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CHAPTER 24

Climate Change and Human Health

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This chapter, *Climate Change and Human Health*, is an extension of the digital textbook. It was co-written in 2023 by Gina Solomon, MD, MPH, Chief of Occupational, Environmental and Climate Medicine, UC San Francisco; Arianne Teherani, Professor of Medicine and Education Scientist, UC San Francisco School of Medicine; Tarik Benmarhnia, Associate Professor in Environmental Epidemiology, UC San Diego, Scripps Institution of Oceanography; and Sheri Weiser, MD, MPH, MA, Professor of Medicine and Internist, UC San Francisco's Division of HIV, Infectious Diseases and Global Medicine at Zuckerberg San Francisco General Hospital.

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Learning Objectives

1. Trace connections between environmental damage, climate change, and human health, including changes in extreme weather, wildfires, population displacement, reduced food security, and mental health impacts.
2. Describe the human health impacts of extreme heat, wildfire smoke, and water contamination.
3. Link climate change to disruptions of the food system, malnutrition, and disease.
4. Articulate ways that social injustice and racism are exacerbated by climate change and may be mitigated by climate action, including geographic locations of lower- or higher-income communities, pollution disparities, historic redlining, and factors that reduce or enhance community resilience.
5. Identify ways to reduce the climate impact and improve the resilience of communities and health systems, including potential synergies between policies and practices that promote environmental sustainability and those that promote health.

Overview

Health leaders worldwide have deemed climate change the greatest public health threat of the twenty-first century. Without ambitious and immediate action, climate change will profoundly shape health at every stage of life, from birth through old age. The climate crisis is already causing widespread harm to public health, and the impacts are projected to become much more severe over the coming decades. Throughout the world, we are facing increasingly frequent and extreme climate-related events including heat waves, wildfires, major storms and floods, rising sea levels, and rapidly warming oceans. Climate-related events are also causing indirect health effects through population displacement, loss of livelihoods, conflict over resources such as freshwater, and food insecurity. Climate change will affect everyone, though it is closely entwined with global inequities and societal disparities. For this reason, the global burden of harm will fall disproportionately on the most vulnerable and marginalized among us—low-income individuals, people of color, people with disabilities, the very young, and the elderly. Globally, the greatest impacts are likely to fall on some of the poorest regions of the world, including the global South, island nations, and Indigenous communities in the Arctic. Building resilience to climate change requires strengthening infrastructure, public health systems, and social support systems. Rapid action to reduce greenhouse gases has the potential to improve quality of life for everyone and to mitigate the worst impacts of climate change.

X.1 General Relationships between Climate Change and Health

The impacts of climate change, including illnesses and deaths, will vary widely across the globe based on geographic, economic, and individual factors. To save lives and improve well-being, it is critical to understand the wide-ranging impacts of climate change on physical and mental health and well-being, and to learn to predict how these linkages will play out globally and locally.

The health effects of climate change are numerous and complex, and we are still learning how they will unfold over time. This chapter will cover many of the effects listed in Table 24.1.1, along with the vulnerabilities of different populations to these health effects.

How did we get here? We are living at a time when the Earth's natural systems are being primarily shaped by human activity, and the scale of our ecological footprint is enormous. According to the Planetary Health Alliance, since 1950 the global population has grown by nearly 200%, and our consumption of fossil fuels has increased by 550%. We use nearly half of all accessible freshwater and about half of the planet's livable surface to grow and raise our food. We have dammed 60% of the world's rivers and cleared nearly half of all temperate and tropical forests. Finally, marine fish capture has increased by 350% since 1950.

Human activities are driving fundamental ecological changes including climate change, air pollution, biodiversity loss, land degradation, and resource scarcity. We humans have degraded air, water, and land systems in unprecedented ways. For example, atmospheric carbon dioxide levels have increased 24% since 1950. There is a high likelihood that global temperatures will reach more than 1.5°C above preindustrial levels in the next 5 years. Oceans are now 30% more acidic than during the Industrial Revolution. Biodiversity loss is proceeding rapidly, with species extinction rates 1,000 times higher than baseline rates.

TABLE 24.1.1 Summary of health effects from climate change

<i>Climate-Related Stressor</i>	<i>Climate-Related Causes</i>	<i>Secondary Effects</i>	<i>Health Effects</i>
Heat	Overall warming	Extreme heat days Ozone smog pollution Reduced work capacity	Heat-related illness Respiratory illness Cardiovascular illness Cerebrovascular disease Kidney failure Increased violence Increased accidents Economic stress
Drought	Shifts in rainfall patterns	Reduced agricultural yields Food scarcity Loss of livelihoods Dust storms	Malnutrition Population displacement Valley fever Economic stress Conflict and violence
Wildfire	Shifts in rainfall patterns	Smoke (particulate matter) Property damage Drinking water contamination	Injury and death Respiratory illness Cardiovascular illness Population displacement Mental health effects
Increased weed pollen	Higher CO ₂ levels Overall warming	More weeds and invasive plant species	Worsened allergies and asthma
Sea level rise	Melting of Antarctic and Greenland ice	Coastal flooding Property damage	Population displacement Drownings Chemical contamination Mental health effects
Extreme precipitation events	Increased atmospheric energy Warming of oceans	Coastal and river flooding Property damage Crop loss Drinking water contamination Mold growth	Population displacement Drownings Diarrheal disease Respiratory and skin disease Chemical contamination Mental health effects
Changes in vector ecology and biology	Overall warming Shifts in rainfall patterns	Mosquito- and tick-borne illnesses shifting north and to higher elevations	Malaria Dengue fever Zika virus Chikungunya Lyme disease West Nile virus Emerging illnesses
Algal blooms	Overall warming Ocean warming Runoff from heavy rains	Marine mammal and bird die-offs Fishery contamination and loss	Diarrheal disease Liver damage Skin rashes Neurological disease Economic stress Malnutrition
Food scarcity	Shifts in rainfall patterns Overall warming Ocean acidification	Loss of crops Loss of livestock Fisheries collapse Shellfish die-offs	Starvation Conflict and violence Population displacement Sexually transmitted diseases Chronic diseases

24.2 Direct Health Threats from Fossil Fuels

Fossil fuels, including coal, oil, and natural gas, continue to be the main sources of energy in our global economy. These energy sources fuel power plants, providing us with electricity; they fuel our automobiles and trucks; and they fuel our industrial sector, producing plastics, chemicals, cement, and consumer products. Fossil fuels also are used in agriculture to make fertilizer, pesticides, and all the equipment used to grow, harvest, process, and transport food.

