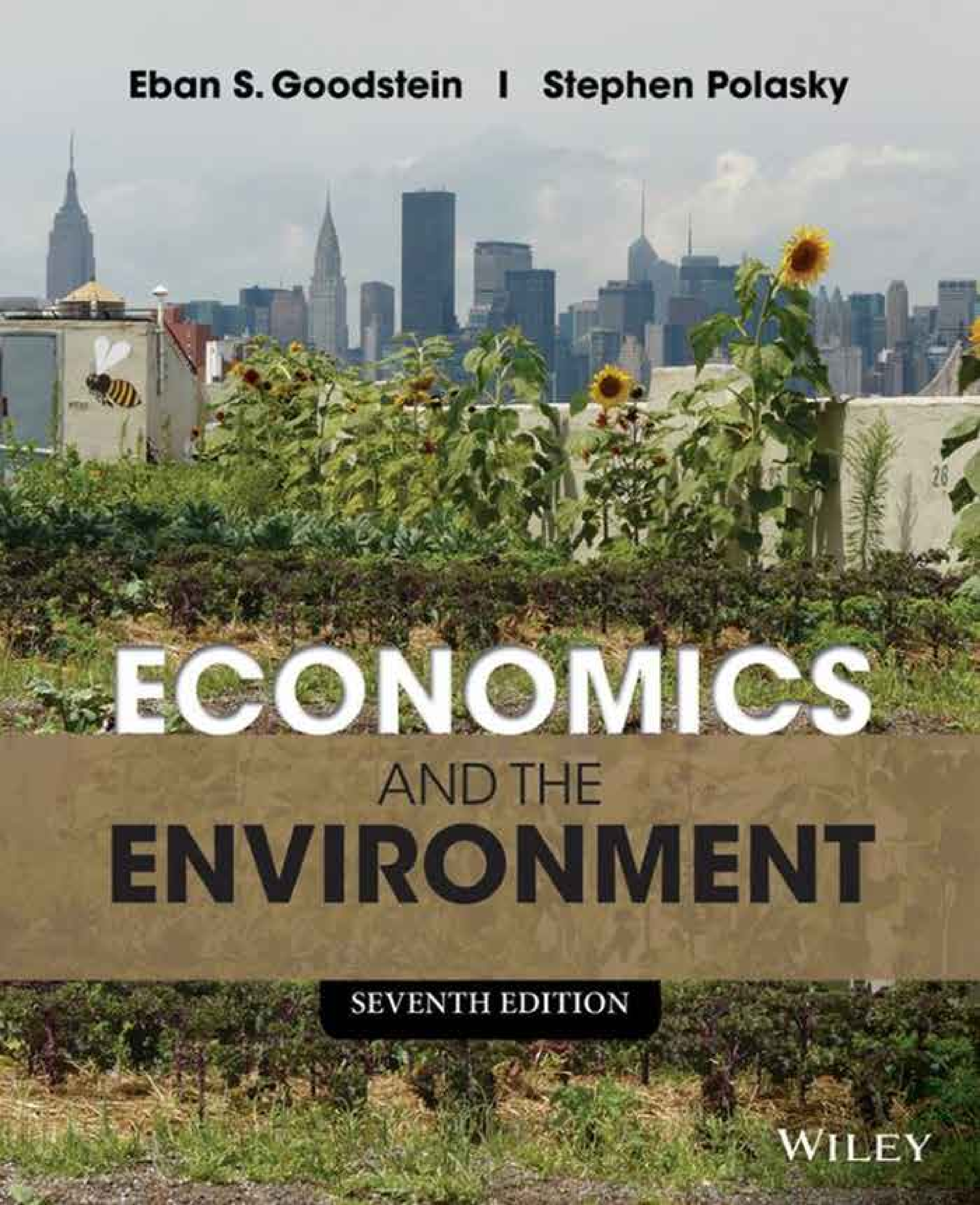
Eban S. Goodstein | Stephen Polasky



ECONOMICS AND THE ENVIRONMENT

SEVENTH EDITION

WILEY

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Eban S. Goodstein

Bard College

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University of Minnesota

WILEY

By this international commerce of geese, the waste corn of Illinois is carried through the clouds to the Arctic tundras, there to combine with the waste sunlight of a nightless June to grow goslings for all the land in between. And in this annual barter of food for light, and winter warmth for summer solitude, the whole continent receives as a net profit a wild poem dropped from the murky skies upon the muds of March.

