite the rapid pace of climate change and limited financial resources, many Arctic communities are implementing successful adaptation measures. In Alaska, for example, the tribal health system has developed a health impact assessment that combines community observations and research findings to help identify impacts of climate change and to develop and prioritize adaptation meaures.[3] (See Box 11-2 in Chapter 11.)

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Box 1-3 Workers: The "Climate Canaries"?

Cora Roelofs and David H. Wegman

Climate change has a disproportionate impact on many classifications of workers, especially workers who are economically marginalized. Yet government officials and others have been slow to recognize workers' vulnerability to climate change.[1]

Workers' exposures due to climate change include extremes of temperature (Chapter 4A) and precipitation, as well as air pollution (Box 5-1); infectious diseases (Chapters 6 and 7); wildfires, severe weather events, and emotional stress (Chapter 9); and safety hazards, such as working at heights.[2] The number of potentially affected workers is huge, and their range of occupations is vast. While most outdoor workers and those dependent on climate-controlled work environments are at high risk, there are diverse categories of workers that may be severely impacted, including those in emergency response, utilities, transportation, healthcare, delivery of goods, environmental remediation, demolition, construction, landscaping, agriculture, forestry, wildlife management, heavy manufacturing, and warehouse work. In response to climate change impacts, employment in many of these categories is expected to grow, along with new mitigation-related "green jobs" in renewable energy, biofuels, and recycling, thereby expanding the numbers of workers exposed to serious workplace hazards. Recognition of these hazards can sound a warning as canaries did in mines.

Many of the occupational hazards worsened by climate change are not new, but they will increase in frequency, intensity, and duration. And they will have the greatest impact on workers who are already highly vulnerable. Workers are likely to experience health effects earlier and more severely than the rest of the population. However, unlike other vulnerable populations, such as older people and people suffering from chronic diseases, workers may be *required* by their jobs and employers to be exposed to climate-related hazards. Workers need special attention and protection because their working conditions and exposures are controlled by their employers, who may not be sufficiently prepared or compelled to adapt their workplaces to create safer conditions. Other than walking off their jobs when it is too hot or not reporting to work when air pollutant levels are too high, workers are highly constrained in responding and adapting to climate change.

Already, "climate canaries" include the more than 20,000 sugar cane workers in Central America who have died from chronic kidney disease due, in part, to extreme temperature and employment conditions that prevent adequate hydration and rest.[3,4] These workers, like farmworkers, day laborers, and many government employees in the United States and elsewhere, are at especially high risk because of their lack of power and because of inadequate protection by government agencies and labor unions. Without adaptive action, occupational morbidity and mortality will likely increase as climate change continues.

In the United States, there have been no national regulations and few state actions to force employers to recognize climate-related impacts as occupational hazards. The regulatory framework is inadequate to protect the most vulnerable workers who are also those most likely to be affected by climate change. "Documented" and "undocumented" immigrant workers, who are already heavily represented in hazardous occupations, may be among the first workers to take advantage of the employment opportunities that arise in response to disasters caused by climate change.

Increased recognition of the vulnerability of workers and the inadequacy of regulations may empower government agencies, public health organizations, and employers to address these problems and thereby contribute to the co-benefits of climate change adaptation and mitigation. To assist with this process, the National Institute for Occupational Safety and Health has established a website to disseminate information on occupational safety and health problems associated with climate change.[5]

