Environmental Economics

Fourth Canadian Edition

Field • Olewiler

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Brief Contents

Preface

This book is an introduction to environmental economics. It is about the way human decisions affect the quality of the environment; about how human values and institutions shape our demands for improvement in the quality; and, most especially, about how to design effective public policies to bring about these improvements.

Problems of environmental quality are not something new; in fact, history is filled with bleak examples of environmental degradation, from deforestation by ancient peoples to raw sewage in the streets, and mountains of horse manure in urban areas in the days before automobiles. But today's world is different. Many people are beginning to ask what good is material wealth if it comes at the cost of large-scale disruptions of the ecosystem by which we are nourished? More fundamentally, with contemporary economic, demographic, and technological developments around the world, the associated environmental repercussions are becoming more widespread. What once were localized environmental impacts have now become global and potentially more severe. It is no wonder that the quality of the natural environment has become a major focus of worldwide concern encompassing the public, elected officials, and private-sector decision makers in every country.

Environmental economics focuses on all the different facets of the connection between environmental quality and the economic behaviour of individuals and groups of people. The economic system creates environmental degradation, but can also be harnessed to provide incentives that improve environmental quality. There are major problems in measuring the benefits and costs of environmental quality changes, especially intangible ones. Complicated macroeconomic questions, for example, the connection between economic growth and environmental impacts and the feedback effects of environmental regulations on growth, are also prevalent. There are also the critical issues of designing environmental policies that are both effective and equitable.

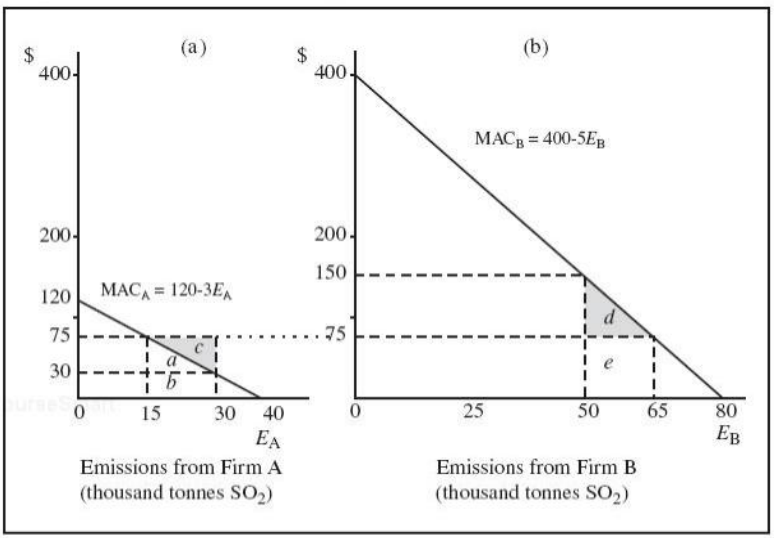
The strength of environmental economics lies in the fact that it is analytical and deals with concepts like efficiency, trade-offs, costs, and benefits. It is also a valuable means of inquiring why people behave as they do toward the natural environment, and how we might restructure the current system to rectify harmful practices. As an introduction to the principles of environmental economics, the examples discussed represent a sample of the full range of issues that exist. When you confront the real world of environmental politics and policy, you will find it necessary to adapt these principles to all the details and nuances of reality. There is not enough space in one book to look at all the ways environmental economists have found to make the basic concepts and models more specific and relevant to concrete environmental issues. We stick to the basic ideas and hope that they excite your interest and make you want to pursue further study of environmental economics.

WHAT'S NEW IN THE FOURTH CANADIAN EDITION

This fourth edition of ***Environmental Economics*** retains the organization, content, and writing style of the third edition. Those who have used the third edition will find the same thorough and systematic treatment of environmental economics that offers readers a Canadian text highlighting Canadian issues, data, and policies. Updates of Canadian environmental data and policies can be found in the introductory chapters, as examples in Section 4, and throughout Section 5. Notable changes from the third edition include greater emphasis in Section 1 on greenhouse gas emissions, air pollution from transportation, and Canada's environmental performance compared to other countries.

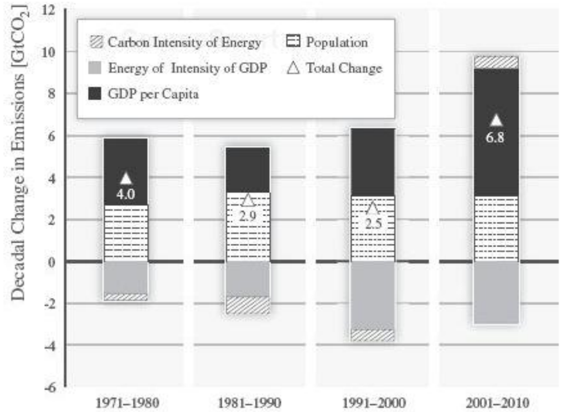
The key elements of the book are outlined below.

- *New material* is added to update environmental policy, especially policies to mitigate the emissions of greenhouse gases and the use of economic instruments such as carbon taxes and emission trading.
- *Environmental policy* chapters have updated data and environmental policies that focus on Canada, and illustrate how Canada's policies compare to policies in other countries, comparisons such as controlling sulphur dioxide in the United States and greenhouse gases in Europe. The emphasis is on links between theory and policy, with more Canadian examples.
- *Improved linking between chapters* via in-text references from one chapter to another allow students and instructors to move between theoretical concepts and application. More examples of policy in action occur in the theory chapters of Section 4.
- *Example boxes* are used throughout the book to highlight key theoretical and policy issues such as how benefit–cost analysis helped change policy and remove lead from gasoline.
- *Canadian case studies* bring the real world into the text. These provide illustrations of how economic principles can be applied to environmental issues, and contain thought-provoking questions for discussion, assignments, and research papers.
- *Worked examples* are provided in most chapters to improve understanding of theoretical concepts and to show how to solve problems.



- *All theoretical models* have verbal, graphical, and algebraic solutions to show the different ways to analyze environmental problems. Specific functional forms are used so that calculations are transparent and easy to follow.
- *Graphs* are enhanced with detailed captions.
- *Data* on environmental indicators is provided to not only provide a snapshot of the state of the environment, but also to facilitate research and discussion.

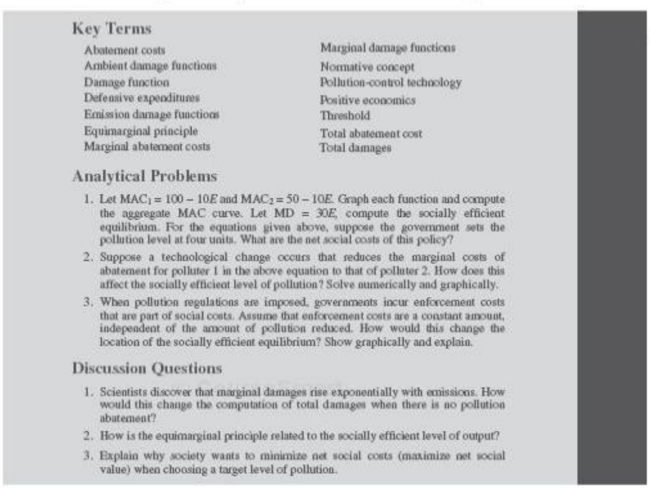
FIGURE 1-4 Decomposition of the Change in Total Global CO_2 Emissions from Fossil Fuel Combustion



The absolute changes in total CO2 emissions per decade can be decomposed into those arising from population growth (dotted box), GDP per capita (black), the energy intensity of GDP (gray), and carbon intensity of energy (crosshatch box). Total decadal changes in CO2 emissions are indicated by a white triangle. Changes are measured in gigatonnes of CO2 emissions per year (Gt/yr).