Fossil fuels have direct health effects at every stage of their production and use. Coal mining, oil drilling, and hydraulic fracturing (“fracking”) for oil and gas cause emissions of toxic chemicals to air and water as well as occasional dramatic disasters, ranging from worker fatalities in mine collapses, explosions, or fires, to massive spills such as the 2010

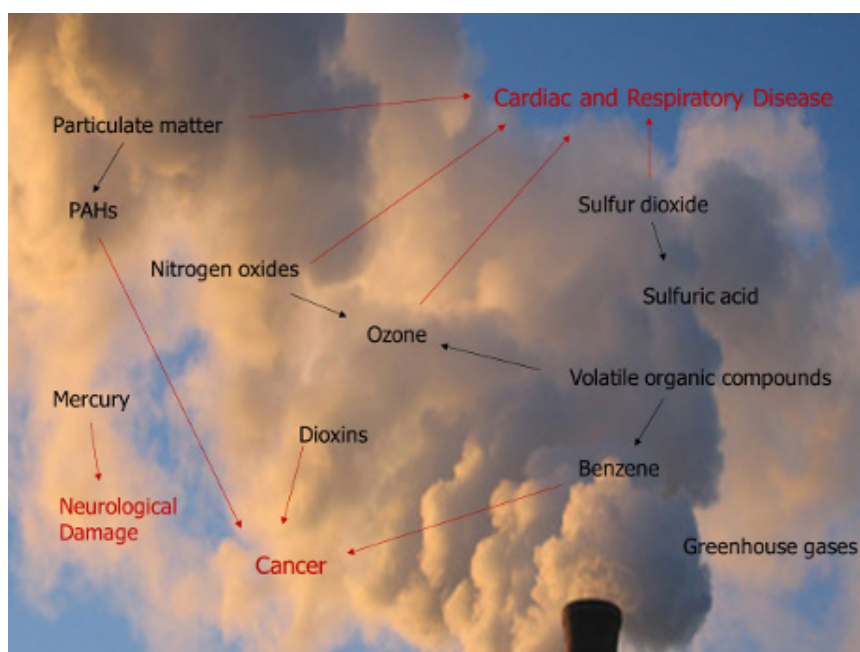


FIGURE 24.2.1 Complex mix of toxic air pollution from a power plant. Image by Gina Solomon.

Deepwater Horizon British Petroleum oil spill in the Gulf of Mexico, which caused significant ecological damage. Fuel transportation involves pipeline leaks, rail disasters, including explosions, and spills from ocean tankers. Processing of fossil fuels at refineries impacts local communities, on a daily basis, with air pollution that includes known human carcinogens such as benzene and formaldehyde, asthma-causing chemicals like nitrogen oxides, and reproductive toxicants (Figure 24.2.1). Worse still, the highly flammable mixtures under high pressures and temperatures at refineries can result in explosions and fires, sometimes killing workers or sending hundreds or even thousands of local residents to emergency departments.

People living in poverty and people of color are more impacted by the fossil fuel industry, from the point of production near refineries, to the point of emissions near power plants, major roadways, ports, rail yards, and airports. An analysis of the demographic patterns of exposure to particulate matter from coal-burning power plants in the US found that power plants in the north central states inequitably expose Black populations, and facilities in the western US disproportionately impact Native American communities.

24.3 The Climate Gap

Climate change converges with disadvantage to amplify existing disparities, leading those who contribute the least to greenhouse gas emissions to be the ones who suffer first and worst from its harmful health effects. This is referred to as the climate gap and is most pronounced for vulnerable and marginalized groups, including migrants, people of color, the elderly, and children. These populations have greater exposure to climate impacts due to material deprivation and injustices like racism and colonialism. For example, they are more likely to live in low-wealth areas that offer little protection from climate hazards like flooding, or in urban “heat islands” especially prone to extreme heat. While marginalized populations are the ones that must bear the brunt of negative impacts, they contribute much less to the problem, with more affluent populations having much higher carbon footprints. Countries with the highest per capita carbon dioxide (CO₂) emissions (that is, the greatest consumers), including the United States, Canada, Australia, and Russia, also have the lowest mortality linked to climate change. Meanwhile, South American and African countries, which have some of the lowest per capita emissions, suffer some of the highest climate-related mortality rates. Vulnerabilities are compounded by difficulties preparing for, recovering from, and adapting to these impacts. The most climate-vulnerable regions and populations throughout the world already face high levels of food insecurity and poverty, large disease burdens, weak public health infrastructure, and political conflict.

The climate gap has immediate and far-reaching implications for health, livelihoods, and well-being. For example, research has identified a link between residing in so-called sacrifice zones and living with environmental pollutants that cause climate change and increase risk for asthma, diabetes, and some forms of cancer. Sacrifice zones are communities considered less important than economic growth and that therefore become sites of direct and indirect cumulative environmental

impacts. Climate change undermines human rights, has asymmetrical impacts on the poor and vulnerable, and requires disproportionate action from developing countries. The impacts of climate change are intergenerational. CO₂ and other greenhouse gasses persist in the atmosphere for centuries, causing cumulative warming and demonstrating that human actions today have repercussions into the future. This is a fundamental aspect of sustainable development: that resources be used and our environment be managed in a way that meets the needs of the present without compromising the needs of future generations.

The climate gap manifests in all climate events. In the context of extreme heat, for example, African Americans in Los Angeles are twice as likely to die from heat waves as are other residents. This is because families living below the poverty line are less likely to have access to air conditioning or cars that allow them to escape from the heat. In addition, communities of color and the poor will breathe dirtier air: five of the smoggiest cities in California also have the highest densities of people of color and low-income residents. Studies examining the relationship between occupation and climate events have found that the risk of heat-related death is increased by 35 times for agricultural workers and 13 times for construction workers. The risk of occupational death is 3.2 times higher for Latinx workers and 1.5 times higher for African American workers, highlighting the disparities of risk for minority groups. In a study of over 100 American cities, formerly redlined neighborhoods were shown to be 5°F hotter on average during the summer than nonredlined neighborhoods. These neighborhoods have less access to air conditioning, fewer trees, and more paved surfaces that trap and radiate heat, creating what is known as the heat island effect.

Substantial disparities also exist in wildfire impacts. Communities of color and lower-income residents are disproportionately impacted because they tend to live in homes that have higher infiltration of outdoor smoke pollutants. A Denver-based study demonstrated that wildfires lead to levels of indoor air pollutants that are nearly four times higher in homes with residents of low socioeconomic status. Given that people of color already experience disproportionately more air pollution as a result of environmental racism, these wildfire effects have the potential to exacerbate already existing health disparities.

Extreme weather events yield disparities in injuries, fatality rates, and long-term economic impacts associated with displacement and livelihood disruption. For example, during Hurricane Katrina, New Orleans mortality rates were 1.7 to 4 times higher for African American residents than for white residents. Floods during Hurricane Sandy in New York City in 2012 had greater impacts on those with higher poverty rates, including African American, Latinx, and elderly residents. These problems are furthered by the drastic environmental damage that is done during these extreme weather events; for instance, Tropical Storm Harvey in Texas and Louisiana resulted in an estimated 100 toxic spills into water, land, and air, polluting local neighborhoods. Similarly, Hurricane Maria in Puerto Rico led to the largest blackout in health care in United States history and left many residents without access to clean drinking water. It is important to weigh climate-related policy decisions and solutions in a way that addresses not only climate issues, but also health inequities. Actions toward climate justice and health should be guided by the following criteria:

- Action should acknowledge and repair structural discrimination. This involves assessing successes in research, policy, and action that account for the most affected people and areas. Support for initiatives that foster healing and repair should be bolstered.
- Justice and equity needs to be the starting point, interwoven through all planning and decisions.
- The voices and solutions in research, policymaking, advocacy, and action should be determined in a way that is centered around the most affected communities.
- Adoption of a solidarity-driven approach brings together intersecting issues, such as migrant and racial justice, to help address multiple, often compounding issues.

