Chapter 8

Health Risks and Costs of Climate Variability and Change

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INTRODUCTION

The scientific community agrees that climate change is happening, is largely human induced, and will have serious consequences for human health (Field and others 2014). The health consequences of climate variability and change are diverse, potentially affecting the burden of a wide range of health outcomes. Changing weather patterns can affect the magnitude and pattern of morbidity and mortality from extreme weather and climate events, and from changing concentrations of ozone, particulate matter, and aeroallergens (Smith and others 2014). Changing weather patterns and climatic shifts may also create environmental conditions that facilitate alterations in the geographic range, seasonality, and incidence of some infectious diseases in some regions, such as the spread of malaria into highland areas in parts of Sub-Saharan Africa. Changes in water availability and agricultural productivity could affect undernutrition, particularly in some parts of Africa and Asia (Lloyd, Kovats, and Chalabi 2011). Although climate change will likely increase positive health outcomes in some regions, the overall balance will be detrimental for health and well-being, especially in low- and lower-middle-income countries that experience higher burdens of climate-sensitive health outcomes (Smith and others 2014).

The pathways between climate change and health outcomes are often complex and indirect, making attribution challenging. Climate change may not be the most important driver of climate-sensitive health outcomes over the next few decades but could be significant past the middle of this century. Climate change is a stress multiplier, putting pressure on vulnerable systems, populations, and regions. For example, temperature is associated with the incidence of some food- and water-borne diseases that are significant sources of childhood mortality (Smith and others 2014). Reducing the burden of these diseases requires improved access to safe water and improved sanitation. Poverty is a primary driver underlying the health risks of climate change (Smith and others 2014). Poverty alleviation programs could improve the capacity of health systems to manage risks and reduce the overall costs of a changing climate.

Climate change entails other unique challenges:

- The magnitude, pattern, and rate of climate change over smaller spatial scales are inherently uncertain.
- Weather patterns will continue to change until mid-century, no matter to what extent greenhouse gas emissions (which drive climate change) are reduced in the short term.
- The magnitude and pattern of health risks past mid-century will be determined largely by the extent to which emissions are reduced in coming decades and the extent to which health systems are strengthened to manage current risks and prepare for projected ones in coming decades (Field and others 2014).

Significant reductions in greenhouse gas emissions (mitigation) in the next few years will be critical to preventing more severe climate change later in the century, but

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they will have limited effects on weather patterns in the short term. In terms of costing, another complexity is that these policies and technologies are associated with short-term health benefits (Garcia-Menendez and others 2015).

Reducing and managing health risks over the next few decades will require modifying health systems to prepare for, cope with, and recover from the health consequences of climate variability and change; these changes are part of what is termed *adaptation*. Adaptation will be required across the century, with the extent of mitigation being a key determinant of health systems' ability to manage risks projected later in the century (Smith and others 2014). No matter the success of adaptation and mitigation, residual risks from climate change will burden health systems, particularly in low- and middle-income countries (LMICs).

Given these complexities, estimating the costs of managing the health risks of climate variability and change is not straightforward. The wide range of health outcomes potentially affected means counting (1) costs associated with increased health care and public health interventions for morbidity and mortality from a long list of climate-sensitive health outcomes; (2) costs associated with lost work days and lower productivity; and (3) costs associated with well-being. Costs could also accrue from repeated episodes of malaria, diarrhea, or other infectious diseases that affect childhood development and health in later life. Costs associated with actions taken in other sectors are also important for health, such as access to safe water and improved sanitation. A portion of the costs of managing the health risks associated with migrants and environmental refugees could be, but has not been, counted.

Further, costs and benefits will be displaced over time, with costs associated with increased health burdens occurring now because of past greenhouse gas emissions and benefits occurring later in the century because of mitigation implemented in the next few years. A few preliminary estimates have been made of the costs of adaptation. However, more work is needed to understand how climate variability and change could affect the ability of health systems to manage risks over long temporal scales.

This chapter reviews the health risks of climate variability and change, discusses key components of those risks, summarizes the attributes of climate-resilient health systems, provides an overview of the costs of increasing health resilience that arise from other sectors, reviews temporal and spatial scale issues, and summarizes key conclusions regarding the costs of the health risks of climate change.

HEALTH RISKS OF CLIMATE VARIABILITY AND CHANGE

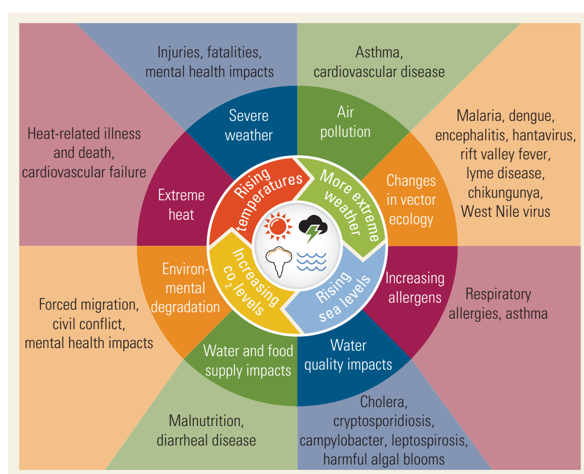
Climate change is affecting morbidity and mortality worldwide, with the risks projected to increase over coming decades (Smith and others 2014). Many health outcomes are affected by weather and climate, as shown in figure 8.1. The poor and vulnerable in LMICs, particularly children, are and will continue to be affected most. Until mid-century, the adverse health risks of climate change will mainly be exacerbations of current health problems, with the possibility that diseases (for example, vector-borne infections) may extend their geographic range into new areas. The largest risks will occur in populations that are currently most affected by climate-related health outcomes (Smith and others 2014).

Climate change affects health through various pathways:

- Changes in the frequency and intensity of extreme weather (including heat, windstorms, and heavy rain)
- Effects mediated through natural systems (for example, changes in the geographic range and incidence of infectious diseases, such as water-, food-, and vector-borne diseases, and health outcomes associated with poor air quality, such as high concentrations of ozone and aeroallergens)
- Effects heavily mediated by human systems (for example, occupational impacts, undernutrition, migration, and mental stress).

Climate change will affect mean weather variables (for example, temperature and precipitation); the frequency, intensity, and duration of some extreme weather and climate events; and sea level. Changes in the mean and variability of weather and climate can independently and jointly influence the burden of climate-sensitive health outcomes. For example, rising mean temperatures can create conditions conducive to the geographic spread of vector-borne diseases such as

Figure 8.1 Impacts of Climate Change on Human Health



Source: Slide courtesy of George Luber, CDC.

