UNDER WATER IN THE UNITED STATES

Violet, her husband, and two children live in a small trailer behind the ruins of their former house, destroyed by Hurricane Gustav in 2008. The trailer is moldy from regular flooding. They cook on a hotplate because their stove was ruined by flooding. Suffering from lupus, Violet worries that she won’t be able to reach a doctor when needed if the bridge that connects the island she lives on to mainland Louisiana is flooded. Dreams of college for her children dim further every time they miss school because the bridge is flooded, which is often.

Isle de Jean Charles, where Violet and approximately 60 others live, is ravaged by climate change. In addition to flooding, the pecan and banana trees once plentiful on the island are all but gone—victims of salt water soaked into the soil. More than 90 percent of the island’s land has disappeared—washed away through the channels cut across the island by loggers and oil companies, washed away by hurricanes. Flood control measures block the free-flowing rivers that brought fresh water and sediment to replenish the island. There are few animals to hunt or trap; the land is not arable. The island is not habitable.

What little is left of their island is likely to be under water as ice caps melt and the sea level rises. The islanders are identified as among the most vulnerable in the United States to climate change. Their island cannot be saved. Even if it were rebuilt, rising seas and extreme climate events continue to threaten and destroy it. They are slated to be the first U.S. climate change refugees. The community, lives, and culture of the islanders are in danger. Isle de Jean Charles is tribal land. The islanders’ families have lived there for hundreds of years. Although the government’s plan is to move the entire community to a new location, hoping to preserve the culture, some islanders do not want to leave. Others, like Violet, see nothing except misery ahead on the island. “I just want to get out of here,” she proclaims. (Davenport and Robertson 2016)

LEARNING OBJECTIVES

After completing this chapter, students will be able to do the following:

14.1 Identify the variety of signs or symptoms of climate change
14.2 Analyze the sources of climate change related to human activity
14.3 Assess the threats to global stability posed by elements of climate change considering rising sea levels, extreme weather events, food insecurity, and violent conflict
14.4 Evaluate the potential of various methods proposed for improving the earth’s health and limiting climate change
14.5 Compare and contrast the measures that should be taken at global, societal, and local levels to combat climate change
THE THREAT OF CLIMATE CHANGE

As with Violet and the residents of Isle de Jean Charles, some forced displacements occur gradually. They don’t often make the headlines. Forced by rising sea levels that make homes uninhabitable and fields infertile with salinity, Violet and her family are likely to be joined by hundreds of thousands more refugees forced out by rising seas. Pacific Island nations are among the most vulnerable. Kiribati, an atoll with about 100,000 residents, lies only 6 feet above sea level. The Maldives, Tuvalu, the Marshall Islands, Micronesia, the Caribbean, and Mauritius, among others, all are endangered by the rising sea levels.

National security experts from all over the world, including James Mattis, U.S. President Donald Trump’s secretary of defense, cite climate change as one of the greatest threats, if not the greatest threat, to national and global security. Knowledge that climate change creates conditions of instability is not new. In 2007, an authoritative report compiled by military and intelligence officials warned that climate change debates focused on economics and neglected, for the most part, foreign policy and national security issues (Busby 2007).

Climate change and its effects are threat multipliers in regions already facing security challenges. The potential and likely direct and indirect consequences of climate change are severe for both developed and developing nations. Extreme weather events increasing in frequency and intensity can overwhelm the capacity of authorities to respond, causing widespread death, public health crises, and a breakdown of law and order. Less direct but even more deadly are the long-term effects of climate change. Increasing temperatures, drought, desertification, and food shortages devastate regions and spawn social unrest. The Paris Agreement plans deign to prevent a global 2° C rise in temperature by 2100. In sub-Saharan Africa, temperatures already reached the 2° C rise and could reach a 4° or 5° C rise by 2100 (Pereira 2017; Serdeczny et al. 2016). Precipitation in the region decreased. Desertification is expanding. Every year, 12 million hectares of land turn to dust—land that could have grown 20 million tons of grain (British Broadcasting Corporation 2017). Africa has been the region most vulnerable to climate change. Vulnerability is not confined to the driest areas, but 80 percent of armed conflicts in 2007 occurred in dry ecosystems (United Nations Convention to Combat Desertification n.d.). Desertification brings food shortages. Food shortages bring conflict and rioting. It was food shortage that ignited the rioting in Tunisia and gave rise to Arab Spring across North Africa. Syria had faced its driest years in five years and most devastating crop failures perhaps in its history, leading to its long-lasting civil war.

Shoreline erosion, coastal flooding, and agricultural destruction threaten hundreds of thousands of people in Asia. In Bangladesh, efforts continue to reclaim land to house the roughly 200,000 people whose lands are washed away by erosion. Anywhere from 20 to 25 percent of Bangladesh’s land will be under water if sea levels rise 1 meter—an event expected by the end of the century and displacing approximately 18 million people. Migration of Bangladeshis into India has already created tension and incited violence. On another front, rivers originating in Kashmir supply the majority of water needed for Pakistan’s agricultural irrigation. As the region becomes drier, India’s dam building on these rivers deprives Pakistan of this much-needed water. Similarly, river basins that originate in China on which India depends are threatened (Lone 2015). Kashmir is a flashpoint between India and Pakistan, inciting three wars since World War II between these two nuclear armed states.

Discovering Climate Change

Studying climate change is not new. In 1859, John Tyndall wondered what caused the glaciers across Europe to melt. In his lab, he discovered that while most of the sun’s heat radiated back from the earth and passed easily through the atmosphere, several gases could trap heat waves. He found that water vapor was a powerful block. In combination with carbon dioxide (CO₂), its heat-trapping potential was exacerbated.

In 1896, Svante Arrhenius discovered that concentrations of CO₂ regulate water vapor and that cutting the CO₂ in the atmosphere by half would lower the temperature in Europe by 4 to 5° C (7–9° F).

Arrhenius’s friend, Arvid Högbom, calculated that factories and industrial sources were adding CO₂ to the atmosphere and would cause the earth’s temperature to rise. They did not see it as much of a problem at the time because at the rate CO₂ was being generated in 1896, they calculated that it would take 3,000 years for the temperature to rise significantly. By 1908, however, Arrhenius suggested that the warming might occur in 300 years. Now, of course, we know that we are generating much
more CO₂ and other greenhouse gases than these early climate scientists could have anticipated. Consequently, the earth’s temperature rose and continues to rise much more quickly than they predicted (Weart, 2016).

**Popular Opinion and Climate Change**

People in the developing world are the most likely to experience the most harm from climate change. It is not surprising that a Pew Research Center (2015) Global Attitudes and Trends poll showed that people in Latin America and Africa are the most concerned about climate change as a serious problem and how it can hurt them personally. In Europe, where a majority (54 percent) agree that climate change is a serious problem and 60 percent believe that it is already harming people, only 27 percent are “very concerned” that it will harm them personally. Americans and Chinese, who create the most greenhouse gases, are the least concerned.

What people are most concerned about is drought and water shortages. When asked to choose their biggest concern from among these four choices—all of which kill people—they choose in this order of concern:

- Drought/water shortage (44 percent)
- Severe weather such as intense storms and floods (25 percent)
- Long periods of unusually hot weather (14 percent)
- Rising sea levels (6 percent)

With the exception of rising sea levels scoring above unusually hot weather in the United States and Europe, this pattern of priority was the same across all regions (Pew Research Center 2015).

Experts the world over agree that the effects of climate change are far-reaching. They include agriculture, health and disease, energy supply and demand, increased intensity and frequency of wildfires and extreme weather events, coastal and marine ecosystems, water quality and supply, transportation, and a factor often overlooked—the national security of every nation.

**Climate Change Cycles and Feedback Loops**

The earth’s climate is changing. Across the earth, the regional patterns of temperature, precipitation, and seasons that scientists have relied on for centuries to predict weather are changing, each in different ways. Some seasons are shortening, some lengthening. Some regions of the world are getting more rain and snowfall, some less. The overall temperature of the atmosphere and seas is changing. These changes are occurring significantly more rapidly than would be the case if the changes were occurring from natural cycles. With these changes in climate come day-to-day changes in weather patterns making them less predictable and making extreme weather events more frequent and more intense.