24.4 Health Effects of Extreme Heat

All heat-related deaths and hospitalizations are preventable. Yet, in the US, more than 12,000 deaths each year are attributable to direct and indirect impacts of extreme heat. Extreme heat also drastically increases the number of hospital admissions and emergency room visits. A 2019 study by Vaidyanathan et al. estimated that about 7,000 hospital admissions occur every summer (June–September) in California alone due to heat exposure. These heat-related hospital admissions are most commonly caused by cardiovascular diseases, respiratory diseases, diabetes, fluid and electrolytes disorders, renal failure, and poor mental health. In parallel, an emerging body of epidemiological evidence shows that extreme heat is also associated with other health issues, including birth outcomes, pregnancy complications, and occupational illnesses or injuries.

Because of these factors, extreme heat is considered the leading cause of climate-related mortality and morbidity in the US, causing many more deaths than hurricanes, wildfires, or floods. However, the **Centers for Disease Control and Prevention (CDC)** reports that only about 750 people die directly from heat-related illnesses each year. To make sense of the discrepancy between this reported number and the reality of extreme heat's wide-reaching impact, it is important to understand the multiple, often insidious mechanisms through which exposure to extreme heat leads to health impacts. Extreme heat has been described as a silent and invisible killer.

The direct impacts of extreme heat

Cramps in leg or abdominal muscles (“heat cramps”) can be an early sign of heat illness, but more severe heat-related illness can occur without the occurrence of heat cramps. Heat exhaustion is associated with heavy sweating, pale skin, decreased urination, dark urine, fatigue, headache,

irritability, and nausea. Some protective behaviors can reduce these symptoms, including staying hydrated, reducing/stopping outdoor and physical activity, lying down, and moving to a cool (especially air-conditioned) location. If people develop heat exhaustion and do not quickly achieve cooling and hydration, the symptoms can progress to heat stroke, which can be fatal. Symptoms of heat stroke include confusion, agitation, rapid pulse, red and dry skin, seizures, and unconsciousness. Heat stroke is a medical emergency and requires immediate cooling, intravenous hydration, and aggressive lifesaving care. Although the elderly and young children are particularly vulnerable, the direct impacts of heat can affect everyone, including young adults (especially when engaging in strenuous physical activity). However, these direct impacts only constitute a relatively small portion of the total burden of extreme heat.

The indirect impacts of extreme heat

Extreme heat, through a variety of physiological mechanisms, can exacerbate existing chronic conditions such as cardiovascular diseases, metabolic disorders, respiratory diseases, kidney or renal diseases, and mental health disorders. This explains not only the discrepancy between direct and indirect estimates of heat-related deaths, but also why the burden is so unequally distributed, making extreme heat an issue of environmental justice. To understand the indirect impacts, it is important to describe the physiological mechanisms associated with extreme heat.

When we are exposed to high temperatures, two main responses occur in the body: (1) blood vessels dilate (this is called vasodilation) to assist in redirecting blood from the core to the periphery of the body and the skin, which allows for more efficient cooling; and (2) we sweat, which helps to dissipate heat to the environment through evaporative cooling. These responses have several consequences, which can be detrimental to health. First, sweating can lead to dehydration and electrolyte imbalances. Second, vasodilation reduces the availability of blood (ischemia) and oxygen (hypoxia) to the internal organs. Finally, vasodilation also causes the heart rate to increase significantly, while also causing a drop in blood pressure. If no preventative measures are taken, these coping mechanisms can lead to several significant impacts to health. Increased heart rate may lead to cardiovascular complications

(including heart attacks and cardiac arrest), especially among individuals with preexisting conditions. Dehydration may lead to kidney failure and potassium deficiency. Dehydration may also lead to increased intestinal permeability, which is associated with many complications, including disseminated intravascular coagulation (blood clotting) and inflammation or sepsis caused by the infiltration of toxins into the bloodstream surrounding various organs, including the brain, increasing the risk of neurological damage. Increasing internal temperatures may also directly kill cells in the body and cause the death of muscle fibers and the release of their contents into the bloodstream. It has been shown that seven vital organs can be critically impacted by exposure to extreme heat through these indirect mechanisms: the brain, heart, intestines, kidneys, liver, lungs, and pancreas. These multiple, complex physiological reactions that occur in the presence of extreme heat explain why the health impacts of extreme heat are so diverse and substantial.

In addition, it is important to highlight how heat does not affect all individuals and communities in the same way. There is substantial epidemiological evidence demonstrating that multiple factors exacerbate the risk associated with extreme heat. These include (but are not limited to) social and demographic factors such as age, race/ethnicity, housing conditions, and access to air conditioning; preexisting conditions including mental health, drugs, and medications; social isolation; compounded environmental risks such as ambient air pollution episodes, including wildfire smoke; and urban characteristics such as living in micro-urban heat islands, a factor driven by historical and contemporary structural racism.

The effect of climate change on heat and health risk

In the context of climate change, the intensity, duration, frequency, and seasonality of extreme heat events are expected to increase in many locations globally, including in the US. In addition, climate change is leading to a change in extreme heat events, with humid heat events becoming more common. This is the case in several areas in the US, including coastal California, where large populations live and where heat events were historically typically dry. Increased humidity is particularly problematic for human health for a few reasons. As described above,

one of the primary ways the human body cools itself is through vasodilation, dissipating heat from the body to the surrounding environment. Heat transfer to outside of the body can occur efficiently via dry transfer processes (convection and radiation), but the effectiveness of such processes decreases as air temperature increases. In air temperatures above about 95°F, the body can only dissipate heat into the air through evaporative cooling, that is, from sweating. However, high levels of absolute humidity disrupt this process. As ambient humidity increases, the proportion of sweat that evaporates decreases, with the remainder either sitting on the skin or dripping off the body without contributing to efficient cooling. In addition, these humid heat events are more prolonged and expressed more strongly during the night, as the humidity helps the atmosphere hold onto heat. Such humid nighttime heat events are associated with high-heat health risk, as exposed populations do not have a chance to cool down during the night as they normally would during drier heat events.

Human activities, which are unambiguously responsible for climate change, have already led to an increasing number of heat-related deaths. A recent global study estimated that about 37% of heat-related deaths in the last three decades can be attributed to anthropogenic climate change. Several studies have also projected large increases in heat-related deaths in the coming decades according to various climate models and mitigation scenarios, indicating the urgency of reducing greenhouse gas emissions. In conjunction with mitigation strategies, given the already substantial burden associated with heat, the timely implementation of adaptation strategies is crucial.