—ALDO LEOPOLD

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Library of Congress Cataloging-in-Publication Data

Goodstein, Eban S., 1960-
Economics and the environment / Eban S. Goodstein, Bard College,
Stephen Polasky, University of Minnesota. – Seventh Edition.
pages cm
Includes index.
ISBN 978-1-118-53972-9 (pbk.)

1. Economic development—Environmental aspects. I. Polasky, Stephen. II. Title.

HD75.6.G66 2014
333.7—dc23

2013022158

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

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Preface

This seventh edition of *Economics and the Environment* welcomes 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 four years prior 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 one years later, CO_2 levels are at 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 content, several new end-of-chapter problems and exercises, and updated examples and information throughout.

A complete set of ancillary materials is available for adopters of *Economics and the Environment*. These resources can be found on the book's companion site at: www.wiley.com/college/goodstein.

- An Instructor's Manual containing suggestions for teaching from this book, sample exams, and chapter practice questions.
- PowerPoint Presentations for course lectures. In addition, electronic files for all the figures in the text are available in an Image Gallery.

Major changes to this edition include:

- The formerly separate chapters on Neoclassical and Ecological Economics have been reworked into two new chapters: The Sustainability Standard (Chapter 8) and Measuring Sustainability (Chapter 9). The discussion of the two perspectives is recentered around weak and strong sustainability. And in this edition, chapters on Measuring the Benefits of Environmental Protection (Chapter 6) and Measuring the Costs of Environmental Protection (Chapter 7) now precede the sustainability discussion.

- An all new chapter on Natural Resources and Ecosystem Services (Chapter 10) covers optimal non-renewable resource extraction; predictions about price paths; optimal renewable harvesting strategies; and the new economics involved in estimating the value of jointly produced ecosystem services.
- The discounting discussion has been reframed around the Ramsey equation, and it is made clear that discounting at a positive rate only makes sense if weak sustainability is assumed.
- The former chapter on benefit-cost analysis has been shortened and now appears as the concluding section to the chapter on the efficiency standard (Chapter 4).
- The former chapter on enforcement has also been shortened, and the material is included in the chapter covering the accomplishments and challenges of regulation (Chapter 14).
- Updated and in-depth discussions of California's new CO_2 emission trading and the EU ETS are provided.
- The Obama Administration's far-reaching impact on regulation and enforcement is discussed.

In terms of content, the book provides 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 new 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 of long-run resource scarcity. Also new to the text this edition is 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?" (Section 3) 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 section 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 into a well-developed economic analysis ideas that have emerged in the environmental and ecological sciences over the past few decades.

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, cost-benefit 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 studies 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 the 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 twenty 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 Courtney Luzzi, Joel Hollenbeck, Production Editor Yee Lyn Song at John Wiley & Sons and Project Manager Lavanya Murlidhar at Laserwords Pvt Ltd.

Introduction

CHAPTER 1

Four Economic Questions About Global Warming

1.0 Introduction

One of us 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 over 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 tens of 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 earth, reengineering production processes, reimagining the global food system, reinventing transportation.
>
> World population grew from 6 to 8 to, eventually, 10 billion people, before it finally stabilized in 2063. And through a heroic effort, ramping up in

the 2020s, your generation managed to completely phase out 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 pollution by 80% 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 lifetimes: global warming.

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 the warming is uncertain: low-end estimates suggest an increase in the earth's average surface temperature 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,

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 22.

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 diebacks in, among other places, the southern and eastern United States and the Amazon Basin. Human and animal diseases and agricultural pests will also thrive in a warmer climate.