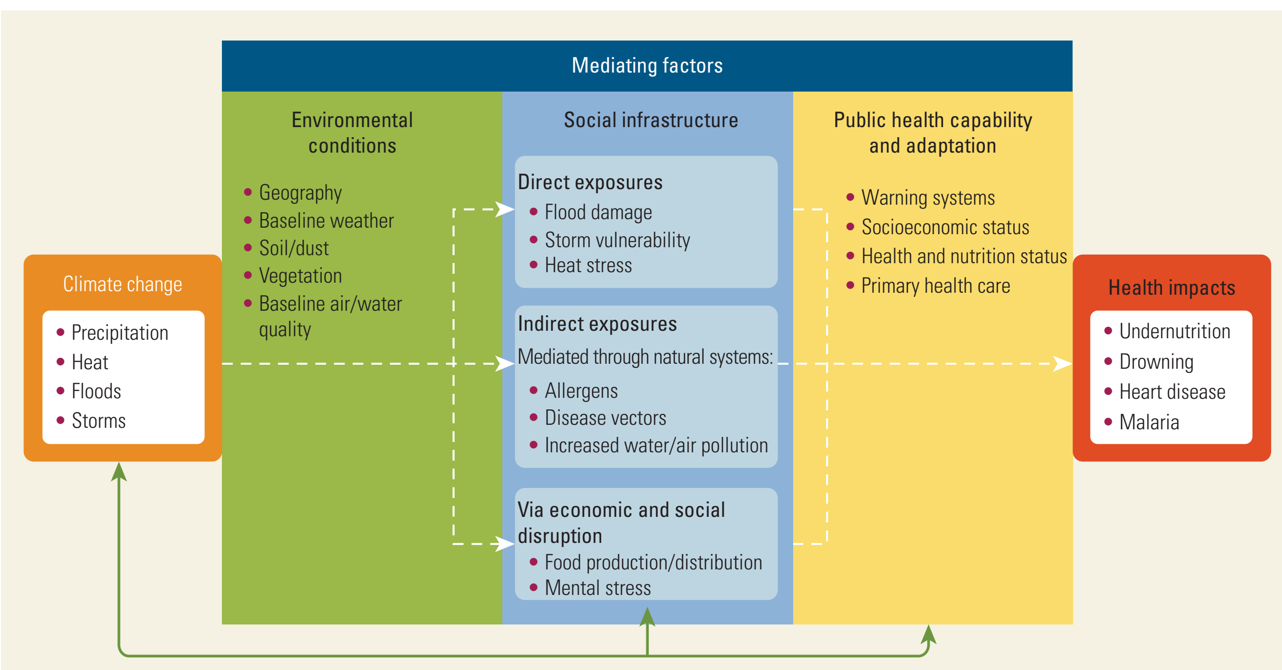
malaria. At the same time, heavy precipitation events can wash away breeding grounds, resulting in short-term reductions in the number of *Anopheles* mosquitoes that can carry malaria. As changes continue over the century, thresholds may be crossed that could result in large increases or decreases in the incidence of climate-sensitive health outcomes.

Figure 8.2 shows the primary exposure pathways for the health risks of climate change. The figure shows that mediating factors, including environmental, social, and health factors, affect the burden of climate-sensitive health outcomes associated with changing weather patterns. The green arrows at the bottom indicate the possibility of positive or negative feedback mechanisms.

In the human health chapter of the Working Group II Contribution to the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report, Smith and others (2014) conclude the following:

- The health of human populations is sensitive to shifts in weather patterns and other aspects of climate change. The effects occur directly, because of changes in temperature and precipitation and because of the occurrence of extreme weather and climate events (heatwaves, floods, droughts, and wildfires). Climate change can lead to ecological disruptions that indirectly affect health (for example, by reducing crop yields and altering the habitat of disease vectors). Social responses to climate change, such as migration, also can affect human health.
- Until mid-century, climate change mainly will exacerbate preexisting health problems. New health conditions may emerge, and diseases such as vector-borne infections may extend their geographic range into areas that currently are unaffected. The risks will be highest in populations most affected by climate-related health outcomes, such as in regions that currently are food insecure.
- Over the past few decades, climate change contributed to the burden of climate-sensitive health outcomes; however, the worldwide burden of ill health caused by climate change is relatively small compared with that caused by other stressors and is not well quantified.
- The major concerns with climate change include (1) morbidity and mortality from higher ambient temperatures and intense heatwaves; (2) higher risk of undernutrition from reduced food production in poor regions; (3) health consequences of lost work capacity and reduced labor productivity; and (4) higher risks of food-, water-, and vector-borne diseases.

Figure 8.2 Conceptual Diagram of the Health Risks of Climate Change



Source: Figure 11-1 from Smith, K. R., A. Woodward, D. Campbell-Lendrum, D. D. Chadee, Y. Honda, Q. Liu, J. M. Olwoch, B. Revich, and R. Sauerborn. 2014: "Human Health: Impacts, Adaptation, and Co-Benefits." In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C. B., V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White, eds.]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, United States.

- Impacts on health will be reduced, but not eliminated, in populations that benefit from rapid social and economic development, particularly among the poorest.
- The most effective measures to reduce vulnerability in the near term are programs that implement and improve basic health system measures, such as providing safe water, improving sanitation, securing essential health care, strengthening the capacity for disaster preparedness and response, and alleviating poverty.
- Important research gaps remain regarding the health risks of climate change, particularly in low-income countries (LICs).

The magnitude and pattern of risks in future decades will depend on actions taken to strengthen the resilience of health systems to prepare for, cope with, and recover from changing burdens of climate-sensitive health outcomes and on actions taken to reduce emissions of greenhouse gases that are driving climate change, sea-level rise, and ocean acidification.

VULNERABILITY TO THE HEALTH RISKS OF CLIMATE VARIABILITY AND CHANGE

The magnitude and pattern of risks from climate change are due to the characteristics of the hazards created by changing weather patterns, the extent of exposure of human and natural systems to the hazard, the susceptibility of those systems to harm, and their ability to cope with and recover from exposure (Field and others 2012; Steinbruner, Stern, and Husbands 2013). Climate-related hazards can alter vulnerability to future events by changing the following (Field and others 2012; Steinbruner, Stern, and Husbands 2013):

- Extent of exposure (for example, reducing the presence or effectiveness of coastal barriers)
- Susceptibility of exposed human and natural systems (for example, making individuals and communities more or less susceptible by affecting their access to and the functioning of health care facilities or the proportion of the population vulnerable to an event)
- Ability of organizations and institutions to prepare for and manage events effectively and efficiently.

Understanding the magnitude and pattern of impacts and the factors that increase or decrease susceptibility and coping abilities is vital to modifying current policies and to implementing new policies and programs to increase resilience to climate change.

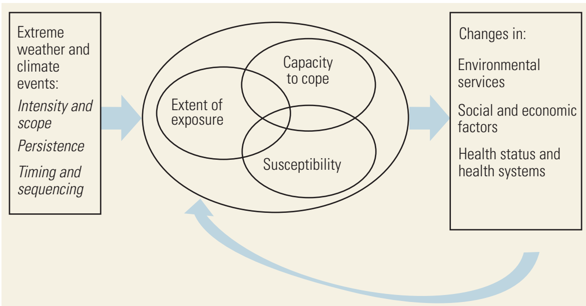
The wide range of factors that describe vulnerability to climate-related hazards can be divided into environmental, social, economic, health, and other dimensions (Cardona and others 2012; Field and others 2012). Environmental dimensions include physical variables (location-specific context for human-environment interactions); geography, location, and place; and settlement patterns and development trajectories. Social dimensions include demographic variables such as education and human health and well-being; cultural variables; and institutions and governance. Cross-cutting factors include relevant and accessible science and technology. In the health sector, important factors include the health of the population and the status of health systems (for example, the ability of health care facilities, laboratories, and other parts of the health system to manage an extreme event).

