Navigating the Numbers

Greenhouse Gas Data and International Climate Policy

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The Authors

Foreword

President Lyndon B. Johnson famously said: "We can draw lessons from the past, but we cannot live in it." In the case of climate change, this is an unfortunate truth. Human activity has irrevocably changed the composition of the world's atmosphere, and we will never again be able to live, as our parents and grandparents did, without the consequences of global warming.

The impacts are staggering. Antarctic ice is thinning at increasingly rapid rates—with correspondingly massive influxes of fresh water into the world's oceans. Siberia has warmed 3° C since 1960. Humanity is increasing hurricane intensity and rainfall. And make no mistake: this is not a problem whose consequences lie in the distant future or in the furthest uninhabited reaches of the world. Lima, Peru, located in the world's driest desert, expects the Andean glaciers that provide water to the city's 9 million people to disappear by 2030. Scientists at the World Health Organization have established clear links between climatic factors and disease rates for malaria, dengue, cholera, meningitis and encephalitis. And climate change induced sea-level rise is expected to displace as many as 50 million people worldwide by 2050.

Dr. Thomas Fuller, a British physician living in the 18th century said: "Get the facts, or the facts will get you. And when you get them, get them right, or they will get you wrong." In this volume, the World Resources Institute has provided the facts, setting them out accurately and accessibly. And those facts speak clearly: emissions that drive global warming are ubiquitous. They come from the energy we consume, the food we produce and the forest stocks we deplete. They come from the very fabric of modern life. While a relatively small number of countries produce the overwhelming majority of emissions, those countries include both developing and developed nations. And these emissions are growing at a pace too rapid to ignore, rising more than 15 percent in the last decade alone.

However, this book would be only an interesting collection of facts (alarming though they may be) if it did not also seek to evaluate what might be extracted from these trends to help prepare for a more stable and climate-friendly future. What do we know? We know that some countries have both more responsibility and more capacity than others. These countries must move first if we are to succeed. But a solution will only be found by working to adopt policies that fit the needs of both developed and developing nations. We know that it is possible to decouple our energy use from the emissions of greenhouse gases that are causing the problem. While this certainly offers hope for the future, we know that the longer we wait, the bigger a step will be needed to bring the climate system into balance. We know that some sectors contribute more than others to the global climate problem. Transport and energy production—which are also implicated in issues such as energy security and balance of trade payments—are ones we need to address quickly. But taken too narrowly, action in any one of these sectors alone will not form an adequate basis for international agreements. We know that solving this problem requires a broad, comprehensive effort covering multiple sectors and multiple gases and nations from around the world. Only through global coordination will we be able to move our society to a more sustainable future.

As Yogi Berra said: "The future ain't what it used to be." But if we can translate the facts into an impetus for action, we may still be able to forestall the worst of the damages that climate change will bring. But we must hurry; time is not on our side.

Jonathan Lash
President
World Resources Institute

Executive Summary

This report examines greenhouse gas (GHG) emissions at the global, national, sectoral, and fuel levels and identifies implications of the data for international cooperation on global climate change. Emissions are assessed within the broader socioeconomic context faced by countries, including factors such as economic output, population size, trade, investment, and sectoral structure.

Our hope is to make several contributions to the international dialogue on climate change policy. First, an exploration of the myriad sources of GHG emissions sheds significant light on the nature, challenges, and opportunities faced by governments, the private sector, and advocates in addressing the issue of climate change. Second, by giving policy-makers and other stakeholders sound, comprehensive information, we hope this report will contribute to better-informed debate and better decision-making, thereby advancing the prospects for compromise and cooperation. The key data and policy-related findings are summarized here.

- ***Global trends.*** Worldwide emissions of GHGs have increased steeply since 1945, with the largest absolute increases in carbon dioxide (CO_2) emissions occurring in 2004. This year also represented the largest percentage increase in emissions since 1976. Mid-range projections suggest that, in the absence of policy actions, GHG emissions will increase by another 50 percent by 2025 compared to present levels, with emissions in developing countries growing the fastest. Avoiding dangerous climate change will require slowing this global trend in the short term, and reversing it over the next one to two decades.
- ***Contributions of different GHGs.*** CO_2 comprises the majority of GHG emissions, at about 77 percent of the worldwide total (measured in global warming potentials). The remainder comes mostly from methane (CH_4) and nitrous oxide (N_2O), with small shares coming from fluorinated gases (SF_6, PFCs, and HFCs). The contributions of CH_4 and N_2O are significantly larger in developing countries, and in some cases are larger than energy-related CO_2 emissions. Emission estimates of CH_4 and N_2O, however, are subject to higher measurement uncertainties than energy-related CO_2 emissions.
- ***Contributions of different sectors.*** GHG emissions come from almost every human activity. The GHG Flow Diagram (Figure 1.3, p.4) illustrates the contributions that different sectors and activities make to the worldwide annual emissions of GHGs. Because of their large contributions, key policy targets are electricity and heat, transport, buildings, industry, land-use change and forestry, and agriculture. Future growth is likely to be especially high in the electricity and transport sectors, suggesting that these are particularly important sectors for promoting policy change, investment, and technology innovation.
- ***Current emissions by country.*** A relatively small number of countries produce a large majority of global GHG emissions. Most also rank among the most populous countries and have the largest economies. The major emitters include almost an equal number of developed and developing countries, as well as some transition economies of the former Soviet Union. An international climate change regime that does not establish adequate GHG mitigation incentives and/or obligations within these political entities—through domestic initiatives, international agreements, or both—will fail environmentally.
- ***Emission projections by country.*** Emission projections at the national level are highly uncertain. Uncertainties are especially acute in developing country economies, which tend to be more volatile and vulnerable to external shocks. Furthermore, past projections have a dubious record of accuracy. This presents serious difficulties for policy approaches that are based on such forecasting. For instance, fixed emission "caps" (such as Kyoto Protocol-style targets) are less likely to be viable in developing countries than in industrialized countries.