The singular most important cause is the accumulation of CO₂ and other gases in the earth’s atmosphere (Figure 14.1). Combustion of carbon-based fuels spews CO₂ into the atmosphere. Along with nitrous oxide from both combustion and fertilizers, methane from decomposing human, animal, and other organic wastes, and fluorinated gases from industrial processes, these gases form a barrier around the earth that, like a greenhouse, traps heat and causes the earth’s temperature to rise. The gases and rising temperature create condensation increasing atmospheric water vapor, the most abundant greenhouse gas. Clouds and precipitation enhance the greenhouse effect. Deforestation complicates this further, weakening the earth’s ability to absorb CO₂, increasing its concentration in the atmosphere.

The increase in the earth’s atmospheric, oceanic, and land temperatures causes the climate changes that the earth experiences. Overall, the earth’s average temperature increased 1° F in the 20th century. It does not sound significant, but it already has created a cavalcade of climate events. Small changes in temperature have oversized effects. Already we have experienced the following:

- Sea level rise from melting of glaciers, snow, and ice
- Less reflection of radiation back out of the atmosphere because of loss of ice and snow
- Increase in ocean temperatures, which also causes sea level rise
- Acidification of oceans
- Increased vulnerability of coral reefs
- Decreasing plant and animal biodiversity in many ecosystems
- Changing ocean current and wind patterns
- Increase in extreme weather events
Imbalance in hydrological cycles—drought in some areas, flooding in other areas

Desertification

Shifting animal habitats and patterns of animal migration

Decreasing biodiversity and potential extinction of many plant and animal species

THE SYMPTOMS OF A CHANGING CLIMATE

Climate change discussions often focus on one or two aspects of it; rising temperatures and rising sea levels. These are critical but not the only aspects of climate change, nor are they the ones that most of us experience directly.

Climate change is reflected in long-term patterns in seasons, temperatures, precipitation, and ocean and wind currents. Hadley’s cell, El Niño, and La Niña are climate patterns. Trends of climate over long periods tend to be relatively stable. Understanding them enables us to predict the weather and ecosystem characteristics. Weather is the day-to-day, or even minute-to-minute, fluctuations in temperature, precipitation, and so on.

As climate changes, it affects weather patterns. It is weather that we notice day to day. Weather is becoming less predictable. This is one cost of climate change. The costs of climate change, the externalities, are not paid by the industries doing the polluting or supplying the oil and coal companies that furnish combustible fuels; they are borne by everyone in damage to our health, our natural environment, and our built environment.

DATA ON ATMOSPHERIC CO₂, OCEAN TEMPERATURE, EARTH TEMPERATURE, AND PRECIPITATION ALL POINT TO A RAPIDLY CHANGING CLIMATE.

FIGURE 14.1 CO₂ Levels Through History

This graph compares samples of atmospheric CO₂ from ice cores with more recent samples. It provides evidence of the increase in CO₂ since the Industrial Revolution.

Source: National Aeronautics and Space Administration (2017a).
Climate scientists from four research centers have little disagreement on the degree of the earth’s temperature changes.

**Figure 14.2** Temperature Increases From 1880

Climate scientists from four research centers have little disagreement on the degree of the earth’s temperature changes.

Source: National Aeronautics and Space Administration (2017b).

Boulder Glacier in Glacier National Park has nearly disappeared, as shown by these comparison photos.

**Photo 14.1A** Boulder Glacier, Montana, 1932
TJ Hileman, GNP Archives.

**Photo 14.1B** Boulder Glacier, Montana, 2005
G. Pederson, USGS.
Surface Temperature

Thousands of measures of the earth’s land, water, and air temperatures are taken every day by hundreds of independent monitors. Many governments and scientific organizations have tracked temperatures over the last hundred or more years. These consistently show an increase in average air, water, and land temperatures to the point that as of 2017 16 of the 17 hottest years on record have occurred since 2001 (National Aeronautics and Space Administration [NASA] 2017c).

Every year since 1970 has been above the global 1951 to 1980 average (NASA 2017c). At 99° C, this is a full 1° higher. Contrast this with average variation of less than 1° over the last thousand years and 4° to 7° over the last million years (World Meteorological Organization [WMO] 2013). Each of the last three decades has been progressively warmer than any preceding decade since 1890, and 1983 to 2012 has likely been the warmest 30-year period in 1400 years (Intergovernmental Panel on Climate Change [IPCC] 2014). The first 16 years of the 21st century were among the hottest 17 years on record, which dates back to 1880 (1998 is the third hottest year) (National Oceanic and Atmospheric Administration [NOAA] 2016b). The warmest year on record dating back to 1850 was 2016 (Figure 14.2) (Met Office Hadley Centre and Climatic Research Unit 2016).

It is not the case that every day will be warmer than the average for that day or that the earth will be uniformly warmer. Some regions such as the Arctic, which so far has been warming most rapidly, warm more quickly than others. Some days, months, or years may have cooler than average temperatures. That does not mean that overall the earth is not warming, but it is reason to use “climate change” to capture the full range of effects and global warming more specifically, even though it is the crux of climate change.

When a weather event such as a drought or flood occurs in one part of the world, it is not in isolation. There is a global pattern of variability. With global warming, increased evaporation becomes balanced by increased precipitation. The hydrological cycle is intensified; wet areas become wetter and dry areas become drier. At the same time, subtropical dry zones expand poleward. This will cause regions such as the U.S. Southwest to dry.

Scientific evidence supports the argument that the increase in the earth’s temperature is due to human activities. Worldwide greenhouse gas emissions increased by 35 percent from 1990 to 2010 (Environmental Protection Agency [EPA] 2016). CO₂, methane, and nitrous oxide can be measured in the earth’s atmosphere, and their concentrations have increased markedly. Scientists have also known since the mid-19th century that these gases trap heat. In fact, many of the instruments flown by NASA use this basic knowledge to navigate.

Oceans: Sea Level, Salinity, and Acidity

The effects of pollution and climate change on the oceans are profound. While most of the greenhouse gases accumulate in the atmosphere, causing the greenhouse effect, most of the excess energy produced, as much as 90 percent, is stored in the oceans, increasing the ocean temperature. Since 1969, the top 700 meters of the ocean warmed 0.302° F, significantly more than the average for the earth’s surface (NASA 2017c). In regions where evaporation dominates precipitation, ocean surface salinity increased. In regions where precipitation dominates, surface salinity decreased. This is indirect evidence of changes in the water cycle associated with greenhouse gases (IPCC 2014).

The oceans are also affected by glacier melting. Glaciers and the ice sheets associated with them are land ice and hold the largest stores of fresh water. They are melting, and as they melt the fresh water eventually winds its way to the salty seas, raising the temperature and affecting salinity. To get an idea of how fast glaciers are melting, consider Glacier National Park in the United States (Photos 14.1A and 14.1B). In 1910, Glacier National Park had 150 glaciers. Now there are 30 and the melting continues. Glaciers in the Garhwal Himalaya are melting so quickly that they may be gone by 2035, and 80 percent of the “snows of Kilimanjaro” have disappeared. In Indonesia, Peru, Switzerland, and Greenland—all over the world—glaciers, ice sheets, and snow caps are shrinking fast (Glick n.d.). The effect is synergistic; as snow and ice melt, the thinner layer left melts more quickly, increasing the rate of melting.

The Antarctic ice sheet is the largest repository of fresh water in the world. Since 2002, it has been losing ice at a rate of 134 gigatons per year. The Greenland ice sheet is melting even faster, at a rate of 287 gigatons per year (NASA 2017d). Snow and ice act like mirrors. As the ice sheets melt, the earth also loses reflective capacity (albedo) and global warming is intensified. Snow and ice reflect back nearly all of the sunlight, 85
percent, that strikes it. The open water left by ice melt reflects back only 7 percent.

These are the two mechanisms causing the rising sea levels: expansion and melting ice and snow locked into glaciers, snowcaps, and other land formations. Like other consequences of the greenhouse effect, sea level doesn’t rise uniformly across the world. In some places it is not rising at all, and in others it is decreasing. Overall, the sea level rose about 8 inches from the beginning of the 20th century. It could rise by 3 feet or more by the end of this century (Figure 14.3) (NASA 2017e).