From the perspective of the health sector, vulnerability is the summation of all risk and protective factors that determine whether an individual or subpopulation experiences adverse health outcomes from exposure (Balbus and Malina 2009). Sensitivity to an event is a measure of the responsiveness of an individual or subpopulation to an event, often for biological reasons such as the presence of a chronic disease. A rich literature describes factors that increase vulnerability to extreme events. Individuals who are low on the socioeconomic scale, children, pregnant women, individuals with chronic medical conditions, and individuals with mobility or cognitive constraints are at higher risk of adverse health outcomes during an extreme event (Balbus and Malina 2009). In addition, the social determinants of health influence vulnerability. These determinants include access to health care services, access to and quality of education, availability of resources, transportation options, social capacity, and social norms and culture.

Figure 8.3 shows the framework used to explore the key drivers of vulnerability to extreme weather and climate events in the health sector (Ebi and Bowen 2016). Impacts can be categorized into those that affect environmental services, social and economic factors, or health status and health systems:

- Impacts on environmental services include availability of safe water (including quality and quantity), food security, and consequences that affect ecosystem services such as wildfires, coastal erosion, and saltwater intrusion into freshwater sources.
- Impacts on social and economic factors (such as community services, livelihoods, and social capital) include economic resources, infrastructure, access to services, and social capital.

Figure 8.3 Key Drivers of Health Vulnerability to Extreme Weather and Climate Events



Source: Ebi and Bowen 2016.

- Impacts on health status and health systems include stress, mental illness as a consequence of the event or recovery, worsening chronic diseases, and undernutrition.

CLIMATE-RESILIENT HEALTH SYSTEMS

Preparing for and managing the health risks of climate variability and change require strengthening the capacity of health systems to protect and improve population health in an unstable and changing climate (WHO 2015). To that end, the World Health Organization (WHO) defines a climate-resilient system as a system capable of anticipating, responding to, coping with, recovering from, and adapting to climate-related shocks and stresses to bring sustained improvements to the health of the population.

Health systems vary across and within countries, but all share common building blocks:

- Leadership and governance
- Health workforce
- Health information systems
- Essential medical products and technologies
- Service delivery
- Financing.

Figure 8.4 shows the 10 components for building climate-resilient health systems within these building blocks.

Within each component, specific characteristics or activities are needed to achieve resilience. For example, within leadership and governance, leadership and political will are needed to ensure collaboration across all relevant departments within a ministry, such as environmental health; vector control; water, sanitation, and hygiene; and disaster risk management. Also needed are policy prioritization and planning that explicitly incorporate the risks of climate change; legal and regulatory systems that protect health; institutional mechanisms, capacities, and structures; accountability; and community participation. Indicators are needed to describe the current baseline and to measure progress as climate change is incorporated into policies and programs.

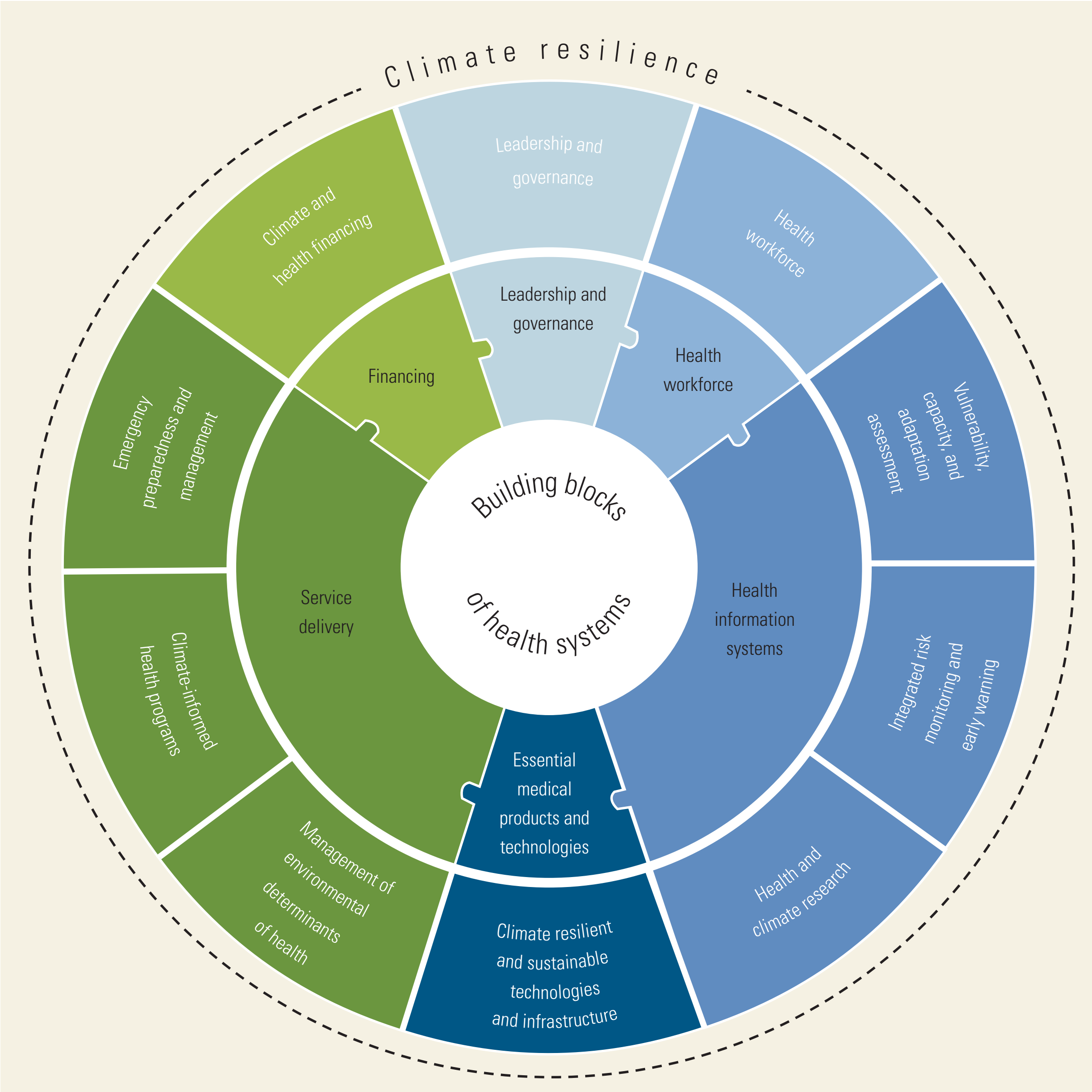
Costs are associated with implementing climate-resilient policies and programs within each component. Few efforts have been made to estimate these costs. Some costs will be limited, such as modifying five-year plans to incorporate climate change. Others will likely be significant, such as developing new products and technologies, ensuring adequate human and financial resources (particularly in LMICs), or improving infrastructure to ensure that health care facilities can withstand (and continue to function during) more frequent and intense floods and storm surges. Some costs will be ongoing, such as the need for regular reassessments of current and projected burdens of climate-sensitive health outcomes. Such assessments require ongoing research and development to project the magnitude and pattern of climate-sensitive health outcomes as the climate continues to change, taking into account multiple drivers and adaptation options to reduce risks. Investments in surveillance, monitoring, and evaluation will be needed across the century to continue to prepare for and manage changing vulnerabilities and risks. New tools for mapping vulnerability, modeling future risks, developing scenarios, evaluating the effectiveness of public health prevention, and undertaking other activities are all components of the iterative management of climate change.