- ***Emissions intensity.*** Emissions intensity—the level of CO_2 emissions per unit of economic output—varies widely across countries, reflecting differences in economic structure, energy efficiency, and fuel mix. Over time, intensity levels decline in most countries because GDP usually increases at a faster rate than emissions. Declining carbon intensity in many developed and developing countries may suggest a preliminary or gradual "decoupling" of emissions and economic growth, although some of these trends are reversing. Intensity indicators present some advantages in establishing emission targets, but also some challenges, which in some cases could outweigh the benefits. The challenges include incorporation of non-CO_2 gases and complexity.
- ***Per capita emissions.*** Only a handful of the countries with the largest total emissions also rank among those with the highest per capita emissions. For some countries, per capita emissions vary significantly when CO_2 from land use and non-CO_2 gases are taken into account. Although per capita emissions are generally higher in wealthier countries, there are notable and diverse exceptions. Some middle-income developing countries, for instance, have per capita emission levels similar to those of richer industrialized economies. Accordingly, international agreements predicated on equal per capita emission entitlements will face difficulty garnering consensus because of the diverse national circumstances facing countries with similar per capita emissions profiles.
- ***Cumulative emissions.*** Most of the largest current emitters also rank among the largest historic emitters, with developed countries generally contributing a larger share, and developing countries a smaller share, of cumulative emissions (CO_2 emissions summed over time). A country's historic contribution may differ substantially depending on the time period assessed and whether or not CO_2 from land-use change is included in the calculation. Policy proposals that rely on historical emissions prior to 1990 face considerable barriers related to data quality and availability.
- ***Socioeconomic development.*** A striking aspect of the major GHG-emitting countries is their disparities in development levels, as measured by income per capita and other economic and human development indicators. Although in percentage terms, per capita income is growing faster in developing countries than in industrialized countries, in absolute terms, the income gap is actually widening. Successful international policy responses must account for differing national capacities, and support rather than threaten development prospects. In addition, further consideration of country classifications—in Annexes to the Climate Convention and Protocol—may be warranted in light of changes in development levels since the adoption of those agreements.
- ***Energy and fuels.*** Coal, the highest carbon fuel, plays a dominant role in global electric power generation, and its future growth is expected to be significant. Avoiding dangerous climate change will require reduced coal use or geologic sequestration of coal-related emissions. Similarly, major emitting countries will need to reduce their dependence on oil, particularly in the transport sector where it has near monopoly status. Natural gas, because of its lower carbon content and increasing cross-border trade, has the potential to offer climate benefits if it can offset coal and oil consumption in key sectors.
- ***Trade.*** Global trade—including energy fuels, raw materials, and manufactured goods—has increased remarkably over the past few decades. Traded products that are carbon-intensive include chemicals, motor vehicles, steel, and aluminum, among others. The significant quantities of energy and GHG emissions that are embodied in these products are, under prevailing GHG accounting systems, attributed to the country of production, not consumption. While an alternative accounting system is not warranted, sectors that are deeply integrated into the world economy may warrant attention under international agreements.
- ***Sectoral cooperation.*** Not all sectors or subsectors are conducive or appropriate as a basis for organizing international cooperation. A range of considerations, such as international competitiveness, uniformity of products/processes, and concentration of actors (such as domestic and multinational corporations) are likely to influence whether sectoral agreements or other initiatives are feasible or appropriate. Sectors such as motor vehicles, steel, and aluminum score well in regard to these characteristics. Overall, the findings suggest that a "sector-by-sector" approach to international cooperation is likely to be infeasible. Comprehensive agreements (covering most sectors and gases), with special provisions or supplementary agreements for specific sectors, offer greater promise. The sectoral analysis also helps illuminate both the perceived successful and unsuccessful aspects of the Kyoto Protocol. One of the characteristics of the Protocol that fostered consensus was that it did *not* establish sector-by-sector requirements. On the other hand, the Protocol includes sector-specific provisions, and some of the objections to Kyoto might be partially remedied by advancing cooperation in specific sectors.

CHAPTER 1

Introduction

Obtaining relevant and reliable data is the first step in addressing any environmental problem; global climate change is no exception. In considering next steps in the international effort against climate change, policy-makers and stakeholders are confronted by a wealth of data on everything from century-old emission trends to likely economic growth decades into the future. Turning these data into useful input for decision-making is an enormous challenge.

This report seeks to convey the wide range of greenhouse gas (GHG) emissions data in digestible form, with the hope of increasing knowledge and awareness within the climate change policy community. In addition, the report offers a set of policy-relevant insights and observations that flow from the data. In some cases, an understanding of GHG emissions and related trends can help illuminate particular national circumstances faced by countries and inform the international community's policy responses. Data in this report are drawn primarily, though not exclusively, from the Climate Analysis Indicators Tool (CAIT) developed by the World Resources Institute (WRI) (Appendix 1). Using CAIT and other databases, WRI has organized data relevant to climate change policy and extracted some of the most relevant details and findings. The hope is that sound information will contribute to a better-informed debate among stakeholders and, ultimately, to improved decision-making.

While GHG emissions and other data can lend important insight into the international climate policy challenge, they must also be treated with some caution. As will be seen, some of the data are more reliable than others. In some cases, the aura of precision projected by a table of figures masks considerable uncertainty in the underlying data. As with any complex issue, a given trend or relationship can be viewed through any number of lenses, with the potential for differing conclusions.

The remainder of this introduction briefly outlines the challenge of climate change and the major policy responses taken by the international community to date. This includes the adoption of the 1992 Climate Convention and the 1997 Kyoto Protocol. Looking ahead, much of the international community is turning its attention to a successor agreement that builds on—or replaces—Kyoto. A more complete understanding of GHG emissions should inform future decisions. The introduction also includes an overview of global GHG emissions—by sector, activity, and gas—to provide the context for the remainder of the report. It concludes with some explanations and caveats that should be kept in mind throughout the report.

The global picture of GHG emissions data is complex, and may be examined using a variety of perspectives. This report adopts two principal approaches to examining the data. First, Part I of this report employs a country-level perspective on emissions data and a range of related indicators. A country-level perspective is useful primarily because governments tend to be the primary actors and subjects of international efforts to mitigate GHG emissions. Chapters 2–6 examine national emissions from several angles—historical, current, projected, per capita, and intensity. Because climate change issues cannot be fully appreciated from emissions data alone, Chapters 7–9 of Part I examine country-level socioeconomic indicators, energy data, and international trade issues. Our hope is that these chapters will enhance the understanding of cross-country differences by highlighting the national contexts within which emissions arise.

Since the beginning of the industrial revolution, atmospheric concentrations of carbon dioxide, the chief heat-trapping greenhouse gas, have risen 35 percent. This increase is primarily from the burning of fossil fuels and from deforestation.

