ENVIRONMENTAL AND NATURAL RESOURCE ECONOMICS: A CONTEMPORARY APPROACH

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CHAPTER 12

Global Climate Change: Science and Economics

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CHAPTER 12 FOCUS QUESTIONS

- What are the impacts of global warming/global climate change?
- What consequences can we expect in the future?
- Can economic theory help evaluate the impact of climate change?
- How can we model the long-term impacts of climate change?

12.1 CAUSES AND CONSEQUENCES OF CLIMATE CHANGE

Scientists have been aware since the nineteenth century of the planetary impacts of carbon dioxide (CO_2) and other **greenhouse gases** in the atmosphere. In recent decades, concern has grown over the issue of **global climate change** caused by increased accumulations of these gases. (The problem often referred to as **global warming** is more accurately called global climate change. A basic warming effect will produce complex effects on climate patterns—with uneven patterns of warming, increased climatic variability and extreme weather events.) The horizon of projections for major consequences of climate change has become closer as scientific understanding of the physical processes has increased in recent years. What previously appeared as a future threat for generations to come, in the late twenty-first century and beyond, is increasingly understood as an immediate and urgent issue, as many countries are already experiencing some of the disruptive consequences of climate change (see Box 12.1).

global climate change the changes in global climate, including temperature, precipitation, storm frequency and intensity, and changes in carbon and water cycles, that result from increased concentrations of greenhouse gases in the atmosphere.
global warming the increase in average global temperature as a result of emissions from human activities.
greenhouse gases gases such as carbon dioxide and methane whose atmospheric concentrations influence global climate by trapping solar radiation.

Multiple studies published in peer-reviewed scientific journals show that 97 percent or more of actively publishing climate scientists agree: climate-warming trends over the past century are extremely likely to be due to human activities.[1] The Intergovernmental Panel on Climate Change (IPCC) clearly attributes the majority of recently observed global climate change to human-made greenhouse gas emissions.[2]

Statements by the U.S. Global Research Program and the American Geophysical Union indicate the widespread scientific acceptance of the reality of climate change, and the human role in its recent pattern:

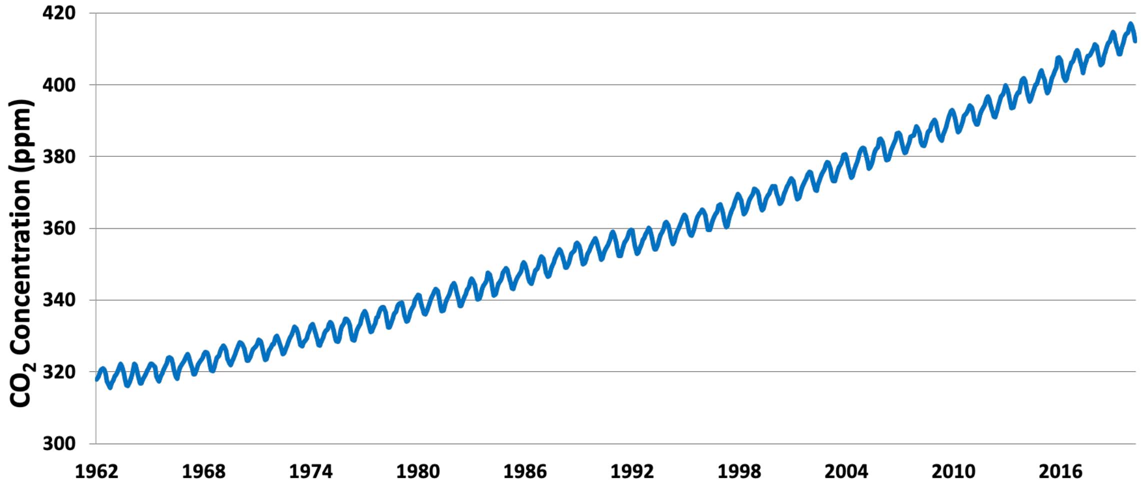
> Evidence for climate change abounds, from the top of the atmosphere to the depth of the oceans. Scientists and engineers from around the world have meticulously collected this evidence, using satellites and networks of weather balloons, observing and measuring changes in location and behaviors of species and functioning of ecosystems. Taken together, this evidence tells an unambiguous story: the planet is warming, and over the half century, this warming has been driven primarily by human activity.[3]

> Humanity is the major influence on the global climate change observed over the past 50 years. Rapid societal responses can significantly lessen negative outcomes.[4]

Putting climate change into the framework of economic analysis, we can consider greenhouse gas emissions, which cause planetary warming and other changes in weather patterns, as both a cause of environmental externalities and a case of the overuse of a **common property resource**.

common property resource a resource that is available to everyone (nonexcludable), but use of the resource may diminish the quantity or quality available to others (rival).

Figure 12.1 Atmospheric Carbon Dioxide Levels



Source: National Oceanic and Atmospheric Administration, Earth System Research laboratory, Global Monitoring Division, http://www.esrl.noaa.gov/gmd/ccgg/trends/data.html.

Note: ppm = parts per million. Seasonal variations mean that CO_2 concentrations rise and fall each year with growth and decay of vegetation and other biological systems, but the long-term trend is a steady upward increase due to human emissions of CO_2.

The atmosphere is a **global commons** into which individuals and firms can release pollution. Global pollution creates a "public bad" affecting everyone—a negative externality with a wide impact. As we have discussed in earlier chapters, many countries have environmental protection laws limiting the release of local and regional air pollutants. In economic terminology, such laws to some degree internalize externalities associated with local and regional pollutants. But until relatively recently, few controls existed for carbon dioxide (CO_2), the major greenhouse gas, and concentrations of CO_2 in the atmosphere have risen steadily, crossing the benchmark of 400 parts per million (ppm) atmospheric concentration in 2015 (Figure 12.1).

Impacts of climate change have already begun to affect climate patterns (see Box 12.1). If indeed the effects of climate change are likely to be severe, it is in everyone's interest to lower emissions for the common good. Climate change can thus be viewed as a **public good** issue, requiring collaborative action to develop adequate policies, as noted in Chapter 4. In the case of climate change, such action needs to involve all stakeholders, including governments and public institutions as well as private corporations and individual citizens.

global commons global common property resources such as the atmosphere and the oceans.
public goods goods that are available to all (nonexclusive) and whose use by one person does not reduce their availability to others (nonrival).

After decades of failures at the international level to produce an agreement including all countries, significant progress was achieved in Paris in December 2015, when 195 nations, under the auspices of the United Nations Framework Convention on Climate Change, signed the first global agreement aiming at keeping the overall increase in global average temperature under 2°C (compared with pre-industrial times), with a more ambitious goal of no more than 1.5°C. In addition to the actions taken by national governments, hundreds of cities, regions, and corporations have pledged to make significant reductions in their CO_2 emissions over the next five to 25 years. During the Trump administration, the United States did not comply with and briefly withdrew from the Paris Agreement, but the Biden administration has since re-joined the international effort. We will return to a detailed analysis of the Paris Agreement in Chapter 13.

greenhouse effect the effect of certain gases in the earth's atmosphere trapping solar radiation, resulting in an increase in global temperatures and other climatic impacts.

Box 12.1 What Is the Greenhouse Effect?

The sun's rays travel through a greenhouse's glass to warm the air inside, but the glass acts as a barrier to the escape of heat. The interior temperature rises, so that plants that require warm weather can be grown in cold climates. The global greenhouse effect, in which the earth's atmosphere acts like the glass in a greenhouse, was first described by French scientist Jean Baptiste Fourier in 1824.

Clouds, water vapor, and the natural greenhouse gases carbon dioxide (CO_2), methane, nitrous oxide, and ozone allow inbound solar radiation to pass through but serve as a barrier to outgoing infrared heat. This creates the natural **greenhouse effect,** which makes the planet suitable for life. Without it, the average surface temperature on the planet would average around -18°C (0°F), instead of approximately 15°C (60° F).

The possibility of an *enhanced* or *human-made* greenhouse effect was introduced by the Swedish scientist Svante Arrhenius in 1896. Arrhenius hypothesized that the increased burning of coal, which had paralleled the process of industrialization, would lead to an increased concentration of carbon dioxide in the atmosphere and warm the earth.[5] Since Arrhenius's time, the emissions of greenhouse gases have grown dramatically. CO_2 concentrations in the atmosphere have increased by over 40 percent compared to pre-industrial levels (see Figure 12.1). In addition to increased burning of fossil fuels such as coal, oil, and natural gas, manmade chemical substances such as chlorofluorocarbons (CFCs) as well as methane and nitrous oxide emissions from agriculture and industry contribute to the greenhouse effect.

Scientists have developed complex computer models that estimate the effect of current and future greenhouse gas emissions on the global climate. While considerable uncertainty remains in these models, a broad scientific consensus has formed that the human-induced greenhouse effect poses a significant threat to the global ecosystem. The global average temperature increased by about 0.7°C (1.3°F) during the twentieth century. The Intergovernmental Panel on Climate Change (IPCC, 2014) has concluded that "Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history . . . Warming of the climate system is unequivocal, and since the 1950s many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen." The IPCC projected a global average temperature increase by 2100 of between 1.5°C and 4.8°C, (between 2.7°F and 8.6°F) above pre-industrial levels. By 2020, the world had already reached an average temperature increase of over 1°C compared with 1880 levels, with two thirds of the warming occurring since 1975.