Other costs will be borne primarily by other sectors, such as developing and deploying new agricultural cultivars that are heat, drought, or salt tolerant. These activities will be critical for ensuring food security over coming decades. In the absence of these activities, the costs for health systems to manage risks will be considerably higher.

Table 8.1 lists some possible interventions within each of the six building blocks of health systems, providing an overview of the wide range of efforts needed to strengthen resilience. The costs associated with some of these activities, such as establishing and maintaining a malaria treatment program, are estimated in other chapters.

Limiting the magnitude of climate change risks past mid-century requires significant reductions in greenhouse gas emissions and deforestation, both now and in the years to come (Field and others 2014). Estimates of the costs of mitigation generally do not take into account the growing evidence that some mitigation options have extensive health co-benefits (Smith and others 2014). Mitigation policies and technologies (such as

Figure 8.4 Components for Building Climate-Resilient Health Systems



Source: WHO 2015.

transitioning energy generation to reduced use of fossil fuels; altering policies to increase mass transit and encourage active transportation such as walking and biking; and promoting dietary changes to reduce consumption of red meat) are associated with significant health benefits (termed *co-benefits*) that primarily will be local and will accrue well before the benefits of mitigation become evident, potentially making mitigation implementation more politically feasible.

Estimating the overall costs and benefits of mitigation to reduce health risks associated with climate change is an important research need.

COSTS ARISING IN THE HEALTH SECTOR

The health effects of extreme weather and climate change will lead to potential costs. Important categories to consider when estimating impacts and subsequent

Table 8.1 Examples of Climate-Informed Health Interventions

Climate-related health risks and mechanisms	Examples of interventions
Extreme heat and thermal stress	• Establish occupational health exposure standards. • Improve health facility design, energy-efficient cooling and heating systems. • Ensure public education to promote behavior change (in relation to clothing and ventilation). • Develop heat-health action plans (including early warning, public communication, and response plans) such as cooling centers for high-risk populations.
Water- and food-borne diseases	• Enhance disease surveillance systems during high-risk seasons or periods. • Establish early warning systems to anticipate outbreaks associated with extreme weather and climate events. • Strengthen food and water quality control.
Zoonotic and vector-borne diseases	• Expand the scope of diseases monitored and conduct monitoring at the margins of current geographic distributions. • Establish early warning systems when data are sufficient and the association between environmental variables and health outcomes is robust. • Establish vector or pest surveillance and control programs. • Enhance diagnostic and treatment options in high-risk regions or periods. • Ensure adequate animal and human vaccination coverage.
Allergic diseases and cardiopulmonary health	• Develop exposure forecasts for air quality, allergens, and dust. • Enforce stricter air quality standards for pollution. • Establish programs to monitor pollen levels. • Establish allergen management. • Create plans for handling increased demand for treatment during high-risk seasons or weather conditions.
Nutrition	• Perform seasonal nutritional screening in high-risk communities. • Scale up integrated food security, nutrition, and health programming in fragile zones. • Promote public education and food hygiene.
Storms and floods	• Include climate risks in siting, designing, or retrofitting health infrastructure. • Establish early warning and early action systems, including education and community mobilization. • Assess and retrofit or construct public health infrastructure (health facilities in flood-prone areas) to be resilient to extreme weather conditions, warmer temperatures, and environmental changes.
Mental health and disability	• Address special needs of mental health patients (as well as patients with other disabilities) by developing emergency preparedness plans. • Address mental health needs of disaster- and trauma-exposed populations. • During extreme weather conditions, establish community watch for people with mental illness.

Source: Adapted from WHO 2015.

responses include immediate health sector response costs (additional medicine and costs of treatment) when an extreme weather event occurs or an impact arises from changing weather trends. Other costs arise for those affected, including injuries, illnesses, and deaths and lost work time. Further effects relating to the impact on people's quality of life and well-being (or in economic terms, welfare) exist, even if these impacts are not captured by markets. Quantifying and valuing these effects is possible, expressing them in monetary terms to capture the economic, social, and environmental costs borne by society as a whole.

Estimating the full costs of climate variability and change includes three components: resource costs (medical treatment costs); opportunity costs (lost productivity); and welfare costs or disutility (pain or suffering, concern, and inconvenience to family and others). The magnitude of welfare costs usually is derived through elicitation techniques such as contingent valuation and stated preference. This valuation is somewhat controversial, but it is included because it is a way of comparing impacts using a common metric.

Methods

A wide variety of methods have been used to estimate the costs of climate change effects on health. These methods capture different aspects of the resource, opportunity, and well-being costs and can use different approaches for valuation of these elements. Also, differences exist between the direct costs of the events and the indirect, wider costs for the economy.

Many studies focus on resource costs, although differences emerge even in the approach used for valuation. One set of studies explored the costs of adaptation to climate change using preventative costs. As an example, in the case of malaria, valuation includes estimating the number of malaria cases from climate change, then looking at the costs of adaptation (a proxy for impacts) based on the costs of programs and unit costs (per beneficiary) for insecticide-treated bed-nets plus case management and indoor residual insecticide spraying. These approaches have been widely used, particularly in studies in LMICs. Other approaches look at resource costs directly, for example, looking at the number of additional impacts, and then estimating the health care costs of treatment, that is, using estimates of the health care cost per patient and the number of hospital days spent on average for respiratory admissions. A variation on the resource cost method can be undertaken when working at aggregated scale, using investment and financial flow assessments. These look at existing expenditures and then apply a mark-up (an increase) to reflect rising impacts from climate change. One issue with all of these approaches is that they only cover one element of the total health costs.

One additional cost that arises from impacts is associated with the time or productivity lost from the illness—the opportunity costs. Some studies also estimate these, often using values based on loss, earnings, or, more appropriately, labor productivity. These costs are particularly relevant for studies that focus on outdoor worker productivity; the primary impact for these workers is associated with lost time, as worker output is reduced because of heat and humidity. However, these opportunity costs also apply to other health impacts, and many studies estimate these in addition to resource costs.

Another set of studies takes the resource and opportunity costs estimated from these methods and inputs them into economy-wide economic models. This approach captures the impacts of costs on the wider economy, the linkages across sectors, and macroeconomic metrics such as gross domestic product (GDP).