Source: IPCC, 2014: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Figure TS.1; Figure TS.6. [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schloemer, C. von Stechow, T. Zwickel, and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

- ***Key points*** are bulleted and bolded.
- ***Key terms*** are bolded within the text, listed at the end of each chapter, and defined in the pop-up box displayed when the cursor passes over the term in the eBook.
- ***End-of-chapter questions*** are split into discussion questions and analytical problems to give students a variety of ways to test their knowledge.



Key Terms

Abatement costs
Ambient damage functions
Damage function
Defensive expenditures
Emission damage functions
Equimarginal principle
Marginal abatement costs
Marginal damage functions
Normative concept
Pollution-control technology
Positive economics
Threshold
Total abatement cost
Total damages

Analytical Problems

1. Let $MAC_1 = 100 - 10E$ and $MAC_2 = 50 - 10E$. Graph each function and compute the aggregate MAC curve. Let $MD = 30E$, compute the socially efficient equilibrium. For the equations given above, suppose the government sets the pollution level at four units. What are the net social costs of this policy?
2. Suppose a technological change occurs that reduces the marginal costs of abatement for polluter 1 in the above equation to that of polluter 2. How does this affect the socially efficient level of pollution? Solve numerically and graphically.
3. When pollution regulations are imposed, governments incur enforcement costs that are part of social costs. Assume that enforcement costs are a constant amount, independent of the amount of pollution reduced. How would this change the location of the socially efficient equilibrium? Show graphically and explain.

Discussion Questions

1. Scientists discover that marginal damages rise exponentially with emissions. How would this change the computation of total damages when there is no pollution abatement?
2. How is the equimarginal principle related to the socially efficient level of output?
3. Explain why society wants to minimize net social costs (maximize net social value) when choosing a target level of pollution.

A GUIDE TO THE FOURTH CANADIAN EDITION

This book is an introduction to the basic principles of environmental economics as they have been developed in the past and continue to evolve. It is designed for a one-semester course. Each section is self-contained; users can rearrange the sequence of topics to suit their specific course.

Section 1 is designed not only to provide an overview of environmental economics, but also to introduce right away how economics can be used to analyze important real-world problems. This section is revised not only to update data on environmental impacts, but to provide a clearer introduction to a number of the key issues addressed in environmental economics. Chapter 1 notes why problems emerge and why they are so difficult for market economies to deal with. It defines key terms—efficiency and equity—and how they will be used to assess policies to help improve environmental quality. The role of incentives in economic systems is highlighted in the context of two major environmental problems—urban smog and motor vehicles and global climate change due to greenhouse gas emissions. The second major theme of Chapter 1 is sustainability and economic growth. The concept of trade-offs, illustrated by the production possibility frontier, is highlighted to show the choices society faces between economic growth and environmental quality, and the role of technological change. Chapter 2 introduces the notion of natural capital and ecosystem goods and services—the stock of our environmental resources and the goods and services it provides to sustain life on the planet and our economy. It highlights how the economy and natural environment are linked, using the concepts of a circular flow and how wastes can be reduced to sustain natural capital. Important terminology that is used throughout the book is defined. Canada's emissions of greenhouse gases is compared to other countries. Recent Canadian progress on reducing other pollutants is also highlighted.

Section 2 is devoted to the tools of economic analysis. Chapter 3 covers the economic principles of demand and supply. The concepts of willingness to pay and opportunity cost are the underpinnings of understanding all the benefits and costs of economic decisions. Supply and demand curves under conditions where markets work to allocate resources are derived. Chapter 4 examines markets and shows how market failure occurs because external costs and benefits arise when environmental resources are used in the economy. The important role of property rights is addressed. Causes of market failure are examined and economic efficiency is contrasted with social efficiency—the inclusion of all external benefits and costs into decision making. Chapter 5 develops a simple model of pollution control that is based on the notion of a trade-off between environmental damages and pollution abatement costs. Marginal damage and marginal abatement cost functions are derived and used to determine socially efficient levels of pollution. An important concept that will be used to assess the efficiency of environmental policies—the equimarginal principle—is derived.

Section 3 focuses on benefit–cost analysis. Chapter 6 introduces the main concepts and steps for doing a benefit–cost study, addressing the decision rule, and how to discount future benefits and costs, distributional issues, and uncertainty. Chapter 7 is devoted to the examination of techniques for measuring the benefits of improving environmental quality when market prices exist or when values have to be imputed. These include direct approaches that use market prices and indirect approaches such as preventive expenditures, hedonic estimation, travel cost, and contingent valuation techniques. A new example illustrates how contingent valuation methods can be used to estimate Canadians' willingness to pay to protect endangered marine mammals. Chapter 8 examines the cost side using the concept of social opportunity cost. Costs are viewed at different levels of economic activity from the level of the firm to the nation as a whole.

Section 4 provides the backbone for environmental policy analysis—the theoretical examination of different policy options. Chapter 9 covers criteria for evaluating environmental policies—efficiency, cost effectiveness, equity, incentives created, enforceability, and moral issues. Each of the next four chapters examines specific public policy instruments and initiatives, using graphical and algebraic analysis. A number of worked examples appear in each chapter. Chapter 10 examines decentralized approaches—liability rules, private property rights and bargaining, moral suasion, and the introduction of green goods into the market economy. Chapter 11 covers standards, a type of command-and-control policy. Different types of standards (performance and technology-based) are examined using the criteria of Chapter 9. Chapter 12 examines market-based incentive policies—taxes, subsidies, deposit–refund systems. The cost-effectiveness of taxes is contrasted with standards. The Porter hypothesis linking environmental regulation to innovation is presented. Chapter 13 presents another market-based incentive, the transferable emission permit. This is a method of assigning property rights to the environment and using market forces to achieve efficiency. Using the sulphur trading market in the United States as an example, issues in setting up and operating an emission market are covered. Chapter 14 pulls together and extends the theoretical analysis using the simple algebraic model developed in Section 4 to contrast costs of controlling pollution, incentives created to develop new cost-saving technology for pollution control, and information required. The model is also extended to cover uncertainty about the marginal damage and abatement cost curves.

Section 5 examines environmental policy in practice and is thoroughly updated to reflect current Canadian policies. The analytical tools developed earlier are applied to policies being used and contemplated in Canada are highlighted, with examples provided as well from the United States and other countries. Chapter 15 introduces key characteristics of Canadian environmental policy—the Constitution and the features of parliamentary government in our federal system. Conflict between federal and provincial powers over the environment is highlighted and illustrated with examples of regulation of Alberta's bitumen (oil sands) extraction and the proposed Northern Gateway pipeline from Alberta to the B.C. coast. Recent changes in federal legislation that affect assessment of projects with environmental impacts and environmental protection are highlighted. The next five chapters illustrate federal and provincial policies for water and air pollution, toxic compounds, recycling and solid waste disposal, and global environmental issues. Water pollution-control policies at the federal and provincial level are illustrated in Chapter 16, with emphasis on federal drinking water guidelines, national standards, and interjurisdictional policies. An example is provided of the use of an offset system similar to emission trading for water pollutants in an eastern Ontario watershed. Chapter 17 provides examples of federal and provincial regulation of air pollutants, covering the key urban air pollutants and acid rain. Featured are the significant changes underway that moves Canada's regulation from non-binding air quality objectives to air quality regulation. Progress toward air quality targets is illustrated with recent data. Chapter 18 focuses on the cornerstone of federal policy, the *Canadian Environmental Protection Act* and recent significant changes in toxic waste policy. Examples of toxic waste management policies at the provincial level are examined. A case study of pollutants from the pulp and paper industry illustrates the extensive use of command-and-control regulation in Canada. Chapter 19 begins with an analysis of technical options for reducing solid waste, and then focuses on the economics of recycling. A significant update covers recycling and solid waste disposal as well as the emerging topic of food waste and recovery. Chapter 20 rounds out the policy section by addressing global environmental pollutants and has undergone a major reorganization and update to better integrate the theory with policy chapters. A thorough update exists for Canadian greenhouse gas policy and the use of carbon pricing worldwide is a focus of the chapter. This allows for direct connection with Chapters 12 and 13 to show where international leadership and best practices are occurring. Canada's policies are contrasted with those of other countries. The successful

Montreal Protocol to eliminate ozone depleting compounds is contrasting with the less successful efforts to reach international agreement on greenhouse gas emissions. We also touch on the important issue of protecting biodiversity of the earth's ecosystems.