Major impacts in the ocean 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 the 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% 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 lifetimes—would flood many parts of Florida, Louisiana, Boston, and New York City as well as much of low-lying countries like Bangladesh and the Netherlands (unless they were protected by dikes). As many as 1 billion people live in areas that might be directly affected.[2]

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. A greater 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 think that a warming of 4 degrees F or more would significantly raise the probability of this occurrence. 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 . . . .

2. IPCC (2007) details these impacts.

> 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.[3]

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

Global warming 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 substantial changes in Western 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 like 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: 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 amount of carbon dioxide 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 rewrite 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 the challenge.

   The first Earth Day was April 20, 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

3. See Hansen (2006) and Hansen (2005).

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 carbon dioxide emissions to their 1990 level by 2020. 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% of the world's population, we account for over 19% 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 global warming 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. The 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 true planet's blanket of water vapor, carbon dioxide, and other gases, the average temperature on 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 carbon dioxide blanket in the atmosphere has increased by more than 25%, 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 degree F over the last century, and the warming has accelerated in the last few decades. The years 2005 and 2010 tied for the hottest on record, and the last decade was probably 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—the greenhouse effect is 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.[4]

Today, scientists are virtually unanimous in their belief 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 due primarily 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 the warming (positive feedback) or a deceleration (negative feedback).

Two examples of the latter include the possibility that increasing cloud cover will reduce the amount of radiation entering the earth's atmosphere, or that higher rates of carbon dioxide will lead to higher rates of plant growth and thus more trapping of carbon dioxide. 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 like the 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 carbon dioxide 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?

First of all, where do we now stand on global warming emission targets? At the Earth Summit meeting in Rio de Janeiro back in 1992, attended by the leaders of more than 140 countries, the industrialized nations signed a pledge to "try" to stabilize greenhouse gas emissions at 1990 levels by the year 2000. However, this promise was not kept. In the United States, low energy prices and strong economic growth boosted greenhouse gas emissions by 19% between 1990 and 2009.

Faced with the failure of this voluntary approach, at a meeting in Kyoto, Japan, in 1997, the industrial countries of the world signed the **Kyoto global warming treaty**. The accord requires participating countries to reduce their emissions of greenhouse

4. See IPCC (1996) and IPCC (2007).

gases to around 5% below 1990 levels by 2012. Poor countries—including major emitters like India and China—were explicitly excluded under the reasoning that rich countries should shoulder the initial burden of developing clean-energy technologies like wind and solar power, making it affordable in the long run for the developing world to come on board. The treaty was ratified by the European countries, as well as Russia, Japan, and Canada, and entered into force in early 2005. All of these nations are taking implementation measures, though not all are likely to achieve the Kyoto targets. More on this in Chapter 21.

However, President Bush pulled the United States out of the Kyoto process, arguing that the country simply could not afford to tackle the global warming problem. Instead, he called for industry to take *voluntary* measures to reduce the rate of increase of emissions (not to reduce emissions themselves). In 2009 President Obama proposed U.S. cuts of around 17% by 2020, which would bring the nation back to 1990-level emissions, not quite achieving the Kyoto targets, ten years late. Was Kyoto the right short-term goal? Should emissions be reduced even further, as some European countries are already doing? Or, as Bush argued, should they not be reduced at all?

One way to answer this question is to use a benefit-cost framework. 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 fewer 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 certain countries will lose more than 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%, 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%.)

Nordhaus is much more sanguine, arguing that by 2100, the impacts would be closer to a significant but much smaller 3% 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% below 1990 levels by 2050. However, since emissions from India, China, and Brazil will keep growing for some time, this means 80% reductions by 2050 for the developed countries. Stern estimates that this policy would cost—in the form of reduced consumption—about 1% 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% below business-as-usual, rising to 25% by 2050 and 45% by 2100. Because emissions will increase a lot under business-as-usual, relative to 1990 levels, Nordhaus is actually *recommending an increase* in global annual emissions of around 40% 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 acting 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 emissions 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 lifetimes. 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% 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

5. The discussion in these paragraphs is drawn from Stern (2006) and Nordhaus (2008). Ackerman and Stanton (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.
6. Sokolov et al. (2009).