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CLIMATE CHANGE SCIENCE

The Facts

In this chapter, we present a short summary of weather and climate as well as an overview of climate change causes, evidence, and impacts. We also introduce actions needed to reduce greenhouse gas emissions, thus mitigating climate change. Because environmental educators know their communities, they can play a key role in distilling scientific information and guiding discussion about complexities associated with weather, climate, and climate change. They can also lead their students and communities in taking meaningful action to reduce greenhouse gases.

Weather and Climate

Weather varies minute to minute, hour to hour, day to day, month to month, and season to season. Temperatures go up and down; some days are cloudy and rainy, while others are sunny; and sometimes the air is still, whereas other times we are refreshed by a gentle breeze or buffeted about by a strong wind. Occasionally, we get floods or droughts.

In contrast to the short-term atmospheric changes we call weather, climate refers to longer-term variations. We can think of climate as the *average* weather for a particular region and time period, usually over thirty years. For example, increases in average temperatures over decades provide evidence of a changing climate. Looking to the future, scientific climate models predict longer and more severe periods of dry weather in some regions, while other regions will likely experience an increase in annual precipitation, as well as more severe rain events. In 2017, warmer and wetter atmospheric conditions and warmer ocean temperatures intensified Hurricanes Harvey, Irma, and Maria in the eastern United States, while dry weather exacerbated California wildfires—all the result of a warming planet. The more extreme weather events that we are experiencing currently will likely only intensify as average global temperatures continue to rise.

Greenhouse Gases and Climate Change

Humans, like all life on earth, depend on energy coming from the sun. But we also depend on the energy reflected from the earth's surface back into the atmosphere. This balance between energy coming in and energy going out has been maintained for billions of years, allowing life on earth to survive and thrive.

But what happens if excess greenhouse gases in the earth's atmosphere block more energy from leaving the atmosphere, upsetting that balance? What if, instead of leaving the atmosphere and going back into space, some of the excess energy is returned to the earth's surface? Put simply, the surface of the earth—including its oceans, land, and air—heats up.

Greenhouse gases are essential to life on earth. For example, plants depend on carbon dioxide (CO_2), which is also an important greenhouse gas contributing to global warming. And greenhouse gases help to maintain the earth's surface and oceans at temperatures that enable life to flourish on our planet. But as greenhouse gases accumulate beyond their historic levels, they prevent more and more of the energy reaching the earth from going back into space.

The earth absorbs sunlight energy and reemits it as heat, or what scientists call long-wave infrared radiation. Imagine this infrared radiation heading toward space. It bumps into gases in our atmosphere, like oxygen and nitrogen, and continues on its way. But if it bumps into a molecule of a greenhouse gas—say CO_2—that molecule absorbs the infrared radiation coming from the earth's surface. The molecule of CO_2 then vibrates and releases heat. The heat from the molecule can go in any direction, including up toward space or back down toward the earth.

So far, no problem. Some heat radiates out to space, and some warms up the atmosphere, oceans, and land surface (figure 1.1). But when humans start changing the balance of gases in the atmosphere—specifically, by significantly increasing the concentration of CO_2 and other greenhouse gases—more heat is emitted, including heat headed back toward the earth's surface. This leads to warming of the atmosphere, the oceans, and the land surfaces.