Part II employs a different perspective: emissions at the sectoral level. This perspective is useful because it helps illuminate which activities are contributing most to the buildup of GHGs in the atmosphere and, accordingly, where policy-makers and investors need to focus the most attention. Equally important, an examination of individual sectors—in terms of production processes, product mixes, corporate presence, trade, and other factors—can also yield insights into which sectors might be attractive candidates for cooperation on climate change. Chapter 10 discusses the sectoral perspective, its rationale, and describes an analytical approach for comparing and evaluating sectors. Chapter 10 also summarizes the findings of the remainder of Part II. Chapters 11–17 examine specific sectors and subsectors using available data and the methodology described in Chapter 10.

Taken together, Parts I and II provide a data-intensive analysis with important implications for international climate change cooperation from two different but complementary perspectives.

Introduction to Global Climate Change

Addressing global climate change is a paramount challenge of the 21st Century. Since the beginning of the industrial revolution, atmospheric concentrations of carbon dioxide (CO_2), the chief heat-trapping greenhouse gas, have risen 35 percent, from about 280 to 377 parts per million (ppm) (Figure 1.1). This increase is primarily from the burning of fossil fuels and from deforestation. Atmospheric concentrations of methane (CH_4), the second leading GHG, have more than doubled over the past two centuries. These and other GHG increases have led to a 0.6° C (1.1° F) increase in the global average surface temperature since 1900. If current emissions trends are not altered, global temperatures are expected to rise a further 1.4 to 5.8° C (2.5 to 10.4° F) by 2100, according to the Intergovernmental Panel on Climate Change (IPCC). The effects of such temperature changes on agricultural production, water supply, forests, and overall human development are uncertain, but are likely to be detrimental to a large portion of the world's population, particularly in developing countries.

To keep the global average temperature from rising more than 2° C (3.6° F) above pre-industrial levels, worldwide emissions would need to peak around 2015 and subsequently decline by 40 to 45 percent by 2050 compared to 1990 levels.[2] Yet, over this century, the global population is expected to increase by 40 to 100 percent and economic growth is projected to climb 10- to 20-fold. Reducing emissions to levels that avoid dangerous human interference with the climate system, in the face of economic and population growth, will require substantial changes in energy use, including technological innovation plus advances in efficiency, conservation, and alternative energy sources.

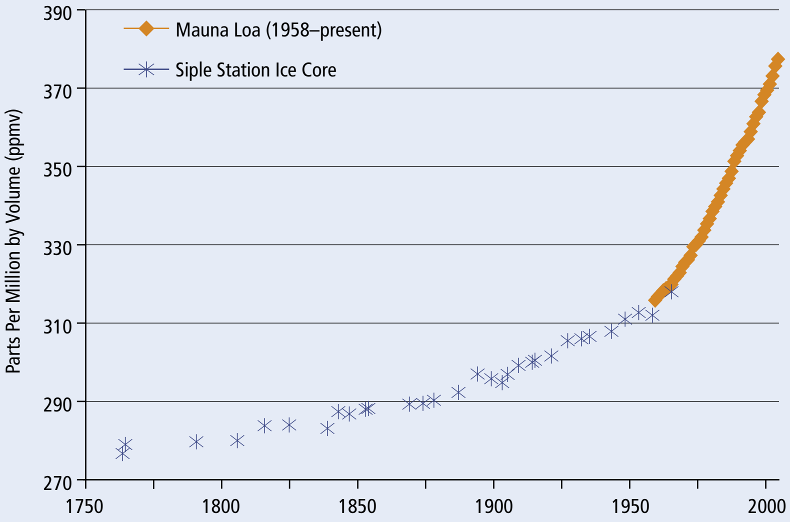
The characteristics of climate change create unique policy challenges, and provide the foundation for appropriate policy responses. At the most basic level, climate change is a global problem, necessitating a coordinated international response. But countries do not have equal interests in reducing emissions, nor are they all equally significant. The problem is also long term, since CO_2 emissions, on average, remain in the atmosphere for about 100 years (some other gases persist for thousands of years). Left unchecked, some consequences of climate change, such as sea level rise, can be irreversible. Finally, responding to climate change implicates essential interests such as economic development and national security. As will be illustrated in this report, nearly the full range of human activities is associated with GHG emissions, including transport, industrial activities, and electric power usage. Collectively, these features create considerable challenges facing the development of a consensus-based international legal process.

Because of the nature and scale of the climate change problem, it is not surprising that the global agreements needed to adequately address climate change are only partially formed (Box 1.1). Governments adopted the UN Framework Convention on Climate Change (UNFCCC, or "Climate Convention") in 1992. This agreement has nearly universal membership—including the United States and all major GHG emitting countries—and establishes the basic principles and preliminary steps for addressing climate change at a global level. Most importantly, the Climate Convention establishes an ultimate objective of stabilizing atmospheric concentrations of greenhouse gases at a level that avoids dangerous human interference with the climate system. Yet, the Convention established little in the area of firm governmental commitments. Recognizing this shortcoming, and responding to firmer scientific findings, governments agreed in 1997 to the Kyoto Protocol.

Under the Kyoto Protocol, industrialized and transition economies assumed legally binding emission caps to be achieved during the five-year period from 2008 to 2012. Targets ranged from a decrease of 8 percent relative to 1990 (European Union and others), to an increase of 10 percent (Iceland). However, developing countries, including major emitters such as China and India, have no emission limits under Kyoto. Furthermore, two industrialized countries—the United States and Australia—have not acceded to the Kyoto Protocol, and are therefore not bound by its emission controls.

Since the Protocol entered into force in February 2005, much of the international community has turned its attention to a successor agreement that builds on—or replaces—Kyoto by incorporating new features that attract the interest of the United States, Australia, and key developing countries. It is within this context that a more complete understanding of GHG emissions—at the global, national, and sectoral levels—should inform future decision-making.

Figure 1.1. Atmospheric Carbon Dioxide (CO_2) Concentrations, 1750–2004



Source: WRI, based on A. Neftel et al., 1994; C.D. Keeling and Whorf, 2005.