Sources: Fankhauser 1995; IPCC, 2014a, b, and c; NASA, Earth Observatory, https://earthobservatory.nasa.gov/world-of-change/global-temperatures.

Because CO_2 and other greenhouse gases such as methane, nitrous oxide, and fluorinated gases including chlorofluorocarbons and hydrofluorocarbons,[6] continuously accumulate in the atmosphere, stabilizing or "freezing" annual emissions will not solve the problem. Greenhouse gases persist in the atmosphere for decades or even centuries, continuing to affect the climate of the entire planet long after they are emitted. This is a case of a **cumulative or stock pollutant**. As discussed in Chapter 8, only major reductions in emissions levels of a stock pollutant – ideally to zero – will prevent ever-increasing accumulations. Development of national and international policies to combat global climate change is therefore a huge challenge, involving many scientific, economic, and social issues. In this chapter we address the issues of analysis of climate change, using techniques and concepts developed in earlier chapters, and in Chapter 13 we turn to policy implications.

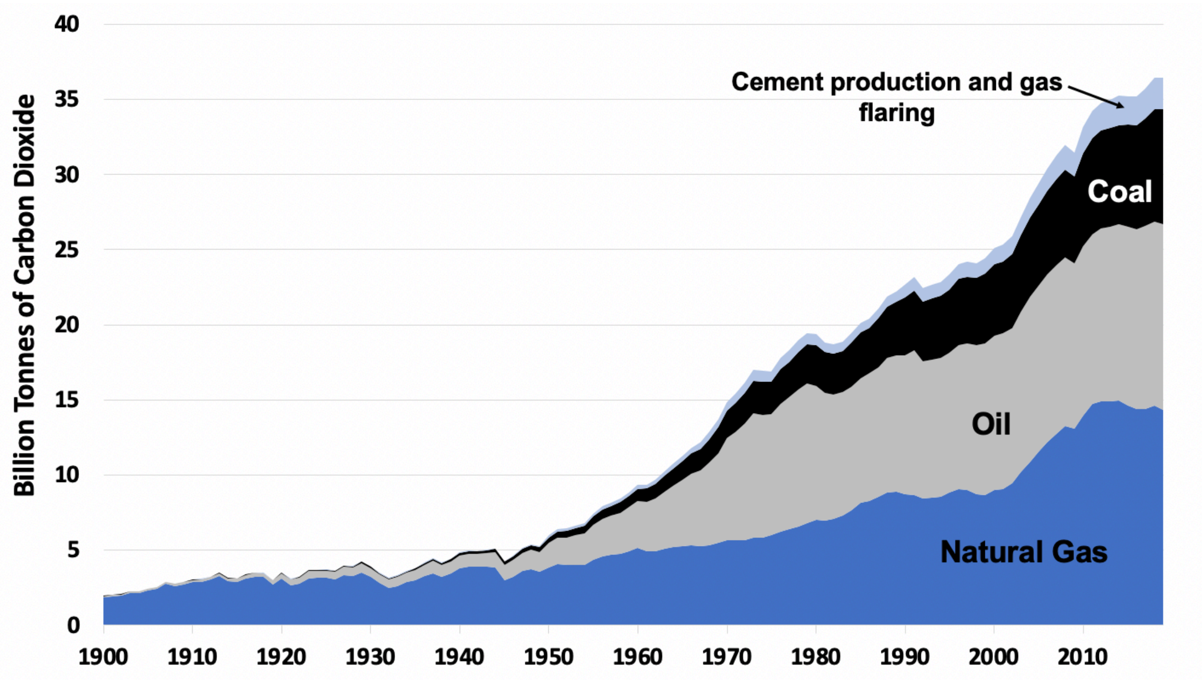
cumulative or stock pollutant a pollutant that does not dissipate or degrade significantly over time and can accumulate in the environment, such as carbon dioxide and chlorofluorocarbons.

Trends in Global Carbon Emissions

Global emissions of CO_2 from the combustion of fossil fuels have increased dramatically since about 1950, as illustrated in Figure 12.2. Emissions in 2019 reached a new record high of 36.4 billion tons of CO_2, with coal accounting for 39%, oil 34%, natural gas 21%, and the remainder from cement production, gas flaring, and other sources.[7] Figure 12.2 shows emissions from 1900 to 2019, expressed in million metric tons of carbon.

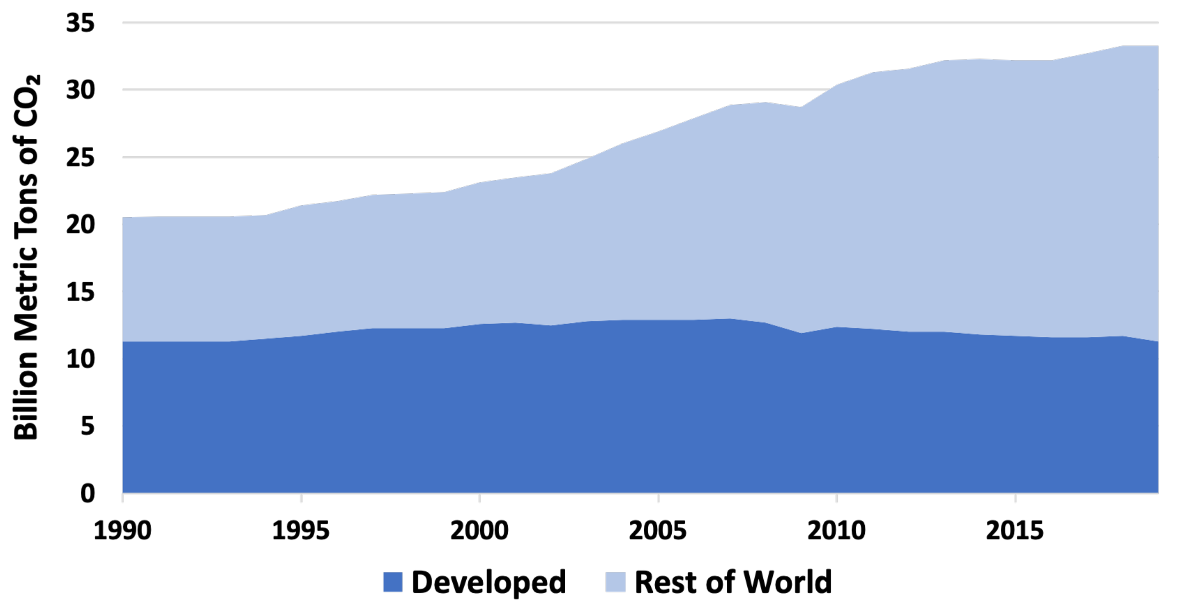
Figure 12.3 focuses on the distribution of emissions between two groups of countries: advanced industrialized countries including the United States and Europe; and the rest of the world, comprising developing countries including China. The share of emissions attributable to the advanced industrialized countries has been steadily declining since 2007, and these emissions have also decreased in absolute terms. Meanwhile the share of the developing world has increased significantly, with 46% growth since 2007, largely due to rapidly increasing emissions in China. Since about 2012, however, there has been a slowdown in the growth rate of emissions from developing countries.

Figure 12.2 Global Carbon Dioxide Emissions from Fossil Fuel Consumption, 1900-2019



Source: Global Carbon Project, Global Carbon Budget 2020.

Figure 12.3 Carbon Dioxide Emissions, 1965–2019, Industrialized and Developing Countries

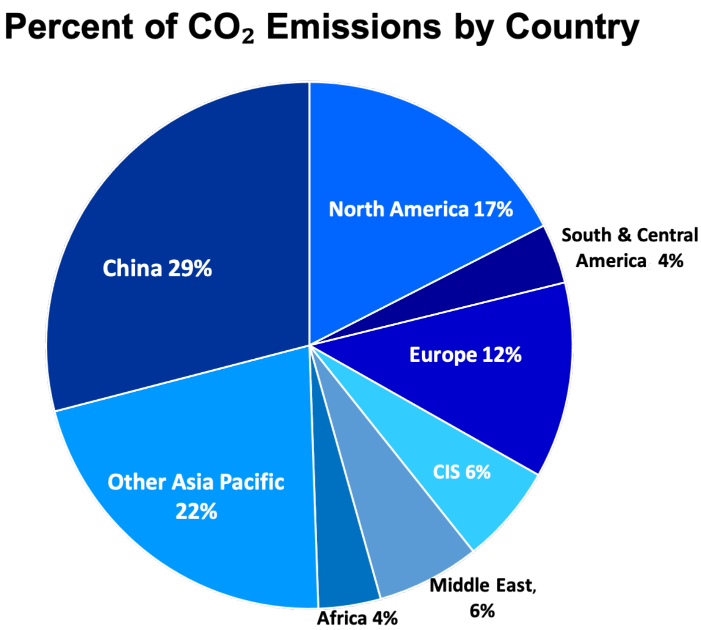


Source: International Energy Agency, https://www.iea.org/articles/global-co2-emissions-in-2019