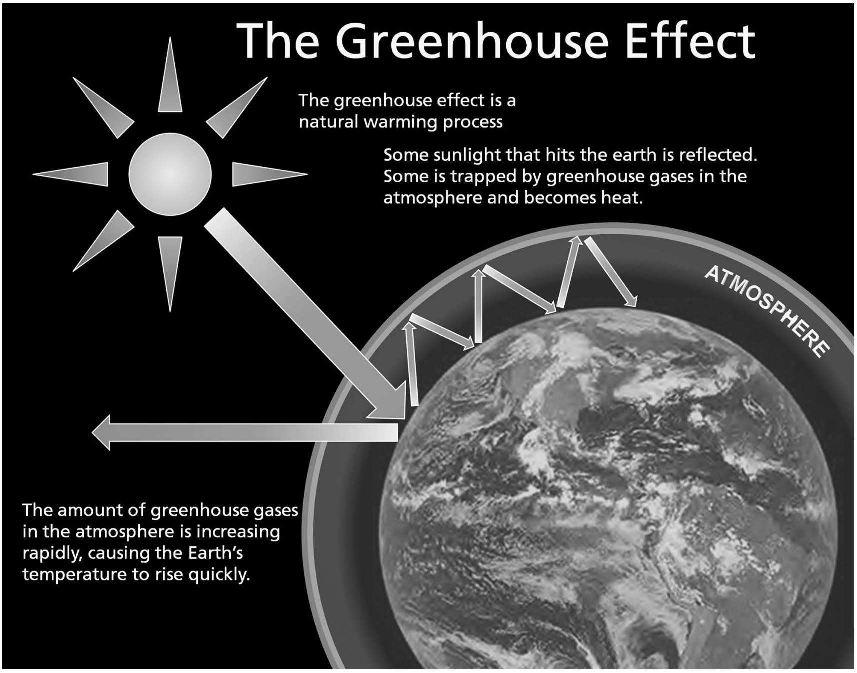

FIGURE 1.1 The greenhouse gas effect
Lindsay Modugno, Jeff Pace, and Dan Lidor, "The Effects of Climate Change and Sea Level Rise on the Coast," Sandy Hook Cooperative Research Programs, January 2015

To help people envision this process, scientists have used the analogy of a blanket surrounding the earth. On a cold night, you sleep under a blanket, and your body generates heat. The blanket traps that heat, allowing you to sleep through the night. But if your blanket is too thick, it may trap too much heat, and you start sweating and feel uncomfortable. So you can imagine the earth as being wrapped in a blanket of greenhouse gases that is trapping more heat.

So what are these greenhouse gases, and where do they come from? The most common greenhouse gas is carbon dioxide, or CO_2, which accounted for 82 percent of U.S. greenhouse gas emissions by weight in 2015 (figure 1.2). When we burn fossil fuels like coal, natural gas, and oil, which consist largely of carbon, the carbon combines with oxygen to form CO_2. Other sources of CO_2 include burning wood and decomposition of solid waste. Cement manufacturing is another significant source of greenhouse gases, accounting for 5 percent of global CO_2 emissions.[1]

Other greenhouse gases are less common but more potent than CO_2—that is, they absorb and release more heat per pound emitted. These include methane,

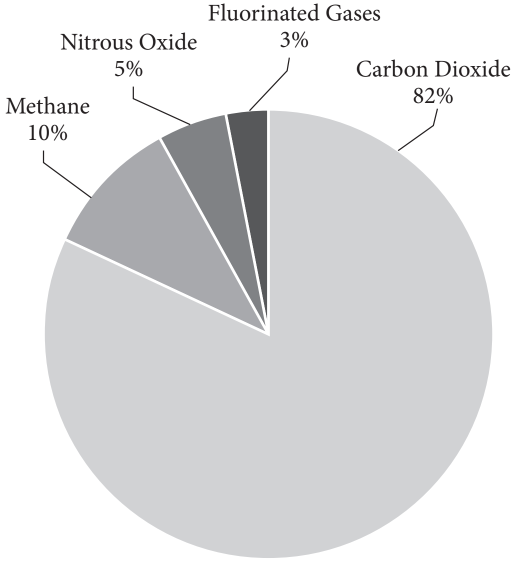

FIGURE 1.2 U.S. greenhouse gas emissions in 2015
U.S. Environmental Protection Agency, 2017

which accounted for 10 percent of U.S. greenhouse gas emissions in 2015. Methane (CH_4) is emitted in the mining and transport of natural gas, by livestock, through rice cultivation and other farming practices, and when organic waste in landfills decomposes. Similarly, nitrous oxide (N_2O), 5 percent of emissions, is emitted by agricultural and industrial activities, burning fossil fuels, and solid waste decomposition. Finally, fluorinated gases are produced by some industries and have the highest global warming potentials. Whereas methane is about thirty times more potent as a greenhouse gas relative to CO_2, nitrous oxide is nearly three hundred times as potent, and fluorinated gases can be thousands or even tens of thousands of times more potent.[2]

In fact, scientists have known about the heating effect of CO_2 since the 1850s, when the scientist John Tyndall conducted meticulous experiments on the ability of atmospheric gases to absorb and transmit radiant heat.[3] He found that CO_2 absorbed heat more readily than other atmospheric gases, like oxygen and nitrogen, which have simpler molecular structures relative to CO_2. Tyndall also speculated that small changes in gasses that absorbed the sun's heat "would produce great effects on the terrestrial rays and produce corresponding changes of climate"[4]—something that has since come to pass.

