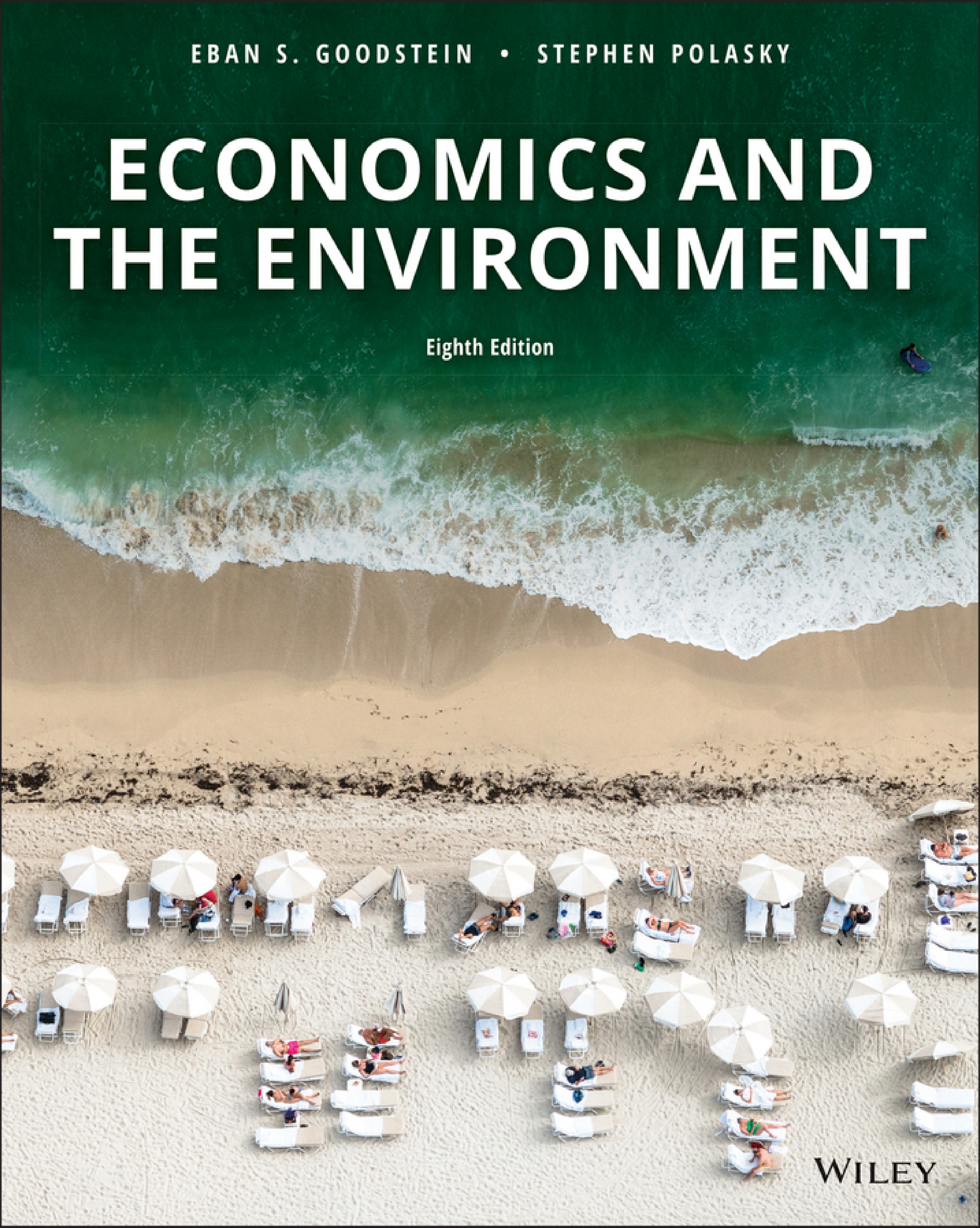
EBAN S. GOODSTEIN • STEPHEN POLASKY

ECONOMICS AND THE ENVIRONMENT

Eighth Edition



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ECONOMICS AND THE ENVIRONMENT

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Bard College

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WILEY

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PREFACE

This eighth edition of *Economics and the Environment* is the second to include Dr. Stephen Polasky as a co-author, who brings to the text a reworked and stronger focus on natural resource economics and ecosystem services. This book was first published in 1992, as the Rio Earth Summit was concluding. Global warming had been brought to national and global attention only 4 years previous by James Hansen's famous congressional testimony. The first President Bush would soon sign the UN Framework Convention on Climate Change. At the time, CO_2 in the atmosphere stood at 356 parts per million.