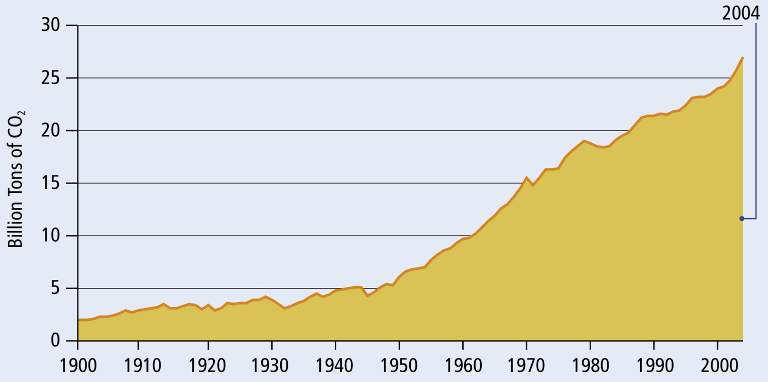
Box 1.1. Major Milestones in the International Climate Change Regime

1988	UNEP and WMO establish the Intergovernmental Panel on Climate Change (IPCC), which produces regular scientific and technical assessments on climate change
1992	The U.N. Framework Convention on Climate Change is agreed to at the Earth Summit in Rio de Janeiro, Brazil. The Convention enters into force in 1994.
1995	The IPCC Second Assessment Report concludes that the balance of evidence suggests a discernible human influence on the global climate
1997	Adoption of the Kyoto Protocol to the UN Climate Convention
2001	The IPCC Third Assessment Report finds stronger connections between human activities and the global climate system The United States announces that it will not become a Party to the Kyoto Protocol Other signatories adopt the "Marrakesh Accords," a set of detailed rules for the implementation of the Kyoto Protocol.
2004	Russian Federation ratifies the Kyoto Protocol, triggering its entry into force in February 2005
2005	First meeting of the Parties of the Kyoto Protocol takes place in Montreal, Canada

Overview of Global Greenhouse Gas Emissions

Worldwide emissions of GHGs have risen steeply since the start of the industrial revolution, with the largest increases coming after 1945 (Figure 1.2). In the past 200 years, more than 2.3 trillion tons of CO_2 have been released into the atmosphere due to human activities relating to fossil fuel consumption and land-use changes.[3] Fifty percent of these emissions have been released in the 30-year period from 1974 to 2004.[4] The largest absolute increase in CO_2 emissions occurred in 2004, when more than 28 billion tons of CO_2 were added to the atmosphere from fossil fuel combustion alone.[5] The year 2004 also represented the largest percentage increase in emissions since 1976.[6]

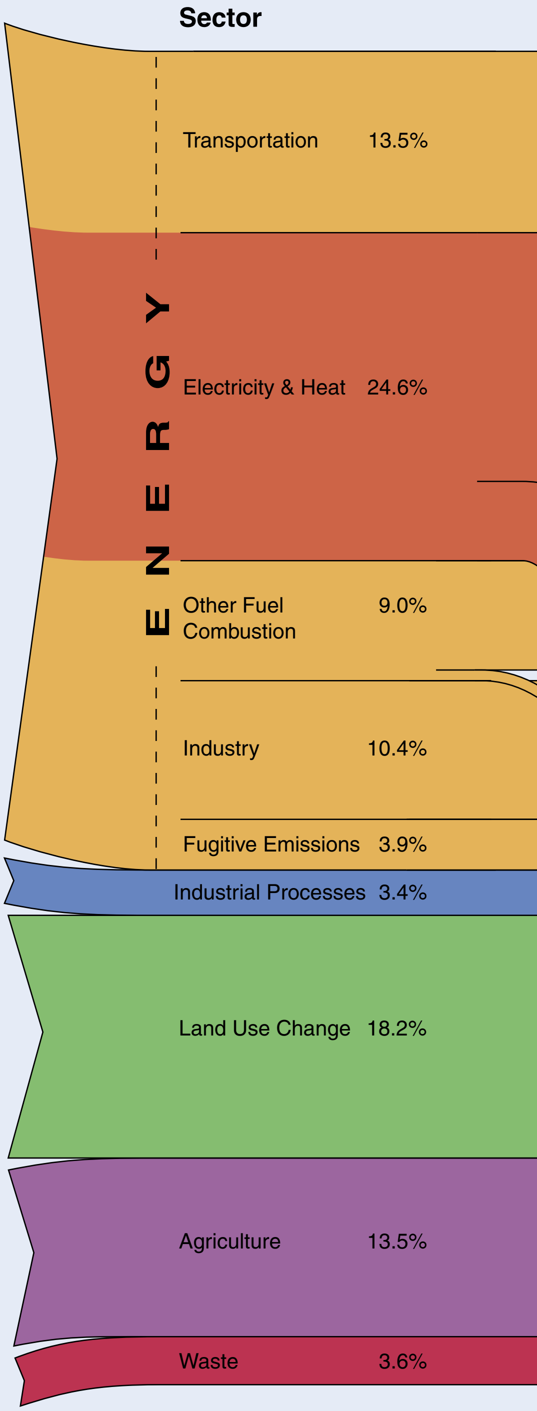
Figure 1.2. Global Emissions of CO_2 from Fossil Fuels, 1900–2004