But even before Tyndall, Eunice Foote conducted an experiment in which she placed cylinders containing CO_2 and normal air in the sun and compared their temperatures. Just as Tyndall grasped the connection between CO_2 heating up faster than other gases, Foote wrote about CO_2: "An atmosphere of that gas would give to our earth a high temperature; and if as some suppose, at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature from its own action as well as from increased weight must have necessarily resulted."[5]

It appears that Foote was not allowed to present her work at a scientific conference, as female presenters were uncommon in that era. Instead, in 1856, Professor Joseph Henry presented Foote's work at the meetings of the American Association for the Advancement of Science in Albany, New York, where he prefaced his explanation by pointing out that science is "of no country and of no sex."[6] More recently, researchers discovered that Foote herself published a short paper outlining her results recounting how the container containing CO_2 (known at the time as "carbonic acid gas")

> became itself much heated—very sensibly more so than the other—and on being removed, it was many times as long in cooling. . . .
>
> . . . On comparing the sun's heat in different gases, I found it to be in hydrogen gas, 104°; in common air, 106°; in oxygen gas, 108°; and in carbonic acid gas, 125°.[7]

In short, thanks to the experiments of Foote and Tyndall, we have known for over a century and a half about the connection between CO_2 and heating of the atmosphere.

Evidence of Climate Change

So far, we have explored the mechanisms for how greenhouse gases trap heat. But what is the evidence that the earth's climate is heating up? And even if it is warming, how do we know that factors other than greenhouse gases are not responsible? The evidence comes from measurements of greenhouse gases in the atmosphere and of recent and historical changes in the earth's surface temperature.

Between 1970 and 2000, total greenhouse gas emissions from human activities like burning fossil fuels increased an average of 1.3 percent each year. Between 2000 and 2010, total emissions increased an average of 2.2 percent per year. While this may not seem like a lot, it is similar to compound interest rates—a little bit each year can mean big changes over multiple years.

In the year 1970, humans emitted twenty-seven billion tons of greenhouse gases into the atmosphere, whereas by 2010, we emitted forty-nine billion tons of greenhouse gases per year.[8] Focusing just on CO_2, in 1850, around the time

Foote and Tyndall were conducting their experiments, the average CO_2 concentrations in the atmosphere were about 280 ppm (parts per million).[9] As of 2016, the global average CO_2 level in atmosphere was 403 ppm and increasing by 2–3 ppm per year. The last time earth's atmospheric CO_2 concentration exceeded 400 ppm was three to five million years ago, a time when global temperatures were 2° to 3°C warmer and sea levels were ten to twenty meters higher than today.[10]

Just since the late nineteenth century, the planet's average surface temperature has risen about 1.1°C (2.0°F). The current rate of warming is roughly ten times faster than the average rate of warming after ice ages of the past million years.[11] And for each decade since 1950, the global average land and ocean surface temperatures have been warmer than those for the preceding decade.[12] Temperatures are increasing faster over land and in the Northern Hemisphere than over the ocean and in the Southern Hemisphere. Temperatures are increasing fastest in the high northern latitudes such as Alaska, northern Canada, and Russia, and across the Arctic.

Could these changes be the result of natural shifts in the earth's climate? A number of natural processes cause the earth's climate to change over time. Variations in the earth's tilt and orbit around the sun, called Milankovitch cycles, change the earth's climate over the course of tens or hundreds of thousands of years by impacting how much solar radiation reaches the earth.[13] Additionally, the El Niño and La Niña ocean warming and cooling cycle impacts temperatures and rainfall in places around the world.[14] These patterns still affect earth's climate today, but their influence over decades or even centuries is very small, much smaller than the rate of change we are now measuring. In short, these natural patterns do not explain the rapid warming that the earth has experienced since the onset of the Industrial Revolution.[15] Instead, we know from multiple sources of evidence—including long-term observations, experiments, modeling, and measurements showing that recent changes in weather patterns fit with the predictions of greenhouse gas climate change models—that increases in human-emitted greenhouse gases are responsible for climate change.