Emissions are closely connected with the economic cycles, and the 2008–2009 recession is clearly visible on the graph. Data for the recession of 2020 are not included in Figure 12.3, but it led to an even more significant decrease in emissions during 2020, estimated at about 8%.[8] Even prior to the 2020 recession, emissions growth had slowed, partly due to a slowing down of global economic growth (with a decrease in China's economic growth rate). The declining growth rate of emissions also reflects new energy investments in renewables (solar and wind), which as noted in Chapter 11 have dominated additional energy production capacity in recent years. In developed countries, there has been a rapid switch from coal to natural gas and renewable energy, lowering overall CO_2 emissions (although natural gas is a fossil fuel, it has about 50% lower CO_2 emissions per unit of energy provided than coal). In developing countries, coal production is still expanding, but an increasing share of new energy production is also coming from renewables.[9]

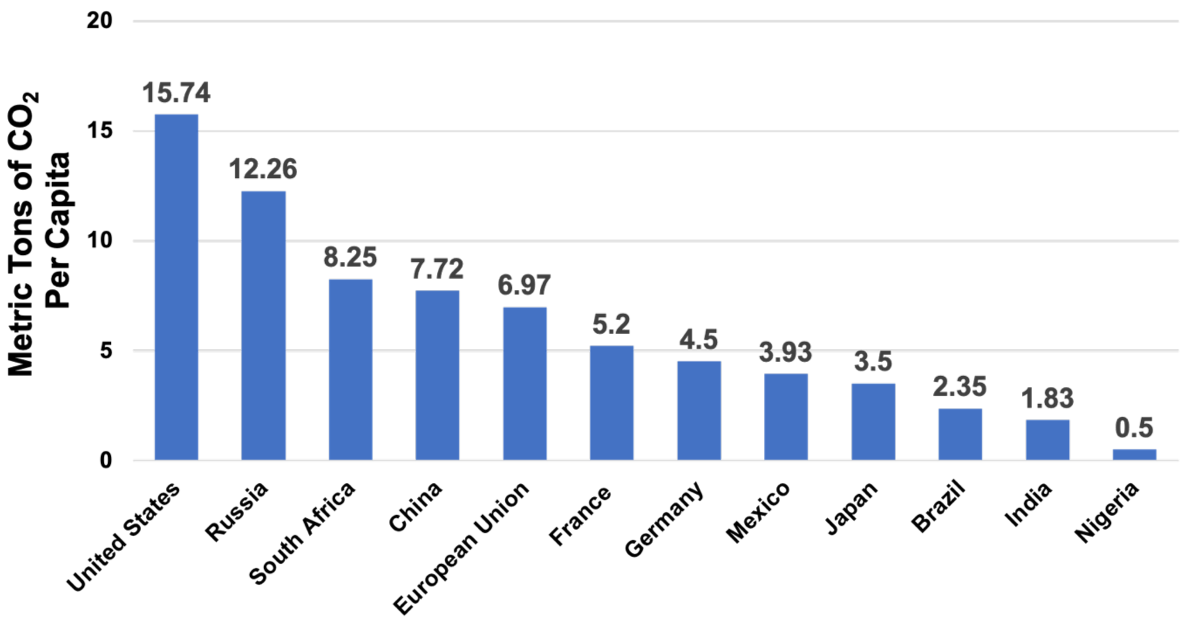
business as usual a scenario in which no significant policy, technology, or behavioral changes are expected.

Figure 12.4 Percentage of Global CO_2 Emissions by Country/Region.



Source: *BP Statistical Review of World Energy, 2020.*

Figure 12.5 Per-Capita Carbon Dioxide Emissions, by Country



Source: European Commission EDGAR Database for Global Atmospheric Research, 2020 (data for 2017 emissions).

Figure 12.4 shows the distribution of CO_2 emissions among the main emitters: China (29 percent), North America (17 percent), Europe (12 percent), India (6 percent), Russia and former Soviet republics (6 percent), Middle East (6 percent), Africa (4%) and the Asian/Pacific area excluding China (22 percent). Most of the future growth in carbon emissions is expected to come from rapidly expanding developing countries such as China and India. China surpassed the United States in 2006 as the largest carbon emitter in the world. It is important to note, however, that in terms of cumulative historical emissions, over 60% has come from currently developed countries.[10]

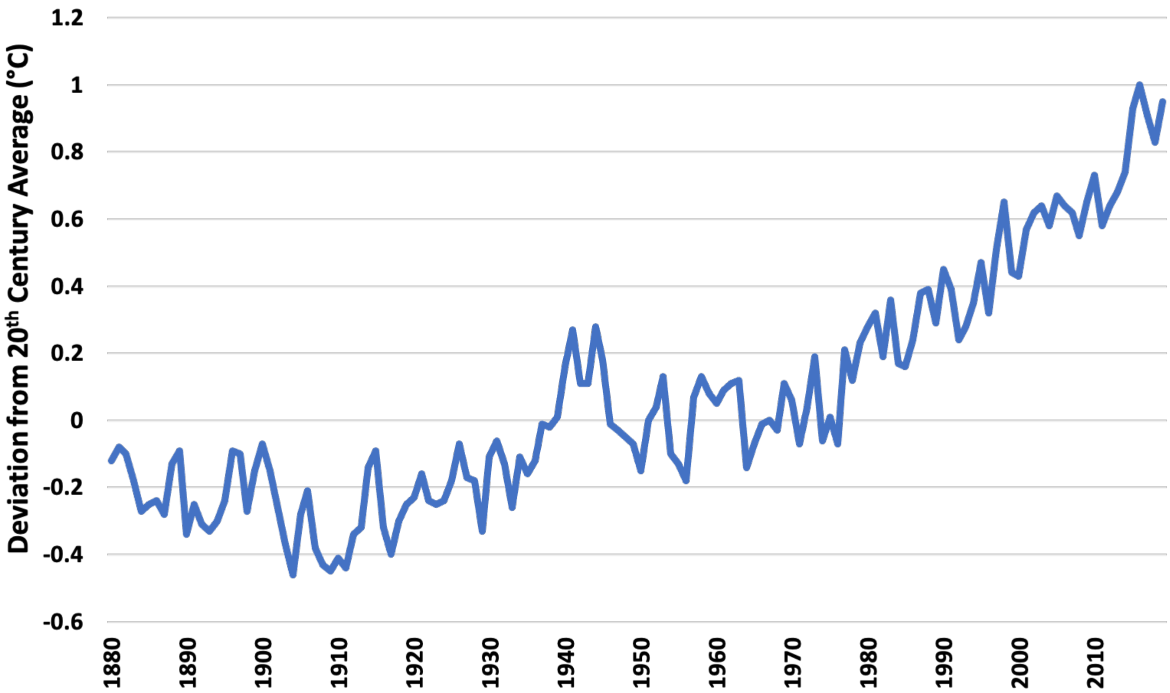
In addition to total current and cumulative emissions, we also need to consider per capita emissions. Per capita emissions are generally higher in developed countries, as shown in Figure 12.5. The United States has the highest rate among major countries, with 15.7 metric tons of CO_2 emissions per person, followed by Russia with an average of 12.3 tons per person, while other developed countries are in the range of 4 to 10 metric tons per capita. Most developing countries have low rates per capita, typically less than 4 tons of CO_2 per person, except China, whose per capita emissions have grown to 7.7 tons per person, and South Africa, with a rate of 8.2 tons per person.

Trends and Projections for Global Climate

The earth has warmed significantly since reliable weather records began to be kept in the late nineteenth century (Figure 12.6). In the past 100 years the global average temperature has risen about 1°C, or about 1.8°F. Nine of the ten warmest years in the modern meteorological record occurred between 2005 and 2019.[11] The years 2015 to 2020 were the six warmest years in temperature records. As this text went to press, the year 2020 had been recorded as tied with 2016 for the hottest year on record.[12]

Evidence indicates that the rate of warming, currently about 0.13°C per decade, is increasing. A study by the U.S. Department of Energy's Pacific Northwest National Laboratory shows that the rate at which temperatures are rising could be 0.25°C per decade by 2020.[13] Not all areas are warming equally. The Arctic and Antarctic regions have been warming at about double the global rate.[14]

Figure 12.6 Global Annual Temperature Anomalies (°C), 1850–2019



Source: NOAA Global Time Series, https://www.ncdc.noaa.gov/global/time-series/globe/land_ocean/ytd/12/1880-2019

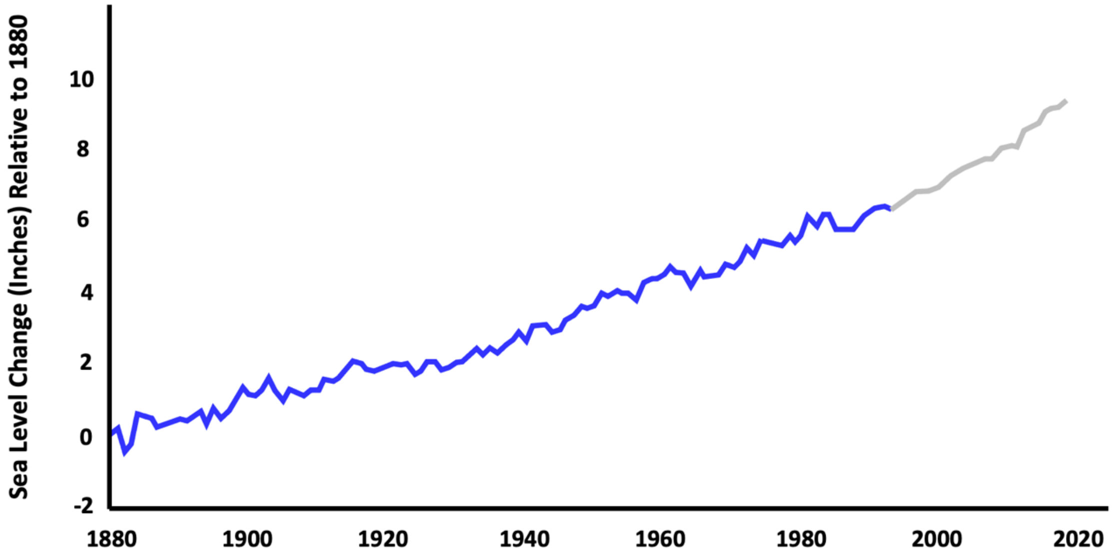
Note: The zero baseline represents the average global temperature for the twentieth century.