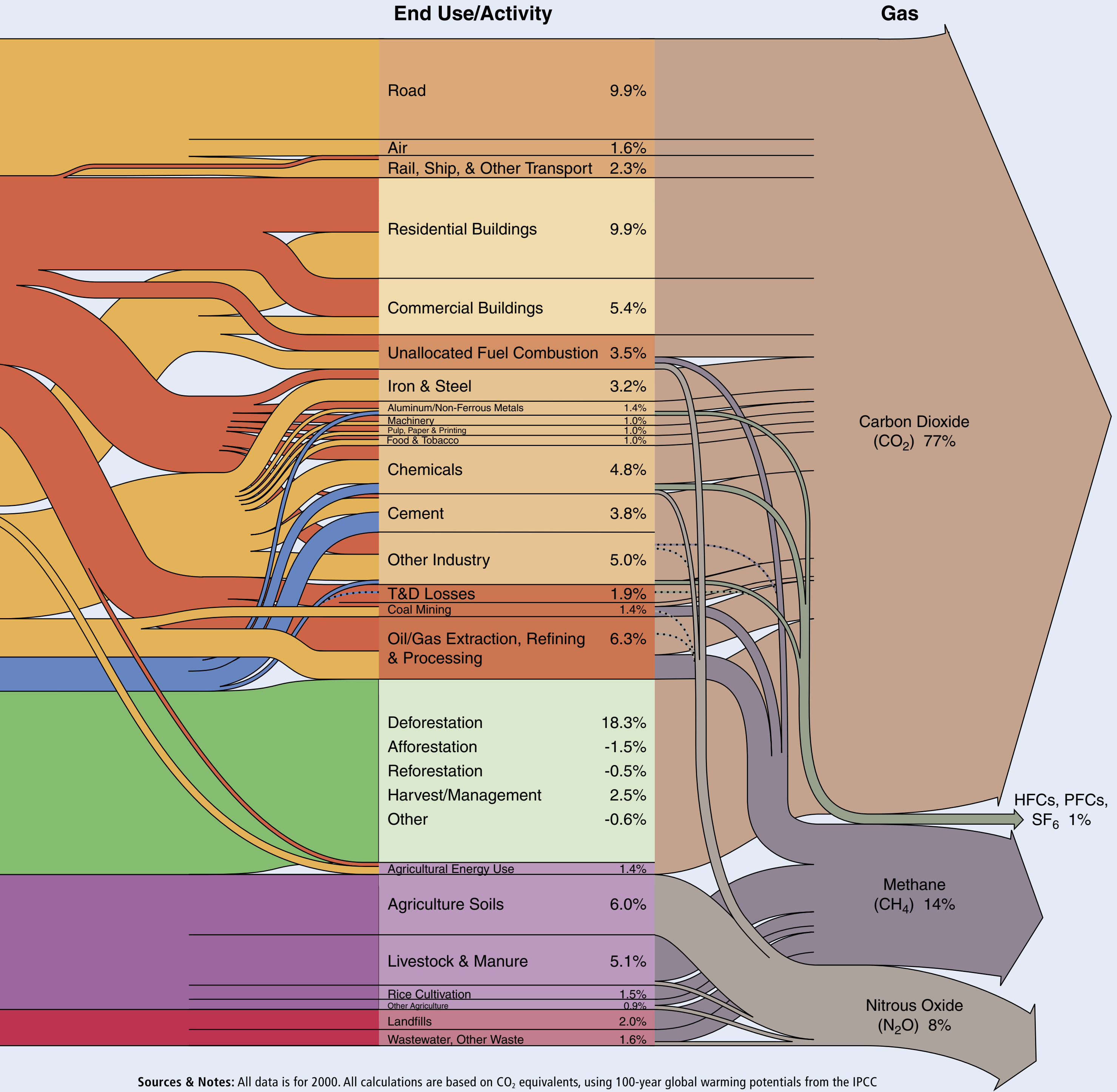


Sources & Notes: WRI estimates based on IEA, 2004; EIA, 2004; Marland et al., 2005; and BP, 2005. Emissions include fossil fuel combustion, cement manufacture, and gas flaring.

One of the great challenges of climate change is that GHG emissions result from almost every major societal function, spanning transportation, agriculture, space heating, and many more activities. Using data from a wide range of sources, the GHG Flow Diagram (Figure 1.3) shows a complete picture of global GHG emissions. The left side of the figure shows that energy-related emissions account for about 60 percent of the world total. (Energy-related emissions come from the production and combustion of coal, oil, and natural gas, and are discussed in more detail in Chapter 8 and throughout Part II.)

Figure 1.3. GHG Flow Diagram, Global Greenhouse Gas Emissions





Sources & Notes: All data is for 2000. All calculations are based on CO_2 equivalents, using 100-year global warming potentials from the IPCC (1996), based on a total global estimate of 41,755 $MtCO_2$ equivalent. Land use change includes both emissions and absorptions; see Chapter 17. See Appendix 2 for detailed description of sector and end use/activity definitions, as well as data sources. Dotted lines represent flows of less than 0.1% percent of total GHG emissions.

At the sector level, the largest contributors to global emissions are electricity and heat (collectively 24.6 percent), land-use change and forestry (18.2 percent), transport (13.5 percent), and agriculture (13.5 percent). Figure 1.3 also shows emissions by "activity" or end-use (middle column). Here, the largest emissions come from road transport (9.9 percent), residential buildings (9.9 percent), oil and gas production (6.3 percent), agricultural soils (6.0 percent), commercial buildings (5.4 percent), and chemicals and petrochemicals (4.8 percent).[7] Many of these sources include direct emissions (such as fossil fuel combustion, industrial process emissions) as well as indirect emissions (such as electricity consumption). Collectively, the industry-related subsectors shown in the middle column of Figure 1.3 (spanning "iron & steel" down to "other industry") comprise about 21 percent of global emissions. Sectors and subsectors are discussed in greater detail in Part II and Appendix 2 of this report.

The data in Figure 1.3 includes the six major GHGs. Carbon dioxide (CO_2) contributes the largest share of the global total (77 percent, using global warming potentials[8]), followed by methane (CH_4, 14 percent) and nitrous oxide (N_2O, 8 percent). Most of the energy and land-use activities result in CO_2 emissions, although there are also significant CH_4 emissions from mining, processing, and refining of fossil fuels. Emissions from agriculture and waste, on the other hand, are largely comprised of CH_4 and N_2O. About 1 percent of global emissions (by global warming potentials) are from fluorinated gases (SF_6, HFCs, PFCs). Further details on non-CO_2 gases are described in Figure 1.4.

Guide to This Report

The following conventions and caveats apply to the data and analysis presented in this report:

- ***Data Sources.*** Most information presented in this report is drawn from CAIT version 3.0 (see Appendix 1). Where no data source is provided, it can be presumed that CAIT is the source. This report—and CAIT—use data from a wide variety of sources, including the Carbon Dioxide Information Analysis Center (Marland et al., 2005); Houghton (2003a); the Intergovernmental Panel on Climate Change (IPCC, 2000a); International Energy Agency (IEA, 2004a); U.S. Environmental Protection Agency (EPA, 2004); U.S. Energy Information Administration (EIA, 2003, 2004); RIVM/TNO (2003); and the UN Framework Convention on Climate Change (UNFCCC, 2005).[9] For more information, see Appendices 1 and 2 and the CAIT website (http://cait.wri.org).
- ***Definition of Sectors.*** When examining GHG emissions, this report follows the sector and subsector definitions adopted by the IPCC (1997). However, there are many exceptions that are explained in Appendix 2, endnotes, and supporting documentation to CAIT (WRI, 2005a; WRI, 2005b). In some cases, the report deviates from IPCC guidelines because the underlying GHG data sources do not match IPCC definitions. In other cases, definitions are refined to enable a more comprehensive accounting of a particular end-use activity (for example, combining energy-related emissions with industrial process-related emissions for cement).