Twenty-five years later, CO_2 levels are over 400 parts per million and climbing. Climate change remains front and center, now understood less as an environmental problem than as a challenge to civilization. As in the first edition, global warming remains the topic that launches the book and provides the framing example for a comprehensive look at environmental economics. With Steve's help, the book now provides a stronger resource and ecosystem processes lens for exploring climate change and other critical environmental issues.

The book retains the three interrelated advantages of its earlier incarnations: broad content; pedagogical clarity; and timely, well-integrated examples. There are a few significant additions to the content, several new end-of-chapter problems and exercises, a set of PowerPoint slides, and updated examples and information throughout. For chapter-by-chapter suggestions for teaching from this book, please see the Instructor's Manual, online at www.wiley.com.

Major changes to this edition include the following:

- A refocus of the climate change discussion throughout on to the Paris Climate Agreement and the Trump election.
- Inclusion of the Flint, Michigan case in the discussion of environmental justice.
- Addition of a new section on Behavioral Economics, and insights for policy change within organizations and communities.
- A new section on the the application of the Clean Air Act to greenhouse gas regulation, and the basis for Executive Action behind the Paris Climate Agreement.
- A discussion of the 2016 TSCA reform—an interesting switch from an (unworkable) efficiency standard to a (weak) safety standard.
- Updated and in-depth discussions of California's CO_2 emission trading, and the EU ETS.
- The new UN Population forecasts—1 billion more people now expected by 2100.
- A reframing of the final section of the book around the UN's Sustainable Development Goals.
- A look at the "Climate Club" model recently developed by William Nordhaus.

In terms of core content, the book continues to provide a rigorous and comprehensive presentation of the "standard analysis," including the property-rights basis of environmental problems, efficient pollution control, benefit-estimation procedures, and incentive-based regulation. However, *Economics and the Environment* also incorporates broader topics as separate chapters, notably, the ethical foundations of environmental economics, a focus on ecological economics and strong sustainability, a safety-based approach to controlling pollution, the ecological economic critique of economic growth, the potential for government failure, the promotion of "clean technology," and opportunities for sustainable development in poor countries.

The second major advantage of the book is pedagogical clarity. In contrast to other texts that work from a "topics" perspective—water, oil, forests, fish—*Economics and the Environment* is centered around four clearly focused questions:

1. How much pollution (or resource degradation) is too much?
2. Is government up to the job?
3. How can we do better?
4. How can we resolve global issues?

These questions are all introduced through a detailed case study of the "big" issue of the century—global warming. The first section of *Economics and the Environment* then proceeds to explore the explicitly normative question, "How much pollution is too much?" The tools of welfare economics and benefit–cost analysis are used to explore three possible answers. The first is the efficient pollution level. Here students are introduced to the fundamentals of benefit and cost estimation and benefit–cost analysis. The second pollution standard is a safety standard, including questions of environmental justice, which in fact continue to drive much environmental policy. The advantages and drawbacks of safety as a goal are analyzed. Efficiency and safety are also contrasted in the context of the economic growth debate; students particularly enjoy Chapter 11, "Is More Really Better?"

The third standard is sustainability, defined as an intergenerational equity constraint. In two chapters, we explore weak (Neoclassical) and strong (Ecological) sustainability and, in the process, consider natural capital measurement techniques, the logic of discounting, the importance of investing resource rents productively, substitution possibilities between manufactured and natural capital, the precautionary principle, and questions on long-run resource scarcity. There is also a separate chapter focusing on "Resource Economics" (renewable and non renewable resource management), the Peak Oil debate, and recent attempts by economists to model and value ecosystem services through ecological production functions.

Tying together this first, normative section of the book is a vital discussion that is missing from other texts: the utilitarian ethical basis for the normative analysis and its relation to an "environmental ethic." Many students come into an environmental economics course thinking that saving polar bears is important, without knowing exactly why they think so. The explicit welfare-based analysis in Chapter 2 asks students to confront the assumptions underlying their own and others' worldviews.

The text fills a second major void through the second big question, "Is Government Up to the Job?" Most existing texts simply note that "government failure" is a potential problem when correcting for market externalities. In *Economics and the Environment*, the question of government's ability to effectively regulate pollution is carefully examined. The section begins with a discussion of the two primary obstacles to effective government action: imperfect information and the opportunity for political influence over government policy. It then provides a succinct review of existing legislation and accomplishments on air, water, solid and hazardous waste, toxic pollution, and endangered species. Part II ends with a discussion of the often neglected subject of monitoring and enforcement.