Warmer temperatures have produced noticeable effects on ecosystems. In most regions of the world, glaciers are retreating. For example, Glacier National Park in Montana had 150 glaciers when the park was established in 1910. As of 2021 only 25 glaciers remained, and it is estimated that all of the park's namesake glaciers will be gone by the end of the century.[15]

Climate change is also leading to rising sea levels. Sea-level rise is attributed to the melting of glaciers and ice sheets and to the fact that water expands when it is heated. In 2015 the global average ocean temperature was nearly 1°F above the average for 1971-2000.[16] The combination of warmer oceans and melting ice has led sea levels to rise about 2 millimeters per year, and in 2012 the sea level was already 9 inches (23 cm) above the level of 1880 (see Figure 12.7 and Box 12.2).[17] The impact of rising seas threatens numerous coastal areas; for example, the U.S. government has identified 31 Alaskan towns and cities at imminent risk, and cities in Florida are already experiencing significant damage from a major increase in flooding.[18]

Recent research on the West Antarctic ice sheet shows that this area, larger than Mexico, is potentially vulnerable to disintegration from a relatively small amount of global warming, and capable of raising the sea level by 12 feet or more should it happen. Even without disintegration of the West Antarctic ice sheet, researchers found that the total sea rise could reach five to six feet by 2100, and would continue to increase, with the seas rising by more than a foot per decade by the middle of the twenty-second century. Researchers found that "the rate of ice loss has risen by 57 % since the 1990s – from 0.8 to 1.2 trillion tonnes per year – owing to increased losses from mountain glaciers, Antarctica, Greenland and from Antarctic ice shelves.”[19]

Figure 12.7 Sea-Level Rise, 1880–2018



Source: U.S. Global Change Research Program, https://www.globalchange.gov/browse/indicators/global-sea-level-rise.

Note: The blue line up to 1993 represents data measured using tide gauges. The gray line afterward represents data from satellite measurements.

Box 12.2 Pacific Islands Disappear as Oceans Rise

The island nation of Kiribati, a collection of 33 coral atolls and reef islands, lying no higher than 6 feet above sea level, scattered across a swath of the Pacific Ocean about twice the size of Alaska, is facing the risk of going under in the next few decades.

Two of its islands, Tebua Tarawa and Abanuea, have already disappeared as a result of rising sea level. Others, both in Kiribati and in the neighboring island country of Tuvalu, are nearly gone. So far the seas have completely engulfed only uninhabited, relatively small islands, but the crisis is growing all around the shores of the world's atolls.

Populated islands are already suffering. The main islands of Kiribati, Tuvalu, and the Marshall Islands (also in the Pacific) have suffered severe floods as high tides demolish sea walls, bridges and roads, and swamp homes and plantations. Almost the entire coastline of the 29 Marshall Islands atolls is eroding. World War II graves on its main Majuro atoll are washing away, roads and subsoils have been swept into the sea, and the airport has been flooded several times despite the supposed protection of a high sea wall.

The people of Tuvalu are finding it difficult to grow their crops because the rising seas are poisoning the soil with salt. Many islands will become uninhabitable long before they physically disappear, as salt from the sea contaminates the underground freshwater supplies on which they depend. In both Kiribati and the Marshall Islands families are desperately trying to keep the waves at bay by dumping trucks, cars, and other old machinery in the sea and surrounding them with rocks. The situation is so bad that the leaders of Kiribati are considering a plan to move the entire population of 110,000 to Fiji. The inhabitants of some villages have already moved.

Sources: Mike Ives, "A Remote Pacific Nation, Threatened by Rising Seas," *New York Times*, July 2, 2016; "Kiribati Global Warming Fears: Entire Nation May Move to Fiji," Associated Press, March 12, 2012.

In addition to rising ocean temperatures, increased CO_2 in the atmosphere results in **ocean acidification**. According to the U.S. National Oceanic and Atmospheric Administration, "around half of all carbon dioxide produced by humans since the Industrial Revolution has dissolved into the world's oceans. This absorption slows down global warming, but it also lowers the oceans pH, making it more acidic. More acidic water can corrode minerals that many marine creatures rely on to build their protective shells and skeletons."[20]

ocean acidification increasing acidity of ocean waters as a result of dissolved carbon from CO_2 emitted into the atmosphere.

A 2012 report in *Science* magazine found that the oceans are turning acidic at what may be the fastest pace in 300 million years, with potential severe consequences for marine ecosystems.[21] Among the first victims of ocean warming and acidification are coral reefs, because corals can form only within a narrow range of temperatures and acidity of seawater. The year 2015 saw a record die-off of coral reefs, known as coral bleaching, due to a combination of the most powerful El Niño (Pacific warming) climate cycle in a century and water temperatures already elevated due to climate change.[22] Oyster hatcheries, which have been referred to as "canaries in a coal mine" since they may predict effects on a wide range of ocean ecosystems as ocean acidification increases, are also affected, threatening the Pacific

Northwest shellfish industry.[23] Other ecosystems such as forests are also severely impacted by climate change (see Box 12.3).

Box 12.3 Forests, Climate Change, and Wildfires

Wildfires were once primarily a seasonal threat, taking place mainly in hot, dry summers. Now they are burning nearly year-round in the Western United States, Canada, and Australia. In May 2016, the state of Alberta was devastated by wildfires expanding over 350 miles, leading to the evacuation of the 80,000 inhabitants of the city of Fort McMurray, which suffered extensive damage. California has suffered record fire damage in recent years; fire-related CO_2 emissions in California, Oregon, and Washington in 2020 were at least 3 times higher than the historical 21st-century average.

Global warming is suspected as a prime cause of the increase in wildfires. The warming is hitting northern regions especially hard: temperatures are climbing faster there than for the Earth as a whole, snow cover is melting prematurely, and forests are drying out earlier than in the past. Dry winters mean less moisture on the land, and the excess heat may even be causing an increase in lightning, which often sets off the most devastating wildfires.

According to a research ecologist for the United States Forest Service: "In some areas, we now have year-round fire seasons, and you can say it couldn't get worse than that. But we expect from the changes that it can get worse." Scientists see a risk that if the destruction of forests from fires and insects keeps rising, the carbon that has been locked away in the forests will return to the atmosphere as carbon dioxide, accelerating the pace of global warming—a dangerous feedback loop.

Sources: Richtel and Santos, 2016; Austen, 2016; World Resources Institute, "The Climate Feedback Loop Fueling US fires," https://www.wri.org/blog/2020/us-fires-climate-emissions; Center for Climate and Energy Solutions, "Wildfires and Climate Change," www.c2es.org/content/wildfires-and-climate-change/

Future projections of climate change depend on the path of future emissions. Even if all emissions of greenhouse gases ended today, the world would continue warming for many decades, and effects such as sea-level rise would continue for centuries, because the ultimate environmental effects of emissions are not realized immediately.[24] Figure 12.8 presents three scenarios for global greenhouse gas emissions from 2020 to 2100. The data include emissions for all greenhouse gases, with gases other than CO_2 converted to **CO_2 equivalent (CO_2e)**.

The scenario with the highest emissions in Figure 12.8 is based on national policies that countries currently have in place. In this scenario, global emissions level off in the 2040s and then gradually decline. By 2100 emissions are about 15% lower than they are currently. Under this scenario temperatures are expected to rise 2.7-3.1°C by the end of the century (relative to pre-industrial temperatures), significantly exceeding the 2°C target set by the Paris Climate Agreement.

In the middle scenario, countries implement sufficient policies to meet their existing commitments under the Paris Climate Agreement. Note that this requires additional national policies beyond those already in place. In this scenario global emissions peak around 2030 and fall to about half of current levels by 2100. But even if all countries meet their existing pledges, warming is still expected to be 2.3-2.6°C by the end of the century, again failing to meet the 2°C target.