The importance of adaptation strategies to build heat-resilient communities

Individual behavior change and medical interventions are crucial but are not sufficient for mitigating heat impacts. It is also vital to maintain and expand existing evidence-based heat adaptation strategies to build heat-resilient communities, and to experiment with new strategies. In general, we can distinguish two main types of adaptation strategies for extreme heat: (1) strategies focusing on housing, infrastructure (including the electrical grid), and urban planning; and (2) seasonal and

emergency responses through heat action plans, education, and early warning systems.

Housing characteristics such as building and roof materials, orientation of buildings (relative to the sun), rooms with high ceilings, and large openings to improve ventilation have been shown to be effective strategies to reduce indoor temperature exposure during heat events. One of the most common approaches to deal with high temperatures is using air conditioning, and several studies have shown the benefits of air conditioning to reduce the risk associated with extreme heat. However, it is crucial to ensure that the electrical grid is well designed to support the significant surge in electricity demand during heat events brought about by increased usage of air conditioning, as the compounded impacts of a heat event and a power outage can have devastating effects. In addition, it is important to consider the energy justice implications of air conditioning use and ensure that electric bills can be affordable for the communities that are most vulnerable. In parallel, the urban structure and built environment are strong predictors of spatial variation in micro-urban heat islands (which occur due to a lack of green space and/or the abundance of impervious surfaces) that strongly modulate the heat-related health risk. Continuing education efforts are needed in multiple sectors, including among clinicians and health professionals as well as urban planners and in academic settings, to better understand the complex mechanisms through which extreme heat impacts human health.

Around the US, local authorities have started to implement heat action plans and heat early warning systems. While there are many differences between local plans regarding their management, the type of actions in place, and targeted populations, there are commonalities between most local plans. Heat action plans typically include a variety of collective measures that can either be active during the whole warm season or become activated in conjunction with early warning systems, which, in the US, are typically codeveloped with the National Weather Service. Some examples of heat action plan measures are opening community-based cooling centers, adjusting working hours and activities at workplaces, and having community health workers make daily calls and/or visits to vulnerable individuals. Cooling centers are typically set up at

locations such as libraries, community centers, and houses of worship and provide places where people can go during the day for respite from the heat. Use of cooling centers by vulnerable populations can be limited due to lack of transportation, concern about exposure to communicable illnesses, or the perception that these locations are only for unhoused people. There is still a lot of work to be done to evaluate the effectiveness of heat action plans for maintaining health and well-being, as well as whether the benefits are equitably distributed. It is also critical that planning of heat resilience strategies and action plans is integrated across multiple actors and sectors, with support from diverse stakeholders, including representatives from local universities, different levels of government, the private sector, nongovernmental organizations, and neighboring jurisdictions.

24.5 Health Effects of Air Pollution

Ozone smog

As ambient temperatures rise, ground-level ozone levels also rise. Ozone in the upper atmosphere is beneficial because it protects us from the damaging ultraviolet rays of the sun. However, ground-level ozone is extremely toxic to our lungs. Ozone in the lower atmosphere is also known as smog because it creates a gray-brown haze that looks like a combination of smoke and fog (Figure 24.5.1). Ozone is created from other pollutants such as **volatile organic compounds (VOCs)** and **nitrogen oxides (NOx)** that are emitted from industrial sources, power plants, cars, and trucks. These chemicals are transformed by sunlight in a chemical reaction that breaks down oxygen in the air and results in ozone formation. Heat dramatically speeds up this chemical reaction.

The health effects of inhaled ozone include cough, difficulty breathing, chest pain, decreased lung function, and asthmatic symptoms. These symptoms range from mild and uncomfortable, to severe illnesses that send people to the emergency department. Over time, ozone can also cause significant long-term damage to airways and can suppress the normal function of white blood cells that protect the lungs from infections.

Airborne allergens

Warmer weather conditions with higher concentrations of CO₂ in the air also foster the growth of allergenic weeds such as ragweed. Studies in greenhouses with carefully controlled atmospheric compositions have shown that air slightly enriched in CO₂, at concentrations we expect to see due to climate change within the coming decades, causes ragweed not only to grow more lushly, but to produce about three times more pollen. That extra airborne pollen will seriously worsen the suffering of individuals with pollen allergies. These findings suggest greater health



FIGURE 24.5.1 Smog in Los Angeles. From US EPA 2020. Image source: US EPA (<https://www.epa.gov/sciencematters/how-science-protecting-air-we-breathe>)

challenges associated with nuisance symptoms such as hay fever, as well as more serious conditions such as asthma.

Particulate matter

Particulate matter is produced in massive quantities from wildfire smoke and from burning petroleum and coal—the same sources that produce most of the CO₂ in the atmosphere. Some examples of petroleum-related sources of air pollution include diesel trucks, buses, construction and farm equipment, refineries, industrial facilities, and power plants. Particulate matter ranges in size from large visible particles of soot to tiny particles that are invisible to the naked eye. Larger sooty particles irritate the eyes, nose, and throat and can deposit in the sinuses, causing inflammation. These black particles also contribute to climate change by absorbing heat in the air and on places where they land; for example, when sooty particles land on glaciers or snowpack, they absorb heat and accelerate melting of the snow and ice. Sooty particles also damage the linings of our airways and our immune cells. The smallest particles, **particulate matter 2.5 microns or less in diameter (PM_{2.5})**, are not visible

to the eye but are more dangerous. These particles evade the defenses in our noses and upper airways, instead landing deep in the most vulnerable areas of the lungs, causing inflammation that results in impaired lung function, cough, phlegm, bronchitis, asthma attacks, heart attacks, heart failure, strokes, and premature death. These effects especially occur in people with underlying health conditions, such as heart disease, lung disease, and asthma. Even healthy people can be sickened when particulate matter concentrations are high, leading to decreased exercise tolerance, cough, sore throat, and eye irritation. In many communities, the air is polluted with both particulate matter and with ozone, along with other contaminants. These pollutants interact in complex ways to damage the health and shorten the life-spans of people breathing the air.

Wildfires

A warming climate places enormous stress on many species of trees, as weather conditions become too warm and either too wet or too dry compared with the climate the forests are adapted to. Stressed trees are more susceptible to fungal infestations and pests such as pine beetles. The combined stresses of heat, drought, and infestations kill large numbers of trees. Dead trees produce less shade, allowing so-called ladder fuels such as grasses and shrubs to grow densely between the trees. Rainy conditions that may follow a drought come too late to save the trees, but rain results in fast growth (and subsequent dieback) of grasses and shrubs that act as kindling to start massive wildfires. In 2022, the US Forest Service estimated that 36 million trees died in California forests, mostly due to drought and beetle infestation. Drought conditions, coupled with warmer temperatures, in numerous countries around the world are similarly fueling fires in places ranging from Australia and Indonesia to Canada.