The increase in temperature and changing salinity affect the habitat of marine life. Another threat to the oceans posed by greenhouse gases is the direct effect of CO₂ in the oceans. Not all of the greenhouse gases emitted remain in the atmosphere. About 25 percent of the CO₂ we create is absorbed by the oceans, increasing its acidity. The increase in temperature, the increase in acidity, and changes in salinity all disturb the delicate balance of the oceans, endangering plant and animal life, including the coral reefs (IPCC 2014).

Permafrost Thaw

In the coldest parts of the world, only the upper layer of the earth, the active layer, thaws in spring and summer. Below the active layer is an “ice-rich layer” and below this is permafrost. As its name implies, permafrost remains frozen all year round. Through various mechanisms, such as disturbance of soil or vegetation, surface water and groundwater interaction, and loss of snow cover, rather than direct response to air temperature, climate change is causing permafrost thaw in many

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**A CLOSER LOOK**

**SEA LEVEL CHANGE**

**FIGURE 14.3 Sea Level Changes, 1870–2000**

Sea level has risen about 8 inches from the beginning of the 20th century. Even if global warming slows, the rise will continue. This NASA chart is online in interactive form, giving precise reading of the increase in sea level year by year.

*Source:* National Aeronautics and Space Administration (2017f).
regions (Hong, Perkins, and Trainor 2014). Twice as much carbon gas is locked into permafrost of the Arctic and boreal forests as is in the atmosphere. Some of these gases have been locked there for thousands of years from the decay of organic matter.

Permafrost thaw feeds back into climate change and is one of the most significant contributions of land ecosystems to the atmospheric warming. Over time, the release of greenhouse gases into the atmosphere from permafrost thaw outweighs the uptake of carbon from any increase in vegetation that arises from the warming (Schuur et al. 2009). The Arctic permafrost alone stores 1.5 trillion tons of carbon gases, including methane. Methane, which is being released at a rate of 50 billion tons a year and heats the atmosphere 25 times more efficiently than CO$_2$, accelerates global warming. The East Siberia Arctic Shelf also contains significant stored methane. Subsea permafrost thawing and decrease in ice are expected to significantly increase methane emissions there as well (Shakhova et al. 2017).

Permafrost thaw poses hazards in addition to greenhouse gas release. Different types of permafrost are affected to a greater or lesser extent by thawing, but all types decrease in stability. This poses risks to ecosystems and human infrastructure. Permafrost is a critical component of a soil ecosystem. Permafrost thaw poses significant hazards:

- Dependent on drainage, the thaw is likely to create subsidence and overly saturated soils. This can cause trees to die. In an area of good drainage, it will improve the drainage and create drier conditions.
- Because permafrost affects vegetation, thaw can result in boreal forest being replaced with steppe-like habitats when drier conditions result or with wetlands where more highly water-saturated conditions result. Over the long term, thaw will produce better drainage and dry conditions stressing vegetation, shrinking ponds within the area and affecting aquatic life.
- Microbial activity will increase, releasing CO$_2$ and methane.

PHOTO 14.2  This apartment building was destroyed due to settling caused by permafrost thaw.

Professor Vladimir Romanovsky, University of Alaska Fairbanks.
Infrastructure damage to roads, buildings, airports, and facilities due to thaw and permafrost settlement poses significant expense. Many structures may need to be abandoned if funding is not available for continued repairs. (National Snow and Ice Data Center 2013)

Sea Ice and Animal Life

Arctic Sea ice is measured by the extent of its coverage and its depth. The period 2005 to 2010 recorded the lowest summer’s end (September) ice coverage ever, dipping to a low in 2007 of 4.26 million km² (1.65 square miles), 39 percent below the long-term average. This record low was broken in 2012 with summer ice extent diminishing to 3.42 million km², 18 percent lower than 2007 (WMO 2013). As with land ice, when sea ice melts, albedo is diminished and more energy is absorbed, increasing the temperature. Perovich and Polashenski (2012) found that once sea ice had melted, the seasonal ice that followed in its wake on the next freezing did not rebound to the reflecting capacity of the multi-year ice. A study by Lund University (2015) found that sea ice loss not only affects the oceans but also affects ecosystems farther away and on land. The increase in temperature from Arctic sea ice melt stimulates microorganisms in the Arctic tundra ecosystem to release more methane.

Maximum and minimum sea ice levels and when each level occurs are important measures of the sea ice. The maximum extent is reached toward the end of winter, in March, and the minimum extent is reached toward the end of summer, in September. For the sea ice year beginning in October of 2014, the maximum was reached 15 days earlier than average on February 25. This means that warming started earlier in the year. Its maximum extent was the lowest value on record, dating back to 1979. The minimum in September was the fourth lowest on record. There was also twice as much “first-year” ice as there was 30 years ago. The loss of sea ice and increased temperatures are forcing warm water fish communities in both the Atlantic and Pacific oceans farther north. The Atlantic Ocean meets the Arctic Sea at the Barents Sea. Larger predator fish, such as cod, beaked redfish, and long rough dab from the southwestern Barents Sea are entering the north parts in large numbers.

As the climate is changing, the water temperature is now more favorable to these predator fish than the Arctic fish species native to that area. The Arctic fish tend to be smaller and have a more specialized diet, and they are not likely to withstand a move farther north (Fossheim et al. 2015).

Walruses in the Arctic

Walruses use sea ice throughout the seasons for mating in winter, birthing in spring, and haul out (congregating) platforms throughout the year. Because they can also use land, they are not as threatened as other species. Two types of walrus exist in the Arctic, and their habits and habitats are somewhat different. The Pacific walrus population probably declined significantly from 1980 to 2000. On the one hand, its population had reached the carrying capacity of the environment. On the other hand, the carrying capacity was diminished by the loss of sea ice. The loss of sea ice reduced Pacific walruses' access to prey, affecting the health of female walruses, resulting in less healthy calves. In addition, using land-based haul out platforms increases mortality of young walruses due to trampling events. Besides the loss of sea ice, threats to walruses in the Arctic include declines in the clam population, acidification of the sea, oil and gas extraction, and disease and contaminant risks from fish species new to the Arctic (Kovacs et al., 2015). Both Atlantic and Pacific species of walrus were decimated in the past by hunting. Hunting the Pacific walrus is not prohibited by the United States, Canada, or Russia, in part because of its importance to Arctic natives, although there are controls in place. The Atlantic walrus is listed as a species of “special concern” by the Committee on the Status of Endangered Wildlife in Canada (Committee on the Status of Endangered Wildlife in Canada 2011). The Pacific walrus was to be considered for the U.S. Endangered Species Act protection in 2017.4 It is fully protected in Norway, and while the ice melt is dramatic there, the ban on hunting and reserve areas where they are not subject to human interference have allowed the population to resurge. Greenland also has put protections in place (Kovacs et al. 2015).

Polar Bears at Risk

Polar bears are at greater risk from climate change than are walruses. Polar bears are ice dependent. Arctic sea ice is necessary to their survival. Along with the “ringed seal,” their prey, they are the “canary in the mine shaft” indicators of the state of climate change in the Arctic. Polar bears need 60 percent more calories than realized,
CONSIDER THIS
BLACK CARBON IN THE ARCTIC

Black carbon, soot, is one of the keys to understanding climate change in the Arctic. Because the Arctic has no direct sources of pollution, the likely culprit is gas flares from oil extraction. They spew black carbon, gas nitrogen dioxide and particles, and/or aerosols. Until recently, gas flares were overlooked as a source of climate change. With the recent boom in oil exploration activity in Canada and the United States, significantly more greenhouse-generating soot and gases are reaching the Arctic, where even small disruptions are amplified (Li et al. 2016). The Arctic is particularly vulnerable to the effects of global warming. As snow and ice diminish, their reflective power is weakened, as discussed. More radiation will be absorbed, accelerating warming. Vegetation is increasingly moving north due to warming, which will also decrease reflection and increase absorption. These feedback effects result in the Arctic temperatures rising at twice the rate of the global average. Since 1978, Arctic sea ice is disappearing at an average rate of 3 percent per decade; portions are disappearing at a rate of 7 percent per decade. These are much greater losses than occur with normal fluctuations.