Interestingly, some natural processes also result in cooling of the earth's climate. In 1783, while he was serving as a diplomat in Paris, Benjamin Franklin observed that both Europe and the United States experienced unusually cold temperatures, as well as a constant fog. Although Franklin may not have discerned the cause, we now know that catastrophic volcanic eruptions in Iceland not only rained acid on the island itself, devastating livestock and causing widespread famine, but also caused cooling in Europe and North America. Volcanic eruptions spew tiny ash particles in the atmosphere, which decrease the amount of sunlight reaching the surface of the earth, thus lowering average global temperatures. Volcanoes that release large quantities of sulfur dioxide have an even greater effect on global temperatures; the sulfur dioxide combines with water to make a haze of tiny droplets of sulfuric acid that absorb incoming solar radiation and scatter it back out into space, thus cooling the earth's surface. Scientists today are reconstructing the history of earth's climate using tree rings and other data sources and have noted multiple periods of cooler temperatures following volcanic eruptions, which they refer to as "little ice ages."[16] However, scientists do not expect such volcanic eruptions to counteract the effects of greenhouse gas emissions.

Climate Change Impacts

In addition to scientists, many people whose lives and livelihoods are affected by changes in our oceans and on land have observed the impacts of climate change. These include coastal residents, farmers, fishermen, and leaders in the armed services. In this section, we briefly review some of these impacts.

Ocean Waters Are Becoming More Acidic

About one-quarter of the CO_2 humans produce each year is absorbed by oceans. This CO_2 reacts with seawater to form carbonic acid, thereby increasing the ocean's acidity. Similar to how the rate of CO_2 accumulation in the atmosphere is many times faster than we have seen during other periods in earth's history, the current rate of increase in the acidity of ocean surface waters is roughly fifty times faster than known historical change.[17]

What happens to sea life as the oceans acidify? The increase in carbonic acid makes calcium carbonate less available to marine organisms for building their shells. Corals, crabs, clams, oysters, lobsters, and other marine animals that form calcium carbonate shells are particularly vulnerable. Because these animals are often at the bottom of the food web, this impacts other animals, including humans.

Ocean Temperatures Are Rising

In addition to absorbing CO_2, oceans absorb heat caused by emissions from human activity. Over 90 percent of earth's warming over the past fifty years has occurred in the oceans, which have warmed 1.0°C (1.5°F) since the late nineteenth century. Rising ocean temperatures are disrupting fish populations and killing off coral reefs, in turn impacting ocean food webs, humanity's food supply, jobs, and tourism.[18]

Ice Is Melting

Glaciers in countries around the world and sea ice at the poles are melting. On average, Arctic sea ice now starts melting eleven days earlier and refreezing twenty-six days later than it did in the late 1970s. In October 2017, the volume of Arctic sea ice was 65 percent below the maximum October ice volume in 1979. Although Antarctica had been gaining ice from the 1970s to 2016, this gain was more than offset by annual losses of Arctic sea ice. Then, in 2017, Antarctic sea ice decreased to record lows.[19]

Ice loss impacts Arctic peoples who depend on traditional weather patterns for hunting and threatens animals that inhabit the Arctic. But most people don't live near glaciers and sea ice (one reason why using an image of a polar bear to inspire climate action has not been particularly effective). So why should people who do not live in icy places on the planet care about loss of glaciers and sea ice? Both melting glaciers and polar land ice cause sea level rise. Further, the loss of glaciers in the Himalayas and other mountain ranges results in changes in water flow into rivers such as the Ganges, which millions of people depend on for their water supply.[20]

Sea Level Is Rising

As glacial and polar ice melts from land, more water flows into the oceans. As water warms, it expands in volume. Both more water and warmer water are causing sea level rise. Between 1880 and 2014, sea level rose about 8 inches; by 2100, scientists are predicting an increase of 1–4 feet (0.3–1.2 meters) over the 2014 global average level, with potential for a rise of 8 feet (2.4 meters) or more if greenhouse gas emissions continue increasing. This sea level rise is not distributed evenly around the world. For example, because of ocean currents, land subsidence, and other factors, the rate of sea level rise for the East Coast of the United States is about 50 percent higher than the global average.[21]