Wildfires are a natural part of forest cycles, but the fires that occur with climate change are intense firestorms that cover vast areas and burn so hot that they destroy everything in their path, damaging ecosystems and, increasingly, whole communities. In recent fires such as the 2018 Paradise fire, 2023 Maui fires, and 2025 Los Angeles fires, deaths have occurred among both emergency responders and local residents who were unable to escape in time.

How can air pollution affect our health?

Particulate matter air pollution has been shown (through a branch of scientific study called epidemiology) to increase our risk of experiencing the following health problems:

Chronic obstructive pulmonary disease, or COPD, meaning a reduction in the amount of air going in and out of the lungs

Lower respiratory infections, including pneumonia, some types of flu, and bronchitis

Problems during pregnancy, including pre-term delivery, low birth weight, and other issues

Stroke, a reduction in blood flow to the brain, which can be fatal if not treated right away

Heart disease, meaning a reduction in blood flow to the heart, which increases the risk of heart attack and stroke

Heart attack, a very dangerous condition where part or all of the heart muscle is deprived of oxygen

Lung cancer, one of the most common and deadly forms of cancer

FIGURE 24.5.2 Health effects of particulate matter. From Buis 2020. Image source: Buis, 2023

Wildfire smoke can be different from the smoke you might encounter from a fireplace or wood fire. Wildfires burn a mixture of wood and other vegetation, but also buildings, vehicles, plastics, furniture, and even toxic materials such as pesticides. The smoke may therefore be more hazardous, especially in areas close to the fire (Figure 24.5.2). People with asthma, elders, and children are especially vulnerable to wildfire smoke. Children have narrower airways than adults, so their airways close off more easily during asthma attacks. During pregnancy, wildfire smoke exposure is also harmful, resulting in higher risk of premature birth and low-birthweight babies. People who spend a lot of time outdoors are exposed to more air pollution and wildfire smoke, so farmworkers, construction workers, and others who work outdoors are also more likely to suffer adverse effects.

24.6 Climate Change, Water, and Health

Currently, one in three people globally lack access to safe drinking water, and over half of the world's population doesn't have access to safe sanitation. Climate change is exacerbating this problem. By 2025, it is predicted that half of the world's population will be living in water-stressed areas, meaning regions with rapidly increasing amounts of water as well as those with rapidly decreasing amounts of water, both of which cause water insecurity and pose major threats to human health. For example, drought can lead to malnutrition and dehydration, both of which can impair immune response and increase one's susceptibility to infections. Water insecurity is associated with having an AIDS-defining illness, low health-related quality of life, and depression. Flooding can increase the spread of waterborne illness like cholera and cause direct injury and death.

Health effects of flooding

Climate models show that extreme weather fluctuations are increasing as the Earth warms, leading to extremes of drought and heavy precipitation. Sea level rise will result in inundation of low-lying coastal areas, especially during high tides and storm surges. Hurricanes and typhoons are projected to become more powerful due to warming oceans. The combination of major storms and sea level rise will predictably result in coastal and river flooding.

At least 15% of all deaths related to natural disasters are due to floods. People who are disabled or elderly are often less able to evacuate before a major storm. In some floods, nursing homes and hospitals are inundated, leaving elderly and sick people in miserable conditions and without adequate care. In the flooding after Hurricanes Katrina (2005), Sandy (2012), Maria (2017), and Helene (2024), emergency generators at medical facilities failed, and oxygen supplies, respirators, heart monitors, and other

advanced medical systems stopped functioning, as did air conditioners and lighting. Conditions in these facilities were horrific, and many people suffered and died in the days and weeks following these storms.

Flood waters are often contaminated with sewage and chemicals, resulting in gastrointestinal illnesses, skin rashes, or other symptoms after direct contact with the water or with sediment left behind when the water recedes. Mold proliferates in flooded buildings, growing on wet carpets, walls, and furniture (Figure 24.6.1). Mold can cause allergic reactions, sinusitis, asthma, and other health problems. For these reasons, returning home even briefly to try to salvage personal possessions can be dangerous and requires a respirator, protective coveralls, and impermeable gloves.

Floods also cause massive destruction of residential and commercial structures, making neighborhoods uninhabitable. There can be damage to oil and gas pipelines, water and sewage lines, roads, sewage treatment plants, and other infrastructure. Industrial facilities, hazardous waste sites, and petroleum storage tanks may leak and spread toxic contamination into the mud and soil, both outdoors and inside the flooded homes (Figure 24.6.2). Testing in New Orleans after the flooding in 2005 revealed toxic petroleum chemicals, heavy metals such as lead and arsenic, and pesticides in the sediment in some flooded neighborhoods. Cleanup can be extremely expensive, yet if adequate cleanup is not done, which is often the case after flooding, there is a risk of future harm to returning residents.

Floods cause massive population displacement and homelessness. Some people can evacuate the area and stay elsewhere with family or friends, at least for a while. Others have no place to go and must be housed in temporary shelters, sometimes for months. The large numbers of displaced people need food, water, and health care. Evacuees



FIGURE 24.6.1 Mold growing in a flooded home after Hurricane Katrina, New Orleans, 2005. Photograph by Gina Solomon.



FIGURE 24.6.2 Flooded site with petroleum contamination after Hurricane Katrina, New Orleans, 2005. Photograph by Gina Solomon.

with underlying chronic diseases frequently experience exacerbations of their illness, often from lack of essential medications. For example, people with diabetes who don't have their insulin, people with seizure disorders, and people with severe psychiatric illnesses are all at high risk of serious and sometimes life-threatening exacerbations. Family and community structures and daily routines are completely disrupted, leading to depression, anxiety, post-traumatic stress disorder, and confusion for many people, especially the elderly. Rates of suicide almost always spike after hurricanes and floods.

Water contamination

Flooding causes obvious immediate risk of injury and death, but it also can impair drinking water quality by increasing runoff of contaminants into surface water sources. Runoff of soil and sediment into rivers and streams can lead to growth of parasites in the water, especially *Cryptosporidium* and *Giardia*. Both of these parasites can cause diarrhea and especially severe illness in people with immunosuppression. The

combination of extreme rainfall and a malfunction at a drinking water treatment facility is the most likely set of factors that can lead to a major outbreak of one of these parasitic diseases.

Unexpectedly, recent studies have found that wildfires can result in drinking water contamination with cancer-causing chemicals. This problem has now occurred after multiple wildfires, and on an especially large scale after the Camp Fire burned the town of Paradise, California, in 2018. Approximately 1,400 homes were still standing after the Camp Fire came through the area. When residents returned to their homes, some people complained about odd smells and taste in the water. Meanwhile, testing by state officials and the local water utilities found high concentrations of benzene and other toxic volatile organic compounds in parts of the drinking water system. Research showed that the water system lost pressure and drained off water during the fire, allowing contaminated smoke to enter the pipes. This can happen both because of the enormous demands of water for firefighting, and because broken pipes in burned homes and businesses lose large volumes of water. In Paradise, even though the water treatment plant pumps continued to push water into the system, the water drained out so fast that pipes filled with air and smoke. Contamination likely came from several sources, including smoke from burning buildings and furniture that was sucked into pipes, and melting of plastic water pipes. Addressing the contamination took months of work and cost billions of dollars in testing, pipe replacement, and system flushing. One of the lessons from this example is that it is difficult to predict all the possible health hazards that can occur due to climate change.