It has consequences. The hunting season of indigenous Arctic peoples is shorter. Their “drying” season is unseasonably wetter, making it difficult to dry food for storage to feed themselves in the fall and winter months. Reindeer and caribou will work harder to find food due to heavier snows and rain, depleting their populations. Shorter ice seasons and less ice mean that baby seals and walruses might not have enough time to wean and may die. Caribou and polar bears might not have enough ice path for migration (Union of Concerned Scientists n.d. b).

About 12,325 every day. They hunt from ice floes. As the ice melts, polar bears starve (Leahy 2018). Polar bears are uniquely adapted to the Arctic environment with wide paws that act something like snowshoes and strong legs and webbing between their toes that aid in swimming. Like Arctic ice, their transparent fur reflects light, but they have a black skin and thick layer of fat that insulates them, trapping heat (National Wildlife Federation n.d.). They are dependent on sea ice for breeding as well as feeding. In 2008, when they were considered for and placed on the endangered species list, scientists argued that melting sea ice could bring about their extinction in parts of Alaska and Canada. In 2003 and 2004, when the number of ice-free summer days rose to 135, their population dropped by 25 percent. In that period, researchers also observed emaciated bears, starving bears, drowning bears, and bear cannibalism—things they had never seen before. It was clear that climate change challenged their survival (Madin 2008).

A Complication: Polar Bears and the Endangered Species Act

The “poster child” of climate change, campaigns on behalf of the plight of the polar bear, such as the World Wildlife Fund (WWF) and Coca-Cola joint endeavor, captured much of the public’s imagination and helped people to understand the threat of climate change. Although polar bears are listed as a threatened species, it is not clear that the Endangered Species Act (ESA) can protect them. At issue is whether or not the ESA has the authority to combat global warming. Although by ESA regulations polar bears are clearly in danger, the decision to list them contained this caveat: “Listing will not stop climate change or prevent sea ice from melting” (Kearney 2014). In other words, the listing of polar bears as endangered is not cause to act on their behalf in fighting climate change, for instance, by requiring further regulations on greenhouse gas emissions.

The EPA should, on the face of it, be able to protect polar bears on the basis of the critical habitat designation (CHD) because Arctic ice is necessary for the survival of the species. CHD would provide special management of the habitat. In the 2013 case Alaska Oil and Gas Association v. Salazar, the court vacated the CHD designation (Kearney 2014). The ESA is currently powerless to protect any animal or plant species due to destruction of its environment from climate change. This would apply to Pacific walruses and others if they are added to the list.
A CLOSER LOOK

WALRUS HAUL OUT

PHOTO 14.3 In 2017, loss of sea ice caused the earliest walrus haul out ever. Diminishing sea ice leaves walruses with fewer and smaller ice floes, forcing more onto land. Because they are easily startled, human activity can cause stress and stampede, in which many may die.


A New Threat to Polar Bears

Now, the polar bear species faces a new threat. Polar bears and grizzly bears are the most closely related bear species, with their evolution having diverged only about a million years ago. Their habitats overlapped for some time in the western Canadian Arctic, where grizzlies had been showing up for about 50 years. The bears have mated in captivity, but the first instance in the wild was observed in 2006. At that time, it was too soon to tell whether this would become a regular occurrence resulting from climate change (Roach 2006). However, a decade later in 2016, many more hybrid bears have been found and it seems as though there have been decades of sporadic interbreeding. Islands off Southeast Alaska have bears that have polar bear DNA but look more like grizzlies. Scientists

PHOTO 14.4 As Arctic ice diminishes in area, it also diminishes in depth. This polar bear broke through the Arctic ice in 2009.

Canadian Coast Guard, Public Domain.
with long histories in studying Arctic bears fear that grizzly bears have more to gain than polar bears. Eventually, they fear, the polar bear population could dilute to where it does not exist at all (Popescu 2016).

**EXTREME WEATHER AND DISPLACED PEOPLE**

> Developing countries will suffer the most from the weather-related disasters and increased water stress caused by global warming. . . . Even 2°C warming above pre-industrial temperatures—the minimum the world will experience—would result in 4–5 percent of African and South Asian GDP [gross domestic product] being lost, and developing countries are expected to bear 75–80 percent of impact costs.
>
> —Zou Ji, quoted in World Economic Forum (2015)

Most people experience climate change through their day-to-day experiences with weather. The most noticeable of the weather changes is the greater frequency and intensity of extreme weather events—more and stronger hurricanes, winter storms, landslides, forest fires, heat waves, drought, and flooding. While the link between extreme weather and climate change took years to verify, climate scientists are now able to untangle the natural variability in climate and weather from the effects of global warming.

From 1995 to 2015, there were 6,457 weather-related disasters. Breaking this down by decade, there was a 14 percent increase for 2005–2014 over 1995–2004 and an increase of 200 percent over the level recorded for 1985–1994 (Table 14.1) (Center for Research on the Epidemology of Disasters [CRED] 2015).

These events claimed 606,000 lives—that is, 30,000 lives on average per year—and affected more than 4 billion people. Low-income countries suffer the most, but high-income countries were not without death and

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**A CLOSER LOOK**

**EXTREME WEATHER EVENTS**

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<th>Flood</th>
<th>Storm</th>
<th>Earthquake</th>
<th>Extreme Temperature</th>
<th>Landslide</th>
<th>Wildfire</th>
<th>Drought</th>
<th>Volcanic Activity</th>
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<td>5%</td>
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<td><strong>Number of people affected</strong></td>
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<td>660 million</td>
<td>a</td>
<td>94 million</td>
<td>8 milliona</td>
<td>1.1 billion</td>
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<tr>
<td>Number of deaths</td>
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<td>242,000</td>
<td>164,000</td>
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<td>22,000</td>
<td>a</td>
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</table>

*Data not given.
*Landslides and wildfires combined.*

Source: Adapted from Center for Research on the Epidemology of Disaster (2015).
injury. Because of greater infrastructure in higher-income countries, the economic loss was much greater than it was in low-income countries; however, it was a much smaller percentage of gross domestic product (GDP) (Figures 14.4 and 14.5).²

The economic cost of extreme weather events is also high. HSBC, one of the world’s largest financial services firms, estimates the cost of extreme weather to G20 countries from 2005 to 2014 at U.S. $309 billion. Of the 2014 cost of $44 billion, $11 billion came from droughts and $31 billion came from flooding. Indirect costs such as disruption of the supply chain, as happened when rain forced hard drive factories in Thailand to shut down, add significantly to the total (Holodny 2016).

The Summer of 2017

The summer of 2017 brought one natural disaster after another across the world. In Asia and Africa, the death toll was alarming. A heavy monsoon season brought...
flooding that killed more than 1,200 people in India, Nepal, Pakistan, and Bangladesh and forced millions from their homes. In Mumbai, India, which had some of its heaviest rainfall in 15 years, a building collapsed, killing as many as two dozen people and injuring dozens more. More than 3,000 villages in India and one third of those in Bangladesh were submerged (Dhillon 2017).

Tropical storms, intense rains, and mudslides killed more than 1,200 people across Africa in August 2017. In Freetown, Sierra Leone, a mudslide destroyed hundreds of homes and killed more than 1,000 people. A mudslide also claimed more than 200 lives in a village in the Democratic Republic of the Congo. Thousands of people were evacuated in Niamey, Niger, due to flooding that killed at least 40 people. Intense rains displaced more than 100,000 people in Benue state, Nigeria (Kazeem 2017).

In one of the most active and devastating hurricane seasons on record, Hurricanes Harvey, Irma, Jose, and Maria devastated Texas, Mexico, and the Caribbean, all within a month of one another. It is rare for a hurricane to “sit still,” yet Harvey hovered for five days, bringing 53 inches of rain along with devastation and death in parts of Houston. Irma’s path of destruction swept through the Caribbean and Florida. In the two-island nation of Antigua and Barbuda, Barbuda is now deserted, left uninhabitable by Irma. About 40,000 people were evacuated from St. Martin. Six islands of the Bahamas were evacuated. The death and destruction tolls would take months to figure. Maria left millions of people, more than three quarters of the population, without power and more than a third without drinking water at home in Puerto Rico. Nearly a thousand people had died and hundreds were missing a month later. It would be months, and in many places years, before living conditions could be restored. Some places never may be.