Figure 1.4. Selected Sources of Non-CO_2 Greenhouse Gases

Methane (CH_4)	Nitrous Oxide (N_2O)	High GWP Gases (HFCs, PFCs, SF_6)
Landfills	Agricultural Soils	Substitutes for ozone-depleting substances (HFCs, PFCs)
Coal mining	Adipic and nitric acid production	Industrial activities, including:
Natural gas & oil systems	Fossil fuel combustion	semiconductor manufacturing (PFCs, SF_6, HFCs)
Livestock (enteric fermentation)	Livestock manure management	electrical transmission & distribution (SF_6)
Livestock manure management	Human sewage	aluminum production (PFCs)
Wastewater treatment		magnesium production (SF_6)
Rice cultivation		
Biomass combustion		
Fossil fuel combustion		

- ***Treatment of Different Gases and Sources.*** When examining GHG emissions, this report's default approach is to include six greenhouse gases: CO_2, CH_4, N_2O, sulfur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs). Unless noted otherwise, CO_2 emissions from land-use change and forestry are generally not included in national totals due to large data uncertainties. In addition, data on emissions of non-CO_2 gases is generally unavailable after 2000. All emissions figures in this report are expressed in *CO_2 equivalents*, using 100-year global warming potentials from the IPCC (1996).
- ***Data Uncertainties.*** In many cases, there is significant uncertainty with respect to emission estimates. This is true even for CO_2 from fossil fuels, although uncertainties tend to be smaller in OECD countries (Andres et al., 2000). The largest uncertainties are for CO_2 from land-use change and forestry (LUCF). Chapter 17 discusses global and national-level uncertainties for this sector, and caution is urged when analyzing LUCF data. For non-CO_2 data, the largest uncertainties tend to be for N_2O, followed by CH_4 (WRI, 2005a). For more detailed information about uncertainty, readers should also refer to documentation from individual data sources.
- ***The European Union.*** The European Union (EU) is in most cases treated as a separate entity. This is because the European Community has acceded to the UNFCCC as a regional economic integration organization, with "Party" status. The EU is typically considered here as a 25-member state body ("EU-25"), rather than the 15-member state body that existed when the EU ratified the Kyoto Protocol. Member states of the EU are also listed in many tables and figures. Where data are summed—for example, emissions of the "top 25 countries"—the EU figure is included in this total, but individual member states are not (to avoid double counting).
- ***"Developed" and "Developing" Countries.*** References to "developed" and "developing" countries correspond to the distinction under the UNFCCC between "Annex I" and "non-Annex I" countries (with non-Parties placed accordingly). Annex I includes several economies in transition. See Glossary and Abbreviations.
- ***Top 25 GHG Emitting Countries.*** This report frequently selects for analysis the 25 countries with the largest absolute emissions of GHGs. This is done even for most of the indicators analyzed in this report, including gross domestic product, income, population, and others. The report focuses on these countries more than others for reasons of environmental importance and convenience. The intent is not to suggest that these are the only countries of importance for greenhouse gas mitigation; only that they are the most important.

- ***GDP.*** In this report, except where noted, gross domestic product (GDP) is measured in units of purchasing power parity. These units, while the subject of some controversy, are believed to be more appropriate than market exchange rates for making international comparisons, especially between developed and developing countries.
- ***Figures and Tables.*** Charts, graphs, and tables that appear *within* the body of this report are referred to as "figures." Because this report contains a great deal of data, however, supplementary Data Tables are included at the end of the report. Where the text refers to "tables," readers are directed to those tables. Tables typically provide more quantitative detail than the figures in the body of the report.

PART I. COUNTRY-BASED DATA AND INDICATORS

CHAPTER 2

GHG Emissions and Trends

In absolute terms, a relatively small number of countries produce a large majority of global GHG emissions. Together, the 25 countries with the largest GHG emissions account for approximately 83 percent of global emissions (see Figure 2.1). The largest emitter is the United States, with 21 percent of global emissions, followed by China (15 percent). If the European Union (EU) is treated as a single entity, it and the four other largest emitters—the United States, China, Russia, and India—contribute approximately 61 percent of global emissions. It follows that most of the remaining countries contribute little to the buildup of GHGs in the atmosphere; 140 countries contribute only 10 percent of annual emissions (Figures 2.2 and 2.3). This group includes the least developed countries and many small island states.

There is significant diversity among the 25 highest emitters. As a whole, the group transcends the conventional country groupings (Figure 2.4). It includes:

- 13 Annex I (developed) countries, 11 of which are OECD members
- 11 non-Annex I (developing) countries
- 1 regional Party and six of its member states (EU-25)
- 2 OECD countries not in Annex I (South Korea, Mexico)
- 3 economies in transition (Poland, Russia, Ukraine)
- 3 OPEC members (Indonesia, Iran, Saudi Arabia)
- 4 non-Parties to the Kyoto Protocol (United States, Australia, Turkey, Iran).

Most of the largest GHG emitters have large economies, large populations, or both (Figure 2.5, Table 1). All but eight of the top 25 emitters are also among the 25 most populous nations, with China the most populous and Australia the least (52nd globally). Collectively, the major emitters represent 70 percent of the global population. In other words, the sheer size of some countries mean that they are among the largest emitters, even though per capita emissions may be small (see Chapter 4).

With respect to GDP, all but three of the top 25 emitters are also among the 25 countries with the largest economies, ranging from the United States and the EU (each with over 20 percent of global GDP) to Ukraine (0.5 percent of global GDP)

(Figure 2.5). Together, the 25 top emitters generate 87 percent of global GDP. Some countries rank among the largest economies by virtue of their very large populations (China and India together comprise 38 percent of global population and 18 percent of global GDP); others by virtue of affluence (the United States and the EU together comprise only 12 percent of global population, and nearly 44 percent of global GDP) (Table 1).

Country rankings in GHG emissions vary depending on which gases are counted (Table 2).[10] The estimates described cover CO_2 from fossil fuels and cement,[11] plus emissions from methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs). The inclusion of non-CO_2 gases generally increases the shares of emissions from developing countries (Figure 2.6). In agrarian economies with little heavy industry or energy production, CH_4 is often the largest single source of emissions. Similarly, land-use change also represents a larger share of CO_2 emissions in developing countries, where emissions largely arise from tropical deforestation.