Harmful algal blooms and health

Harmful algal blooms (HABs)—sometimes called red tides—are another water-related health threat associated with climate change. The combination of nutrient-rich water and heat creates conditions ideal for the rapid growth of certain marine organisms and algae. HABs are dangerous because the algae or marine organisms produce toxins. In some cases, HABs are visible, creating greenish, blue, or red scum on the surface of the water. In some cases, the problem is not visible on the surface, thereby failing to alert people to the danger.



FIGURE 24.6.3 Fish kill from a harmful algal bloom in Alaska. Photograph by Dave Caron.

HABs often result in major die-offs of aquatic species, including fish, birds, and marine mammals. Dogs and livestock that drink from, or swim in, contaminated water are also at high risk of death. People can be affected in some cases from skin contact with the contaminated water, or inhalation of ocean spray. In other cases, however, people are poisoned from contaminated seafood. The symptoms of HAB poisoning vary depending on the organism. Brevetoxins, most commonly associated with Florida “red tides,” lead to asthmatic symptoms when inhaled, even in those who do not have asthma. Cyanobacteria, known as blue-green algae, are found in fresh and salt water. They produce toxins that affect the liver and gastrointestinal tract, causing vomiting, diarrhea, and sometimes fatal liver failure. Some of these toxins are also potential carcinogens. Other categories of HAB toxins affect the nervous system through consumption of contaminated shellfish. For this reason, the

names of the diseases include paralytic shellfish poisoning, neurotoxic shellfish poisoning, and amnesic shellfish poisoning.

The first reported outbreak of amnesic shellfish poisoning in humans was in 1987 in Prince Edward Island, Canada. Three people died in that outbreak, and over 100 people suffered permanent memory loss. Since that time, the US, Canada, the European Union, and numerous other countries have put in place programs to monitor seafood and attempt to ensure that scientists detect domoic acid and other HAB toxins before people become ill. Crab and shellfish fisheries have been closed along the Pacific coast of the US repeatedly in recent years, resulting in huge economic losses to the industry.

Sometimes drinking water can be affected by freshwater HABs. In August 2014, the city of Toledo, Ohio, had such severe microcystin contamination in their drinking water system from a HAB event on Lake Erie that city residents were told not to drink or even have skin contact with the tap water, and federal emergency responders provided bottled water to the entire city. The frequency of HABs in drinking water sources may increase because of climate change. During a freshwater HAB event, households with private lake water intakes are at high risk of contamination. Frequent water monitoring for early detection of HABs, partnerships across agencies for public health response, emergency alerts, and provision of alternative drinking water are short-term solutions. Longer-term solutions include transitioning homes with private intakes to public water systems, enhancing the ability of public water systems to deal with HAB contamination, and ongoing public education about HABs.

24.7 Climate Change, Food Insecurity, and Migration

According to the Food and Agricultural Organization, food security exists when all people at all times have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. This is achieved through four dimensions:

1. Food availability—there is the physical presence of sufficient food of adequate quality.
2. Physical, social, and economic access to this food—people have sufficient resources to acquire a nutritionally appropriate diet.
3. Food utilization—people have the ability to utilize this food in ways that are safe and nutritious, such as through clean water and sanitation for safe food preparation.
4. Food stability—there is a stable system that ensures consistent food security conditions. Common sources of instability include market volatility, food price shocks, political conflict, and climate change.

Food insecurity and forced human migration are two of the most harmful and immediate consequences of the climate crisis and serve as pathways toward worse physical and mental health.

Climate-driven food insecurity

Food insecurity has long been a significant global problem. Yet after steadily falling for decades, there has been an increase in food insecurity over the past several years, in part due to climate-related disasters. Nearly one in three people in the world—2.37 billion people—did not have access to adequate food in 2020. Of these, nearly 40% faced severe food insecurity. The distribution of food insecurity varies regionally; in terms of numbers, roughly half of those experiencing food insecurity are in Asia, one-third are in Africa, and 11% are in Latin America and the

Caribbean. These same regions of the world with the highest prevalence of hunger—sub-Saharan Africa, Southeast Asia, and Latin America—are also those most vulnerable to climate threats.

Climate change is affecting food insecurity globally, and this impact has been growing over time. One study published in 2022 pooled data from 83 countries to determine the extent to which temperature change is affecting food insecurity. The study found that in 2014, every 1°C increase in temperature over a historical mean led to a 1.6% increase in moderate to severe food insecurity. By 2019, that increase was 2.1%, and this effect persisted after controlling for drought and the level of development across the 83 countries.

Food insecurity and poor health

Climate change negatively impacts all dimensions of food security. It affects food availability, since drought, high temperatures, and heavy rains contribute to crop loss, animal death, and migration of fish. We see reduced food access through economic impacts of climate change, such as income loss and unemployment. There is reduced food utilization, or reduced ability to consume a nutritious diet, through worsened diet quality and food and water contamination. Finally, the stability of the food system is compromised through market volatility, increased food prices, and climate-related political instability and conflict.

Food insecurity, in turn, is a well-documented driver of a wide range of poor health outcomes through immunological, mental health, nutritional, and behavioral pathways. For example, a lack of sufficient and nutritious food can lead to malnutrition or, alternatively, to obesity when people consume calorically dense, nutrient-poor foods that are more affordable on a low budget. Persistent hunger can cause or exacerbate stress and depression or other mental health problems like anxiety and post-traumatic stress disorder. A poor diet can cause altered gut microbiota, called dysbiosis, which impairs immune functioning and nutrient absorption. Finally, limited financial resources can force people to prioritize food over health care or to engage in sexual exchange for food or money for food. Studies have also shown that food insecurity is associated with worse HIV outcomes along the entire cascade of care, from HIV acquisition to incomplete HIV viral load suppression to higher

HIV-related morbidity and mortality. Food insecurity is associated with other sexually transmitted diseases as well, and with increased mortality from Ebola virus disease. A large body of literature has shown that food insecurity is associated with chronic diseases, such as hypertension, diabetes, coronary artery disease, and chronic kidney disease, and with neurologic and mental health problems such as cognitive decline, depression, and anxiety. These conditions lead to more health care utilization, greater health care costs, and poor health-related quality of life.

Climate change and poor nutrition

The Planetary Health Alliance has evaluated climate change's impacts on micronutrient deficiencies and increased chronic disease burden. Elevated CO₂ levels have been found to contribute to a 3%–17% decline in the amount of protein, iron, and zinc in important crops like wheat and rice. Climate change is also driving a rapid decline in pollinators around the world, and a large proportion of dietary nutrients globally comes from pollinated crops, including fruits, vegetables, and nuts. Finally, over 1 billion people in the world rely on fish in their diet; however, since 1996, fish catch has been falling, largely due to climate change. This puts people at risk of zinc, iron, and vitamin A deficiencies. As an example of how climate change affects nutrition, drought conditions have been consistently linked to a nearly 50% increase in starvation conditions, including physical wasting and underweight conditions in local populations globally. In a prediction model, climate change was estimated to increase the prevalence of malnutrition by more than 50% by the year 2050.