VERSATILITY OF THE TEXT

The book can be used by a variety of different environmental economics courses. Section 1 sets the stage for any type of course and covers core concepts while introducing important policy issues. Section 2 can be covered more or less intensively depending on the strength of students' backgrounds in microeconomic theory. Students who have had an introductory course in microeconomic principles can skim Chapters 3 and 4. Chapter 5 introduces the core model of the text that every course should cover in detail. Section 3 on benefit–cost analysis can be covered either before or after Section 4. For courses with limited time, Chapter 6 is the most important chapter in this section. For those who want to spend more time on benefit–cost analysis, Chapters 7 and 8 provide considerable detail on the methods of measuring benefits and costs. Section 4 is essential for all courses as it provides an in-depth theoretical analysis of the suite of policies that address pollution problems beginning with the criteria one needs to assess policy effectiveness. The order is important—beginning with a thorough examination of the role of property rights and voluntary agreements to reduce pollution (Chapter 10) to command-and-control policies (Chapter 11) to environmental pricing methods (Chapters 12 and 13). Chapter 14 pulls together the theoretical material to compare and contrast the types of policies using the criteria in Chapter 9. Extensions to a world of uncertainty in Chapter 14 can be skipped if time is short. Section 5 covers a broad spectrum of Canadian environmental policies and can be the focus of courses where public policy concerns are emphasized. Individual chapters can also be selected for coverage or the material in these chapters used as examples for the policy analysis in Section 4. Each chapter in Section 5 can stand alone; specific topics can be picked out and integrated with the theoretical discussion of policy instruments in Section 4. Cues are given in Section 4 to guide the reader to specific policy examples in Section 5.

- A short course for those with an economics background and focusing on theory could cover: Chapters 1, 2, 5, 6, 9–14 (first part) with examples taken from Chapters 15–20.
- A course focusing on environmental policy for those without an economics background could cover: Chapters 1, 2, 3, 4, 5, 15–20.

SUPPLEMENTARY MATERIAL

McGraw-Hill Connect™ is a web-based assignment and assessment platform that gives students the means to better connect with their coursework, with their instructors, and with the important concepts that they will need to know for success now and in the future. With Connect, instructors can deliver assignments, quizzes, and tests easily online. Students can practise important skills at their own pace and on their own schedule. With Connect, students also get 24/7 online access to an eBook—an online edition of the text—to aid them in successfully completing their work, wherever and whenever they choose.

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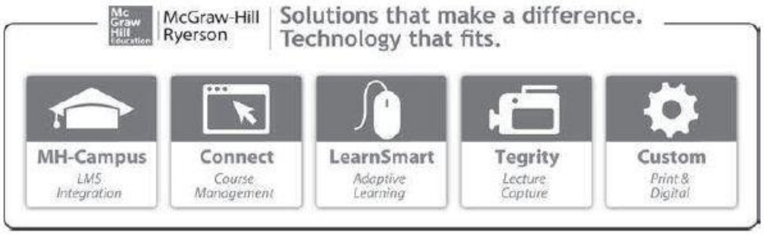

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The Canadian material has come from my teaching experiences at Simon Fraser University, conversations with a number of my colleagues in academia and the government, and many hours of Internet research of government documents and journal articles. So much is being written daily on environmental economic issues that it is a challenge to determine what must be left out. Many thanks to Jonathan Arnold, Masters in Public Policy 2014 graduate, for his excellent research help on this fourth edition. I am most grateful to the following reviewers for their valuable comments and input:

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Section **One**

Introductory

This first section contains two introductory chapters. Environmental economics builds on the foundations of microeconomic analysis, but introduces a number of key features that make it an important field of study in its own right. The first chapter provides an overview of environmental economics and illustrates key concepts by looking at both the global level—greenhouse gas emissions and climate change, and the local level—vehicle emissions. The second chapter explores a basic environment–economy framework and asks how can we sustain both, then defines a number of environmental terms used throughout the book, and provides a picture of the state of Canada's environment.

Chapter 1

What Is Environmental Economics?

After reading this chapter you will be able to:

LO 1 **Distinguish between efficiency and equity concepts and why they are central to environmental economics.**

LO 2 **Describe the incentives that contribute to pollution arising from people and firms.**

LO 3 **Define and distinguish between open access, private, and common property rights and explain why the assignment of property rights can help reduce pollution.**

LO 4 **Explain why people do not take into account the air pollution their vehicle emits when they drive.**

LO 5 **Describe the anthropogenic sources of greenhouse gas emissions and what changes are needed in the economy to reduce these emissions.**

LO 6 **Explain the tradeoffs between economic growth and the environment.**

LO 1

Environmental economics is the study of environmental problems with the perspective and analytical ideas of economics. Economics is the study of how and why people—whether they are consumers, firms, non-profit organizations, or government agencies—make decisions about the use of valuable resources. Economics is about making choices. It is divided into *microeconomics,* the study of the behaviour of individuals or small groups, and *macroeconomics,* the study of the economic performance of economies as a whole. Environmental economics draws from both sides, but primarily from microeconomics. The study of environmental economics, like all economics courses, is concerned with the fundamental issue of allocating scarce resources among competing uses. The concepts of **scarcity, opportunity cost, trade-offs, marginal benefits, marginal costs, efficiency,** and **equity** are key ingredients to understanding environmental problems and what can be done about them.

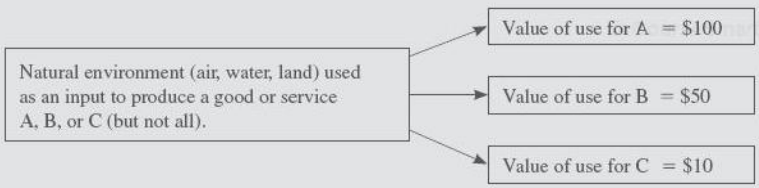
Environmental economics makes use of many familiar concepts in economics. What is different about environmental economics compared to other economic subjects is the focus on how economic activities affect our natural environment—the atmosphere, water, land, and an enormous variety of living species. Economic decisions made by people, firms, and governments can have many deleterious effects on the natural environment. For example, the dumping of waste products into the natural environment creates pollution that harms humans and other living things, production, and degrades ecosystems—the planet's air, water, and land. It leads to wasteful use of resources and threatens the sustainability of both our environment and economy. We ask:

- Why don't people take into account the effects of their economic activity on the natural environment?
- What inhibits economic systems from using its resources wisely and efficiently to protect the sustainability of our planet and people's livelihoods over time?

Environmental economics examines these questions by focusing on ways society can reduce its degradation of the natural environment. Equally as important, environmental economics investigates and assesses different methods of reaching an efficient and equitable use of all resources (including environmental ones) from the viewpoint of society, not just individual decision makers as is the typical focus in economic analysis.