In September, a massive magnitude 8.1 earthquake killed 100 people in Southwest Mexico. This was followed the next day by Hurricane Katia on the east coast, and less than two weeks later another massive earthquake,
of magnitude 7.1, killed more than 200 people in Puebla near Mexico City and displaced thousands.

Strong winds, months of the highest ever recorded temperatures, heavy rainfall the previous winter, and years of prior drought combined to fuel wildfires that spread through eight California counties, more than 170,000 acres of California wine country (Figures 14.6 and 14.7). Fires are more frequent and larger throughout the western United States.

Hurricanes are a feature of the western Atlantic. They may form by Africa or Europe, but they cross the ocean to do their damage. Hurricane Ophelia behaved differently and in October struck in Ireland. It made the extreme event list for how strong it was for where it was. If the winds of 119 miles per hour on Fastnet Rock Island are verified, it would be the strongest ever to hit Ireland (Di Liberto 2017). Hundreds of thousands of people were left without power. Most was restored within 10 days (Power 2017).

Even if we stopped emitting greenhouse gases immediately, it would not stop global warming and climate change. CO₂ stays in the atmosphere for hundreds of years. The feedback loops will continue. Extreme weather events will also continue into the foreseeable future.

HEALTH AND NUTRITION EFFECTS

Death and injury due to extreme weather events are the most dramatic cost to human life. But there are other significant health effects. The most well-documented effects on health are those due to the impact of climate on the

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environment such as degradation of agriculture due to drought, flooding, hurricanes, and tornados, and vector-borne and parasitic diseases such as malaria, dengue, yellow fever, West Nile virus, plague, Lyme disease, and others carried by mosquitoes, ticks, and fleas. These types of disease account for 17 percent of deaths globally, and they are becoming more threatening.

As the climate warms and becomes wetter, vector-borne diseases may be more threatening for several reasons. As the climate warms, the habitat in which mosquitoes, fleas, and ticks can live expands. Their incubation time shrinks, which increases the period during which they can infect a host. Warmer temperatures increase their biting behavior. Increased rainfall increases stagnant pools and puddles, giving the parasites more breeding grounds. Drought pushes people out of rural areas into urban ones, increasing their likelihood of becoming infected. This means that more people spread over more regions are at greater risk of being bitten and infected over a longer period (World Health Organization–Western Pacific Region 2012).

For people with allergies and asthma, climate change will increase respiratory difficulties. Plant biology and plant growth are influenced by temperature, precipitation, and CO₂. This has been ignored in much of the literature on climate change impacts. The possible effects deserve serious study. Increased CO₂ contributes to plant growth and subsequently increasing growth and pollen production in trees, plants, and ragweed, intensifying respiratory allergies. As pollen production is increased several times with an increase in CO₂ and as pollen is seemingly becoming more allergenic, more people may become vulnerable (Ziska and Beggs 2012; Ziska, Epstein, and Schlesinger 2009).

Food supplies have received more attention. They are put into jeopardy with drought in some regions or too early of a snow thaw in others, whereby the water is present but earlier than it is needed and absent when it is needed. There is more to consider than that. Rising temperatures during the reproductive stages of plant growth can adversely affect fertility and fruit and grain production. Nutritional values of food are also affected. More CO₂ from pre-industrial times to the present has reduced the protein content and increased the carbohydrate content of spring and summer wheat. Rice paddy protein is decreased in the presence of higher temperatures and more CO₂. In some cases, increased CO₂ has increased nutritional value. Strawberry antioxidant capacity and mung bean omega-3 fatty acid increased with increased CO₂.
Increased CO₂, temperature, and precipitation all affect the efficacy of chemical weed and pest controls (Ziska et al. 2009). There are two potential scenarios. It could be that more crops are destroyed by pests, pathogens, and weeds that currently consume 42 percent of crops, or more chemicals could be applied. One of these decreases the food supply; the other increases harmful chemicals into the environment and degrades soil (Ziska et al. 2009).

Many questions remain to be answered. Which plant-based medicines will increase or decrease in potency? Will contact dermatitis (e.g., poison ivy and oak) increase in severity of cases, and will more people become allergic as the irritant urushiol increases in toxicity in reaction to increasing CO₂? Will poisons in plants increase in toxicity, becoming more lethal (Ziska et al. 2009)?

The earth’s natural carbon cycle has been altered. Even if all greenhouse gas emissions are eliminated, those still in the atmosphere and the changes they caused will keep the earth warming “by about 6°C over the next century” (NASA n.d.). Where ice and snow have disappeared, water and land will absorb radiation that formerly ice and snow reflected back. This will increase water evaporation, and water vapor—the most potent greenhouse gas—will increase the greenhouse effect. These feedback loops will

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**A CLOSER LOOK**

**GREENHOUSE GAS EMISSIONS AND ECONOMIC SECTOR**

**FIGURE 14.8 Total Annual Anthropogenic GHG Emissions by Gases, 1970–2010**

The rate of greenhouse gas emissions increased from 1.3 percent a year for 1970–2000 to 2.2 percent a year for 2000–2010. The largest increase (59 percent) was from CO₂, fossil fuels and industrial processes.

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continue without greenhouse gas emissions. How long it will take for temperature to stabilize cannot be determined. What is not in doubt is that thermal inertia will keep it rising (Royce and Lam 2013). This makes action to mitigate climate change all the more urgent.

**Greenhouse Gases**

Energy fuels the modern economy. The economic breakthrough of the Industrial Revolution was that it unharnessed massive energy stores found in fossil fuels that could do more work than humans and animals could do and could do it faster. This made electrification of homes and factories possible. It made mass production possible. The energy of fossil fuels and the machines that made use of them could produce enough food, clothing, and shelter for everyone in the world to live comfortably. The cost would not be realized until later. Before the Industrial Revolution, there was not significant inequality among nations. Most people in most nations were poor (Figures 14.8 and 14.9). With industrialization, some nations became wealthy and in doing so changed the climate.
As Europe and the United States took advantage of these productive capacities and became wealthy, greenhouse gases were accumulating. Although pollution by smoke and smog was abundantly evident in industrial towns of the 1800s, the long-term health and environmental effects of pollution and greenhouse gases (CO₂, methane, nitrous oxide, ozone, chlorofluorocarbons, and water vapor) were not evident until much later.

Energy, whether for our homes, industries, agriculture, or transportation, is the main source of greenhouse gas emissions and the key to climate change.

The energy sector is the single biggest contributor to global greenhouse gas emissions, accounting for 35 percent of anthropogenic emissions and 49 percent of energy emissions in 2010 (Bruckner et al. 2014). It takes energy to power economic growth and development. As societies move from agrarian to industrial economies and GDP per capita grows, energy use will grow along with it. Population growth increases energy use as well, but energy use per capita varies by income, lifestyle, available resources, and available technology. Richer nations still consume more energy per capita and release more greenhouse gases despite cleaner technologies (Blanco et al. 2014).

Per capita greenhouse gas emissions are higher in Organisation for Economic Cooperation and Development

![A CLOSER LOOK
GREENHOUSE GAS EMISSIONS BY WORLD REGION AND PER CAPITA BY WORLD REGION](image)

Although Asia now emits the largest share of greenhouse gases, the OECD countries emit far more per person, reflecting their much greater energy consumption per person.