The United States' share of world emissions is estimated at 24 percent when counting only CO_2 emissions from fossil fuel use, but drops to 21 percent when non-CO_2 gases are added, and to 16 percent for all gases and LUCF absorption (although the U.S. nevertheless ranks first in all three methods). Conversely, Indonesia, which ranks 21st in total emissions when only CO_2 from fossil fuels is considered,

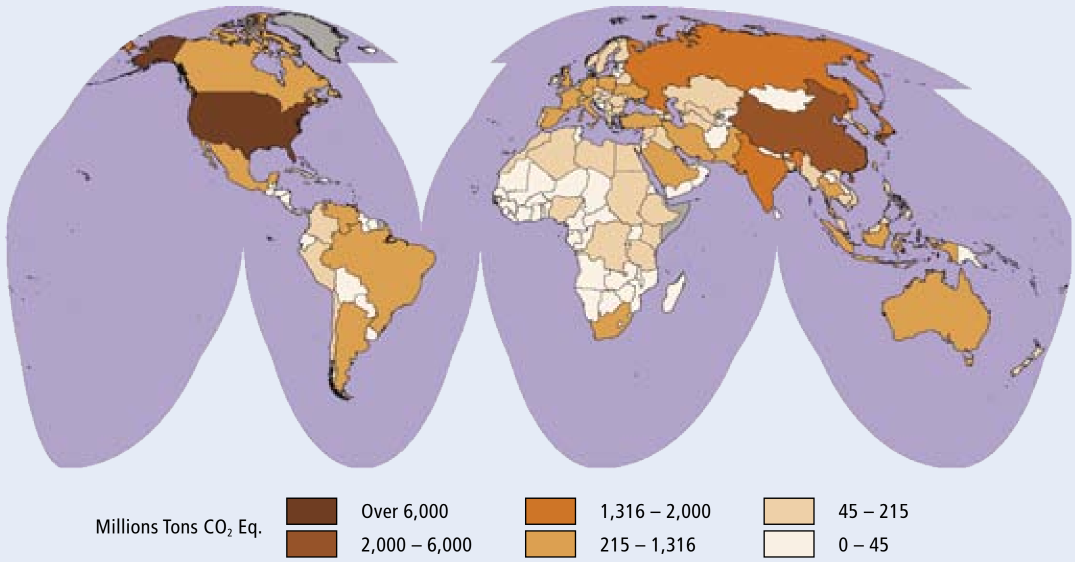
Figure 2.1. Top GHG Emitting Countries

CO_2, CH_4, N_2O, HFCs, PFCs, SF_6

Country	$MtCO_2$ equivalent	% of World GHGs
1. United States	6,928	20.6
2. China	4,938	14.7
3. EU-25	4,725	14.0
4. Russia	1,915	5.7
5. India	1,884	5.6
6. Japan	1,317	3.9
7. Germany	1,009	3.0
8. Brazil	851	2.5
9. Canada	680	2.0
10. United Kingdom	654	1.9
11. Italy	531	1.6
12. South Korea	521	1.5
13. France	513	1.5
14. Mexico	512	1.5
15. Indonesia	503	1.5
16. Australia	491	1.5
17. Ukraine	482	1.4
18. Iran	480	1.4
19. South Africa	417	1.2
20. Spain	381	1.1
21. Poland	381	1.1
22. Turkey	355	1.1
23. Saudi Arabia	341	1.0
24. Argentina	289	0.9
25. Pakistan	285	0.8
Top 25	**27,915**	**83**
Rest of World	**5,751**	**17**
Developed	**17,355**	**52**
Developing	**16,310**	**48**

Notes: Data is for 2000. Totals exclude emissions from international bunker fuels and land use change and forestry.

Figure 2.2. GHG Emission Levels by Country



Sources & Notes: WRI, CAIT. Data is in absolute totals of six GHGs for 2000. EU-25 is not shown collectively.

ranks 4th when land use and non-CO_2 gases are added. Results for all major emitters are shown in Table 2. Uncertainty levels, it should be noted, are very high for land-use change and forestry emissions (see Chapter 17).

Emissions Trends

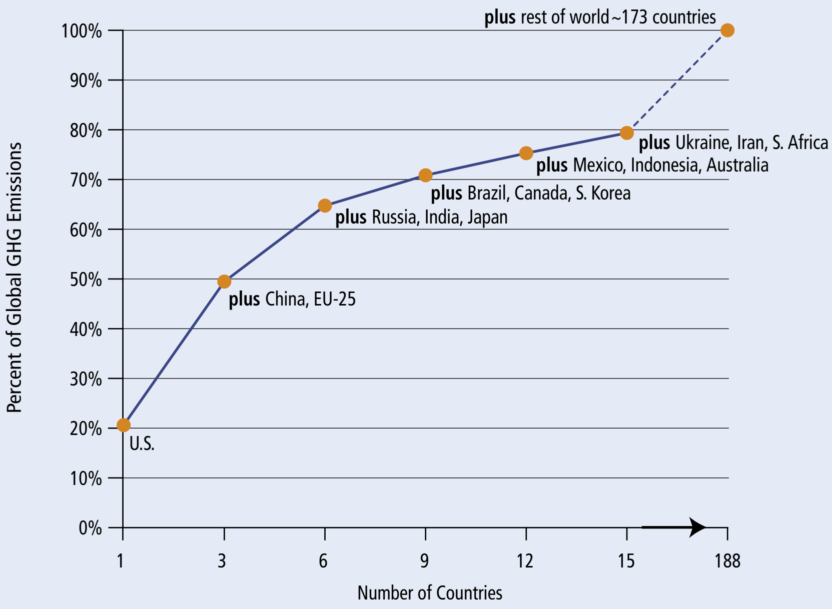
Emissions growth rates are highest among developing countries, where collectively CO_2 emissions increased by 47 percent over the 1990–2002 period. Among the major developing country emitters, growth was fastest in Indonesia (97 percent), South Korea (97 percent), Iran (93 percent), and Saudi Arabia (91 percent) during this period (Figure 2.7, 2.8). Emissions in China grew about 50 percent, although preliminary estimates for 2003 and 2004 suggest extraordinary growth in China, about 35 percent over this two-year period alone.[12] In absolute terms, this CO_2 growth in China accounts for more than half of the worldwide CO_2 increase during the 2003–04 period.[13]

Carbon dioxide emissions in the developed countries were unchanged over the 1990–2002 period, although this figure masks considerable national disparities. Emissions in the EU declined slightly over this period, led by significant GHG (six gas) reductions in the United Kingdom (-15 percent) and Germany (-19 percent). The only other countries with declining emissions are those transitioning from centrally planned economies, such as Russia and Ukraine, where emissions have declined precipitously due in part to economic transition. In contrast, GHG (six gases) growth was significant in the U.S. (13 percent), Canada (20 percent), and Australia (22 percent) over the 1990 to 2002 period (Figure 2.7).[14] These growth rates, while smaller than those of many developing countries, are nonetheless significant in terms of absolute contributions to the growing stock of GHGs in the atmosphere. Because of the sheer size of the U.S., for instance, its jump in CO_2 emissions added roughly the same amount of CO_2 to the atmosphere (863 $MtCO_2$) as the combined 64 percent emissions growth from India, Brazil, Mexico, and Indonesia (832 $MtCO_2$) (Figure 2.8).