The third part of the book, "How Can We Do Better?" tackles the more positive aspects of pollution regulation. Two chapters are devoted to the theory and practical application of incentive-based regulation—marketable permits and Pigovian taxes. Real-world analysis focuses on the technical challenges faced by permit systems (price volatility, hot spots) and the political obstacles to taxes. Appendices explore instrument choice under uncertainty and incentive-compatible regulation. From here, the book examines an argument that attributes the root source of pollution to market failure in technological development rather than in the arena of property rights. We consider the view that the market often fails to generate incentives for investment in clean technology, as well as the feasibility of proposed solutions to this problem. In-depth discussion focuses on areas such as energy policy, pollution prevention, alternative agriculture, recycling, life-cycle analysis, and "green" labeling.

The final question that *Economics and the Environment* explores is: "How Can We Solve Global Issues?" Part IV focuses on global pollution and resource issues and is centered around a definition and discussion of sustainable development. Topics covered include the preservation of natural capital; the economics of population control; rising per-capita consumption pressures; the relationship between poverty, sustainable development, and environmental protection in poor countries; international trade and the environment; and global pollution control agreements.

In sum, *Economics and the Environment* appeals to three groups of instructors. The first are economists who are simply looking for a clear and concise presentation of environmental and resource economics. The four-question format developed in the text provides a simpler and more useful pedagogical handle than is available in the "topics" approach followed by other authors. In addition, the book provides a wealth of examples as well as an explicit consideration of the government's role in environmental policy not available in competing works. Finally, the appendices cover advanced theoretical topics, ensuring that there is enough in-depth material to fill out a one-semester course.

The book will appeal also to those with an interest in expanding the scope of environmental and resource economics. *Economics and the Environment* moves beyond the standard analysis in five important areas. It provides a rigorous normative analysis of environmental goals; an in-depth evaluation of ecological economics and strong sustainability; serious attention to the potential for government failure in pollution control; substantial discussion of dynamic issues of path dependence and technological change; and a sophisticated presentation of sustainable development in poor countries. The book seeks to incorporate ideas that have emerged in the environmental and ecological sciences over the past few decades into a well-developed economic analysis.

Given this orientation, instructors in environmental studies courses will also find this text to be unusually user-friendly. Chapters on measuring the value of nonmarket goods, benefit–cost analysis, markets for pollution rights, incentives for investment in appropriate technology, the governmental role in pollution control, population and consumption pressures, global bargaining, and conservation in poor countries provide accessible material for environmental study courses with a social-science focus.

Ultimately, the test of any textbook comes in the classroom. *Economics and the Environment* was written for students. It addresses important questions raised in their lives and introduces them to the economist's view of some solutions.

A synthetic work such as this depends on the contributions of hundreds of economists and environmental scholars working in the field. Some of their names appear in the list of authors cited at the end of this book; many important contributors were omitted because of the scarce resource of space. In addition, over the last 25 years, dozens of colleagues and anonymous reviewers have provided important comments and feedback. Many of their suggestions have found their way into the final version of this book. We are grateful to all who have contributed and made this a more useful text. Final thanks to our editors "Darren Lalonde, Manager Gladys Soto, Production Editor Padmapriya Soundararajan, and the entire team at John Wiley & Sons."

INTRODUCTION

CHAPTER 1

Four Economic Questions About Climate Change

1.0 Introduction

One of the authors of this book recently had some surprise visitors to his environmental and natural resource economics class. It was alumni week at the college, and four members of the class of 1950, *back for their 60th reunion*, joined our discussion. We were talking about sustainability, and suddenly the day's lecture became very real. How has life really changed since these visitors left college in 1950? Have six decades of intervening economic growth—with per capita gross domestic product (GDP) more than tripling—made life better? Or have the costs of growth made things worse? Is economic growth sustainable? And in the coming decades, will your generation's quality of life rise or fall?

So imagine now: You are that older woman or man, heading to the classroom this week for your 60th class reunion. You are 80-something, and for you, it will be sometime in the 2070s. As you listen to the young professor at the head of the class talking about the latest theories, you sit back and reflect on the changes that you have witnessed in your lifetime. Maybe your story will go something like this:

> Over the 21st century, you lived through both deep recessions and economic booms, through wars and political upheavals. You experienced staggering technological breakthroughs, unprecedented droughts, sea-level rise that forced millions from their homes, large-scale extinctions, and the outbreak of new diseases. Against this background, you and your classmates from around the world maintained a relentless focus: redesigning every city on the earth, reengineering production processes, reimagining the global food system, and reinventing transportation.
>
> World population increased from 8 to, eventually, 10 billion people. And through a heroic effort, ramping up in the 2020s, your generation managed to completely phaseout fossil fuels, rewiring the entire planet with a new generation of renewable energy technologies and stabilizing the global climate.
>
> At the end of the day, you shepherded both the human race and the remaining species on the planet through a critical bottleneck in human history, in which rising populations, aspiring to ever-higher levels of consumption, ran up against critical global resource shortages. Above all, you managed, by 2050, to roll back emissions of

global warming pollutants by 80 percent and stabilize the climate. In doing all this, you created tens of millions of jobs, helped lift billions of people out of poverty, and built a global economy that is truly sustainable.