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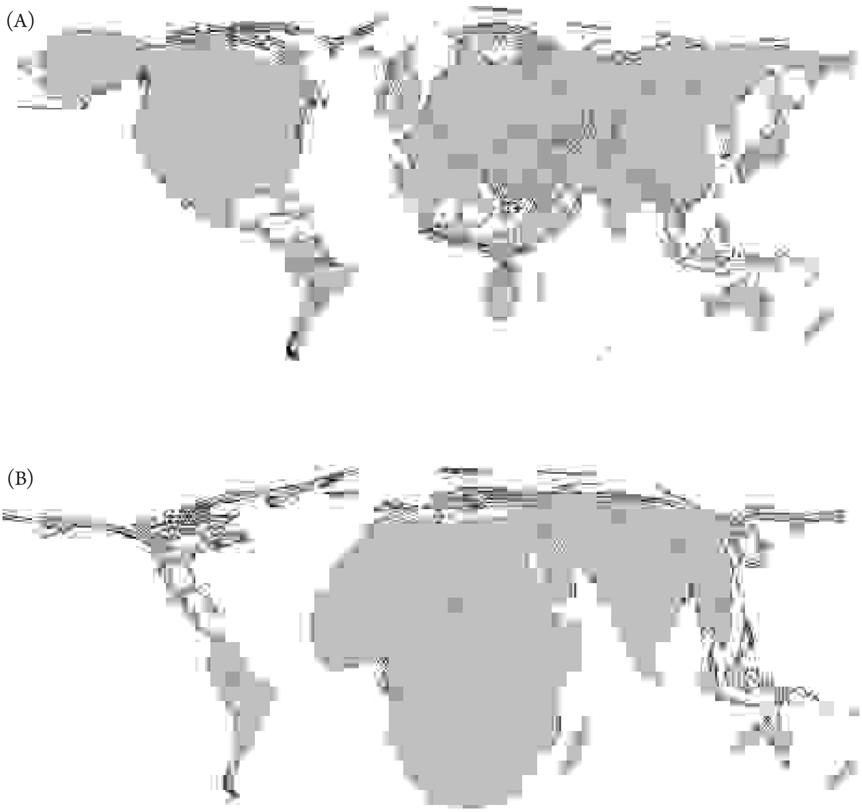

Figure 1-7 Global maps demonstrating (**A**) relative proportions of cumulative carbon dioxide emissions, by country, and (**B**) magnitude and severity of the consequences of climate change, for malaria, malnutrition, diarrhea, and drownings, by country. (*Source:* Patz JA, Gibbs HK, Foley JA, et al. Climate change and global health: Quantifying a growing ethical crisis. EcoHealth 2007; doi.10.1007/s10393-007-0141-1.)

force people to flee their homes and communities in search of safer places with better economic opportunities (Box 10-1 in Chapter 10). Food insecurity and resultant food price shocks are often associated with violence and other forms of conflict (Chapters 8 and 10). Increased temperatures, extreme weather events, sea level rise, and other consequences of climate change impact community mental health (Chapter 9).

PREVENTIVE MEASURES

Consistent with essential public health services and their application to climate change (Table 11-1 in Chapter 11), preventive measures to address climate change fall into two broad categories:

- *Mitigation*, which corresponds to primary prevention, refers to measures to stabilize or reduce the production of GHGs.

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- *Adaptation*, which corresponds to secondary prevention, refers to measures to reduce the public health impact of climate change.

Mitigation and adaptation measures are often implemented by governmental agencies; however, non-governmental agencies (NGOs), the private sector, and individuals play critically important roles (Chapter 15). Communication about climate change facilitates both mitigation and adaptation (Chapter 12).

Mitigation

Stabilizing or reducing the production of GHGs can be accomplished through the implementation of policies and the use of technologies. Policies to promote mitigation span several sectors, including energy (Chapters 13A and 13B), transportation (Chapter 13C), and agriculture (Chapter 13D), and also impact the planning and building of sustainable built environments (Chapter 14). Energy policies promote increased use of renewable energy, such as with solar and wind power; decreased use of fossil fuels; and reduced energy demand. Transportation policies promote walking and bicycling (*active transport*) and use of fuel-efficient vehicles. Agriculture policies promote reduced meat production and consumption, appropriate development of biofuels, and decreased methane emissions. Another aspect of mitigation involves accelerating the removal of GHGs from the atmosphere by increasing carbon dioxide sinks, such as forests, and implementing land use policies involving use and expansion of forests.

Reducing population growth could substantially reduce projections of GHG emissions.[30] For example, if, by 2050, the global population reached only 7.5 billion, rather than the 9 billion currently projected, there would be 5 to 9 billion fewer tons of carbon dioxide emitted into the air in 2050.[31] Reduction in population growth need not depend on coercive government action; it can be achieved by improving access to education, especially for girls, and by implementing policies and actions to reduce infant and child mortality and to increase access to family planning.[30]

Potential Health Co-benefits of Mitigation Measures

There are many opportunities to develop and implement mitigation measures that both reduce emissions of GHGs and improve human health. For example, transportation policies that promote active transport not only reduce GHG emissions but also increase physical activity, improve overall health status, and prevent cardiovascular and other diseases (Chapter 13C). (See Box 1-4.)