A July 2016 headline in the *Navy Times* reads: "Rising oceans threaten to submerge 128 military bases." Norfolk, Virginia, home to the largest U.S. naval base, is already witnessing regular flooding, forcing residents to abandon their homes.[22] Frequent coastal flooding is making it nearly impossible for Norfolk residents to insure—let alone sell—once-valuable oceanfront homes. And at the Naval Academy in Annapolis, Maryland, classrooms, dormitories, and athletic facilities were flooded in a 2003 hurricane, pointing not only to sea level rise but also to stronger storm events as threats to coastal cities.[23] Residents in coastal Alaska and Louisiana, and on islands from the Pacific Ocean to the Chesapeake Bay, are abandoning villages and even whole islands where they have lived for centuries.[24]

Storm surges can cause widespread coastal property damage and kill people during a hurricane. A storm surge is the rise in ocean water above the normal tide due to a storm and is a major cause of flooding in hurricanes. It is caused by water being pushed toward the shore by storm winds. Although many factors, including water depth near the shoreline, impact storm surges, larger storms produce higher surges.[25]

Local and Regional Weather Is Changing

Recent droughts in the western United States are the most severe in over eight hundred years. At the same time, heavy rains associated with warming trends are contributing to more frequent and larger floods. Summer temperatures have exceeded those recorded since the United States began keeping reliable records in the late 1800s. And the length of the growing season between the latest spring frost and earliest fall frost has increased in each region of the United States, with increases of six days in the Southeast, nine to ten days in Northeast, Midwest, and the Plains states, and sixteen to nineteen days in the Northwest and Southwest.[26] These changes have an impact on what farmers and gardeners can grow and on insect pests and diseases affecting not just agriculture but also forests, cities, and even humans.

Although a longer growing season might provide opportunities for growing crops that were previously limited by colder temperatures, such opportunities may be constrained by drought, flooding, or soils that are unsuitable for the new crops. Further, moving production zones comes at great expense to physical, economic, and social infrastructure, and can lead to conflicts as formerly productive populated areas become unproductive because of drought or heat stress.

Human Safety, Health, and Well-Being Are Threatened

Taken together, the changes brought about by climate change threaten human safety, health, and well-being. Floods pose a direct risk of drowning, and heat waves can kill vulnerable individuals like the elderly, especially those without a social support network.[27] Wildfires and dust storms during droughts impact air quality, and populations of disease-carrying organisms like mosquitoes and ticks are up, leading to possible increases in malaria, dengue fever, and other diseases.[28] Parents assessing these risks may direct their children to spend more time indoors, depriving children and families of the multiple health benefits of spending time in nature.[29] And as many environmental educators are aware, the looming threats brought about by climate change can cause stress, sadness, and related mental health issues.[30]

Addressing Climate Change

Addressing climate change involves both mitigation, principally by reducing the amount of greenhouse gases we emit into the atmosphere, and adaptation, or adjusting to the changes brought about by climate change. Consider a ski resort. It can install solar panels to power its lifts, thus helping to mitigate climate change. The resort can also adapt to warmer weather by making more snow. Whereas making more snow results in greater energy consumption and thus does not mitigate greenhouse gas emissions, some types of adaptation, most notably ecosystem-based adaption, integrate action to improve environmental quality.[31] For example, planting trees and other plants that absorb CO_2 helps to mitigate climate change. Trees and bioswale gardens also retain water and soil that otherwise would run off into rivers, thus helping communities adapt to more frequent heavy storms. Two broad strategies for mitigating climate change are (1) reducing greenhouse gas emissions (for example, by converting from coal to solar for electricity generation), and (2) increasing sequestration of CO_2 that has already been emitted (for example, by planting trees).