Finally, in addition to estimating resource and opportunity costs, some studies derive values for the impacts on well-being (for example, the pain and suffering from illness). Techniques are available to capture this component, such as assessing the willingness to pay or the willingness to accept compensation for a particular health outcome. These are derived using survey-based stated preference methods and/or revealed preferences methods.

Review of Studies

Altered weather patterns (particularly, extreme weather and climate events) could affect health sector costs initially through resource costs for diagnosis and treatment. As an example, six of the weather and climate events that struck the United States between 2000 and 2009 included higher concentrations of ground-level ozone, the 2002 outbreak of West Nile virus in Louisiana, the 2003 Southern California wildfires, the 2004 Florida hurricane season, the 2006 California heatwave, and the 2009 flooding of the Red River in North Dakota. In total, these events increased health care costs an estimated US$819 million, reflecting more than 760,000 encounters with the health care system (Knowlton and others 2011). The total health costs, including 1,689 lives lost prematurely (valued using nonmarket economic values), exceeded US$15.5 billion.

Health care facilities themselves can be damaged by extreme weather and climate events, including storm surges, floods, and wildfires, which compromise critical resources required to treat patients and repair or replace damaged or destroyed equipment and buildings (Carthey, Chandra, and Loosemore 2009). In 2011, 139.8 million people globally—57 percent of all disaster victims—were affected by hydrological disasters (floods and wet mass movements). These disasters were responsible for 20 percent of all people reportedly killed in disasters and 19 percent of total damages (Guha-Sapir and others 2012). Although the proportion of individuals seeking medical treatment during a disaster is typically a small subset of the total number of persons affected, the additional burden on health care facilities can be significant (Hess and others 2009). Floods and wildfires also can require the evacuation of critical care patients, with attendant risks.

When these extreme events are very large, they can affect the ability of health care systems to function properly and to care for patients with ongoing health issues that require medication or treatment. In cases where these events become significantly more frequent or intense, health facilities might need to add surge capacity to help them to manage such events without interrupting service (Banks, Shah, and Richards 2007; Hess and others 2009).

Climate change is projected to increase the burden of climate-sensitive health outcomes, leading to increased costs in the absence of mitigation and adaptation. As well as changing the patterns of extreme events, it will lead to shifts in climate variables that will affect health outcomes. This increase in health burdens will increase the demands on public health services (for example, surveillance and control programs) and the demands for health care and relevant supplies (for example, antimalarials and oral rehydration). It also will increase opportunity and welfare costs. Studies use different methods and include different components, making inter-comparisons difficult.

Many earlier estimates of the additional costs of climate change typically focused on the health care costs associated with treating additional cases of disease, not the costs of providing additional health services (health system adaptation costs) or the wider societal costs. Therefore, they underestimated the total costs. Given these limitations, the global costs of treating future cases of adverse health outcomes from climate change from such studies are estimated at billions of U.S. dollars annually (Ebi 2008; Pandey 2010).

Ebi (2008) estimated the worldwide costs in 2030 of additional cases of malnutrition, diarrheal disease, and malaria due to climate change at US$5 billion to US$16 billion a year, for a high-emissions scenario, assuming no population or economic growth (undiscounted US$). This estimate was based on current costs of treatment and assumed no adaptation. The costs for additional infrastructure and health care workers were not included, nor were the costs of additional public health services, such as surveillance and monitoring. The estimated costs were distributed unevenly across regions. Markandya and Chiabai (2009) used these estimates to provide a regional breakdown of costs, finding the highest costs in Africa and South-East Asia.

Pandey (2010) estimated global health costs of climate change based on United Nations population projections, strong economic growth, updated projections of the current health burden of diarrheal diseases and malaria, two climate scenarios, and updated estimates of the costs of malaria treatment. In 2010, the average annual costs for treating diarrheal disease and malaria cases associated with climate change were estimated to be between US$4 billion and US$7 billion, with the costs expected to decline over time as basic health services improve. From 2010 to 2050, the average annual costs were estimated to be around US$3 billion, with most of the costs related to treating diarrheal disease; the largest burden was expected to be in Sub-Saharan Africa. Pandey's estimates differ from those of Ebi's primarily because of the assumption of a lower baseline burden of disease and lower costs for malaria treatment.

These studies considered only malnutrition, diarrheal disease, and malaria and therefore were underestimates. According to Parry and others (2009), the studies estimated only 30–50 percent of the extra health burden of climate change.

World Bank (2010) undertook a similar analysis of diarrheal disease and malaria and reported much lower estimates than these earlier studies. Whereas the earlier studies fixed the baseline incidence of disease, this study incorporated a future baseline based on the WHO Global Burden of Disease projections to 2030 (plus extensions through 2050). This led to a reduction in the baseline incidence of diarrheal disease and malaria, significantly reducing the additional cases due to climate change. The World Bank analysis also incorporated updated unit costs of prevention and treatment and risk factors. The resulting health adaptation costs in LMICs globally were estimated at between US$1.8 billion and US$2.4 billion a year in the period 2010–50, with most of these costs in Africa. Future health outcomes depend on multiple factors beyond the level of greenhouse gas emissions and resulting warming.

The recent Climate Impact Research and Response Coordination for a Larger Europe (CIRCLE) study used a combination of global models: a computable general equilibrium model to project effects to 2060 and the AD-RICE model to project effects beyond 2060 (OECD 2015).[1] It considered heat mortality in a stand-alone analysis, heat- and cold-related morbidity and mortality, and morbidity from infectious diseases such as malaria, schistosomiasis, dengue, diarrhea, cardiovascular disease, and respiratory disease. The changes in labor productivity from climate-sensitive diseases were taken from Bosello, Eboli, and Pierfederici (2012).

By 2060, the largest negative effects were projected to take place in Africa and the Middle East (–0.6 percent for South Africa, −0.5 percent for the Middle East and North Africa, and −0.4 percent for other African countries). Smaller impacts were projected for Brazil, Mexico, and LMICs in Asia (−0.3 percent), as well as for Indonesia, the United States, South-East Asia, and most of Latin America (−0.2 percent). Some regions were projected to experience positive impacts on labor productivity, the highest being the Russian Federation (+0.5 percent), Canada (+0.4 percent), and China (+0.2 percent). In other regions, the projected impacts were either very small or nonexistent. Changes in health care expenditures were also estimated. The costs of vector-borne diseases were based on prevention expenditures and treatment costs per person per month (Chima, Goodman, and Mills 2003).

Changes in health expenditure were small as a percentage of GDP. In 2060, they were projected to be highest in LMICs in Asia (0.5 percent), Brazil, and the Middle East and North Africa (0.3 percent). Additional demands for health services were projected to be very small in other regions and to be negative in Canada and large European Union economies, such as France and Germany (−0.1 percent).