Adaptation

Adaptation measures can reduce the impact of climate change on public health and social systems. For example, anticipation of severe weather events can lead to improved multisectoral preparedness that can improve emergency responses and minimize morbidity and mortality. Vulnerability and adaptation assessment can be used to identify likely events, populations at increased risk, and opportunities to reduce harm.[32–35] (See Box 11-3 in Chapter 11.) Another example of adaptation is public health surveillance to detect outbreaks or disease trends at an early stage so that they are more amenable to control. Ongoing evaluations of preparedness and other adaptation measures can improve the ability of communities to reduce the impacts of climate change on public health and social systems. Design of healthy and sustainable built environments can facilitate adaptation to climate change and improve health status (Chapter 14).

Box 1-4 Health Co-benefits of Climate Change Mitigation Policies

Andrew Haines and Paul Wilkinson

Policies concerning power generation, housing, urban planning, food, and agriculture can both reduce greenhouse gas (GHG) emissions and improve health. However, some poorly designed policies can adversely affect health, such as those that increase production of biofuels (which can compete with production of food) or those that increase home energy efficiency (which can increase indoor air pollution by reducing ventilation). (See Chapters 13A through 13D.)

The magnitudes of GHG emission reductions and health co-benefits resulting from various policies have been assessed.[1] For example, in the United Kingdom, where there is much energy-inefficient housing, the housing sector accounts for about one-fourth of all carbon dioxide emissions, about half of which are due to space heating. These emissions could be greatly reduced by improving energy efficiency, such as by increasing insulation and by transitioning to energy sources that emit less carbon dioxide. A study assessed the impact on GHG emissions and health of four measures: increasing insulation, improving ventilation control, replacing indoor fossil-fuel combustion with electricity, and residents lowering the temperature of homes above 18°C (64.4°F) by 1°C (1.8°F).[2] If all four measures were implemented, about 600 kilotons of carbon dioxide emissions per million people could be averted, and about 89 premature deaths per million people could be prevented in the first year of implementation. Switching to renewable energy could reduce GHG emissions and increase health co-benefits even more.

Another study assessed the benefits of introducing 150 million low-cost, high-efficiency cookstoves in India. It found that, over 10 years, about two million premature deaths, from lower respiratory infections in children and from chronic obstructive pulmonary disease and ischemic heart disease in adults, would be prevented. (See Box 5-3 in Chapter 5.)

Globally, transportation accounts for about one-fourth of carbon dioxide emissions—an amount rising faster than those from other sectors. Urban traffic contributes a greater than proportional share of emissions, largely due to the inefficiency of short trips and stop-and-go traffic. A study of London and Delhi assessed the benefits of urban transportation policies that promote low-emission vehicles and *active transport* (walking and bicycling).[3] In London, much greater health benefits were achieved from increased active transport than from use of low-emission vehicles. In Delhi, the benefits from low-emission vehicles were larger than in London (because of higher background levels of fine particulate matter), but these benefits were again less than those from active transport. In London, active transport was projected to increase road traffic injuries, but the impact of these injuries was greatly outweighed by the health benefits of increased active transport. In Delhi, increased active transport was projected to *reduce* road traffic injuries (compared with a "business-as-usual" scenario of expansion of private car use) because fewer people would be driving. Policies that promote both use of low-emission vehicles and active transport could reduce the ischemic heart disease burden by about 15 percent in London and about 18 percent in Delhi.

Implementation of policies that reduce air pollutants and carbon dioxide emissions, mainly by decreasing coal combustion and increasing carbon capture and storage, could, in 2030, increase about 1,500 life-years (LYs) per million people in India, about 500 LYs per million in China, and about 100 LYs per million in European Union (EU) countries. If these health co-benefits were valued in India in the same way that the EU values health benefits from reduced air pollution, they would offset the costs of mitigation. (See Chapter 5.)