**Figure 14.10** Aggregate GHG Emissions

*Source: Blanco et al. (2014). Reproduced with permission.*

(Continued)
(OEC) countries than in Asia, although Asia has more total greenhouse gas emissions. Key drivers vary by region. In OECD countries, the primary driver is GDP per capita. This is also the case since about 2000 in “economies in transition” (former Warsaw Pact centrally planned economies). Wealthier countries use more energy as the demand for electricity and goods grows and lifestyles of people change. In Asia, Latin America and the Caribbean, and the Middle East and Africa, it is fossil-based energy (territorial use). However, in Asia the second driver is GDP per capita, but in the other two regions the second driver is population (Blanco et al. 2014). In terms of per capita emissions, OECD countries increased energy use about 13 or 14 percent since 1990, whereas Latin America and the Caribbean increased 60 percent, Africa and the Middle East 90 percent, and China 200 percent, reflecting their economic growth and development. However, these three regions are still using only half of the OECD rate per capita of the 1970s (Figures 14.10 and 14.11) (Blanco et al. 2014). While cleaner fuels and technology allowed countries in the developed world to decrease their emissions of CO₂ in recent decades, they still emit significantly more greenhouse gases per capita than the developing regions—10 metric tons per person per year as opposed to 3 metric tons in developing regions. As noted in the 2015 Millennium Development Goals report, the developing regions increased their emissions nearly threefold, from 6.7 to 19.8 billion metric tons per year, due to increasing

**FIGURE 14.11** Per Capita GHG Emissions

<table>
<thead>
<tr>
<th>Year</th>
<th>OECD-1990</th>
<th>LAM</th>
<th>MAF</th>
<th>ASIA</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td></td>
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<td></td>
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<tr>
<td>1990</td>
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<tr>
<td>2000</td>
<td></td>
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<td></td>
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<tr>
<td>2010</td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>


**Note:** EIT = Economies in Transition; LAM = Latin America and Caribbean; MAF = Middle East and Africa.
CONSIDER THIS

THE MECHANICS OF EXTREME WET AND DRY WEATHER EVENTS

The science behind temperature and extreme weather is well established. Hundreds more extreme weather events occur yearly than would occur without climate change. Others would have occurred in any case but with less intensity.

A few principles account for the basics of how various forms of extreme weather are produced. Greenhouse gases trap radiation in the atmosphere. This increases the temperature of the atmosphere. This heat is a source of energy. For every 1°C increase in temperature, moisture in the air increases 7 percent. The increase is not evenly spread around the globe. In some places it is higher, and in others it is lower. For example, Des Moines, Iowa, has had a 13 percent rise in moisture over 50 years.

The increase in moisture brings about an increase in precipitation, rain, and snow. There is a 2 or 3 percent increase for every 1°C increase in warming. The extra moisture plus the extra energy results in a 6 or 7 percent increase in extreme rainfall. Increased intensity of storms means more flash flooding.

When moist warm air meets cooler drier air, thunderstorms result. When there is a rotational source, such as the warm moist air from over the Gulf of Mexico meeting the strong jet stream from the west, tornadoes develop, as happened tragically in the string of tornadoes that hit in April 2011 (Smith et al. 2014).

Drought and Heat Waves

The Union of Concerned Scientists (n.d. a) differentiates three types of drought: meteorological, which is dryness relative to usual rainfall; hydrological, which relates to low water in water systems; and agricultural, which is when there is too little water to meet the demands of crops. The American Southwest is one of the most drought-sensitive areas of the world. Droughts cost the United States about U.S. $9 billion a year.

The consequences of extreme weather events extend beyond the immediate damage in lives lost and infrastructure destroyed. There are also long-term impacts on individuals and communities. While infrastructure may be rebuilt, communities are destroyed. Individuals move on, but the psychological costs and destruction of families continue.

In the least developed nations, agriculture accounts for nearly all greenhouse gas emissions, nearly 90 percent. As these populations urbanize, their energy use and emissions will increase. Help of more developed nations will be critical in mitigating related greenhouse gas issues. Other important drivers of greenhouse gas emissions are agriculture, forestry and other land use, transport, waste, and industry (Blanco et al. 2014).

THE ENVIRONMENTAL REGIME

The global environmental regime is a complex network of nongovernmental and governmental organizations at the local, national, regional, and global levels. It has grown slowly as people increasingly recognized the threat to environments posed by human activity. From its beginnings in the preservation of particular species threatened with extinction to concern for the global threat posed by climate change, it has grown to encompass treaties,
regulations, and programs to analyze environmental problems, legislative provisions to combat them, and actions to remediate and solve them. Many other treaties such as those on trade and jobs also contain environmental concerns. International environmental associations, treaties, and intergovernmental organizations all now number over 150 (Meyer et al. 1997).

COP21, held in Paris in December 2015, was the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change. The convention originated in negotiations at the Earth Summit in Rio de Janeiro, Brazil, in 1992 and entered into force in 1994. COP21, the Paris accord, is the latest conference and the newest set of accords. It will enter into effect after at least 55 countries that are party to the convention and whose total greenhouse gas emissions cumulatively represent 55 percent of the global total ratify it (Article 21). The convention reiterates many of the provisions of past treaties and establishes responsibilities for monitoring their terms.

The substantive text of the treaty is in Article 2. The first point of Article 2 calls on countries to strengthen “the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty,” including to do the following:

- Hold the increase in the global average temperature to well below 2° C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5° C above pre-industrial levels
- Increase the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production
- Make finance flows consistent with a pathway toward low greenhouse gas emissions and climate-resilient development (United Nations [UN] 2015)

These provisions make it clear that poverty reduction and food security are important goals that must be achieved but within the context of sustainability. In other words, food security and poverty eradication must be achieved in such a way as to secure the long-term health of the world. Funding should be consistent with these aims. The second point in Article 2 makes it clear that different nations have different capacities to contribute to these goals. Thus, equity does not mean every country being treated in the same way or subject to the same expectations. Rather, within the overall goal, expectations for each country will vary in relation to its capacity.

Other articles of the agreement clarify that international cooperation, sharing of best practices and technology, and financing should be directed at building the capacity of countries to mitigate and adapt to climate change. Other expectations are for transparency in countries’ actions and support of others. It also calls on “non-party” actors such as civil society groups, philanthropies, the private sector, cities, and other subnational authorities to support actions to reduce greenhouse gas emissions.

“GREENING” THE EARTH: SUSTAINABLE DEVELOPMENT

As this chapter emphasizes, even if we eliminated all greenhouse gas emissions, the globe would continue to warm and the climate would continue to change. That does not mean that there is nothing we can do. Mitigating climate change and adapting to it will increase the health of the planet and subsequently human health and well-being and that of animal and plant life as well.

Stalling Climate Change

Green chemistry and a circular economy, as discussed in Chapter 13, are important steps to reduce greenhouse gases, conserve resources, reduce hazardous substances, grow healthier food, and help restore our ecosystems. They are not enough to stop global warming and climate change. We need to significantly reduce or eliminate anthropogenic sources of greenhouse gases. How close to stalling global warming are we?

Carbon Reduction Through Carbon Pricing Strategies

Cap and trade (emissions trading system), carbon tax, clean coal, and carbon sequestering are strategies that aim to reduce carbon and other pollutants in the atmosphere by reducing the amount of source carbon or preventing carbon released in combustion from polluting the environment. The costs of greenhouse gases and other
carbon pollution—the externalities—are staggering in all of the damage to health, the natural environment, and our built environment. Carbon pricing is a strategy to make the polluters pay for the damage they do.

Many environmental and industry groups support carbon pricing. Cap and trade is the most common form. Every country’s programs are somewhat different, but all cover CO₂ and most major industrial sectors such as transportation, power generation, and manufacturing. The “cap” is an upper limit to the emissions allowed by a major pollution source. Each cap represents a portion of the reductions in greenhouse gases necessary for a country to meet targets. Polluters covered under the policies have a cap, or allowance, to release a certain amount of carbon. The caps are to be adjusted downward yearly.

The trade comes into play because a polluter may release more pollutants than its cap allows provided that it buys allowance from an entity that is emitting less than its cap. Allowances may be bought from any participating countries. This opens up an international market for emissions and puts a price on emissions, which should be motivation to reduce pollution. As of 2016, 35 countries, 17 provinces or states in the United States and Canada, and 7 cities (5 in China and 2 in Japan) were participating. When China began its national program in 2017, participants accounted for 49 percent of global GDP (International Carbon Action Partnership [ICAP] 2016).

The European Union initiated cap and trade for greenhouse gases and all large industrial facilities in 2005, aiming at a 20 percent reduction by 2020. After the Paris meetings, an accelerated timetable was set for the 2020–2030 period aiming at a 43 percent reduction from 2005 levels to meet its new target—a reduction of 80 to 95 percent by 2050 (ICAP 2016). Through a combination of policies, the U.S. state of California reduced greenhouse gas emissions per GDP by 20 percent and per capita by nearly 15 percent from 2000 levels (ICAP 2016).