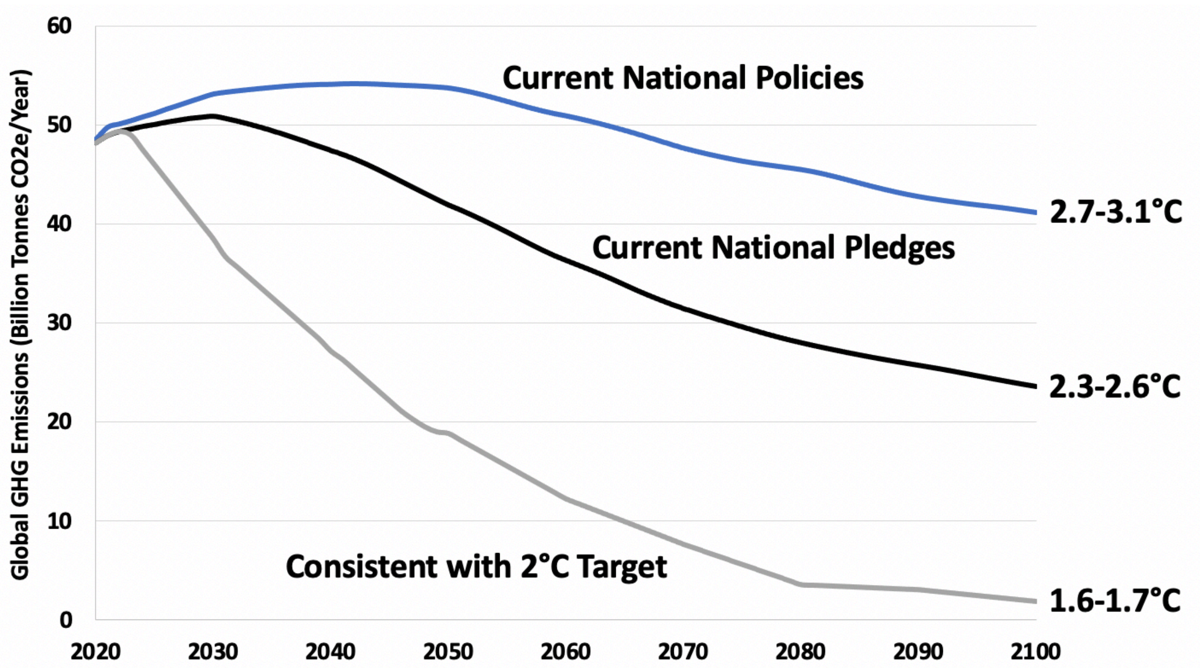
The lowest-emission scenario in Figure 12.8 is consistent with keeping warming under the 2°C target. In order to meet this goal, emissions must start to decline almost immediately, and continue to decline rapidly for the next half-century. In this scenario, emissions in 2100 are over 95% lower than current levels. Clearly, a substantial strengthening of current policy commitments will be needed in order to meet this target, as we discuss in the next chapter.

The magnitude of actual warming and other effects will depend upon the level at which atmospheric concentrations of CO_2 and other greenhouse gases are ultimately stabilized. Pre-industrial levels of concentration were around 280 parts per million (ppm). In an article titled "Target Atmospheric CO_2: Where Should Humanity Aim?" a group of climate scientists argued that: "If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO_2 will need to be 350 ppm."[25]

In 2015, the atmospheric CO_2 concentration passed the milestone of 400 ppm and it is now close to 420 ppm (Figure 12.1).[26] When we include the contribution of other greenhouse gases, the overall effect is equivalent to a concentration of about 450 ppm of CO_2 equivalent. This level of CO_2 equivalent has not been experienced for over 800,000 years, and at current rates of increase the level will soon equal that of about 15 million years ago, when temperatures were 3-4° hotter and sea levels were 20 meters higher.[27] The stabilization goal of 350 ppm would imply a significant reduction from current atmospheric concentration levels—something which, as we have discussed, is very difficult to achieve for a stock pollutant.

CO_2 equivalent (CO_2e) a measure of total greenhouse gas emissions or concentrations, converting all non-CO_2 gases to their CO_2 equivalent in warming impact.

Figure 12.8 Projected Global Greenhouse Gas Emissions, 2020-2100



Source: Climate Action Tracker, https://climateactiontracker.org/global/temperatures/.

12.2 Responses to Global Climate Change

The onset of climate change demands both **preventive strategies** and **adaptive strategies**. Consider, for example, the damage caused by rising sea levels. The only way to stop this would be to prevent climate change entirely—something that is now impossible. It might be possible in some cases to build dikes and sea walls to hold back the higher waters. Those who live close to the sea—including whole island nations that could lose most of their territory to sea-level rise—will suffer major costs under any adaptation strategy. But a prevention strategy that could slow, though not stop, sea-level rise requires convincing most of the world's countries to participate. The Paris Agreement of 2015 represented a step toward realization, on the part of the 195 signatory countries, that there was a common interest in combatting climate change. But even if significant action does come from global agreements, adaptation costs will still be very large.

preventive measures actions designed to reduce the extent of climate change by reducing projected emissions of greenhouse gases.
adaptive measures actions designed to reduce the magnitude or risk of damages from global climate change.

Scientists have modeled the results of a projected doubling of accumulated carbon dioxide in the earth's atmosphere. Some of the predicted effects are:

- Loss of land area, including beaches and wetlands, because of sea-level rise
- Loss of species and forest area
- Increased intensity of storms, hurricanes, and other extreme weather events
- Increased occurrence of severe drought and flooding
- Disruption of water supplies to cities and agriculture
- Health damage and deaths from heat waves and spread of tropical diseases
- Loss of agricultural output due to extreme weather variability
- Increased air conditioning costs

Beneficial outcomes might include:

- Increased agricultural production in cold climates
- Lower heating costs
- Fewer deaths from exposure to cold

The potentially beneficial outcomes would be experienced primarily in northern parts of the Northern hemisphere, such as Iceland, Siberia, and Canada, where agricultural output might increase (although these areas would also suffer from significant negative effects). Most of the rest of the world, especially tropical and semi-tropical areas, are likely to experience strongly negative effects from additional warming.

In addition, other less predictable but possibly more damaging and permanent effects include:

- Sudden major climate changes, such as a shift in the Atlantic Gulf Stream, which could change the climate of Europe to that of Alaska, or other drastic changes to the thermohaline circulation (large-scale ocean currents driven by heat and freshwater flows).
- Positive **feedback effects**, such as an increased release of CO_2 from warming arctic tundra, which would speed up global warming. (A feedback effect occurs when an original change in a system causes further changes that either reinforce the original change (positive feedback) or counteract it (negative feedback)).
- New emerging diseases, including new pathogens that could create pandemics perhaps more devastating than COVID-19, either due to expanding the range of existing diseases

such as mosquito-borne dengue and malaria, or as a result of melting permafrost that could "liberate" viruses that have been dormant for millions of years. [28]

- A rapid collapse of the Greenland or Antarctic ice sheets, leading to much higher sea-level rise that could drown coastal cities.[29]

According to IPCC projections, with increasing emissions and higher temperatures, negative effects will intensify, and positive effects diminish (Table 12.1). As shown in Figure 12.8, there is considerable uncertainty about the expected global warming in the next century. We need to keep such uncertainties in mind as we evaluate economic analyses of global climate change.

Given these uncertainties, some economists have attempted to place the analysis of global climate change in the context of **cost-benefit analysis**. Others have criticized this approach as an attempt to put a monetary valuation on issues with social, political, and ecological implications that go far beyond dollar value. We will first examine economists' efforts to capture the impacts of global climate change through cost-benefit analysis and then return to the debate over how to assess potential greenhouse gas reduction policies.

feedback effect the process of changes in a system leading to other changes that either counteract or reinforce the original change.
cost-benefit analysis (CBA) a tool for policy analysis that attempts to monetize all the costs and benefits of a proposed action to determine the net benefit.

12.3 Economic Analysis of Climate Change

Numerous economic analyses have estimated costs and benefits under various climate change scenarios. When economists perform a cost-benefit analysis, they weigh the consequences of the projected increase in carbon emissions versus the costs of current policy actions to stabilize or even reduce CO_2 emissions. Strong policy action to prevent climate change will bring benefits equal to the value of damages that are avoided. These benefits of preventing damage can also be referred to as **avoided costs**. The estimated benefits must then be compared to the costs of taking action. Various economic studies have attempted to estimate these benefits and costs.

avoided costs costs that can be avoided through environmental preservation or improvement

Table 12.1 Possible Effects of Climate Change

	Eventual Temperature Rise Relative to Pre-Industrial Temperatures				
Type of Impact	**1°C**	**2°C**	**3°C**	**4°C**	**5°C**
Freshwater Supplies	Small glaciers in the Andes disappear, threatening water supplies for 50 million people	Potential water supply decrease of 20–30% in some regions (Southern Africa and Mediterranean)	Serious droughts in southern Europe every 10 years; 1–4 billion more people suffer water shortages	Potential water supply decrease of 30–50% in southern Africa and Mediterranean	Large glaciers in Himalayas possibly disappear, affecting ¼ of China's population
Food and Agriculture	Modest increase in yields in temperate regions	Declines in crop yields in tropical regions (5–10% in Africa)	150–550 million more people at risk of hunger; yields likely to peak at higher latitudes	Yields decline by 15–35% in Africa; some entire regions out of agricultural production	Increase in ocean acidity, possibly reduces fish stocks
Human Health	At least 300,000 die each year from climate–related diseases; reduction in winter mortality in high latitudes	40–60 million more exposed to malaria in Africa	1–3 million more potentially people die annually from malnutrition	Up to 80 million more people exposed to malaria in Africa	Further disease increase and substantial burdens on health care services
Coastal Areas	Increased damage from coastal flooding	Up to 10 million more people exposed to coastal flooding	Up to 170 million more people exposed to coastal flooding	Up to 300 million more people exposed to coastal flooding	Sea-level rise threatens major cities such as New York, Tokyo, and London
Ecosystems	At least 10% of land species facing extinction; increased wildfire risk	15–40% of species potentially face extinction	20–50% of species potentially face extinction; possible onset of collapse of Amazon forest	Loss of half of Arctic tundra; widespread loss of coral reefs	Significant extinctions across the globe

Sources: IPCC, 2007b; Stern, 2007.