The food and agriculture sector produces GHG emissions due to changes in land use (such as fertilizer application, deforestation, overgrazing, and conversion of pasture to arable land), methane emissions from ruminant animals and rice paddies, and energy use. In the United Kingdom, use of technological strategies (such as improved efficiency of livestock farming, decreased dependence on fossil fuels, increased carbon capture through management of land use, and improved manure management) combined with a 30 percent reduction in livestock production could reduce GHG emissions from the food and agriculture sector by 50 percent.[4] If this 30 percent reduction in livestock production resulted in 30 percent reductions in both food from animals and dietary saturated fat and if dietary unsaturated fat was replaced by unsaturated fats of plant origin on an isocaloric basis, years of life lost due to ischemic heart disease could be reduced by about 16 percent. (See Chapter 13D.)

These estimates must be interpreted with caution, given related uncertainties and underlying assumptions. Changing the underlying assumptions results in different estimates of emission reductions and health co-benefits. There are a number of other plausible mechanisms for health co-benefits from dietary change that results in reduced GHG emissions, including as a result of reducing red and processed meat intake and consuming more fruit, vegetables, and whole grains.[5,6]

Strategies need to be developed and implemented that avoid unintended adverse consequences, such as increased consumption of refined carbohydrates. In some situations, such as in nomadic pastoralist communities where animal products provide essential protein and calories for disadvantaged populations, policymakers need to avoid creating policies with adverse effects on nutritional status.

Taxation of GHG emissions could lead to major reductions in such emissions. For example, a GHG-weighted tax on animal food of 60 euros per ton in the EU could reduce GHG emissions in agriculture by 32 million tons of carbon dioxide equivalent. This benefit is estimated to be six times greater if lignocellulosic crops, such as switch grass (*Panicum virgatum*) and elephant grass, are grown on land previously used to produce meat and are substituted for coal as fuel in power plants.[7]

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INTERNATIONAL AGREEMENTS TO ADDRESS CLIMATE CHANGE

In September 2014 at the United Nations Climate Summit in New York, 125 world leaders met to discuss measures to address climate change and make national commitments to reduce GHG emissions. At this meeting, many important initiatives were announced or discussed, including:

- The Green Climate Fund, which promotes low-emission and climate-resilient development by providing support to developing countries to limit or reduce their GHG emissions.
- The Compact of Mayors, in which more than 200 cities, with more than 400 million people, will set ambitious targets to reduce GHG emissions, develop strategies to mitigate and adapt to climate change, and track, report, and publicly disclose data about their emissions.
- The Business Leadership Criteria on Carbon Pricing, to which companies are invited to align to limit the increase in global mean temperature to 2°C (3.6°F) above pre-industrial levels.

In addition, a special session on health at the Climate Summit confirmed global recognition that human health is a central concern for policies and other measures addressing climate change.

In November 2014, President Barack Obama and President Xi Jinping announced a United States–China agreement on climate change. This agreement is especially noteworthy because the United States and China account for more than one-third of global GHG emissions. President Obama agreed to decrease U.S. carbon emissions by 26 to 28 percent below its 2005 level by 2025, which would be double the pace of reduction it had previously targeted for the 2005–2020 period. President Xi pledged, by 2030, for China to (a) reach peak carbon emissions and (b) derive 20 percent of its total energy production from clean energy sources, such as solar power and windmills. Achievement of these targets by the United States and China would represent a giant step forward in addressing global climate change. This agreement will likely encourage other countries to make commitments to reduce carbon emissions.

In December 2015, the 21st Conference of the Parties of the United Nations Framework Convention on Climate Change is scheduled to take place in Paris. Its objective is to achieve, for the first time in over 20 years of United Nations negotiations, a binding and universal agreement on climate that will be supported by all countries.

CONCLUSION

Human-induced climate change is occurring, causing adverse health consequences via multiple direct and indirect pathways. Populations vary considerably in their vulnerability to these risks. Mitigation measures, through the implementation of policies and the use of technologies, can stabilize or reduce the production of GHGs—and also create "co-benefits" to improve human health. While mitigation measures are developed and implemented, adaptation measures can reduce the public health consequences of climate change. Popular will and political leadership to address climate change is growing.