ECONOMIC EFFICIENCY

Economic efficiency is all about using resources wisely. An outcome is said to be economically efficient if all resources are put to their highest value use, or equivalently, the economy reaches a desired outcome using the fewest resources. Chapter 4 develops efficiency concepts fully, but for now, consider this illustration.



Should we pick A, B, or C? An economically efficient choice would be to pick A. Good or service A maximizes the value of the end use for which resources are being put. In using economic efficiency as an objective, economists are making a value judgment as well as empirical observation. The value judgment (known as a 'normative' approach—see Chapter 5) is that something has value if someone wants it. That 'something' can be a computer or the ability to always take a walk in a forest—it need not be a good that is produced and sold in the marketplace. Both the computer and the walk in the forest use inputs from the natural environment—minerals for the computer components, the ecosystem supporting the forest environment for the walk. Environmental economics emphatically asserts that if individuals value the forest for taking walks more than the computer, than it is the highest value use, even if there is no explicit market for walks in the forest. The empirical observation behind efficiency is hundreds of years of observing people make decisions that indicate they are looking for maximum value such as profit maximization by the owners of firms, or utility maximization by individuals. Environmental economists may have a broader definition of what constitutes utility—walks in the forest count, not just buying goods, but the notion of maximizing or making the best use of what resources are available is still fundamental to how outcomes are assessed.

To accomplish these tasks, a simple but powerful analytical model is developed that builds on, but modifies and extends standard economic principles, in particular, the marginal valuations that involve trade-offs between marginal costs and marginal benefits. While **economic efficiency** remains the central criterion for evaluating outcomes and policies, environmental economists also examine other criteria for choosing among alternative policies that attempt to improve the environment—for example, **equity** or fairness. If economic efficiency cannot be obtained, and environmental targets are established using other criteria, an economic approach can still greatly assist decision makers in reaching whatever target is set. This book focuses on how individual actions give rise to environmental degradation and what can be done about these actions. Another branch of economics—*natural resource economics*—examines ways to achieve efficient use of our natural environment over time—energy, forests, land, and harvested species such as fish stocks. We look more closely at the distinction between environmental and natural resource economics in Chapter 2.

The objective of this chapter is to acquaint you with some of the basic ideas and analytical tools of microeconomics that are used in environmental economics. We will illustrate how environmental economics helps answer important questions about our environment and economy with real-world examples. We first consider briefly what we mean by the "economic approach," then turn to two pressing environmental problems; starting first with a local and regional concern—motor vehicle pollution, then turning to a global threat—greenhouse gas emissions. In Chapter 2 we will take a look at the broad linkages existing between economy and environment and define a number of important pollution terms. After that we will be ready to study the economic principles we will need.

EQUITY

Equity is about how the economic 'pie' is divided up. Who gets how much income or wealth? Dictionary definitions of equity talk about ideals of being "just, impartial, and fair," but who decides what is fair or just? We are in normative/subjective territory again. Think about the following: suppose our government decided that every adult should earn exactly the same income; it will take the total earnings of everyone in the economy and divide them by the total number of workers. Is this equitable? In one sense it is. Every adult receives the same income as another adult regardless of circumstances. But what if a person's circumstances differ and as a society we want to take that into account. We may want to divide up the country's total income according to age, number of children people have, whether they are able to work or not due to factors beyond their control such as illness or accidents. The dilemma is that there are many possible ways to divide things up and people may have very different notions of what is or is not equitable. Economists, philosophers, and many other disciplines wrestle with the notions of fairness going back hundreds of years to the early writings in moral philosophy and economics. Environmental economics uses a number of different definitions of equity to help evaluate economic outcomes (efficient or not). These include:

- *Horizontal equity* treats similarly situated people the same way. For example, an environmental program that has the same impact on an urban dweller with $20,000 of income as on a rural dweller with the same income is horizontally equitable.
- *Vertical equity* refers to how a policy impinges on people who are in different circumstances, in particular on people who have different income levels.
- *Intergenerational equity* looks at whether future generations have the same opportunities as current ones. How does society trade off using its resources today when their loss may affect the ability of future generations to enjoy the same quality of life?

Subsequent chapters return to equity as one of the vital criteria in assessing how well the economy is doing.

LO 2

THE ECONOMIC APPROACH

Why do people behave in ways that cause environmental destruction? There are several types of answers to this question. One goes like this: Environmental degradation comes about from human behaviour that is unethical or immoral. Thus, for example, the reason people pollute is because they lack the moral and ethical strength to refrain from the type of behaviour that causes environmental degradation. If this is true, then the way to get people to stop polluting is somehow to increase the general level of environmental morality in the society. In fact, the environmental movement has led a great many people to focus on questions of environmental ethics, exploring the moral dimensions of human impacts on the natural environment. These moral questions are obviously of fundamental concern to any civilized society. Certainly one of the main reasons environmental issues have been put on the front burner of social concern is the sense of moral responsibility that has led people to take their concerns into the political arena.

But there are problems with relying on moral reawakening as our main approach to combating pollution. People don't necessarily have readily available moral buttons to push, and environmental problems are too important to wait for a long process of moral rebuilding. Nor does a sense of moral outrage by itself help us make decisions about all the other social issues that also have ethical dimensions: poverty, housing, health care, education, crime, and so on. In a world of competing objectives we have to worry about very practical questions: are we targeting the right environmental objectives; can we really enforce certain policies; are we getting the most impact for our money; and so on. But the biggest problem with basing our approach to pollution control strictly on the moral argument is the basic assumption that people pollute because they are somehow morally underdeveloped. It is not moral underdevelopment that leads to environmental destruction; rather, it is the way we have arranged the economic system within which people go about the job of making their livings.

So, a second way of approaching the question of why people pollute is to look at the way the economy and its institutions are set up, and how they lead people to make decisions that result in environmental destruction. Economists argue that

people pollute because it is the cheapest way they have of solving a certain very practical problem: how to dispose of the waste products remaining after production and consumption of a good.

People make these decisions on production, consumption, and disposal within a certain set of economic and social institutions;[1] these institutions structure the incentives that lead people to make decisions in one direction and not in another. An **incentive** is something that attracts or repels people and leads them to modify their behaviour in some way. An "economic incentive" is something in the economic world that leads people to channel their efforts at production and consumption in certain directions. Economic incentives are often viewed as consisting of payoffs in terms of material wealth; people have an incentive to behave in ways that provide them with increased wealth. But there are also many non-material incentives that lead people to modify their economic behaviour; for example, wanting your children to have the same opportunities as you have, self-esteem, the desire to preserve a beautiful visual environment, or the desire to set a good example for others. Happiness is a function of many things, not solely material wealth. What we will study is

- how incentive processes work, and
- how to restructure them so that people will be led to make decisions and develop lifestyles that have more benign environmental implications.

1. By "institutions," we mean the fundamental set of public and private organizations, customs, laws, and practices that a society uses to structure its economic activity. Markets are an economic institution, for example, as are corporations, a body of commercial law, public agencies, and so on.

One simplistic incentive-type statement that you often hear is that pollution is a result of the profit motive. According to this view, in private-enterprise economies of industrialized nations people are rewarded for maximizing profits, the difference between the value of what is produced and the value of what is used up in the production process. Furthermore, the thinking goes, the profits that entrepreneurs try to maximize are strictly monetary profits. In this headlong pursuit of monetary profits, entrepreneurs give no thought to the environmental impacts of their actions because it "doesn't pay." Thus, in this uncontrolled striving for monetary profits, the only way to reduce environmental pollution is to weaken the strength of the profit motive.