Attempting to measure the costs of climate change in monetized terms, or as a percentage of GDP, poses several inherent problems. In general, these studies can only capture effects of climate change insofar as they impact economic production, or create non-market impacts that can be expressed in monetary terms (as discussed in Chapters 6 and 7). Some sectors of the economy are especially vulnerable to the effects of climate change, including farming, forestry and fishing, coastal real estate, and transportation. But these comprise only about 10 percent of GDP. Other major areas, such as manufacturing, services, and finance, may be only lightly affected by climate change.[30] Thus an estimate of GDP impacts may tend to omit some of the most powerful ecological effects of climate change. According to William Nordhaus, who has authored many cost-benefit studies of climate change:

> [T]he most damaging aspects of climate change—in unmanaged and unmanageable human and natural systems—lie well outside the conventional marketplace. I identified four specific areas of special concern: sea-level rise, hurricane intensification, ocean acidification, and loss of biodiversity. For each of these the scale of the changes is at present beyond the capability of human efforts to stop. To this list we must add concerns about earth system singularities and tipping points, such as those involved in unstable ice sheets and reversing ocean currents. These impacts are not only hard to measure and quantify in economic terms; they are also hard to manage from an economic and engineering perspective. But to say that they are hard to quantify and control does not mean that they should be ignored. Quite the contrary, these systems are the ones that should be studied most carefully because they are likely to be the most dangerous over the longer run.[31]

Cost-benefit analysis, as discussed in Chapter 7, can also be controversial because it puts a dollar figure on the value of human health and life. As noted in Chapter 7, most studies follow a common cost-benefit practice of assigning a value of about $8–11 million to a life, based on studies of the amounts that people are willing to pay to avoid life-threatening risks, or are willing to accept (e.g., in extra salary for dangerous jobs) to undertake such risks. But as also noted in Chapter 7, lower human life values tend to be assigned in developing nations, since the methodology for determining the value of a "statistical life" depends on monetary measures, such as incomes and contingent valuation. Since many of the most serious impacts of climate change will be experienced in developing nations, this economic valuation bias clearly raises both analytical and moral issues.

The issue of uncertainty, also discussed in Chapter 7, is central to cost-benefit analysis of climate change. Damage estimates tend to omit the possibility of the much more catastrophic consequences that *could* result if weather disruption is much worse than anticipated. A single hurricane, for example, can cause tens of billions in damage, in addition to loss of life. Hurricane Katrina in August 2005, for example, caused over $100 billion in damage, in addition to loss of over 1,800 lives. Hurricane Sandy, in 2012, caused about $50 billion in damages, disrupting power to nearly 5 million customers and leaving lasting effects on an extensive area of shoreline in New York and New Jersey. Hurricane Maria, the deadliest US-based natural disaster in 100 years, devastated Puerto Rico in September 2017, killing 2,975 people. It damaged hundreds of thousands of homes and most of the island's infrastructure, left 3 million people without power for several months, and caused about $90 billion in damage.[32]

If climate change causes severe hurricanes to become much more frequent, cost-benefit analyses would have to estimate the costs of destruction at a much higher level than they have done previously. Another of the unknown values—human morbidity, or losses from disease—could well be enormous if tropical diseases extend their range significantly due to warmer weather conditions.

"Integrated assessment" models have been used by scientists and economists to translate scenarios of population and economic growth, and the resulting patterns of greenhouse gas emissions, into changes in atmospheric composition and global mean temperature. These models then apply "damage functions" that approximate the global relationships between temperature changes and the economic costs from impacts such as changes in sea level, hurricane intensity, agricultural productivity, and ecosystem function. Finally, the models attempt to translate future damages into present monetary value.[33]

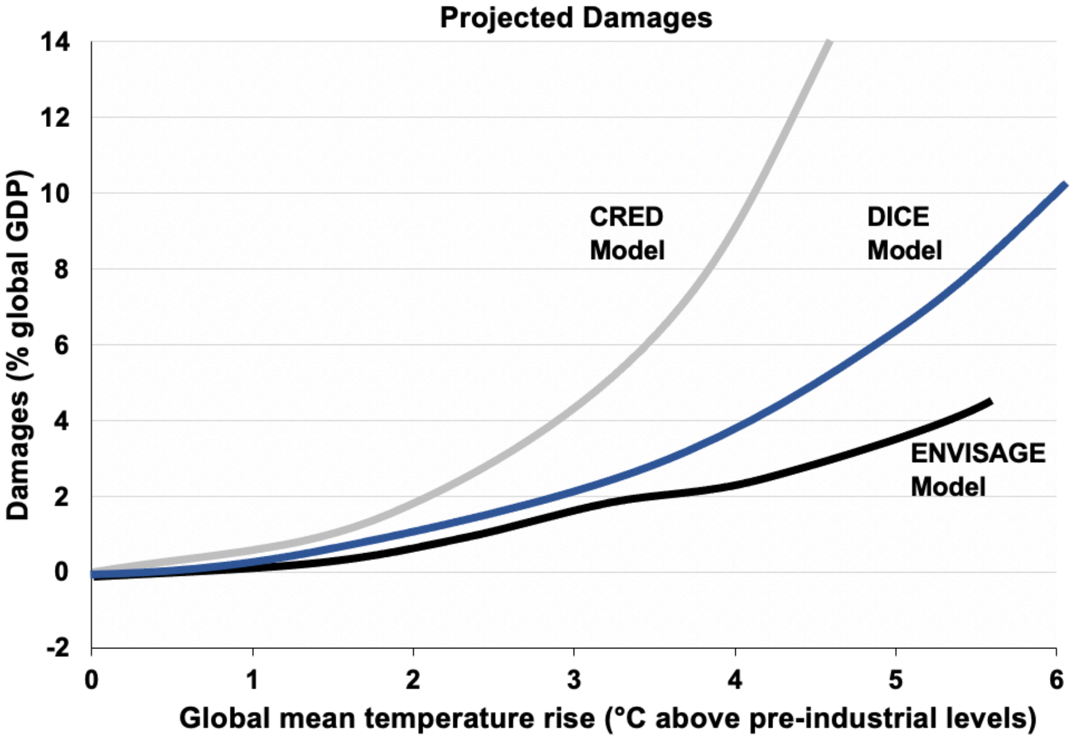
Higher ranges of temperature change lead to dramatically increased damage estimates at the global level, as shown in Figure 12.9. Different models yield different estimates for future damages and in turn different impacts on the economy, ranging from 2 percent to 10 percent or more of global GDP per year, depending on the global mean temperature rise. Modeling for damages to the United States economy show a similar pattern, with effects becoming "disproportionately larger as temperature rise increases."[34]

The values in Figure 12.9 show results from three widely used models with damage estimates based on the IPCC estimates of likely temperature change by 2100. These monetized estimates of damage may be subject to controversy and may not cover all aspects of damage, but suppose that we decide to accept them—at least as a rough estimate. We must then weigh the estimated benefits of policies to prevent climate change against the costs of such policies. To estimate these costs, economists use models that show how inputs such as labor, capital, and resources produce economic output.

To lower carbon emissions, we must cut back the use of fossil fuels, substituting other energy sources and investing in new infrastructure for renewables, energy efficiency, and other carbon abatement strategies. Economists calculate a measure of **marginal abatement costs**—the cost of reduction of one extra unit of carbon—for various measures, such as energy efficiency, shifting to solar and wind power, or avoided deforestation. Some of these measures are low cost, or even negative cost (meaning that they bring a net economic benefit in addition to their carbon-reducing contribution—more on this in the next chapter). But especially for very substantial carbon reduction, most economic models predict some negative impact on GDP. One summary of a broad array of studies, known as a meta-analysis, found that estimates of the impact on GDP vary based on assumptions about the possibilities for substitution of new energy sources, technological learning, and general economic flexibility.[35]

marginal abatement costs costs of reduction for one extra unit of pollution, such as carbon emissions.

Figure 12.9 Increasing Damages from Rising Global Temperatures



Sources: Revesz *et al*., 2014, http://www.nature.com/news/global-warming-improve-economic-models-of-climate-change-1.14991; Ackerman, Stanton, and Bueno, 2013.