Several regional and country studies support or extend these assessments:

- In India, Chiabai and others (2010) reported adaptation costs for malaria, diarrhea, and malnutrition. Using a similar prevention cost approach to the studies above, costs under different development scenarios were in the range of US$183 million to US$584 million with no mitigation and US$151 million to US$476 million with mitigation achieving stabilization at 550 parts per million.
- In Kenya, the Stockholm Environment Institute used a malaria risk model based on altitude to assess the national impact of future climate change (SEI 2009). The model projected that, by 2055, as a result of average climate warming of 4.3°F (2.3°C) across the projections, the population annually affected by malaria in rural areas above 1,000 meters (63 percent of the population) would increase as much as 74 percent (in the absence of adaptation). It also presented results for scenarios with average temperature increases of 2.2°F (1.2°C) and 5.6°F (3°C). The 10 model projections used a range of average climate warming increases from 36 to 89 percent. The additional economic burden of endemic malaria disease in the 2050s was estimated to be more than US$92 million annually (with a range of US$51 million to US$106 million annually across the temperature projections) based on the clinical and economic burden of malaria. The estimated welfare costs increased to a range of between US$154 million and US$197 million annually when disutility costs (discomfort, pain, and inconvenience measured by survey-based willingness-to-pay estimates) were taken into account.
- In 25 African countries, Egbendewe-Mondzozo and others (2011) used a semiparametric econometric model to estimate the climate change–related costs for inpatient and outpatient treatments for malaria at the end of the century (2080–100). Even marginal changes in temperature and precipitation were projected to affect the number of malaria cases, with most countries projected to see an increase and others a decrease. The end-of-century treatment costs as a proportion of year 2000 health expenditures per 1,000 people would be higher in the vast majority of countries, with increases of more than 20 percent in the costs of inpatient treatment in Burundi, Côte d'Ivoire, Malawi, Rwanda, and Sudan.
- In Tanzania, Traerup, Ortiz, and Markandya (2011) estimated the costs of cholera cases due to climate change in 2030 to be in the range of 0.32–1.4 percent of GDP.
- In India, Ramakrishnan (2011) estimated the costs of treating additional cases of diarrhea and malaria in 2030 to range between Rs 3,648 lakhs and Rs 7,787 lakhs, depending on the emissions scenario.[2]
- In Saint Lucia, the Economic Commission for Latin America and the Caribbean (ECLAC 2011) estimated the present value of treatment costs under two scenarios of greenhouse gas emissions in the period 2010–50 as US$634,000 for cardiorespiratory disease, US$33,000 for malaria, US$36,000 for dengue, and US$3.5 million for gastroenteritis, using a discount rate of 1 percent.
- In Paraguay, the United Nations Development Programme (UNDP 2011) applied an investment and financial flow assessment to health, estimating total costs to be US$160.5 million by 2030 (2005 US$).

Because adverse health outcomes are projected to occur predominantly in LICs, treatment costs will be borne primarily by families where governments provide limited health care (WHO 2004). Time off from work to care for sick children will have an adverse effect on productivity.

Estimates of the impact of climate change on outdoor worker productivity (primarily through heat stress) indicate that productivity has already declined during the hottest and most humid seasons in parts of Africa and Asia, with more than half of afternoon hours projected to be lost to the need for rest breaks in 2050 in South-East Asia and up to a 20 percent loss in global productivity in 2100 under a moderately low emission scenario (Representative Concentration Pathway 4.5) (Dunne, Stouffer, and John 2013; Kjellstrom and others 2009; Kjellstrom, Lemke, and Otto 2013). Trade-offs between worker health and productivity will be of particular concern for workers with limited control over work practices.

Kovats and others (2011) estimated the labor productivity losses for Europe at between US$321 million and US$792 million a year in the 2080s for a high-emissions scenario, falling to between US$64 million and US$160.5 million a year under a mitigation scenario, with impacts primarily in Southern Europe. For the loss of labor productivity, a value was derived from the GDP per labor force member. This represents the loss to society, differentiating it from a loss of earnings measure that reflects only the loss for the individual.

The CIRCLE project also considered these impacts and found that the highest impacts on labor productivity caused by occupational heat stress in 2060 likely would occur in regions with relatively large proportions of outdoor workers and warm climates (OECD 2015). The most severely affected regions were projected to experience productivity losses between 3 and 5 percent for outdoor activities for a 1.9°F (1°C) temperature increase in non–Organisation for Economic Co-operation and Development (OECD) countries, non–European Union European countries, Latin America (including Brazil and Chile), Mexico, China, LMICs in Asia, and South Africa. Most OECD countries, including Japan, the United States, and the OECD European Union countries, were projected to experience effects of less than 1 percent.

Nevertheless, some health impacts from climate change are likely to affect OECD countries, particularly mortality and morbidity from higher temperatures and heat extremes. Studies have assessed the impacts and full economic costs (including nonmarket valuation) in OECD countries. Watkiss and Hunt (2012) quantified and valued temperature-related mortality effects, salmonellosis, and coastal flooding–induced mental health impacts resulting from climate change in Europe in 2071–100, assessing the full welfare costs. The analysis found that the choice of valuation metric and inclusion or exclusion of acclimatization (autonomous adaptation)[3] had a major impact on the results, much more so than climate uncertainty.

In model runs without acclimatization, economic costs in current values were estimated at US$12.6 billion to US$31.6 billion a year by the 2020s using a value of statistical life metric, but US$1 billion to US$4.2 billion a year when acclimatization was included. By the 2080s, the annual values ranged from US$52.6 billion to US$189.5 billion (according to choice of function and climate model) without acclimatization, and US$8.4 billion to US$84.2 billion with acclimatization. The additional welfare costs for salmonellosis from climate change were estimated to be several hundred million dollars annually by 2071–100. They also found the potential reduction in cold-related mortality to be at least as large as the increase in heat-related mortality, although recent literature (for example, Ebi and Mills 2013) has questioned whether these effects will be fully realized.

A similar analysis for Europe (Kovats and others 2011) estimated annual welfare costs for heat-related mortality at US$32.6 billion by the 2020s (2011–40), US$108.4 billion by the 2050s (2041–70), and US$154.8 billion by the 2080s (2071–100) under a high-emissions scenario. These values were more than an order of magnitude lower when using a different valuation approach. Under a mitigation scenario, broadly equivalent to the 3.7°F (2°C) target, these values fell significantly (after 2040), to US$84.2 billion a year by the 2050s (2041–70). Again, including (autonomous) acclimatization reduced these impacts significantly. As these studies highlight, choices regarding the response functions and valuation metrics, as well as autonomous adaptation, can have a very large impact on estimated overall health costs, leading to order of magnitude differences.

At the global level, OECD (2015) reported heat-related mortality under climate change in high-income countries. Using a value of statistical life approach, they projected that the economic costs of heat-related deaths would increase from around US$100 billion today to US$320 billion in 2030 and US$670 billion in 2050, with the highest costs in Europe and North America.

COSTS ARISING IN OTHER SECTORS

Adaptations in health systems and the health sector more generally are not the only climate change adaptations required to protect human health. Although determining the extent to which other sectors protect health can be challenging, certain sectors (such as electrical and water utilities) are clearly intimately tied to public health. These ties are complex. Some sectors provide health benefits via smooth and continuous operations, while the health sector, through regulation and other activities, minimizes the adverse health impacts imposed by other sectors. For example, electrification and a sustained, reliable power supply supports public health and health care delivery in numerous ways; power outages are associated with significant impacts on health. Yet, power generation, particularly based on fossil fuels, has serious adverse health consequences that regulations have only partially succeeded in limiting in most countries. Similarly, water treatment and distribution are fundamental to health, while certain water management decisions (such as dam construction) can have significant, if localized, adverse health consequences. Thus, in considering the costs associated with adaptation, costs also arise in sectors other than health whose activities are central to protecting health or whose adaptation choices may be maladaptive from a public health perspective.