But this proposition doesn't stand up to analysis. It is not only "profit-motivated" corporations that cause pollution and threaten the environment with their activities; individual consumers are also guilty when they do things like pour paint thinner down the drain, use anti-bacterial soap, or leave all the chargers for their electronic gadgets plugged in. Since individuals don't keep profit-and-loss statements, it can't be profits per se that lead people to environmentally damaging activities. The same can be said of governments that have sometimes been serious polluters and subsidize industries that degrade the environment even though they are not profit-motivated. But the most persuasive argument against the view that the search for profits causes pollution comes from political events in Eastern Europe, the former USSR, and the rapid development in China. We have become aware of the enormous environmental destruction that has occurred in some of these regions—heavily polluted air and water resources in many areas, with major impacts on human health and ecological systems. China, a country with communist leadership, has areas of the country contaminated by toxic compounds and regions where air and water pollution are at levels dangerous to human health. Many of these problems exceed some of the worst cases of environmental pollution experienced in market-driven countries. But they have happened in an economic system where the profit motive has been entirely lacking. Which means, quite simply, that the profit motive in itself is not the main cause of environmental destruction.

In the sections and chapters that follow, incentives will play a major role in the analysis of how economic systems operate. *Any system will produce destructive environmental impacts if the incentives within the system are not structured to avoid them.* We have to look more deeply into any economic system to understand how its incentive systems work and how they may be changed so that we can have a reasonably progressive economy without disastrous environmental side effects. Two concepts that are important to an understanding of the incentives that exist regarding the environment are **externalities/external effects** and **property rights.** These concepts are illustrated in the following two examples and explained in detail in later chapters. Essentially, they involve the question of a lack of ownership of environmental resources. A fundamental point is that

> *lack of ownership rights to environmental resources means that there are few incentives to take the environmental consequences of our actions into account.*

LO 3

EXTERNALITIES AND PROPERTY RIGHTS

In Section 4, we will examine the role of property rights in reaching a **socially efficient level of pollution.** Property rights—or the lack thereof—are crucial in understanding why we have today's environmental problems. The basic point is that environmental resources generally do not have well-defined property rights. No one owns the atmosphere, our oceans, or large underground aquifers. A term used by economists to describe the lack of ownership of the natural environment is **open access.**

An open access resource is one that anyone can use without paying for it. Oceans and the atmosphere are examples. See the classic article by Hardin (1968). **Private property rights** give the owner the right to exclude others from using or consuming their resource. Think of owning a private forest woodlot. No one can cut the trees or trespass without permission of the owner. **Common property rights** give the community the power to govern the resource within its borders. Outsiders to the community are excluded. A small fishing community is an example. Two examples illustrate how externalities are connected to property rights.

Auto emissions. *When an SUV releases carbon monoxide and carbon dioxide into the atmosphere, you cannot jump out in front of the vehicle and shout "Stop! You are polluting my air and releasing greenhouse gases that contribute to global climate change!" We all breathe the same air in our communities and GHGs travel to our global atmosphere. For externalities that involve many different sources of pollution, perhaps spread over large areas, there is no effective way to reach any sort of private agreement to limit the emissions. Designing environmental policy is more challenging the more pervasive the externality is across regions or countries and for different sources.*

Dog waste. *You detect your neighbour's dog leaving its waste products on your lawn. This too is an externality. The dog and its owner do not take into account the impact dog waste is having on your lawn when they go about their activities. Contrary to the case of automobile air contaminants and GHG emissions, you and your neighbour would find it relatively easy to negotiate a mutually agreeable resolution to this problem. The neighbour might agree to keep the dog on a leash or to pick up its waste. You may build a fence, or get the neighbour to pay for it. The dog externality is internalized through discussion and negotiation. A solution that is mutually agreeable to both parties can be worked out; the only difference in possible outcomes is who pays for them. That is a function of our bargaining strengths and other factors.*

Why is the dog case different from the auto emissions case? You own your property and the dog is essentially trespassing. Laws say you can keep others off your property. There is also just one other person to bargain with—the dog owner. This case could be more like urban air pollution if you don't know whose dog is dumping on your lawn. Then you must incur search costs, set up dog surveillance, and so on to detect the perpetrator.

Our most serious environmental problems are closer to the vehicle smog case than the case of the wandering dog. They involve lots of possible polluters, with perhaps very little knowledge about even the source of emissions or the link between emissions and environmental impact. Society members may not recognize that an activity they have been doing for years has a deleterious impact on the environment. For example, manufacturers of leather products in eastern Canada used to use mercury in the tanning process. They would simply dump their wastes in streams or on the ground. Over the years, the mercury percolated into groundwater and contaminated people's drinking water. But people didn't know at the time how toxic mercury is. The tanners themselves suffered from mercury poisoning. This is where the term "mad as a hatter" emerged—mercury poisoning affects brain function. The leather manufacturers are now gone, but mercury still remains a dangerous pollutant in our ecosystem. How can today's population engage in any sort of negotiation with the leather producers of 100 years ago to reach a mutually agreeable level of waste disposal and compensation for disease, shorter lifespans, and contaminated water and soils? This example illustrates the difficulties inherent in depending on individuals who act in their own self-interest to reach a socially efficient outcome. Information about potential problems may be imperfect or non-existent. People today cannot be counted on to make decisions that maximize the well-being of generations who follow. When these conditions exist, some form of government intervention is necessary.

LO 4

PRACTICAL ILLUSTRATION #1: SMOG AND MOTOR VEHICLES

Canada's transportation sector produced 24.2 percent of total national greenhouse gas (GHG) emissions in 2011, with cars, trucks, and motorcycles accounting for almost half this total. The transportation sector discharges approximately 40 percent of carbon monoxide, 21 percent of nitrogen oxides, 11 percent of volatile organic compounds, 8 percent of sulphur dioxide, and 4 percent of fine particulate matter (PM-2.5).[2] These compounds, known as air contaminants contribute to urban smog, acid precipitation, and global climate change. In turn, these environmental conditions adversely affect the health of people and our ecosystem, the survival of many species, the cost of producing goods and services, and our overall enjoyment of our surroundings. Estimates are that 21,000 Canadians die prematurely each year due to air pollution, while tens of thousands more suffer from bronchitis exacerbated by pollution.[3] Exposure to urban smog may increase the likelihood of cancers in children by up to 25 percent and raise the chance of getting childhood asthma by 400 percent. Acid precipitation changes aquatic and land-based ecosystems, killing fish, amphibians, and other aquatic species and affecting forest growth. Global warming could lead to massive ecosystem changes with catastrophic worldwide impact. Motor vehicle use contributes to congestion on our roads. Congestion increases driving times, promotes accidents, costs people lost time, and generally makes people very crabby, contributing to "road rage."

Driving one's car or truck thus affects all sorts of other people (whether they too drive a motor vehicle or not) and our environment. This is an *external effect.* When you drive to school or work or to the beach, you get the direct benefit of transportation services. Others—bystanders—receive the negative impacts of your driving: air pollution, congestion, and associated impacts. The bystanders don't control your driving. And the price you pay for driving your car, your direct costs in the form of gasoline, maintenance, and monthly car payments, do not reflect the negative impacts you impose on others—hence the words *externality* or *external effects* to describe this situation. An externality occurs when the actions of one or more individuals affects the well-being of other individuals without any compensation taking place. While externalities can be positive as well as negative (think enjoying viewing your neighbour's flower garden), pollutants such as air contaminants are negative externalities. We will examine in detail in Section 4 what sorts of initiatives, both individual and with the help of government, can be used to address externalities. For now, let's think a bit more about motor vehicle externalities and what can be done about them. To do so, we look at the concept of incentives.