Note: The three different models (ENVISAGE, DICE, and CRED) shown in this figure give damage estimates that are similar at low to moderate levels of temperature change, but diverge at higher levels, reflecting different assumptions used in modeling.

One estimate of the costs of meeting the Paris Agreement target of no more than 2°C temperature increase is that it would require about 1.5 percent of world GDP (about the equivalent of one year's GDP growth). But this is under best-case assumptions of international cooperation. Under less favorable assumptions, costs are estimated to rise to above 4 percent of global GDP.[36] Similarly, the meta-analysis referred to above finds that costs could vary from 3.4 percent of global GDP under worst-case assumptions to an *increase* in global GDP of 3.9 percent using best-case assumptions.[37]

future costs and benefits benefits and costs that are expected to occur in the future, usually compared to present costs through discounting.
discount rate the annual rate at which future benefits or costs are discounted relative to current benefits or costs.

Balancing Costs and Benefits of Climate Action

If costs and benefits of an aggressive carbon abatement policy are both in the range of several percent of GDP, how can we decide what to do? Much depends on our evaluation of **future costs and benefits**. The costs of taking action must be borne today or in the near future. The benefits of taking action (the avoided costs of damages) are further in the future. Our task, then, is to decide today how to balance these future costs and benefits.

As we saw in Chapter 7, economists evaluate future costs and benefits using a **discount rate**. The problems and implicit value judgments associated with discounting add to the uncertainties that we have already noted in valuing costs and benefits. This suggests that we should consider some alternative approaches—including techniques that can incorporate ecological as well as the economic costs and benefits.

Economic studies dealing with cost-benefit analysis of climate change have come to very different conclusions about policy. According to early studies (2000 to 2008) by William Nordhaus and colleagues, the "optimal" economic policies to slow climate change involve modest rates of emissions reductions in the near term, followed by increasing reductions in the medium and long term, sometimes referred to as a gradual "ramping up" of climate policy.[38]

Most early economic studies of climate change reached conclusions similar to those of the Nordhaus studies, although a few recommended more drastic action. The debate on climate change economics changed significantly in 2007, when Nicholas Stern, a former chief economist for the World Bank, released a 700-page report, sponsored by the British government, titled "The Stern Review on the Economics of Climate Change." While most previous economic analyses of climate change suggested relatively modest policy responses, the Stern Review strongly recommended immediate and substantial policy action:

> The scientific evidence is now overwhelming: climate change is a serious global threat, and it demands an urgent global response. This Review has assessed a wide range of evidence on the impacts of climate change and on the economic costs, and has used a number of different techniques to assess costs and risks. From all these perspectives, the evidence gathered by the Review leads to a simple conclusion: the benefits of strong and early action far outweigh the economic costs of not acting.[39]

Using the results from formal economic models, the Review estimated that if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5 percent of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20 percent of GDP or more. In contrast, the costs of action—reducing greenhouse gas emissions to avoid the worst impacts of climate change—can be limited to around 1 percent of global GDP each year.[40] This benefit/cost ratio of at least 5:1 implies a strong economic case for immediate and major policy action, as opposed to a slower "ramping up."

What explains the difference between these two approaches to economic analysis of climate change? One major issue is the choice of the discount rate to use in valuing future costs and benefits.

As we saw in Chapter 7, the present value (PV) of a long-term stream of benefits or costs depends on the discount rate. A high discount rate will lead to a low present valuation for benefits that are mainly in the longer term, and a high present valuation for short-term costs. In contrast, a low discount rate will lead to a higher present valuation for longer-term benefits. The estimated net present value of an aggressive abatement policy will thus be much higher if we choose a low discount rate.

While both the Stern and Nordhaus studies used standard economic methodology, Stern's approach gives much greater weight to long-term ecological and economic effects. The Stern Review uses a low discount rate of 1.4 percent to balance present and future costs. Even though costs of aggressive action may appear higher than benefits for several decades, the high potential long-term damages sway the balance in favor of aggressive action today. But the use of a standard discount rate has the effect of reducing the present value of significant long-term future damages to relative insignificance. (This is shown in Chapter 7, Table 7.2, indicating for example that at a discount rate of 5 percent the value of $100 worth of damages 50 years in the future is evaluated in today's dollars as only $8.71, and 100 years in the future as a mere 76 cents.)

Another difference between the two studies concerns their treatment of uncertainty. Stern's approach gives a heavier weighting to uncertain but potentially catastrophic impacts. This reflects the application of a **precautionary principle**: If a particular outcome could be catastrophic, even though it seems unlikely, strong measures should be taken to avoid it. This principle, which has become more widely used in environmental risk management, is especially important for global climate change because of the many unknown but potentially disastrous outcomes possibly associated with continued greenhouse gas accumulation (see Box 12.4). A study by Martin Weitzman argues that a serious consideration of the possibilities of catastrophic climate change can outweigh the impacts of discounting, justifying substantial investment in reducing emissions today to avoid the possibility of future disaster—on the same principle as insuring against the uncertain possibility of a future house fire.[41]

precautionary principle the view that policies should account for uncertainty by taking steps to avoid low-probability but catastrophic events.

A third area of difference concerns the assessment of the economic costs of action to mitigate climate change. Measures taken to prevent global climate change will have economic effects on GDP, consumption, and employment, which explains the reluctance of governments to take drastic measures to reduce emissions of CO_2. But these effects will not all be negative.

"backstop" energy technologies technologies such as solar, wind, and geothermal, that can replace current energy sources, especially fossil fuels.
least-cost options actions that can be taken for the lowest overall cost.

The Stern Review conducted a comprehensive review of economic models of the costs of carbon reduction. These cost estimates depend on the modeling assumptions that are used. As noted above, the predicted costs of stabilizing atmospheric accumulations of CO_2 at 450 ppm could range from a 3.4 percent decrease to a 3.9 percent *increase* in global GDP. The outcomes depend on a range of assumptions including:

- The efficiency or inefficiency of economic responses to energy price signals
- The availability of noncarbon **"backstop" energy technologies**
- Whether countries can trade **least-cost options** for carbon reduction using a tradable permits scheme (the economics of tradable permits were presented in Chapter 8)
- Whether revenues from taxes on carbon-based fuels are used to lower other taxes
- Whether external benefits of carbon reduction, including reduction in ground-level air pollution, are taken into account[42]

Depending on which assumptions are made, policies for emissions reduction could range from a minimalist approach of slightly reducing emissions to drastic CO_2 emissions reduction of 80-100 percent (with the possibility of negative net emissions to reduce existing accumulations).

In recent years, however, the positions of Nordhaus and Stern have converged. Nordhaus, in his latest publications, uses an updated version of his model (DICE-2013) projecting a temperature increase of 3°C or more by 2100. He advocates a carbon tax of $21 per ton of CO_2 emitted, rising rapidly over time (the economics of carbon taxes are discussed in detail in Chapter 13).[43] A modification of his model by Simon Dietz and Nicholas Stern, taking into account increased damages and the possibility of climate "tipping points" (see Box 12.4), suggests that carbon taxes should be two to seven times higher, to limit atmospheric CO_2 accumulations to 425–500 ppm and global temperature change to 1.5 to 2.0°C.[44] Thus while differences remain, the trend is generally toward recommendations for more drastic policy measures:

> While Nordhaus and Stern may differ on whether a carbon tax should be imposed either as a ramp or a steep hill, and on the appropriate discount rate for converting anticipated future damages to present terms, this debate is progressively less relevant as they both agree that the steepness of this ramp would increase, with model sophistication and with the further delay of a carbon tax.[45]

The order of magnitude of cost estimates for achieving the Paris agreement goals of 1.5−2°C, which as we have seen is about 1.5%−4% of global GDP, is much lower than the loss of 8.3% of global income that occurred in 2020−2021 as a result of the covid-19 pandemic.[46] This suggests that avoiding catastrophes that could result from climate change, including possible future pandemics (see Box 12.4), would be worth significant investment today. It is worth noting that the stimulus policies of several major countries put in place to address the covid crisis have exceeded 10% of their GDP, and this opens a window of opportunity to use the aftermath of the covid crisis as fiscal leverage for expanded climate action and "green" recovery.[47]

Box 12.4 Climate Tipping Points and Surprises

Much of the uncertainty in projections of climate change relates to the issue of feedback loops. A feedback loop occurs when an initial change, such as warmer temperatures, produces changes in physical processes, which then amplify or lessen the initial effect (a response that increases the original effect is called a positive feedback loop; a response that reduces it is a negative feedback loop). An example of a positive feedback loop is when warming leads to increased melting of arctic tundra, releasing carbon dioxide and methane, which add to atmospheric greenhouse gas accumulations and speed up the warming process.

As a result of various feedback loops associated with climate change, recent evidence suggests that warming is occurring faster than most scientists predicted just five or ten years ago. This is leading to increasing concern over the potential for "runaway" feedback loops, which could result in dramatic changes in a short period. Some scientists suggest that we may be near certain climate tipping points, which, once exceeded, have the potential for catastrophic effects.