Adaptation will vary by baseline status in these sectors and by location, with significant efforts needed to decrease exposure in a changing climate. In the water sector, several adaptations will likely be needed to address water scarcity, changes in water quality, and variability in precipitation. In the agriculture sector, adaptations will be needed to maintain an adequate supply of protein, energy, and micronutrients. In the forestry sector, adaptations will be needed to limit the incidence of forest fires and associated direct and pollution-driven health impacts, and to limit the socioeconomic impacts of disruptions to ecosystem services. In some settings, adaptations will be needed to enhance ongoing activities aimed at increasing resilience to worsening climate-sensitive health threats; in others, such as the water sector in the Arctic, fundamentally new approaches and infrastructure will be needed.

Other adaptations may fall outside of existing sectors. In anticipation of sea-level rise, widespread adaptation activities will be needed to protect infrastructure that is critical to public health (such as hospitals, clinics, and dialysis centers) and to prevent saltwater intrusion into groundwater sources (which can lead to hypertension, crop failure, and limitations on drinking water supply). Other adaptations will be needed to protect communities from extreme weather and climate events, such as flooding, severe storms, and extreme heat. Still others will be needed to manage population dislocation and resettlement, which can be a significant challenge to the health sector. In many cases, adaptation activities will entail managing risk, including risk reduction, risk sharing through insurance and other mechanisms, and enhanced recovery mechanisms.

Successful adaptation will require increased communication, coordination, and integration between health and other sectors. The public health sector has extensive experience collaborating with other sectors to achieve its goals and will need to build on this experience to facilitate intersectoral adaptation.

Some of this coordination will focus on highlighting the potential adverse consequences of adaptation activities in other sectors and, indeed, in the health sector itself. The appropriate balance between expenditures on activities that protect one population at one point in time but that potentially lead to some harm for other populations is not always clear. For instance, the widespread use of air conditioning to protect against extreme heat events is maladaptive to the extent that it has the potential not only to worsen the heat island effect locally in cities but also to affect climate change in the long term when power is generated by coal-fired power plants. Promoting health impact assessments of adaptation activities in other sectors is a powerful means for the health sector to highlight potential disbenefits of adaptation activities in other sectors.

ISSUES RELATED TO SPATIAL AND TEMPORAL SCALE

Costs of preparing for, coping with, and recovering from the health risks of climate variability and change will vary across temporal and spatial scales.

Spatial Scale

Poverty is a major driver of risk, which means that low- and lower-middle income countries generally will be at higher risk of adverse climate-sensitive health outcomes. Undernutrition, malaria, and diarrheal disease—among the largest health concerns related to climate change—are leading causes of morbidity and mortality in children younger than age five years (Liu and others 2015; Smith and others 2014). For example, despite recent progress, diarrhea kills 1,584 children every day, accounting for 9 percent of child deaths. Just 15 countries in Africa and Asia account for 71 percent of childhood mortality from diarrhea and pneumonia (IVAC 2014). These countries include low-income (Afghanistan, Chad, the Democratic Republic of Congo, Ethiopia, Niger, and Uganda), lower-middle-income (Bangladesh, India, Indonesia, Kenya, Nigeria, Pakistan, and Sudan), and upper-middle-income (Angola and China) countries.

The pathways leading to higher burdens of diarrheal diseases vary across countries, with lack of improved sanitation facilities a major risk; other drivers include food and water contaminated by humans or animals, improper food handling, and improper hand washing. Nine of these 15 countries are among the 10 countries that are home to two-thirds of the global population with limited access to improved drinking water sources: Bangladesh, China, the Democratic Republic of Congo, Ethiopia, India, Indonesia, Kenya, Nigeria, and Pakistan. Warmer temperatures mean faster replication of some pathogens associated with diarrheal diseases, and higher precipitation events can wash pathogens into water sources (Cann and others 2012; Kolstad and Johansson 2010). Without a significant improvement in access to safe water and improved sanitation, reducing the extent to which climate change could increase the burden of diarrheal disease will become increasingly challenging.

Temporal Scale

Temporally, the rate of greenhouse gas emissions reductions will affect the magnitude and pattern of climate change past mid-century, with rapid and extensive reductions lowering adaptation needs later in this century (Smith and others 2014). Many policies and technologies to reduce greenhouse gas emissions are associated with health co-benefits; for example, reducing emissions from point sources such as coal-fired power plants and from mobile sources such as transportation could provide significant health benefits by reducing exposure to fine particulate matter (Balbus and others 2014).

Projecting how health costs could evolve as the climate continues to change also requires consideration of future development pathways (Ebi 2013). Five socioeconomic development pathways describe the evolution of demographic, political, social, cultural, institutional, economic, and technological trends through this century, along axes describing worlds with increasing socioeconomic and environmental challenges to adaptation and mitigation. Also considered are ecosystems and ecosystem services affected by human activities, such as air and water quality. Each development pathway has very different implications for the burdens of climate-sensitive health outcomes and health system capacities to prepare for and manage risks associated with climate variability and change. Using these pathways facilitates exploration of the possible impacts and costs associated with mitigating greenhouse gas emissions to a certain level and the extent of efforts required to adapt to that level.

One development pathway is a world aiming for sustainable development (Ebi 2013). This pathway includes the following features:

- Population health improves significantly, with increased emphasis on enhancing public health and health care functions.
- Coordinated, worldwide efforts through international institutions and nongovernmental organizations increase access to safe water, improved sanitation, medical care, education, and other factors in underserved populations.
- Life expectancies increase in LICs with decreasing burdens of key causes of childhood mortality (undernutrition, diarrheal diseases, and malaria).
- Funding increases for public health and health care organizations, and institutions enhance their capacities to prepare for, respond to, cope with, and recover from climate-related health risks.

Improvements in this development pathway will reduce the burden of climate-sensitive health outcomes even before considering any impacts of climate change. Meeting the challenges of climate change will be much easier in this pathway.

Another development pathway describes a world separated into regional blocks with little coordination between them (Ebi 2013). This world is failing to achieve global development goals, with regional blocks characterized by extreme poverty and pockets of moderate wealth and the bulk of countries struggling to maintain living standards for their rapidly growing populations. This pathway includes the following features:

- Mortality rates are high, with mortality from climate-related health outcomes (particularly undernutrition, diarrheal diseases, and malaria) increasing and life expectancy possibly falling in LMICs because of increased childhood mortality, although some subregions enjoy better health. All countries experience a double burden of climate-related infectious and chronic health outcomes.
- Large regions of the world are food and water insecure.
- Most urban growth in LMICs occurs in unplanned settlements and mostly fails to improve access to safe water and improved sanitation.
- Wealthier regions do not invest in research and development to help less well-off regions manage health risks. Further, governance and institutions are weak, international cooperation is limited, investments in public health and health care infrastructure are low, and the number of public health and health care personnel is too small to address health needs.