Incentives: Households and Vehicle Use

When you drive your car, sport-utility vehicle (SUV), or truck, the price you pay per kilometre travelled reflects your **private costs**—gasoline, oil, insurance, and maintenance. These prices do not

2. See Government of Canada, Environment Canada Emission Trends and the National Pollutant Release Inventory, Air Pollutant Emissions Data for the most recent year data on GHGs and criteria air contaminants respectively at www.ec.gc.ca.

3. www.fvrd.bc.ca/Services/AirQuality/Documents/2013TRAPandHealthCanada-Brauer.pdf.

take into account the damage the emissions from your car imposes on others and the environment; rather, they reflect costs of producing gasoline, retailer markups, and so on. You will respond to changes in these private costs, for example, by driving more when gasoline prices fall and less when they rise. What sort of positive incentive could we contemplate that would induce drivers to reduce the number of emissions they release? A simple relationship may help us see where incentives could enter.

Total quantity of emissions = Number of vehicles × Average kilometres travelled × Emissions per kilometre

Incentives can target the number of vehicles on the road, the average number of kilometres travelled, and emissions per kilometre. In addition, we might want to consider where people drive their vehicles. A car driven in downtown Toronto, Montreal, or Vancouver will have a larger impact on urban smog than that same vehicle being driven in Moose Jaw, Saskatchewan. The release of carbon dioxide will, however, contribute to global warming regardless of where the vehicle is driven.

What are some possible incentives to alter people's behaviour? We provide examples for each of the three parts of the word equation above that will help reduce emissions.

Number of vehicles: some jurisdictions levy a charge per year for owning a vehicle in addition to one's licence fee. If this charge is substantial, as it is in places such as Singapore, people will be less inclined to own and operate a motor vehicle. This is especially likely in urban areas that have good public transportation; people will ride the bus or train instead of driving a vehicle. Improving public transit will reinforce the incentive not to own or operate a vehicle because people will have an option for their mobility needs. They can then weigh the relative costs of operating a vehicle versus taking public transit.

Average kilometres travelled: Increasing the cost of driving per kilometre should reduce the average number of kilometres travelled. Higher costs per kilometre provide an incentive for people every time they drive their vehicle to minimize the number of trips, thereby reducing their direct costs. An example of a direct incentive to increase costs of driving is to tax people on the number of kilometres travelled. This could be done using a tax that is payable annually as people renew their vehicle licence. An indirect incentive is to tax gasoline, thereby increasing the costs of driving.

Emissions per kilometre: A tax on emissions would also increase the cost of driving per kilometre. An example is the carbon tax in British Columbia. The carbon tax of $30 per tonne carbon adds 7.8 cents per litre to the cost of gasoline, thus making it more expensive to drive. A buyback program that pays people to retire their older vehicles can also reduce emissions per kilometre. Old vehicles contribute far more per kilometre travelled to air emissions than do newer, more fuel-efficient and less pollution-intensive vehicles. Other policies to reduce emissions could include advertising and education programs that inform people about how their driving decisions affect air quality and, hence, their well-being.

Incentives for Businesses

Incentives can also apply to businesses. Think about the producers of motor vehicles and vehicle parts. All industrial firms work within a given set of incentives: to increase profits if they are firms in market economies. Firms have an incentive to take advantage of whatever factors are available to better their performance in terms of these criteria. One way they have been able to do this historically is to use the services of the environment for waste disposal. The motivation for this practice is that these services have essentially been free, and by using free inputs as much as possible a firm obviously can increase its profits. The challenge is to find incentives to alter firms' behaviour so they treat environmental services as a costly activity rather than a free good.

One policy approach is to introduce and then try to enforce laws or regulations that direct the amount of pollution a firm can emit, thus reducing emissions per kilometre. Canada has company average fuel consumption (CAFC) guidelines for all new cars and light trucks produced in Canada. Vehicle manufacturers have agreed to design their cars and light trucks to meet a voluntary target level of gasoline consumption averaged over their entire fleet of vehicles produced each year. Guidelines were introduced for cars in 1978 at 13.1 litres per 100 kilometres, and then were tightened to 8.6 litres per 100 kilometres in 1986, where they remain today. Guidelines for light trucks were not introduced until 1990 (at 11.8 litres per 100 kilometres) and were gradually tightened to 10.0 litres per 100 kilometres in 2010. In December 2012, the federal government announced that Canada will adopt the same fuel efficiency standards as the United States as its target for 2025. The U.S. standards require a combined corporate average (for all makes and models of vehicles sold each year) of 54.5 miles per gallon (4.4 litres per 100 kilometres). Fuel efficiency of all cars on the road has increased from approximately 15 litres per 100 kilometres in 1965 to 6.7 litres per 100 kilometres in 2010.[4] Light duty trucks were estimated to average 8.6 litres per 100 kilometres in 2010.

The CAFC guidelines have been voluntary, not compulsory. Vehicle manufacturers meet the standards because the United States has the same type of policy and it is compulsory in that country. The North American automobile industry is completely integrated—cars and light trucks produced in Canada are exported to the United States and vice versa. Canadian cars that do not meet the U.S. fuel efficiency standards cannot be sold there. There is a clear profit incentive for Canadian manufacturers to comply with the voluntary standard. Note that CAFC standards require the auto manufacturer to meet the standard *on average* across all its cars or trucks produced each year. If automakers produce a lot of low-polluting cars, they will more readily meet the target than if they produce high-polluting vehicles such as SUVs. The regulations thus provide an incentive for manufacturers to alter the mix of vehicles produced to reduce the emissions that will ultimately come when drivers purchase and use the vehicles. Canadian governments also regulate the sulphur content of gasoline. The regulations specify that oil refiners must produce gasoline containing on average no more than 30 mg/kg of sulphur (and never to exceed 80 mg/kg).[5] Sulphur in gasoline, when combusted, produces sulphur dioxide, a contributor to smog and acid precipitation. The incentive effect here is this: abide by the regulation or you will be fined by the government.

A more effective policy might be to design a system that takes advantage of firms' normal monetary incentives in such a way as to lead them to pollute less. For example, oil refiners could be taxed on the basis of the sulphur content of their gasoline produced. This may induce them to switch their production to lower-sulphur fuels so as to avoid the tax. They might increase the proportion of methanol derived from grains in their fuels. Methanol does not contain any sulphur. Gasoline prices are likely to rise, then providing an additional incentive to drivers to reduce their consumption of gasoline. The Canadian government decided not to tax sulphur, but to subsidize the production of ethanol at the farm level. This lowered the price of ethanol relative to petroleum, but had a number of negative consequences such as raising the cost of corn products worldwide and diverting corn from feeding people to producing vehicle fuels. Corn production is also very fertilizer and pesticide

4. For the history of the development of CAFC guidelines see www.tc.gc.ca/eng/programs/environment-fcp-history-630.htm, accessed September 26, 2010. Information on fuel efficiency of vehicles can be found at www.tc.gc.ca/eng/programs/environment-fcp-cafctargets-385.htm, accessed September 26, 2010.

5. See Chapter 6 for a detailed discussion of the sulphur in gasoline regulations.

intensive, and can lead to undesirable environmental impacts. Section 5 looks at different ways government can design policies that are effective in meeting environmental and equity goals while minimizing adverse impacts to the economy. The essence of the economic incentives approach is to restructure the incentives facing firms and consumers in such a way that it mobilizes their own energy and ingenuity to find ways of reducing their impacts on the environment.