Cap and trade is one method of making industries pay for the privilege of polluting more than their allowance. A direct tax is another. Eighteen countries, cities, or states put a direct tax on carbon. The province of British Columbia reduced fuel usage 16 percent and per capita emissions 3.5 times faster than the rest of Canada. Industry leaders, academics, non-profits, and politicians credit the carbon tax for their success. Because every dollar that the tax generates goes to the public by way of reduced taxes, it has broad appeal. Plans to increase the tax in 2018 were under way.

One lesson to take away from the success of carbon pricing strategies is that industries can be weaned from carbon resources and that carbon pricing may motivate movement toward renewable resources.

Carbon Capture and Sequester

Nearly every plan to reduce climate change calls for reduced but continuing use of fossil fuels at least until 2050. What to do with CO₂ is a problem that cannot be ignored. Carbon capture requires separating carbon from other combustion emissions and trapping it before it escapes. This is an expensive process. After capturing carbon, it must be sequestered. This requires piping it as a gas or transforming it into a liquid so that it can be piped to a suitable location.

From southwest Colorado, drillers piped a huge bubble of CO₂ gas to west Texas to be used in oil recovery. There it is forced into the ground to force oil out of pockets to the surface. Hopefully it will stay there. Gas captures are now planned for power plants that will pipe the gas to oil fields. Storing CO₂ in gaseous or liquid form risks its leakage from storage. Necessary monitoring for leakage adds to the expense (Biello 2014).

Ideally, carbon sequester, if used, would lock the gas into a solid form. The CarbFix Project dissolves the gas with water, making soda water, and pumps it into basalt rock, where it forms calcite, turning it into stone. Experiments in Iceland, which is nearly all basalt, demonstrated that in less than two years 95 percent of the CO₂ turned to calcite. There are still problems to be overcome. The process would need to be scaled up enormously, and it consumes a lot of water. But salt water can be used, and basaltic rock is common along continental margins and the ocean floors (Fountain 2016). While this is not a fix for global warming, it may contribute to a solution for as long as we are burning fossil fuels. Carbon pricing can reduce the expense.

Renewables and Non-Carbon-Based Strategies

The technical capacity of renewables to meet energy demands far exceeds current use. A 2011 IPCC study of 160 scenarios modeled by more than 120 researchers reported that as much as 80 percent of global energy demand could be met by renewables by 2050, cutting greenhouse gas emissions by a third and keeping the
global temperature rise below 2°C, the target set by COP21 in Paris. Currently, close to 24 percent of global energy needs are met by renewables when nuclear energy is included as renewable. Renewables are not necessarily greenhouse gas neutral. The benefits depend on how the resource was acquired, how it is used, construction and operation of the facility, storage, and disposals of wastes. For example, low-grade uranium with a high energy input for mining and milling will have a larger carbon emission than a richer ore with less extensive mining and enrichment.

There are other variables to figure as well. However, nearly every renewable technology, other than charcoal and some other biomass methods, emits far fewer greenhouse gases per kilowatt hour than fossil fuel burning (Table 14.2).

The share of renewables of total energy is growing, albeit slowly. If we omit dams built decades ago from the data above, renewable energy’s contribution is much smaller. If we omit all dams—China has been building many in recent years, not only in China but also in South America and Africa—it is smaller still. In developed

### TABLE 14.2 Estimated Renewable Energy Share of Total Energy Consumption, 2015

Renewable energy is still a small portion of the global total energy used.

<table>
<thead>
<tr>
<th>Type of Fuel</th>
<th>% Use in 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil</td>
<td>78.4</td>
</tr>
<tr>
<td>Renewable</td>
<td>% Use in 2015</td>
</tr>
<tr>
<td>Traditional biomass</td>
<td>9.1</td>
</tr>
<tr>
<td>Modern renewables</td>
<td>10.2</td>
</tr>
<tr>
<td>Modern renewables</td>
<td>% Used in 2015</td>
</tr>
<tr>
<td>Biomass/geothermal/solar heat</td>
<td>4.2</td>
</tr>
<tr>
<td>Hydropower</td>
<td>3.6</td>
</tr>
<tr>
<td>Wind/solar/biomass/geothermal power</td>
<td>1.6</td>
</tr>
<tr>
<td>Biofuels for transport</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Source: Adapted from REN 21 Secretariat (2017).

Note: Biomass and biofuels are renewable but vary in the amount of carbon and many other pollutants they generate. Some biofuels are considered carbon neutral because the CO₂ they produce is offset by growing them.
countries, there is little demand for growth in energy. Populations are not increasing (except in the United States), the energy infrastructure is in place, and there are large stocks of fossil fuels. In developing societies, the move toward industrialization and economic growth along with still increasing populations is driving a rapidly increasing demand.

The Energy Grid and Distributed Renewable Energy

In the developed world, energy grids may stretch across a continent. To get an idea of how large these grids are, consider what happened in a power failure, a blackout. In 1965, 30 million people across Canada and the U.S. Northeast had no power. In 2003, a power line in Ohio brushed against trees, shutting it down, and ultimately 50 million people in the U.S. Northeast and Canada were without power. In India in 2012, half of the country was left without power. Across Germany, Italy, France, and Spain, 10 to 15 million people lost electricity when a German power company switched off a line to allow a cruise ship to pass through the River Ems. China, Thailand, Brazil, and Paraguay all experienced major blackouts. In all of these, people were stranded in subways, in mines, on trains, and in elevators—often without water. People died.

Now the grids of developed countries are aging. Utility companies are talking about smart grids. But whether or not they are better or safer from a cyberattack is debatable. Increasingly, people are considering going “off the grid” or forming much smaller local grids. And in the developing world, where many people are still without electricity, distributed renewable energy is probably the smartest strategy.

Sub-Saharan Africa is one of the most energy-deprived regions in the world; two thirds of the people living there, more than 600 million, do not have access to electricity. Many of these people use dangerous and hazardous sources indoors such as kerosene lamps and inefficient wood-burning stoves. Although many of these people may someday be connected to grids, that prospect is far off for most or may never happen. “Power Africa” is a collaborative effort led by U.S. Agency for International Development partnering with African governments, global philanthropies, aid organizations of other developed countries, and more than 100 private sector partners. The commitment is to add 30,000 megawatts by supplying electricity to 60 million new homes and businesses that are currently without power. The project combines extensions of existing grids and off-the-grid projects. For this to be successful, policy, regulatory, financing, and technical expertise all need to fall into place. The projects need to be environmentally and financially sustainable. Bomi Safi, for example, is a one-woman company in Kenya. She mobilizes women to distribute solar-powered products such as cooking stoves. This type of simple but sophisticated off-the-grid answer can significantly raise the quality of life for millions (Makoye 2016; U.S. African Development Foundation 2016).

Electricity expands life chances; from refrigeration for food and medicines, to studying at night, to starting a small business with a sewing machine, every dimension of life chances is improved with power. Renewable solutions can be as simple as solar-powered lanterns to provide nighttime light or a biomass generator to run a sewing machine. Challenge Power Africa is a competition for entrepreneurs to bring off-the-grid solutions to underserved populations.

Award-winning off-the-grid small projects are wonderfully inventive. Here is a sampling. These were chosen as among the 10 weirdest energy innovations by Smart Villages:10

- GravityLight supplies 20 minutes of continuous light by lifting a bag of dirt with a pulley and letting it down slowly. There are no solar panels, no batteries, and no harmful fumes.
- SOCCKET II is a soccer ball (football) that, after 30 minutes of play, can power a lamp for 3 hours.
- Cloud Collective developed a device whereby tubes of algae could be connected to roads and bridges to feed off the transport CO₂ emissions. The crop could be harvested at some point to make a viable biofuel.
- Hydro Electric Barrel generates enough electricity to power refrigeration by spinning and bobbing in a stream or river.
- Sanitation for human waste and medical equipment is important to the developing world. An off-the-grid device using nanoparticles to concentrate sunlight to heat is so effective that it can turn icy water to steam for sanitizing in...
seconds. The Bill and Melinda Gates Foundation awarded this invention a grant for development. (Fitzgerald 2016)

The Solutions Project: 100 Percent
Clean Is 100 Percent Possible

By 2050, 100 percent renewable energy could be a reality, according to a multi-institution research team centered at the Stanford University Atmosphere/Energy Program. The 100 Percent Project is an extremely detailed plan, a roadmap, of how each of 139 countries and each of the 50 U.S. states can reach the 100 percent renewable 2050 target and an 80 percent renewable 2030 target. The plan does not figure in conservation measures that require “sacrifices” but rather is a “business as usual” plan. It does not rely on technologies that do not exist. It does not build any new dams or nuclear plants. All of the energy in the plan comes from water, sun, and wind.