Will that be your story?

We hope it will. And if so, you have a lot of work to do! Yours will be the "greatest generation" because you must guide the earth through this extraordinary half century. Your decisions will have profound consequences not only for you and your children but indeed for a thousand human generations to follow.

This book introduces you to economic concepts and tools that you will need to make the journey. We begin by framing economics in terms of four basic questions as they apply to the defining environmental—indeed, civilizational—challenge of your lifetime: climate change.

1.1 Four Questions

Did you drive to school today? Or to work? Every mile you drove, you pumped around a pound of carbon dioxide (CO_2) into the air. This is a part of your small daily share of the more than 25 billion pounds people around the world contribute annually from the burning of carbon fuels such as coal, oil, natural gas, and wood. Carbon dioxide is a **greenhouse gas**—a compound that traps reflected heat from the earth's surface and contributes to **global warming**. Other greenhouse gases include nitrous oxide from natural and human-made fertilizers; methane gas emitted from oil and gas production and transport as well as from rice production and the digestive processes of cows and sheep; and chlorofluorocarbons (CFCs), once widely used for air conditioning, refrigeration, and other industrial applications.[1]

As a result of industrialization and the ensuing rapid increase in greenhouse gases in our atmosphere, the vast majority of climate scientists agree that the earth's surface temperature will rise over the next few decades. The extent of warming is uncertain: low-end estimates suggest an increase in the earth's average surface temperature over preindustrial levels of 3 degrees F by the year 2100. The official high-end prediction from the UN's International Panel on Climate Change is 11 degrees over this time period. To put that number in perspective, during the last ice age, the earth's average surface temperature was only 9 degrees F colder than it is today.

The potential consequences of this warming range from manageable to catastrophic. The first major impact will be on patterns of temperature, flooding, and drought, affecting **agricultural output**. As the planet heats up, it "forces" the hydrologic cycle adding more moisture to the air, leading to both more extreme precipitation and flooding, along with increased temperatures, increased drought, and changed patterns of drought. More northerly regions may actually experience an increase in precipitation and yields, but the current grain belts of the United States, Australia, and central Europe will become drier and agricultural output in these regions will probably fall. The net global effect through the mid-century is expected to be, on balance, negative. It will be particularly harsh in many developing countries, which lack resources for irrigation and other adaptive measures. Tens of millions of people are likely to be at risk of hunger as a result of climate change.

Second, **natural ecosystems** will also suffer from climate change. The U.S. Environmental Protection Agency (EPA) has estimated that, by the year 2050, the southern boundary of forest ecosystems could move northward by 600 kilometers, yet forests can migrate naturally at a much slower pace. Several major vegetation models predict large-scale forest dieback in, among other places, the southern and eastern United States and the Amazon Basin. Human and animal diseases and agricultural pests will thrive in a warmer climate.

1. Chlorofluorocarbons also deplete the earth's protective ozone shield. This is a separate issue from global warming and is discussed in more detail in Chapter 21.

Major impacts in the oceans will occur not only because of warming waters that, for example, directly kill coral reefs but also because the oceans are absorbing large quantities of CO_2 released by fossil fuel combustion. This in turn is leading to **ocean acidification**: the pH of the ocean has dropped markedly in the last century. As the ocean continues to acidify, life at the base of the ocean food chain could begin to die off. On both land and sea, massive disruption of ecosystems and widespread extinctions, affecting perhaps 30 percent or more of the life on the planet, are thus likely.

The third concern is the possibility of a **sea-level rise** as ice caps in Greenland and Antarctica begin to melt, and the warming ocean expands. An increase in sea level of 3 feet—well within the realm of possibility within your lifetime—would flood many parts of Florida, Louisiana, Boston, and New York City as well as much of low-lying countries such as Bangladesh and the Netherlands (unless they were protected by dikes). As many as 1 billion people live in areas that might be directly affected.

The globe is very likely locked into a further warming of at least 3 degrees F over the next 100 years. This warming will have far-reaching human and ecosystem effects, but if contained would be a manageable event. Increased warming, however, not only would have a greater impact but also could result in truly **catastrophic outcomes**. One of these would be the collapse and melting of the Greenland and West Antarctic Ice Sheets events that would, over the course of several hundred years, raise sea levels by 40 feet or more and inundate many of the world's major cities. Some scientists believe that a warming of 4 degrees F or more would significantly raise the probability of this event. Dr. James Hansen, NASA's chief climate scientist, stated in early 2006:

> How far can it go? The last time the world was three degrees [C] warmer than today—which is what we expect later this century—sea levels were 25m [75 feet!] higher. So that is what we can look forward to if we don't act soon . . . . I think sea-level rise is going to be the big issue soon, more even than warming itself . . . . How long have we got? We have to stabilize emissions of carbon dioxide within a decade, or temperatures will warm by more than one degree [C]. That will be warmer than it has been for half a million years, and many things could become unstoppable . . . . We don't have much time left.[2]

A catastrophic collapse of the ice sheets is far from certain, but as Dr. Hansen suggests, decisions to be made in the next decade about reducing greenhouse gas emissions could have dramatic consequences lasting for tens of thousands of years.