Incentives in the Pollution-Control Industry

The pollution-control industry develops waste recycling techniques, pollution-control equipment, and pollution-monitoring technology. It sometimes handles and treats waste products, and is often involved in managing waste-disposal sites. It also includes firms that develop new environmentally friendly products like low-sulphur gasoline, low-phosphate detergents, and recyclable paper products. A lively and progressive pollution-control industry is obviously needed if we are to come to grips effectively with all of our present and prospective environmental problems. Thus, one of the major things environmental economists must study is the incentives facing this industry—what causes it to grow or decline, how quickly or slowly it responds to new needs, and so on. In our example of air pollution from motor vehicles, the pollution-control industry could include manufacturers of zero-emission vehicles. These vehicles might run on fuel cells, on electricity, or use other technologies. Are policies needed to encourage these industries? One might argue that the existence of policies that provide incentives to reduce air emissions will be enough to stimulate the development of alternative fuels or engines. However, various governments have also subsidized the research and development costs for these manufacturers either through tax incentives or outright grants of funds. The rationale is that the development of the new technologies will have broad-reaching social benefits.

LO 5

PRACTICAL ILLUSTRATION #2: GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

The carbon dioxide (CO_2) content of the earth's atmosphere has increased by over 2.2 percent per year from 2000 to 2010. This compares to 1.3 percent per year from 1970 to 2000.[6] Figure 1-1 shows the rising trend of emissions by gas since 1970. Carbon dioxide emissions (CO_2) from fossil fuel combustion and industrial process make up the majority of emissions. The key question is what effect these emissions have on the earth's climate now and into the future. The science of climate change is complex, with many uncertainties due to the difficulty of measurement as well as interpretation of the data and attempts to determine cause and effect.[7] It is estimated that the average surface temperature of earth has risen approximately 0.6°C over the 20th century (with a confidence interval of ± 0.2°C).[8]

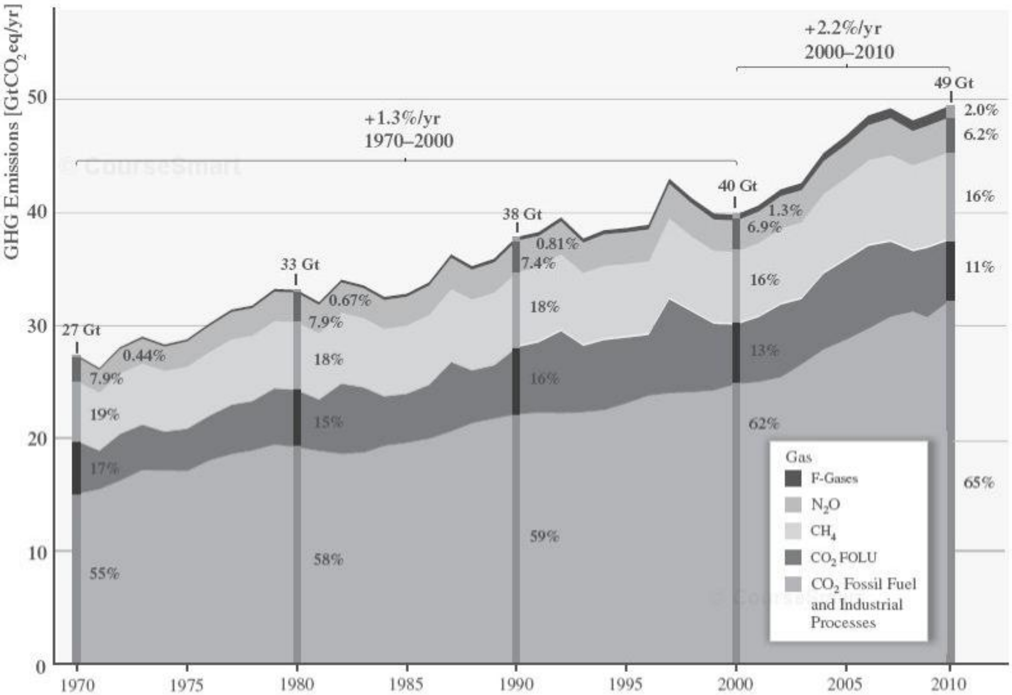
6. See the Fifth Assessment Reports of the Intergovernmental Panel on Climate Change, *Climate Change,* for recent data on climate change and a discussion of the state of climate-change science and policy. Unless otherwise noted, all the numerical estimates presented in this paragraph are from the report of Working Group III. The reports are available at www.ipcc.ch/.

7. Many hundreds of books and articles have been written on the science and economics of global climate change. This section will just scratch the surface and hopefully stimulate more reading. New information is continually released that may help to resolve the uncertainties in climate-change predictions. See Chapter 20 for more detail on Canadian policy and the references at the end of the text.

8. See Goddard Institute of Space Studies (NASA) at http://data.giss.nasa.gov/gistemp/graphs/ for data on world temperatures.

Figure 1-2 shows the amount of carbon dioxide in the atmosphere from the 1950s to 2010, an increase of approximately 25 percent. About half the cumulative increase in CO_2 from 1750 to 2010 attributed to human activity (**anthropogenic** sources) occurred in the last 40 years. Climate change models forecast a rise in the earth's temperature over the 21st century by anywhere from 1.5 to 6°C. Models also predict an increase in climate variability and extreme weather events due to the increase in emissions of greenhouse gases (GHGs)—carbon dioxide (CO_2) and other gases in the atmosphere. However, human and natural factors can affect models' results. Natural processes such as volcanic activity send bursts of gases and particulate matter into the atmosphere, causing changes in rainfall patterns and temporary cooling. Pollution, in the form of accumulated SO_2 in the lower atmosphere, reflects sunlight and works against the greenhouse phenomenon. Carbon dioxide is also absorbed by **carbon sinks** in the form of trees, wetlands, and oceans. Just exactly how much the sinks can absorb and under what conditions is an important area of study.

FIGURE 1-1 Total Annual Anthropogenic GHG Emissions by Groups of Gases, 1970–2010

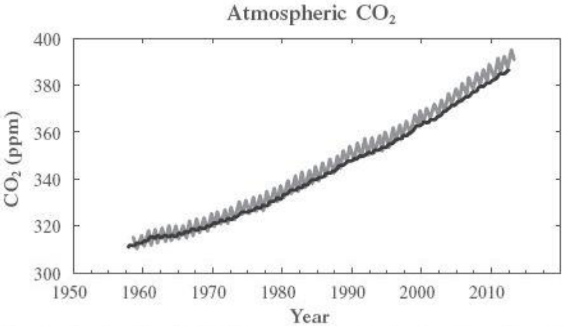


The time trend of CO_2 emissions for the past 40 years is positively sloped and has gotten steeper with emissions rising at 2.2 percent per year since 2000. Anthropogenic sources are those created by human activity.

Note: Total annual anthropogenic GHG emissions ($GtCO_2eq/yr$) by groups of gases 1970–2010: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (N_2O); and fluorinated gases.

Source: *IPCC, 2014: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Figure TS.1; Figure TS.6. [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schloemer, C. von Stechow, T. Zwickel, and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.*

FIGURE 1-2 Atmospheric Carbon Dioxide Levels Since 1950s



Levels of carbon dioxide in the atmosphere have risen by approximately 25 percent from the 1950s to 2010.

Source: *IPCC, 2013: Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Figure SPM.4(a). [Stocker, T.F., D. Qin, G.K.* Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.).] Cambridge University Press, Cambridge, UK and New York, NY, USA.

Climate change, global warming, or the *greenhouse effect* are the common names used to describe the potentially major changes in the world's climate. The principle of a greenhouse is that the enclosing glass allows the passage of incoming sunlight but traps a portion of the reflected infrared radiation, which warms the interior of the greenhouse above the outside temperature. Greenhouse gases in the earth's atmosphere play a similar role; they serve to raise the temperature of the earth's surface and make it habitable. with no greenhouse gases at all, the surface of the earth would be about 30°C cooler than it is today, making human life impossible. Figure 1-3 shows the sources of GHGs by sector.