While adaptation is important to help ensure our short-term survival, mitigation is critical to the long-term continuation of human civilization as we know it beyond about 2050. Absent mitigation, it is estimated that prior to 2100, the earth's average global surface temperature could exceed 4°C (7.2°F) above the preindustrial average. A 2012 study conducted for the World Bank concluded that there is "no certainty that adaptation to a 4°C world is possible," and that "4°C warming simply must not be allowed to occur."[32]

Reducing all sources of greenhouse gases is important. Below we start with what an individual can do in his or her own home or school; such individual behavior change has traditionally been the focus of environmental education. Next, we talk about what people can do working together in their communities. We cannot mitigate or adapt to climate change without collective action, and thus environmental educators need to expand their efforts to get students, families, and neighbors working together to address climate change.[33] Further, environmental educators can help people influence business and government policies.

Individual and Household Behaviors

In deciding how to reduce greenhouse gases, it is important to consider the sectors—electricity production, transportation, industry, commercial and residential, and agriculture—that contribute the most emissions. Burning fossil fuels in electricity production accounts for 29 percent of U.S. greenhouse gas emissions (figure 1.3). Thirty-three percent of that electricity is consumed in homes and businesses.[34] Thus, the first question one might ask is, How can I reduce electricity use in my home and at work? The U.S. Environmental Protection Agency (EPA) has a number of recommendations, including purchasing Energy Star appliances and paying attention to your heating and cooling system, which can use up to half of a home's energy consumption.[35] In many counties and cities, a university extension or other program provides guidance on ways to avoid heat loss in your home and to install rooftop and community solar arrays, heat pumps, and smart meters that enable the consumer to monitor energy consumption and shift energy use to off-peak hours.[36] Nonprofit organizations, government offices, and engineering firms also can advise about financing options, including government incentive programs.

After electricity production, transportation is the second-largest emitter of greenhouse gases in the United States, responsible for 27 percent of total greenhouse gas emissions.[37] Although the solutions are obvious—walk, bike, take public transport, and reduce driving and flying—implementing them can be difficult to fit into one's life. But that doesn't mean we shouldn't try, and there can be side benefits to our health when we walk and bike. An environmental educator in Austin, Texas, worked with his son's school to develop a bike-to-school program, and U.S. cities are expanding bike-share programs based on China's model of "dockless" smart bikes.[38]

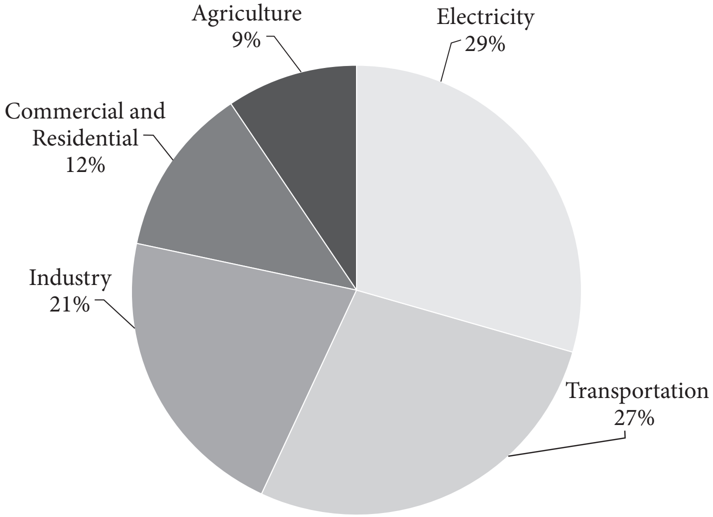

FIGURE 1.3 Sources of greenhouse gas emissions
U.S. Environmental Protection Agency, 2017

Industry is the third-largest U.S. emitter (21 percent of total emissions).[39] Considering climate change ramifications when making consumer choices can help to reduce this source of emissions. In China, the Ant Forest online game rewards consumers who purchase climate-friendly goods, with points that are used to plant trees. This has the potential to reduce greenhouse gas emission by encouraging "green" choices and to sequester CO_2 through tree planting. Whereas Ant Forest uses external incentives,[40] we also make choices based on social norms and individual values, both of which can shift as we observe more and more people making green choices.[41] Educators can play a role in changing social norms by modeling and encouraging climate friendly behaviors in their programs.