Climate change is an environmental reality that presents stark choices. On the one hand, substantial, short-term reductions in the human contribution to the greenhouse effect would require dramatic changes in energy use. In particular, our casual reliance on fossil fuels for transportation, heat, and power would have to be dramatically scaled back and new, clean-energy sources developed. On the other hand, the consequences of inaction are potentially disastrous. By continuing to pollute the atmosphere, we may be condemning the next generation to even greater hardship.

This book focuses on the economic issues at stake in cases such as global warming, where human actions substantially alter the natural environment. In the process, we examine the following four questions.

1. **How much pollution is too much?** Many people are tempted to answer simply as follows: any amount of pollution is too much. However, a little reflection reveals that zero pollution is an unachievable and, in fact, undesirable goal. Pollution is a by-product of living; for example, each time you drive in a car, you emit a small

2. See Johansen (2006: 38) and Hansen (2005).

amount of CO_2 to the air, thus exacerbating the greenhouse effect. The question really is, "At what level are the benefits of pollution (cheap transportation in the case we started with) outweighed by its costs?"

Different people will answer this question in different ways, depending on their value systems: "costs" of pollution may be defined narrowly, as strictly economic, or they may be broadened to include ethical considerations such as fairness and the protection of rights. Costs may also be difficult to measure. Nevertheless, it is clear that a rough weighing of benefits and costs is a critical first step for deciding "how much is too much."

2. **Is government up to the job?** After resolving the first question, we must then rely on government to adopt laws and regulations to control pollution. But, is our government able and willing to tackle the tough job of managing the environment? The costs and mistakes associated with bureaucratic decision making, as well as the likelihood of political influence in the process, will clearly have an impact on government's ability to respond effectively to this challenge.

   The first Earth Day was April 22, 1970. Also that year, the U.S. Congress passed the first major pollution control initiative, the National Environmental Policy Act, which, among other things, created the EPA. Looking back over our 40-plus years of experience in regulating the environment, we have a record of both successes and failures to evaluate. Such an exploration can help us design policies to increase the effectiveness of the governmental response.

3. **How can we do better?** Suppose that as a society we decide on a particular target: for example, reduce CO_2 emissions by 80 percent by 2050. Given the limitations that government might face, identified in the answer to the second question, how can we best achieve that goal? A long list of policies might be used: regulations, taxes, permit systems, technology subsidies (or their removal), research incentives, infrastructure investment, right-to-know laws, product labeling, legal liability, fines, and jail terms. Which policies will most successfully induce firms and consumers to meet the target?

4. **Can we resolve global issues?** Finally, regulating pollution within a single nation is a difficult task. Yet problems such as global warming transcend national boundaries. Brazilians say that they will stop cutting down and burning their rain forests to create crop and rangeland as soon as we stop driving gas-guzzling cars. (Although the United States has only 4 percent of the world's population, we account for close to 17 percent of the greenhouse gases.) How can this kind of international coordination be achieved? Are economic development and environmental quality necessarily in conflict? And to what extent can the explosion in population growth and per capita resource use, which ultimately drive environmental problems, be managed?

Let us return to our discussion of climate change and see what type of answers we might develop to these four questions. Global warming is a consequence of what is known as the **greenhouse effect**. Solar energy enters the earth's biosphere in the form of visible and ultraviolet light from the sun. The first law of thermodynamics—energy can be neither created nor destroyed—requires that this energy go somewhere, and much of it is radiated back into the biosphere as infrared radiation or heat. CO_2 and other greenhouse gases surrounding the earth let in the visible and ultraviolet light from the sun. Yet, like a blanket, these gases trap the reflected infrared radiation (heat) close to the earth's surface.

Until the present time, the naturally occurring greenhouse effect has been primarily beneficial. Without the planet's blanket of water vapor, CO_2, and other gases, the average temperature on the earth would be about 91 degrees F colder—well below the freezing point. The problem we face today is the steady increase in human-made greenhouse gases, which began with the Industrial Revolution but dramatically accelerated after World War II. In less than two centuries, the thickness of the CO_2 blanket in the atmosphere has increased by more than 25 percent, rising from 280 parts per million (ppm) in 1880 to over 400 ppm today. Every year the blanket gets thicker by about 2 ppm. The question facing humanity is, how thick should we let this heat-trapping blanket grow? Should we try to hold it to 450 ppm? 550 ppm? 650 ppm? Or even roll it back to 350 ppm?