If global climate changes result in global warming, the earth may become very different from its current state. The rate of heating is estimated to be at least 0.2°C per decade based on current levels of GHGs in the atmosphere.[9] This may not sound like a very rapid change, but historical studies have shown that in past episodes of warming and cooling, during which agricultural societies of the time suffered major dislocations, climate change occurred at a rate of only about 0.05°C per decade. The forecast rate of change for the 21st century is six times faster than the rates faced by humans in the past. If countries do nothing to offset the increase in greenhouse gas emissions, **adaptation** to climate change by future generations may be very costly, especially for some parts of the world. Adaptation refers to actions taken to offset or reduce the adverse impacts of climate change. Adaptation costs arise from extreme weather events, higher temperatures, droughts, crop losses, impacts on health, loss of ecosystems, and sea level rise. Estimates of the costs of adaptation are highly variable across countries. A study by the World Bank puts the range at between $70 and $100 billion per year from 2010 to 2050 with a 2°C warming by 2050.[10] The Intergovernmental Panel on Climate Change (IPCC) puts an estimate at 0.2 to 2 percent of income, but note that there is a strong consensus that the estimate could exceed 2 percent.[11] Rising sea levels may inundate entire nations, such as some islands

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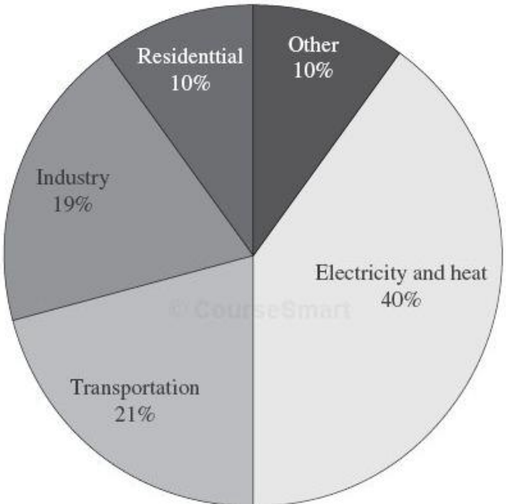
9. Fourth Assessment Report of the Intergovernmental Panel on Climate Change, *Climate Change 2007: Synthesis Report.*

10. World Bank (2010) "Economics of Adaptation to Climate Change, Synthesis Report." Washington, DC: The World Bank.

11. IPCC: Intergovernmental Panel on Climate Change (2014) "IPCC WGII Summary for Policy Makers."

FIGURE 1-3 Global Anthropogenic Sources of GHG Emissions



The largest source worldwide is electricity generation and heat. Coal-fired plants are a major source of emissions from the electricity sector.

Note: Others include commercial/public service, agriculture, forestry, fisheries, industry other than electricity and heat generation, and sources not identified elsewhere.

Source: *Based on IEA data from CO2 Emissions From Fuel Combustion Highlights © OECD/IEA [2012], IEA Publishing, fig. [1] p. [7]; modified by McGraw-Hill Ryerson Limited. License: http://www.iea.org/t&c.*

in the Caribbean and South Pacific, and require relocation of large populations that now live in low-lying coastal regions (e.g., those living along river deltas in Southeast Asia and the Nile). The Arctic polar ice caps are melting at a very high rate, threatening that fragile ecosystem and its inhabitants. Countries differ also in terms of agricultural adaptability—the ability to shift crops, varieties, cultivation methods, and so on—to maintain production in the face of climate changes and are likely to have very different perceptions about how they will be affected by global warming.

Responses to Climate Change: Scientific Uncertainties, the Precautionary Principle and Mitigation Strategies

Given the uncertainties in climate and natural science, there is an argument that until we "know for sure" that climate change is happening and is due to human activity no policies for reduction or **mitigation** of greenhouse-gas emissions should be introduced. There are several problems with this viewpoint. What if society does nothing today to mitigate GHG emissions, but there is a chance that global warming could lead to extremely high adaptation costs in the future? Then, some years from now, the costs of adjusting to climate change could comprise a much larger share of GDP than would be realized if society initiates mitigation policies today. People today would be imposing huge costs on future generations—violating our notions of intergenerational equity. The **precautionary principle** says that society should weigh the trade-off between the cost of measures taken today versus benefits in terms of reduced future risk. Expected net benefits are calculated as the benefits minus the costs of each scenario weighted by the probability of the event occurring, taking into account that these benefits and costs will occur into the future. Chapters 6, 7, and 8 illustrate how these benefits and costs are measured and net benefits computed over time. If the probability that global warming raises average temperatures by 3°C in 50 years is low (e.g., .0005 or .005), society minimizes its costs by doing nothing today because net benefits are higher (a smaller negative number) with no current policies adopted. But if society estimates the probability at a 5- or 10-percent chance, action now to reduce GHG emissions becomes the preferred choice.

GHG mitigation policies could include taxes on carbon emissions, introducing standards to improve energy efficiency of vehicles, appliances, and buildings, and a host of other actions. By waiting to see what happens, society may incur much higher costs than if actions were taken today to put it on a more sustainable path that reduces carbon emissions. As well, if society does nothing and turns out to be wrong, climate change impacts could be devastating. The cost to the global economy would be enormous and inequitably felt across countries and regions. Another uncertainty that is difficult to quantify is the role of technological change in helping to mitigate global warming. It may be in society's interest to delay introducing specific mitigation policies in the present in the hope that technological improvements will allow it to reach a GHG target at much lower costs in the future. However, this does not suggest that no GHG policies should be introduced in the present. For example, a GHG tax at a low rate could be introduced now with the rate rising over time. This tax will signal that it will be increasingly costly over time to release GHGs into the atmosphere. Putting a price on GHG emissions will help incent technological activity.

Recall how total emissions of vehicle pollutants were identified. A similar identity exists for GHGs and illustrates how they can be reduced.

Total GHGs = Population × GDP/population × Energy/GDP × GHGs/energy

Figure 1-4 shows the breakdown for recent decades of the factors that give rise to GHG emissions, looking at each part of the word equation above. While gains in energy efficiency help reduce emissions, they are offset by population and GDP growth as well as a reversal in the trend for carbon intensity of energy in the most recent decade.

The focus in the equation above is on energy because as Figure 1-1 illustrates, combustion of fossil fuels contributes the majority of GHGs to the atmosphere. One can read in for "energy" any other primary source of GHGs. The first term in the word equation is population. Other things remaining equal, larger populations will use more energy and therefore emit larger amounts of GHGs. The second term is GDP per capita, a measure of the domestic output of goods and services per capita. Increases in GDP are normally associated with economic growth. Neither of these first two factors can be considered likely candidates for reducing GHG emissions in the short run. Deliberate population control measures are a complex policy area that many countries do not want to pursue. Countries will be reluctant to reduce their rates of economic growth. In the long run, however, the interaction of these two factors will be important, as history seems to show that increases in income per capita are associated with lower population growth rates over time. This means that significant near-term GHG reductions will have to come from the last two terms in the expression. The third is what can be called **energy efficiency,** the amount of energy used per dollar (or per franc or rupee or peso) of output. The key here is to move toward technologies of production, distribution, and consumption that require relatively smaller quantities of energy. The objective is to **decouple** fossil fuel energy use from economic growth. The last term is GHGs produced per unit of energy used. Since different energy forms have markedly different GHG outputs per unit, reductions in GHG can be achieved by switching to less GHG-intensive fuells.