Climate change and migration

Climate change is often referred to as a threat multiplier, meaning that it exacerbates other risks to create worse outcomes than any one risk would cause on its own. The intersection of climate change, food insecurity, and migration is one example. Climate change is expected to drive the largest mass movement of people in human history. While estimates vary, it is predicted that approximately 200 million people in climate-vulnerable areas of the world will be forced to migrate by 2050, and most of these will be internal migrants. Food insecurity often plays a primary precipitating role in this migration. For example, massive crop

failures and livestock death from extreme heat or drought can disrupt livelihoods and cause food and water insecurity. A feedback loop can emerge wherein the inability to meet food and other basic needs forces people to migrate, and the challenges arising from displacement, including homelessness and poverty, amplify hunger further.

Climate change can influence migration directly, such as through forced displacements from sea level rise, floods, or hurricanes, as well as indirectly by amplifying the socioeconomic and political drivers of migration. Mobility patterns can include migrating away from climate-affected areas, such as from coastal areas inland and from rural to urban areas. People may also migrate into areas with climate risks, particularly if they are living in a region that is highly susceptible to climate change. Finally, immobile populations may fare the worst in terms of climate-related health threats due to their inability to migrate.

Migration and poor health

There are significant health consequences of forced migration from climate change, which, in turn, can further drive mobility. Infectious disease outbreaks are common within refugee camps and crowded settlements. Migrants often have enlarged sexual networks and higher exposure to gender-based violence, which increase the risk of sexually transmitted diseases. Disruptions in livelihoods and social networks can put people at risk for malnutrition and poor mental health. Migrants who move from rural to urban areas face an increased risk of chronic disease due to lifestyle and diet changes and disrupted health care access. While migration can certainly have health risks, it is important to acknowledge that it can also be associated with health benefits. For some, mobility can provide a path to health improvement by offering safety from violence, reduced food and water insecurity, and access to better health care.

Studies have shown that there may be gender differences in climate-related migration. In a recent analysis using Demographic and Health Surveys data from 23 countries in sub-Saharan Africa, women were found to be more likely to migrate than men in conditions of drought and excessive rains. This has important public health implications, since mobility may limit women's access to reproductive health

services, and female migrants are particularly vulnerable to sexual violence. Qualitative research has supported the theory that climate events can drive migration. For example, in a qualitative study in rural Kenya, floods were viewed as a large contributor to migration due to destroyed crops, homes, and infrastructure.

24.8 Assessing Local Risk from Climate Change

Climate vulnerability assessments can be useful for assessing risks from climate change in any geographic area. Because risks vary greatly due to geography, local environment, and social and economic factors, it is most helpful to perform climate vulnerability assessments at a local scale.

The steps to assessing local risk include first identifying the hazards. For example, low-lying areas may be at risk of flooding, especially if they are in the potential path of coastal storm surge or river flooding. However, widespread flooding in September 2018 after Hurricane Florence in North and South Carolina included low-lying areas simply inundated by heavy rainfall. Areas along the wildland-urban interface may face a high risk of catastrophic fire. Highly urbanized neighborhoods without much tree cover may be at particular risk from extreme heat events, especially if many people lack air conditioning, or in the event of a power failure. Coastal and lake areas face the potential for HAB events, and warmer, wetter zones have higher risk of mosquito-borne disease outbreaks. Identifying local hazards from climate change can help create plans to either reduce those hazards or to prepare for a potential event. Local vulnerabilities can also be assessed at any scale from a single family to an entire state. For example, identifying the presence and locations of elderly or disabled people who may need extra assistance in the event of an evacuation, or who may be more vulnerable to heat, can help ensure that those people receive the assistance they need. Schools, day care centers, hospitals, nursing homes, and other facilities that can be difficult to evacuate are also critical to identify and prioritize. Such facilities should have extensive plans for preparing for and responding to disasters. Identifying local resilience factors is also important, including local cooling centers, health facilities, emergency alert systems, and other resources that may be valuable for protecting the community and saving lives.

In climate catastrophes, relatively few people will die in the immediate event. The main brunt of the illnesses and deaths occurs in the aftermath, when the effectiveness of the response and recovery is critical to determining the outcome for many people. For example, if people with underlying illnesses or acute injuries are able to access timely medical care, they may avoid serious outcomes. Mental health services, relocation services, housing, food, safe drinking water, and social support are all essential components for recovery.

24.9 Win-Win Solutions for Climate and Health

There is a lot we can do to tackle how climate change is affecting human health and well-being. According to the *Lancet* Commission on health and climate change, acting on climate change can be the greatest global health opportunity of the twenty-first century. This is because we know that climate solutions have many critical health co-benefits. For instance, decreasing fossil fuel emissions by driving less will decrease the 7 million deaths a year attributed to air pollution and the 5 million deaths linked to physical inactivity.

The health sector has a critical role to play. The US **Department of Health and Human Services (DHHS)** put forward the following critical roles of the health sector in working toward climate change solutions:

- Ensure a healthy and equitable transition to a clean economy.
- Achieve climate-ready health systems.
- Build a climate-ready health workforce.
- Educate public and policymakers on climate change–health equity links.
- Link climate change to global health security.
- Advance knowledge on climate change–health equity links.
- Build health-based climate adaptation and resilience.
- Advance health equity and climate justice.

While there is not an existing framework for categorizing climate and health solutions, a range of solutions touch upon one or more of the DHHS critical roles, including solutions that have health and environmental co-benefits. Ideal solutions address mitigation and adaptation, human sciences, livelihood interventions, built environment, and technology. Health is critical in the larger dialogue on solutions, and equity must be a critical thread through all solutions.

A co-benefit-focused solution that underscores equity has been the effort to retrofit ceilings in Cape Town, South Africa. Cape Town's climate can be moist and cold, making its residents susceptible to tuberculosis and other illnesses, especially in low-income neighborhoods where housing often lacks the appropriate insulation. By retrofitting ceilings, the city could improve not only the health of the community, but also the energy efficiency of buildings, reducing the fuel used to heat homes by up to 74% in the winter. In other words, this is a co-benefit solution that enables a healthy and equitable transition to a clean economy. To date, the city has retrofitted more than 10,500 homes, and it is estimated that the total impact of these retrofits will save approximately 7,400 tons of CO₂ each year. The city's subsidy regulations for new low-income housing were also changed to include properly insulated ceilings moving forward. Residents have reported significant improvements in health and reduced financial burdens because ceiling upgrades led to substantial reductions in energy and health care costs.