Is human-induced warming here yet? The earth's average temperature has risen more than 1.8 degree F over the last century, and the warming has accelerated in the last few decades. The year 2016 was the hottest on record, and the last decade has been the hottest in the last several thousand years. Back in 1995, the Intergovernmental Panel on Climate Change (IPCC), an organization of some 2,500 scientists operating under the auspices of the United Nations, made it official that greenhouse effect was here. According to the IPCC, "the balance of evidence suggests that there is a discernible human influence on global climate." Since then, the evidence supporting human-induced warming has become much stronger.[3]

Today, scientists are virtually unanimous in their opinion that further warming will occur, but the magnitude of the warming is difficult to predict. Nevertheless, we do have a range: recall 3–11 degrees F.

Uncertainty in predicting the degree of global warming is primarily due to the presence of **positive and negative feedback** effects. If it were necessary only to predict the impact of greenhouse gases on global temperature, the problem would be difficult enough. But changing temperatures will in turn affect many different parts of the earth and its surface, leading to either an acceleration of warming (positive feedback) or a deceleration (negative feedback).

Two examples of negative feedbacks include the possibility that increasing cloud cover will reduce the amount of radiation entering the earth's atmosphere or that increasing amounts of CO_2 will lead to higher rates of plant growth and thus more trapping of CO_2. Negative feedbacks would clearly be welcome, but unfortunately, positive feedbacks appear just as likely, if not more so, to occur. For example, higher temperatures may generate widespread forest fires and forest dieback in regions such as Amazon; lead to the emission of methane and CO_2 currently trapped in frozen bogs and peat fields at high latitudes; expose heat-absorbing darker earth under ice shields; or reduce the capacity of ocean organisms to fix CO_2 in their shells. These positive feedbacks have led some researchers to believe that at some point, global warming will trigger a **runaway greenhouse effect**, in which the initial warming will feed on itself. Under this scenario, policymakers no longer face a continuum of temperature possibilities: a warming of somewhere between 4 degrees and 11 degrees. Instead, there are only two options: either hold warming to the low end, 4–5 degrees, or risk triggering positive feedback loops that quickly drive the planet's temperatures up by 9–11 degrees, the equivalent of a swing of ice-age magnitude, only in the opposite direction.

In the face of this uncertainty, what action should be taken to prevent or mitigate the consequences of global warming? Following the outline described, we can begin to tackle this daunting question piece by piece.

1.2 How Much Pollution Is Too Much?

To answer this first question, let us first see where we stand on targets to reduce global warming pollution. At a UN-sponsored meeting in France in 2015, 170 countries across the world agreed to the **Paris Climate Agreement**, a set of voluntary commitments to cut global warming pollution. The United States committed that it would reduce emissions 30 percent below 2006 levels by 2030. China committed to capping their emissions by 2030, and to subsequent reductions. Added together, if the countries all follow through on the actions they committed

3. See IPCC (1996) and IPCC (2014).

to in Paris, scientists estimate that this will hold planetary warming to a total of 6 degrees F above preindustrial levels.

At the same time, world leaders also agreed to convene in 2020 with proposals for deeper global warming pollution cuts that would reduce the total warming to the official UN target of 4 degrees F or lower. Finally, back in the United States, the major Republican candidates for President in 2016 were all opposed to any action on climate change. The reasons? First, most Republican candidates questioned the scientific consensus that humans are causing climate change. And second, they all argued that serious efforts to reduce fossil fuel emissions would be much too costly. Candidate Marco Rubio, reflecting the party's viewpoint, said that reducing fossil fuel use would have "a devastating effect on the economy."[4] Taking no action to reduce emissions and sticking with business-as-usual would likely lock in at least an 8 degree F warming.

So what is the "right" level of global warming pollution? Emissions leading to a 4-degree increase in global temperatures (the Paris goal), a 6-degree increase (the Paris commitments), or an 8-degree increase (the no-action outcome)?

Economists typically answer this type of question using a benefit–cost framework. How big are the benefits of reducing warming? And what would it cost? Would phasing out fossil fuels really wreck the economy? However, quantifying the benefits and costs of reducing emissions is a difficult task, primarily because uncertainties loom very large in the case of climate change. On the benefits side, analysts are required to estimate the damages that will be avoided 100 years hence by stabilizing CO_2 as it affects not only global agriculture and human health but also species extinction and biodiversity. Moreover, across the planet, some regions will gain and others will lose; impacts will be proportionately larger in poor countries and smaller in rich countries. Developing countries will be hardest hit because they tend already to be in warmer and drier parts of the planet—but more importantly, because they have lesser financial resources for adapting their agriculture or building sea walls.