Perhaps the most disturbing possibility is the rapid collapse of the Greenland and West Antarctic Ice Sheets. A 2016 study argued that large chunks of the polar ice could melt over the next 50 years, causing a sea rise of 20 to 30 feet. The paper suggests that fresh water pouring into the oceans from melting land ice will set off a feedback loop that will cause rapid disintegration of ice sheets in Greenland and Antarctica. "That would mean loss of all coastal cities, most of the world's large cities and all their history," according to lead author Dr. James Hansen.

While rapid melting scenarios remain controversial, other dangerous feedback loops have been identified. In recent studies, scientists found that methane emissions from the Arctic have risen by almost one-third in just five years. The discovery follows a string of reports from the region in recent years that previously frozen boggy soils are melting and releasing methane in greater quantities. Such arctic soils currently lock away billions of tons of methane, a far more potent greenhouse gas than carbon dioxide, leading some scientists to describe melting permafrost as a ticking time bomb that could overwhelm efforts to tackle climate change. They fear the warming caused by increased methane emissions will itself release yet more methane and lock the world into a destructive cycle that forces temperatures to rise more rapidly than predicted.

Another possible result of melting permafrost is the release of microbes locked away for millennia, possibly resulting in devastating pandemics. More broadly, loss of biodiversity and destruction of ecosystems, resulting from climate change and other human interventions, is directly connected to the emergence of zoonoses (new diseases transmitted from animals to humans), as well as the spread of existing diseases such as dengue and malaria.

Sources: Adam, 2010; Gillis, 2016; DeConto and Pollard, 2016; Bottollier-Depois, 2020.

Climate Change and Inequality

The effects of climate change will fall most heavily upon the poor of the world. Regions such as Africa could face severely compromised food production and water shortages, while coastal areas in South, East, and Southeast Asia are at great risk of flooding. Tropical Latin America will see damage to forests and agricultural areas due to drier climate, and in South America changes in precipitation patterns and the disappearance of glaciers will significantly affect water availability.[48]

While the richer countries may have the economic resources to adapt to many of the effects of climate change, poorer countries will be unable to implement preventive measures without significant aid, especially those that rely on the newest technologies. This raises fundamental issues of **environmental justice** (discussed in Chapter 3, Box 3.4) in relation to the impact of economic and political power on environmental policy on a global scale. The concept of **climate justice** is a term used for framing global warming as an ethical and political issue, rather than one that is purely environmental or physical in nature. The principles of climate justice imply an equitable sharing both of the burdens of climate change and the costs of developing policy responses (discussed further in Chapter 13).[49]

environmental justice the fair treatment of people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.
climate justice equitable sharing both of the burdens of climate change and the costs of policy responses.

Recent studies have used geographically distributed impacts models to estimate the impacts of climate change across the global domain. As Table 12.2 indicates, the number of coastal flood victims and population at risk of hunger by 2080 will be relatively larger in Africa, South America, and Asia, where most developing countries are located.

A study published in Nature predicted that:

> If societies continue to function as they have in the recent past, climate change is expected to reshape the global economy by substantially reducing global economic output and possibly amplifying existing global economic inequalities, relative to a world without climate change. Adaptations such as unprecedented innovation or defensive investments might reduce these effects, but social conflict or disrupted trade could exacerbate them.[50]

Overall, the study projects that "the likelihood of large global losses is substantial" with the heaviest proportional losses being borne by the poorest countries.

Table 12.2 Regional-Scale Impacts of Climate Change by 2080 (Millions of People)

Region	**Population living in watersheds with an increase in water-resources stress**	**Increase in average annual number of coastal flood victims**	**Additional population at risk of hunger** (figures in parentheses assume maximum CO_2 enrichment effect)
Europe	382–493	0.3	0
Asia	892–1197	14.7	266 (−21)
North America	110–145	0.1	0
South America	430–469	0.4	85 (−4)
Africa	691–909	12.8	200 (−2)

Source: Adapted from IPCC, 2007b.

Note: These estimates are based on a business-as-usual scenario (IPCC A2 scenario). The CO_2 enrichment effect is increased plant productivity, which at maximum estimates could actually decrease the number at risk of hunger.

The way in which economists incorporate inequality into their analyses can have a significant impact on their policy recommendations. If all costs are evaluated in money terms, a loss of, for example, 10 percent of GDP in a poor country is likely to be much less, measured in dollars, than a loss of 3 percent of GDP in a rich country. Thus the damages from climate change in poor countries, which may be large as a percentage of GDP, and have greater impact on human well-being, would receive relatively little weight because the losses are relatively small in dollar terms. The Stern Review asserts that the disproportionate effects of climate change on the world's poorest people should increase the estimated costs of climate change. Stern estimates that, without the effects of inequity, the costs of a business-as-usual scenario could be as much as 11–14 percent of global GDP annually. Weighing the impacts on the world's poor more heavily gives a cost estimate of 20 percent of global GDP.[51]

Climate Stabilization

Assumptions about the proper way to evaluate social and environmental costs and benefits can make a big difference to policy recommendations. As we have seen, cost-benefit analyses mostly recommend action to mitigate climate change, but differ in the strength of their recommendations based on assumptions about risk and discounting. An ecologically oriented economist would argue that the fundamental issue is the stability of the physical and ecological systems that serve as a planetary climate-control mechanism. This means that **climate stabilization**, rather than economic optimization of costs and benefits, should be the goal. Stabilizing greenhouse gas *emissions* is insufficient; at the current rate of emissions carbon dioxide and other greenhouse gases will continue to accumulate in the atmosphere at potentially catastrophic rates.

climate stabilization the policy of reducing fossil-fuel use to a level that would not increase the potential for global climate change.

Stabilizing *accumulations* of greenhouse gases will require a significant cut below present emission levels. As we saw in Figure 12.8, in order to meet the 2°C target set in the Paris Climate Agreement, global greenhouse gas emissions need to fall steadily to nearly zero by the end of this century. This could likely only be achieved with substantially increased global absorption of CO_2, possibly through expanding forests and modifying agricultural techniques in addition to drastic emissions reductions.[52] For the more ambitious goal in the Paris Climate Agreement of limiting warming to no more than 1.5°C, a substantial period of *negative* net emissions would be required.

Clearly, reductions of this magnitude would imply major changes in the way that the global economy uses energy, as well as in sectors such as agriculture and forestry. "Pathways limiting global warming to 1.5°C . . . would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems."[53] As we saw in Chapter 11, energy efficiency and the use of renewable energy could have a significant effect in reducing emissions. Other policies could reduce emissions of other greenhouse gases and promote CO_2 absorption in forests and soils. What combination of policies can provide a sufficient response, and how have the countries of the world reacted to the issue thus far? Chapter 13 addresses these issues in detail.

Summary

Climate change, arising from the greenhouse effect of heat-trapping gases, is a global problem. All countries are involved in both its causes and consequences. Developed countries have been responsible for the major portion of historical emissions, and have the highest per capita emissions, but emissions by developing countries will grow considerably in the coming decades.

The most recent scientific evidence indicates that during the twenty-first century the global temperature may increase more than 3°C if countries do not implement additional policies. In addition to simply warming the planet, other predicted effects include disruption of weather patterns and possible sudden major climate shifts.

Economic analysis of climate change involves estimating costs and benefits. The benefits in this case are the damages potentially averted through action to prevent climate change; the costs are the economic costs of shifting away from fossil-fuel dependence, as well as other economic implications of greenhouse gas reduction.

Relative evaluation of costs and benefits depends heavily on the discount rate selected. Because damage tends to worsen over time, the use of a high discount rate leads to a lower evaluation of the benefits of avoiding climate change. In addition, effects such as species loss and effects on life and health are difficult to measure in monetary terms, as are the possibilities of uncertain but potentially catastrophic "runaway" effects. Also, depending on the assumptions used in economic models, the costs of policies to avoid climate change could range from a 4 percent decrease to a 4 percent increase in GDP.

Impacts of global climate change will fall most heavily on developing countries. Most economic analyses recommend some form of action to mitigate climate change, but vary in terms of the urgency and the extent of proposed remedies. Meeting the targets set in the Paris Climate Agreement will require drastic action to reduce emissions, implying major changes in global patterns of energy use and other policies to promote carbon reduction.

Key Terms and Concepts

adaptive strategies
avoided costs
"backstop" energy technologies
business as usual
climate stabilization
CO_2 equivalent (CO_2e)
common property resources
cost-benefit analysis
discount rate
feedback effect
future costs and benefits
global climate change
global commons
global warming
greenhouse effect
greenhouse gases
least-cost options
ocean acidification
precautionary principle
preventive strategies
public good
stock pollutant

Discussion Questions

1. What is the main evidence of global climate change? How serious is the problem, and what are its primary causes? What issues does it raise concerning global equity and responsibility for dealing with the problem?
2. Do you think that the use of cost-benefit analysis to address the problem of climate change is useful? How can we adequately value things like the melting of Arctic ice caps and inundation of island nations? What is the appropriate role of economic analysis in dealing with questions that affect global ecosystems and future generations?

3. What goals would be appropriate in responding to climate change? Since it is impossible to stop climate change entirely, how should we balance our efforts between adaptation and prevention/mitigation?

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