In the summer of 2019, temperatures in Paris soared to a record high of 108.6°F / 42.6°C during heat waves that killed approximately 1,500 people, particularly the elderly, across France. In response, the city of Paris began mapping its network of "cool islands." These were 800 generally free sites like shaded parks, trees, and fountains that served as refuges for residents during extreme high temperatures. This is another solution that yields co-benefits, and it resulted in the creation of the EXTREMA Paris app (now called EXTREMA Global), which geolocates users and suggests the cool spots closest to their location. Through the EXTREMA project, the city of Paris was able to inform residents about how and where to cool off, while maintaining their health and economic productivity. The EXTREMA app also protects at-risk communities such as the elderly and builds health-based climate adaptation and resilience.

An intervention study in western Kenya called *Shamba Maisha*—which means "farming for life" in Kiswahili—is a climate-adaptive, multisectoral intervention that aims to address broader drivers of food insecurity and poverty, which in this case are frequent droughts and unpredictable rainfall patterns in the setting of climate change. The intervention includes a loan to purchase a human-powered water pump, which enables people to irrigate their land during the progressively longer dry seasons, and

training in sustainable farming practices and financial management. One of the ways that this intervention is positive environmentally is that farmers practice regenerative agriculture, helping to return nutrients to the soil. In an efficacy trial with over 700 participants, improvements were found along many proposed pathways, including improved food security, mental health, women's empowerment, improved social support, improved physical health status among men, and decreased internalized, enacted, and anticipated HIV stigma.

The urban forest is a green infrastructure system that offers many environmental, economic, and social and health services and functions in cities. The urban forest also represents a health equity and health-based resilience solution. A recent review provides a comprehensive summary of the literature on the health impacts of urban trees to inform future research, policy, and nature-based public health solutions. The review noted several categories of health benefits, including (1) "reducing harm" (41% of studies) from environmental exposures such as air pollution, ultraviolet radiation, heat exposure, and pollen; (2) "restoring capacities" (31% of studies), which included improved mental health, stress reduction, and improved chronic disease outcomes; and (3) "building capacities" (28% of studies), which included topics such as active living and weight status.

Ocean farming is another great example of a regenerative intervention that improves health and livelihoods. This is a form of aquaculture that uses a vertical approach to diversify what can be harvested from the ocean. This can include extracting sea salt from the surface; cultivating kelp, seaweed, scallops, and mussels through suspended ropes and nets; and catching fish and growing oysters via cages on the seabed. These ocean farms reduce food insecurity and overfishing. They are also low cost, zero input, and easily scalable, providing a climate-adaptive livelihood option, particularly for women. And they are sustainable since their components feed on and support the growth of each other. Seaweed also has many climate benefits, since it can be added to livestock feed, to reduce methane emissions, and it sequesters carbon, helping to mitigate ocean acidification.

Education is a core solution to the climate crisis, and education around climate change and health is much needed and severely lacking

for the public as well as health scientists and professionals who are facing impacts of the climate crisis in their day-to-day work. Through a worldwide study with climate, health, and justice experts, three facets were found to be necessary to ensure that education for climate and health is relevant to the local context. These include (1) community involvement, in which students become familiar with real-world, locally relevant issues by identifying opportunities for engagement with community members (for example, pulmonary function testing for individuals living near areas affected by wildfires); (2) curricular changes that reflect community priorities, such as inviting community leaders and patients to educate learners; and (3) educational partnerships with local organizations and communities, such as exemplar partnerships in Brazil that link learners with local farmers to provide fresher, pesticide-free foods at hospitals, thus reducing “food miles” and carbon emissions.

The education of a climate-ready workforce includes education of higher-level health professionals and faculty on climate and health links. The University of California Education for Sustainable Healthcare (UC-ESH) Faculty Development Initiative was developed to educate health sciences faculty on eco-medical literacy, empower faculty to build community and lead sustainable health care education at their institutions, and expand coverage of sustainable health care education to reach students beyond those for whom sustainability is already a focus. The initiative provided training to faculty across health professions and UC’s six health science campuses to integrate sustainable health care education into their courses using the “train the trainer” model, key knowledge and pedagogical skills, and longitudinal guidance and networking opportunities. The UC-ESH educated over 100 faculty members and led to sustainable health care education integration into 99 existing and new courses that subsequently reached over 7,000 learners. This university-system-wide initiative provides a transferable model to institutions, schools, and departments seeking to develop eco-medical-literate faculty who educate their students about the climate, ecosystem, and health crisis.

Novel education efforts around the world have seen increased growth. The Planetary Health Report Card is a student-driven, metric-based initiative to inspire planetary health education engagement in

medical schools and is now used globally. The Interviews without Harm Coalition is a group of medical students, residents, and faculty who envision a more sustainable process of interviewing medical trainees. The coalition advocates for an application system that reduces interview-associated carbon emissions and is also equitable and efficient. The Global Consortium on Climate and Health Education works with health professional schools around the world to develop a core global knowledge set and model curricula to prepare health professionals to face climate-related health impacts.

The health care sector, responsible for approximately 5% of global greenhouse gas emissions in 2017, is taking steps to reduce its own environmental impact. Health institutions (including the University of California) have committed to divest more than \$42 billion worth of assets from fossil fuels. Within clinical care, there is recognition of the health impacts of climate change and resulting health care disparities, which are increasingly being covered in conversations with patients. From 2018 to 2019, the coverage of health and climate change in the media increased by 96% worldwide, outpacing the increased coverage of climate change overall. Increased and continued engagement from the health profession now fills a gap in the global response to climate change, and the Conference of the Parties in 2023 (COP28) featured a health-focused day for the first time. COP28 also brought with it many firsts for health: a political declaration on climate change and health signed by over 120 countries, a first-time ministerial on climate change and health with over 70 ministers and delegates from 100+ countries, and \$1 billion in new funding initiatives for climate change and health.

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Figure 24.2.1: Image by Gina Solomon.

Figure 24.5.1: US EPA. 2020, June 8. How science is protecting the air we breathe. *Science Matters*. <https://www.epa.gov/sciencematters/how-science-protecting-air-we-breathe>. Image source: US EPA (<https://www.epa.gov/sciencematters/how-science-protecting-air-we-breathe>)

Figure 24.5.2: Buis, A. 2020, October. Getting to the heart of the (particulate) matter. NASA-ASI MAIA Mission to Study How Particulate Matter Air Pollution Affects Our Health. NASA Jet Propulsion Laboratory. <https://climate.nasa.gov/news/3027/getting-to-the-heart-of-the-particulate-matter/>. Image source: Buis, 2023

Figure 24.6.1: Photograph by Gina Solomon.

Figure 24.6.2: Photograph by Gina Solomon.

Figure 24.6.3: Photograph by Dave Caron.

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Chapter Glossary

Following is a list of terms and acronyms used in the chapter.

TABLE 24.1.1 Glossary Items

Term	Definition
CDC	Centers for Disease Control and Prevention
DHHS	Department of Health and Human Services
EPA	Environmental Protection Agency
HAB	Harmful algal bloom
NO _x	Nitrogen oxides
PM _{2.5}	Particulate matter 2.5 microns or less in diameter
VOCs	Volatile organic compounds