Putting a monetary value on such benefits presents difficult issues, among them: How do we deal with uncertainty and the possibility of cataclysmic change? How do we value damage to future generations? Can we measure the value of intangible or "priceless" benefits such as human suffering and death averted or forests saved? How do we weigh the fact that some countries will lose more compared to others in the warming process? These are issues we explore in detail later in the book.

Nevertheless, and bearing in mind these large uncertainties, two prominent economists—Sir Nicholas Stern, former head of the World Bank, and William Nordhaus from Yale University—have recently offered very different perspectives on the net benefits of aggressively reducing global warming pollution. The two researchers start with different estimates of "business-as-usual" warming by 2100, that is, the warming that would occur in the absence of any laws or government policies requiring or subsidizing emission reductions. Stern explores a range of between 5 and 11 degrees F of warming from current levels, while Nordhaus focuses on a single warming estimate, a "best guess" of under 5 degrees F.

Stern's projections are that, unchecked, global warming would reduce global output of goods and services from 5 to 20 percent, and the higher end is more likely. (For a reference point, the Great Depression of the 1930s led to a reduction in U.S. GDP of 25 percent.) Nordhaus is much more sanguine, arguing that by 2100, the impacts would be closer to a significant but much smaller 3 percent of world output.[5]

With such large damages, Stern's analysis calls for rapid cuts in emissions to hold global warming to the low end: 4 degrees F. This would require *global* reductions of 25 percent below

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4. Rubio is quoted in Carrol (2015). Of the sixteen Republican candidates originally in the field, only one, Lindsay Graham, was an advocate for action on climate change.

5. The discussion in these paragraphs is drawn from Stern (2006) and Nordhaus (2008). Ackerman et al. (2010) point out that Nordhaus's damage function implies that an increase in global temperature of 19 degrees C (34 degrees F) would be required to cut global GDP in half! Nordhaus is clearly a technological optimist.

1990 levels by 2050. However, since emissions from India, China, and Brazil will keep increasing for some time, this means 80 percent reduction by 2050 for the developed countries. Stern estimates that this policy would cost—in the form of reduced consumption—about 1 percent of global GDP per year by 2050, equivalent to about $540 billion (about half a trillion) in today's dollars.

Nordhaus, by contrast, calls for much smaller cuts of about 15 percent below business-as-usual, rising to 25 percent by 2050 and 45 percent by 2100. Because emissions will increase by a large amount under business-as-usual, relative to 1990 levels, Nordhaus is actually *recommending an increase* in global annual emissions of around 40 percent by 2050. Under Nordhaus's analysis, this policy of holding emissions down *relative to their unregulated state* would trim warming from a projected 5 degrees F increase to 4 degrees F. Nordhaus figures that the total benefits of this reduced warming will be $7 trillion, while the costs will run $2 trillion, leaving society $5 trillion better off.

These are two very different policy prescriptions: "deep cuts" in emissions versus "start slow, ramp up." But interestingly, both researchers arrive at similar answers to the "how much is too much" question: both recommend holding further global warming to the low end of 4 degrees F! Their big differences in recommended emission cuts instead reflect disagreement on three points: (1) how much warming will be generated by business-as-usual, (2) the costs of action to slow climate change, and (3) the costs of inaction.

First, on the climate-warming side, Nordhaus sticks with a single "best guess" to back up his start-slow policy recommendation. If business-as-usual "only" leads to a 5 degrees F warming by 2100, it won't require as much in emission cuts to get us back to 4 degrees. Stern, by contrast, is both less certain about the simple correlation between CO_2 buildup and future temperatures and much more worried about the possibility of positive feedbacks and the unleashing of a runaway greenhouse effect of the kind discussed earlier. Stern takes seriously the possibility that business-as-usual will blow quickly past 5 degrees F, and push us beyond 10 degrees F, within your lifetime. A 2009 Massachusetts Institute of Technology (MIT) study clearly supports Stern on this—it pushes the *median* projection of warming by 2100 under business-as-usual to a high-end, catastrophic 10 degrees F, with a one in nine chance that temperatures could rise as high as 12.5 degrees F.[6]

Second, Stern sees deep cuts in emissions as achievable at relatively low cost to the global economy: 1 percent of GDP. The Stern perspective is that energy efficiency and renewable energy technologies such as wind and solar electricity offer great promise for de-linking economic growth from fossil fuel use relatively quickly, thus achieving emission reductions cheaply. In important cases, emission reductions can even be achieved at a profit when initial investments in energy efficiency and renewable energy are offset by reduced spending on fossil fuels. Nordhaus, by contrast, does not believe in the potential of these low-cost alternatives. He reckons instead that Stern-level cuts would require, for example, more than a doubling of the cost of coal-fired electricity, cutting deeply into the growth of the global economy. (See more on this energy cost debate in Chapter 18).