In this development pathway, the challenges to managing the health risks of climate variability and change increase over time, with rising and increasingly unaffordable costs in more vulnerable countries and regions.

The other three pathways explore a world that continues along its current trajectory, with health improving but at a slower rate than in the pathway aiming for sustainable development; a highly unequal world where adaptation is difficult, but technologies are developed and deployed to reduce greenhouse gas emissions; and a world with low challenges to adaptation, but where mitigation of greenhouse gas emissions is difficult for a range of technological and other reasons. Each has different implications for the health costs of climate variability and change.

CHALLENGES RELATED TO ESTIMATING COSTS AND BENEFITS

Estimating the costs and benefits of climate change and adaptation to the associated risks presents many challenges. These include the unique nature of the threat of climate change to the incidence, geographic distribution, and seasonality of a wide range of health outcomes (with risks and uncertainty increasing over coming decades) and the temporal displacement between the causes of climate change (human activities leading to the release of greenhouse gases and natural climate variability) and the projected timing of health impacts. Further, the costs of proactive mitigation for managing health risks of climate change will be incurred years to decades before benefits in reducing climate change are evident. Precisely timing investments will not always be possible given inherent uncertainties about the magnitude, rate, and timing of climate change.

The hazards created by a changing climate will interact with the sensitivity of populations and regions and with their capacity to prepare for and cope with hazards as they arise. This creates complex relationships between climate change and health outcomes that will vary over temporal and spatial scales. Because LMICs have the highest sensitivity to climate-sensitive health outcomes and the least ability to adapt, they will be at highest risk (Smith and others 2014). All countries, however, will experience hazards, and all countries will need to adapt and mitigate. The differences across countries mean that the costs of adaptation will vary over time and space.

Given the limited capacity of health systems to manage current climate variability and change, the costs of adaptation are likely to be high in the longer-term, as health systems incorporate climate change into policies and programs. Once adaptive risk management processes are established and climate change mainstreamed into policies and programs, costs by mid-century will depend on the health impacts associated with the magnitude and pattern of climate change, which, in turn, will depend on the extent of mitigation over coming decades. Adding to these complexities are the costs associated with adaptation in other sectors.

It is not surprising that few costs of adaptation options have been estimated. Information on some adaptation options can be estimated from other chapters in this volume, such as the costs of surveillance and treatment for malaria or other vector-borne diseases. However, there are challenges in estimating what portion of the costs of extending current surveillance and health care systems to prepare for changes in the geographic range of malaria could be due to climate change versus other possible drivers of change, such as land use changes. Similar challenges present in estimating the benefits of interventions.

Other issues that arise when considering the costs of adaptation include how to limit double counting. For example, climate change is increasing the number of cases of undernutrition, malaria, and diarrheal disease in many regions (Smith and others 2014). However, these health outcomes are not independent; undernutrition increases a child's susceptibility to malaria and diarrheal disease. It is not clear how to count the costs of preventing and treating these health outcomes accurately.

Many researchers and modelers are estimating the costs of various mitigation options. Although health systems are a source of greenhouse gas emissions, the sector should reduce these emissions as quickly as possible. Lower emissions benefit everyone later in the century; unlike air pollutants, greenhouse gases do not remain local.

Interest in calculating the loss and damage due to climate change has been growing particularly in countries that are vulnerable to its adverse effects. Loss and damage refers to the impacts of climate-related stressors on human and natural systems that occur despite mitigation and adaptation efforts. Climate change that already is locked in because of the inertia in the climate system could adversely affect development in particularly vulnerable locations and populations. For example, saltwater intrusion from sea-level rise could mean that farmers can no longer grow crops or feed animals. The issue of loss and damage arose because most of the focus of the more than 20 years of negotiations under the United Nations Framework Convention on Climate Change has been on reducing greenhouse gas emissions, with less attention paid to ensuring that countries that are particularly vulnerable to climate change but who historically were responsible for only a tiny proportion of atmospheric greenhouse gases and who are experiencing adverse impacts have the financial resources to adapt. This issue has been contentious because some observers consider it to be synonymous with liability and compensation. This is an active area of research and negotiation.

CONCLUSIONS

Climate variability and change present significant challenges for the health and well-being of individuals, communities, and nations. Preventing, preparing for, and managing climate-related risks to human and natural systems will be a recurring theme throughout the 21st century. Hallegatte and others (2016, xi) explored the intersection of climate change and poverty and offered the following conclusions:

> Without action, climate change would likely spark higher agricultural prices and could threaten food security in poorer regions such as Sub-Saharan Africa and South Asia. And in most countries where we have data, poor urban households are more exposed to floods than the average urban population. Climate change also will magnify many threats to health, as poor people are more susceptible to climate-related diseases such as malaria and diarrhea. . . . We need good, climate-informed development to reduce the impacts of climate change on the poor. This means, in part, providing poor people with social safety nets and universal health care. These efforts will need to be coupled with targeted climate resilience measures, such as the introduction of heat-resistant crops and disaster preparedness systems.

The report further concludes that, without climate-resilient development, climate change could force more than 100 million people into extreme poverty by 2030 (Hallegatte and others 2016). Rapid, inclusive development could avoid most of these impacts, and immediate reductions in emissions could avoid many of the projected risks later in the century.

Climate change underscores the urgency of strengthening basic public health infrastructure, particularly in poor and underserved areas. To be effective, health systems need to incorporate climate variability and change explicitly into all climate-sensitive policies and programs, including disaster risk management, air pollution control, infectious disease monitoring and surveillance, and water and food safety and security. Taking advantage of the growing body of knowledge about environmental drivers of climate-sensitive health outcomes can provide significant public health benefits. Continuing to take a business-as-usual approach to climate change will put lives and livelihoods at risk and result in higher health burdens that could have been prevented.

NOTES

World Bank Income Classifications as of July 2014 are as follows, based on estimates of gross national income (GNI) per capita for 2013:

- Low-income countries (LICs) = US$1,045 or less
- Middle-income countries (MICs) are subdivided:
  a) lower-middle-income = US$1,046 to US$4,125
  b) upper-middle-income (UMICs) = US$4,126 to US$12,745
- High-income countries (HICs) = US$12,746 or more.

1. For information on the CIRCLE study, see http://www.circle-era.eu/np4/home.html.
2. A lakh is 100,000 rupees.
3. Future individuals will respond to higher temperatures through physiological and behavioral adjustments. Most studies ignore this effect and use impact functions derived from the current climate and apply these functions to the future. This overestimates impacts, because it assumes that no autonomous adaptation takes place (acclimatization). In reality, populations will adjust autonomously (that is, without planned adaptation) to climate change, and indeed, mortality rates today are fairly similar in countries with very different climates. Studies that build in acclimatization show much lower future health impacts. However, little information or evidence exists on which to base assumptions about the rate of future acclimatization. Estimating the rate of change of adaptation to climate change and the rate above which impacts might start to increase more sharply is difficult.

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