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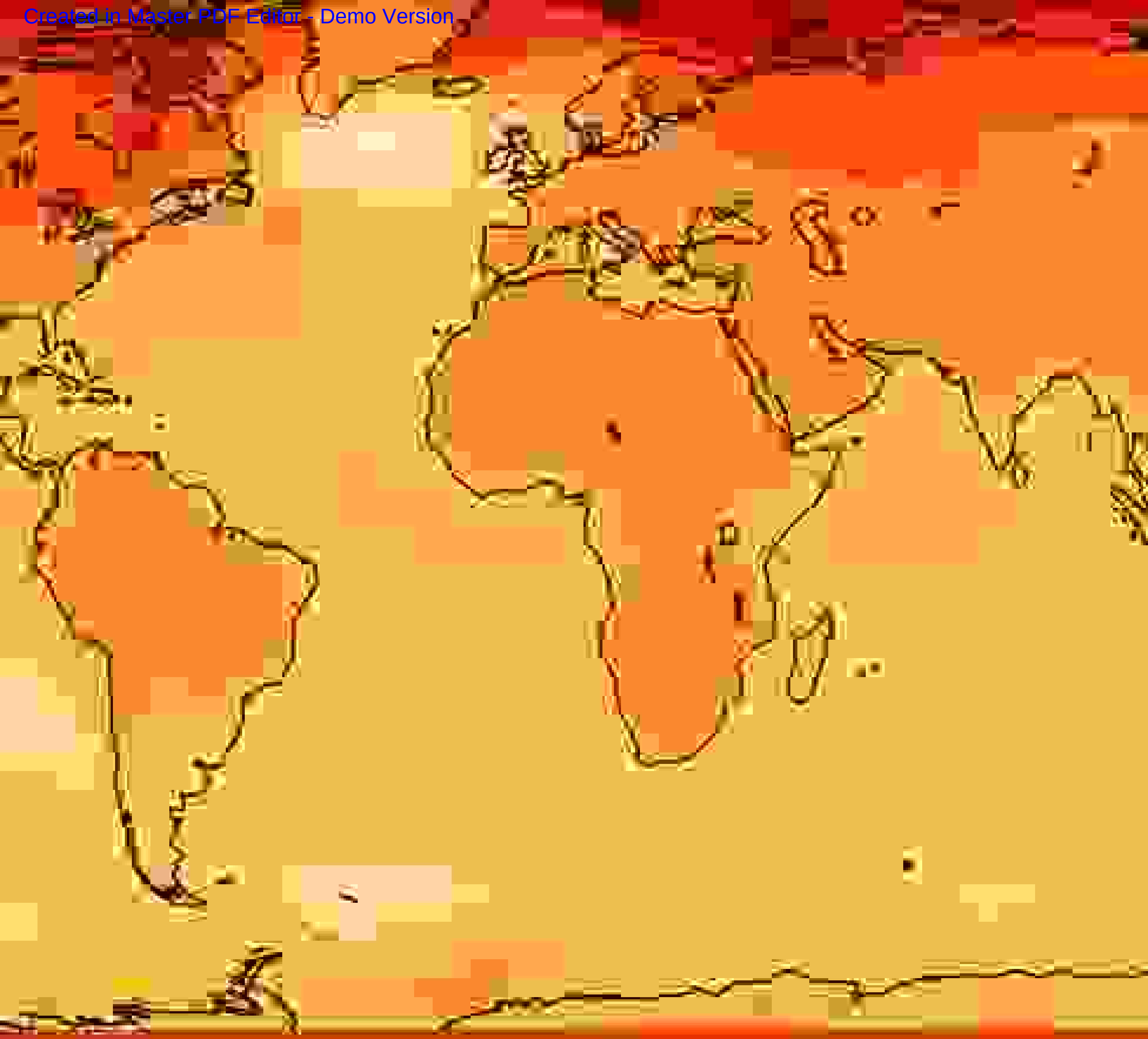
PART I

INTRODUCTION



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