Finally, Stern sees much bigger damages from global warming than does Nordhaus, even for the low end of 4 degrees F. There are three reasons for this. First, Stern includes more "nonmarket" costs of global warming—species extinctions, lost services provided by ecosystems, and negative impacts on human health. Second, Stern explicitly incorporates the fact that people in poor countries will bear the greatest costs of climate change. And finally, Stern puts more weight on the climate change costs borne by future generations than does Nordhaus. Valuing nonmarket goods, human health, and ecosystem services; weighting for equity in benefit–cost analysis; and the appropriate discounting of future benefits and costs are the issues we take up later in the book. For now, recognize that Stern and Nordhaus are the leading economic

6. Sokolov et al. (2009).

voices in a deadly serious debate: is global warming a civilizational challenge demanding immediate and deep emission reductions or is it simply another in a list of big problems, amenable to a go-slow fix?

Underlying the recommendations for only modest emission cutbacks is a belief that climate stability is important but not critical to the well-being of humanity. The argument is that people adapt to changing resource conditions. As emissions of greenhouse gases are regulated, the price of CO_2-based services will rise and new low-CO_2 technologies will come on board, ensuring that greenhouse gas concentrations eventually stabilize. Moreover, the development of new agricultural techniques will ensure that adequate food supplies are maintained even in the face of a changing climate and sea walls can be built to hold back rising sea levels. In addition, agriculture in some regions will gain from a warmer, wetter CO_2-enhanced climate, and cold-related deaths will decline. Some analysts even envision the winners from climate change assisting those (mostly in poor countries) who lose out from sea-level rise and flooding. Clearly, there will be significant losers from climate change, but on balance, it is believed that the quality of life for the average person in most countries can continue to rise even in the face of "moderate" climate change.

This mid-range benefit–cost perspective maintains that a near-term policy of CO_2 cuts below correct levels is too costly. Investing resources and person-power in reducing greenhouse gas emissions will divert investment from schools or health care, lowering living standards for future generations. Benefit–cost analysis is needed to obtain the right balance of investment between climate protection and other goods and services that people value.

It is critically important to recognize that virtually all economists conducting benefit–cost analyses of climate-change policy today agree that government action is needed immediately to cut emissions of global warming pollutants. A recent survey of climate economists puts the number calling for action at 94 percent.[7] The debate is not over whether near-term emission reductions is required but by how much. As noted, in Paris, the United States committed to medium-term reductions of 30 percent below 2006 levels by 2030, and the UN calls for a 2050 goal of much deeper 80 percent cuts. Nordhaus (but not Stern) would be okay with the go-slow 2030 target, while Stern (but not Nordhaus) would be pleased with the ambitious 2050 goal. Perhaps over the coming decade, economists will be able to settle their debate on the appropriate goal for the next half century.[8]

Note that the use of benefit–cost analysis by economists is implicitly endorsing an unstated ethical goal: control pollution only if the measurable monetary benefits of doing so are greater than the measurable monetary costs. This is one answer to the question "how much is too much?" It is called an **efficiency standard** for pollution reduction.

However, there are ways of thinking about pollution standards other than through a narrow comparison of economic costs and benefits. First, there are issues of fairness: inaction on our part—though it may provide for somewhat higher incomes today, particularly for citizens in affluent countries—may condemn future generations, in particular those in already poor countries, to even greater hardship. Can we justify actions today that, for example, will destroy entire island nations and their cultures? A second answer to the question "How much is too much?" emphasizes fairness. This is called a **safety standard**. Safety requires reducing pollution to (socially defined) "safe" levels, unless the costs of doing so are prohibitive.

Finally, there is the question of fundamental uncertainty regarding our impact on the planetary ecosystem. As we saw with Nordhaus, benefit–cost analysts typically assume an intermediate case of predictable damages, but, of course, a worst-case scenario might emerge.

7. Holladay, Horne, and Schwartz (2009).

8. Since the original Stern–Nordhaus debate (circa 2006), both analysts have had their positions evolve. As a consequence of delayed action, Nordhaus (2013: 194) now sees a 4 degree F (2 degree C) target as very likely too costly to achieve, but believes 5 degrees F (2.5 degree C) is a realistic target at a low enough cost to justify action. At the same time, Nordhaus' (2013:229) recommended carbon tax has jumped to $25 a ton (from $7) in 2015, rising to $93 a ton (from $25) in 2040. Dietz and Stern (2015) call for even stronger action than Stern (2006) in terms of carbon pricing.