Commercial and residential sectors accounted for 12 percent of total emissions in 2015. This percentage accounts for both direct and indirect emissions. Direct emissions result from a number of commercial and residential activities. Heating and cooling homes and businesses using fossil fuels releases CO_2. Refrigeration and air conditioning release fluorinated gases. Even waste at the landfill releases methane as it decomposes, and wastewater treatment emits methane and nitrous oxide. When we turn on the lights and use electricity produced by a power plant that burns fossil fuels to make that electricity, we are releasing greenhouse gases indirectly. In addition to recommending individual actions like reducing waste and turning off lights to save energy, some environmental education organizations have taken a different approach. Mass Audubon partnered with Massachusetts Energy Consumer Alliance for a "Make the Switch" campaign that promotes switching to renewable energy; their goal is for at least one thousand Mass Audubon members to switch to renewable electricity sources within a year of the campaign's start. This type of partnership may increase the likelihood that consumers will switch their energy source because the information comes from a trusted conservation source like Mass Audubon. Finally, the EPA states that agriculture contributes 9 percent of U.S. greenhouse gas emissions, much of it from livestock production.[42] Actual contributions of agriculture to greenhouse gases may be higher; some sources put livestock alone as contributing up to 18 percent of global greenhouse gases, with cows, sheep, and goats producing more emissions relative to pigs and chickens.[43] Consumers can make choices to limit meat and dairy consumption to reduce this source of greenhouse gases.

Collective Action

We have seen how addressing greenhouse gas emissions at the individual level involves consumer and lifestyle choices. But environmental education programs also engage participants in collective action and even in influencing policies. One form of collective action is scaling up individual actions, as we saw in the Mass

Audubon example—the more households that reduce their energy use or the more individuals who walk, ride their bike, or take the bus to work, the greater the impact. Other forms of collective action involve community members working together to address structural issues, such as the cost of rooftop solar installation, the lack of bike lanes, or policies that act against energy saving, which prevent people who would otherwise make green choices from doing so. In some states, citizens can work with a solar company to implement community solar, thus enabling more households to buy into renewable energy. Working with private companies to develop a car-sharing program will allow more individuals to reduce car use. Working with farmers to create community supported agriculture (CSA, or group purchasing of local produce) can reduce the need to buy packaged food; in cities where people walk or use public transport to pick up their produce, these practices also reduce gas emissions associated with transporting food.

At the local policy level, environmental education participants could advocate at town hall meetings for wind energy, bike trails, and sidewalks, and preserving forests and wetlands that absorb CO_2. They can also work with their churches, sports clubs, and other civil society organizations to implement organizational practices that reduce greenhouse emissions, such as banning single-use plastic water bottles. They may be able to help draft and implement town climate change mitigation and adaptation plans, such as New York State's Climate Smart Communities,[44] which in turn can serve as examples for other towns and spur action at the state or even national level. Environmental education participants also can call their political representatives and work for candidates who support legislation to address climate change.

Bottom Line for Educators

Like any field of science, climate science is never settled or beyond further modification. However, there is a point at which a scientific consensus is reached based on strong evidence from multiple lines of inquiry. The scientific conclusion that human greenhouse gas emissions and other activities have changed the earth's atmosphere with measurable impacts on global climate has reached that level of certainty. Moreover, climate science allows us to estimate how actions we take now and in the near future can reduce the severity of climate change in the coming decades.

Evidence of warming comes not just from climate models but from actual observations of surface, air, and water temperatures; ocean chemistry; and melting Arctic and glacial ice. In fact, much of the climate "denying" that we see is more a function of people's social and political leanings than of the facts (see chapter 5).

Disinformation campaigns by individuals and organizations who do not wish to see effective action taken to reduce climate change are an unfortunate reality. We cannot allow distortion, bias, and fabrication to prevent the evidence-based decisions and actions required at the individual and societal level to reduce climate change. The very survival of human civilization requires such action. The alternative goes beyond factual disagreement. To ignore clear evidence and fail to act, creating great peril for the near- and long-term future, is beyond a scientific, technological, or political issue; it is a question of morality, ethics, sanity, and self-preservation. Fortunately, we already have many of the scientific and technological capabilities to reduce climate change risk. We need to develop the moral compass and social and political will to use them wisely.

Environmental education can influence participant behaviors and actions at levels ranging from individual choices to local collective action to advocacy for national or global policies, and across the consumer, transport, industry, and agricultural sectors. But first we need to understand the best ways to communicate climate change and inspire action. In the next chapter we turn to explanations for varying views on climate change.

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