Each roadmap calculates and includes the types of energy available in each country and strategies for using each. This includes the following:

- The future demand for every energy sector—electricity, transportation, heating/cooling, industry, and agriculture/fishing/forestry
- The number of wind, water, or sunlight energy generators and the footprint and spacing areas needed to meet demand for each case
- The rooftop areas and solar photovoltaic potentials existing on buildings, carports, garages, parking lots, and parking structures
- The adjusted costs of energy in 2050

The roadmap also includes, in great detail, the benefits that will be realized by the roadmaps:

- Avoiding trillions of dollars a year in damage costs from acid rain and other pollution
- Reductions in trillions of dollars a year in ambient CO₂ and global warming costs
- 51.4 million jobs created globally, more than offsetting the expected loss of 27.1 million jobs in the old energy industry, for a net gain of 24.3 million long-term good jobs
- Price stability (oil prices fluctuate, sometimes wildly)
- The revenue that will be gained
- Energy efficiency (electricity has a higher work-to-energy ratio than combustion)
- Reduced international conflict over energy
- Elimination of “energy poverty”
- Reduced large-scale system disruption through power outages or terrorism

The roadmaps also supply a blueprint by way of a transition timeline and recommended policy measures to implement the roadmaps (Jacobson et al. 2016).

The Solutions Project does not include nuclear facilities, carbon capture, biofuels, or natural gas. It does not add any new hydropower plants but includes existing ones. The technologies that it uses and the contribution of each one to global energy are “19.8 percent onshore wind, ~12.7 percent offshore wind, ~40.8 percent utility-scale photovoltaic (PV), ~6.5 percent residential rooftop PV, ~7.0 percent commercial/government/parking rooftop PV, ~7.7 percent concentrated solar power (CSP), ~0.73 percent geothermal power, ~0.38 percent wave power, ~0.06 percent tidal power, and ~4.3 percent hydropower” (Jacobson et al. 2016).

For light ground transportation, battery electric vehicles and hydrogen fuel cells are planned. All processes relating to transportation by land, air, and sea can be electrified, many by 2030, such as small-scale marine, rails and buses, and heavy-duty truck transport. High-efficiency electric appliances, many of which are already in use, will replace the appliances and technologies that are now gas, oil, or coal driven, even for high-temperature industrial facilities (Jacobson et al. 2016).
SUMMARY

Climate change is the greatest global security threat. Extreme weather events, rising seas, and slow degradation of environments force more people from their homes than any other cause, including war. Climate-driven drought exacerbates food shortages and leads to social unrest. Unless stalled, climate change is likely to add millions more people to the refugee crisis. Although forces already set in motion, such as rising sea temperatures, cannot be immediately halted, climate change can be slowed and kept from becoming catastrophic.

The developed world grew rich through cheap and unlimited use of fossil fuels, filling the atmosphere with greenhouse gases and creating the conditions of climate change in the process. Population growth and improving the living standards in countries at low levels of development will increase demands for energy. These countries must be helped to invest in and rely on clean energies. Replacing fossil fuels with renewable energy and developing efficient mass transportation systems and low- or no-carbon vehicles are necessary steps. Preserving air, land, and water so that it may continue to support life is a necessity.

DISCUSSION

1. Compare and contrast strategies to combat climate change. Which hold the most promise? Consider those in the text and others that you may investigate.

2. The U.S. state of California has developed one of the most ambitious programs to combat climate change. Investigate its plans and report on its goals and strategies that you find promising or innovative. California’s plan, the highlights, strategies for sectors, and legislation can be found at this site: http://climatechange.ca.gov. Specific plans for greenhouse gases are also at this site: http://www.arb.ca.gov/cc/cleanenergy/clean_facts.htm.


4. The competing interests of generating or maintaining jobs and the cost of environmental protections are vigorously debated. Gather evidence on both sides of this debate and evaluate which side has the stronger argument.

5. Assess the impacts of climate change where you live. There are a number of sources for every continent. A few are suggested below.

6. An important factor in solving every global problem is considering the responsibility of richer developed nations to poorer nations. Do richer nations owe poorer nations help in developing cleaner and healthier technologies? Why or why not? If they do, how much help should they provide?
ON YOUR OWN

1. *National Climate Assessment: Future Climate* has interactive maps of the United States that illustrate potential future climate and weather scenarios given both lower and higher emissions of greenhouse gases. It proposes scenarios for the following dimensions of climate: temperature change, soil moisture, precipitation, consecutive dry days, and sea level rise (http://nca2014.globalchange.gov/highlights/report-findings/future-climate).

2. What sacrifices are people willing to make for a sustainable environment? Investigate the survey questions concerning the environment asked in the World Values Survey. Choose a developing country and a developed country to compare and contrast. Compare answers within a country by age and educational level. http://www.worldvaluessurvey.org/WVSOnline.jsp

   Protecting environment vs. economic growth

   - Past two years: Given money to ecological organization
   - Past two years: Participated in demonstration for environment

3. Investigate the Solutions Project Roadmap for your country or U.S. state:

   http://thesolutionsproject.org/why-clean-energy

   How does its formulas for renewable energy potentials compare with those of the National Renewable Energy Laboratory?

   https://www.nrel.gov/docs/fy12osti/51946.pdf

   After reading both of these projections, how feasible is a 100 percent renewable plan? What are the advantages, and are there any disadvantages that the plans may be overlooking?

NOTES

1. The 2°C rise in temperature is in comparison with the 1951–1980 baseline.

2. Permafrost is land that remains at 0°C for at least two years.

3. For the greenhouse effect of greenhouse gases, see the EPA’s Overview of Greenhouse Gases (https://www3.epa.gov/climatechange/ghgemissions/gases/ch4.html).


5. The WWF–Coca-Cola campaign raised $2 million in donations for polar bears. The polar bear has been the Coca-Cola mascot (WWF 2012).

6. Data on deaths, injuries, and economic losses are underreported for many low-income countries. For example, economic losses were reported for only 12.5 percent of disasters (CRED 2015).

7. Vector-borne diseases are those that are transmitted from one organism to another, usually by an arthropod such as a mosquito, tsetse fly, flea, or tick.

8. The EPA distinguished direct greenhouse gases, which are listed above. The indirect ones are “CO [carbon monoxide], NOx [nitrogen oxides], NMVOCs [non-methane volatile organic compounds], and SO2 [sulfur dioxide]. These gases do not have a direct global warming effect, but indirectly affect terrestrial radiation absorption by influencing the formation and destruction of tropospheric and stratospheric ozone, or, in the case of SO2, by affecting the absorptive characteristics of the atmosphere. Additionally, some of these gases may react with other chemical compounds in the atmosphere to form compounds that are greenhouse gases” (taken from the EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2013 published in April 2015: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990–2013.
9. Cap and trade was introduced in the United States in 1990 and used successfully in helping to reduce sulfur dioxide and nitrogen oxides in the environment, combating acid rain.

10. Smart Villages held workshops in every region of the developing world—six workshops over a three-year period from 2014 to 2017—to bring energy innovations to policy makers, donors, and development agencies. Two final workshops were to be held in Brussels and Addis Ababa to bring all of the lessons learned to the UN and other global actors. There are many more inventions on the Smart Villages website (https://e4sv.org).

11. The Solutions Project roadmaps are a much more detailed and refined set of projections based on a series of earlier projections by the head authors, Mark Z. Jacobson and Mark A. Delucchi. “100 Percent Clean 100 Percent Renewable” is a motto of sorts for the project.