Emissions Drivers

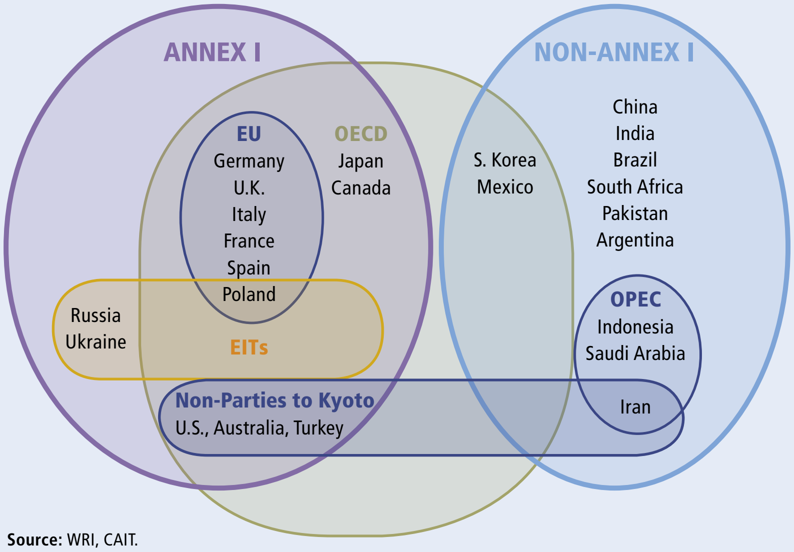
The strong correlation between emissions, population, and GDP rankings reflects the importance of population and economic growth as emissions drivers. Through a *decomposition analysis*, it is possible to derive the relative contribution of several factors to changes in a country's emissions level, including

Figure 2.3. Aggregate Contributions of Major GHG Emitting Countries



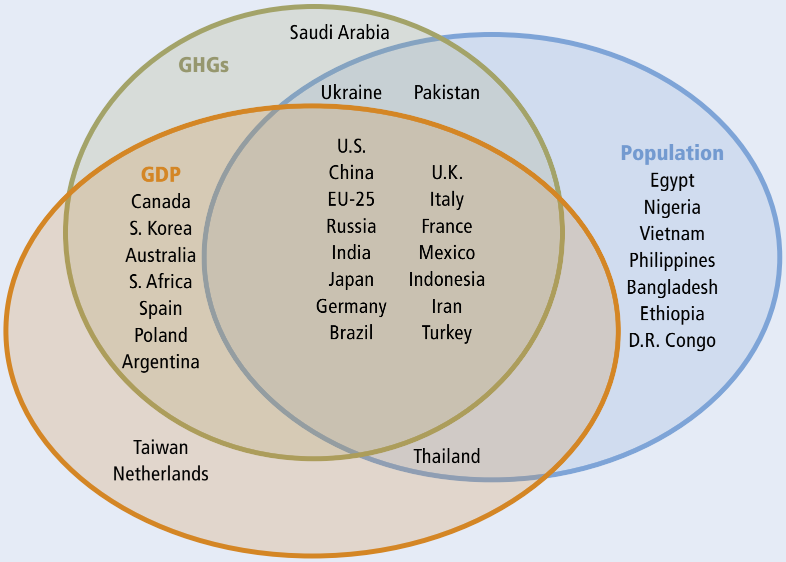
Sources & Notes: WRI, CAIT. Moving from left to right, countries are added in order of their absolute emissions, with the largest being added first. Figures exclude CO_2 from land-use change and forestry and emissions from international bunker fuels.

Figure 2.4. Top 25 GHG Emitters by Region and Organization



Source: WRI, CAIT.

Figure 2.5. Top 25: GHG Emissions, Population, and GDP



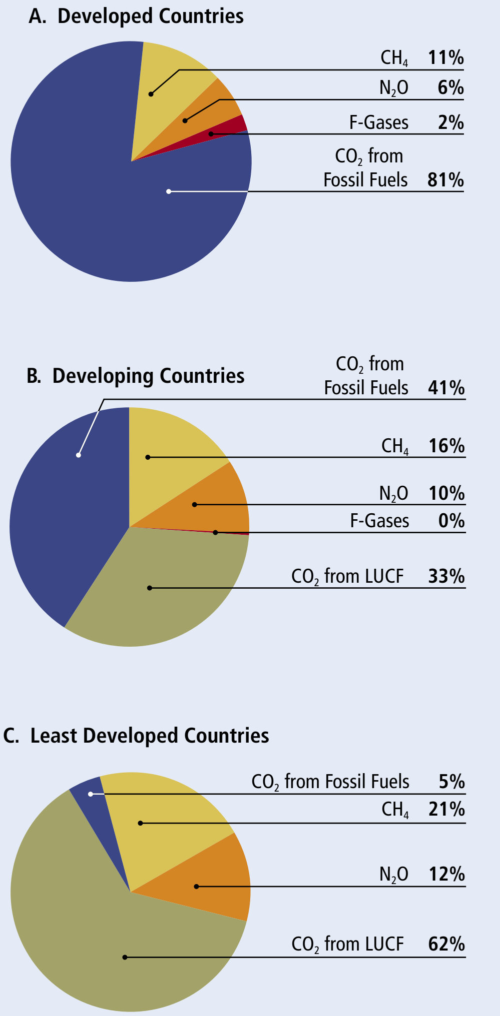
Source: WRI, CAIT.

changes in energy intensity and fuel mix. (See Box 2.1 for a more detailed description of decomposition analysis.) The results for the 25 top emitters, for the period 1990–2002, are presented in Figure 2.8. (For each country, the sum of the four factor contributions is equal to actual percent change in CO_2.)

In a majority of countries, economic growth (measured here as increases in GDP per capita) has the strongest influence on emissions levels, usually putting upward pressure on emissions. This is the case in countries as diverse as the United States, India, Indonesia, Australia, and Iran. In Russia and Ukraine, as noted above, economic contraction contributed to a decline in emissions. Surprisingly, however, economic decline was not the largest contributor to Russia's much-discussed emissions drop. Rather, structural changes in Russia's economy—as evidenced by the energy intensity decline—were a larger factor. Population decline and changes in fuel mix also contributed. In some countries, large movements in one factor were substantially counterbalanced by one or more other factors. China, for instance, experienced a very large decline in energy intensity, putting downward pressure on CO_2 emissions. However, this pressure was more than counterbalanced by astonishingly high GDP growth, leading to an overall increase in emissions over the 1990–2002 time period.

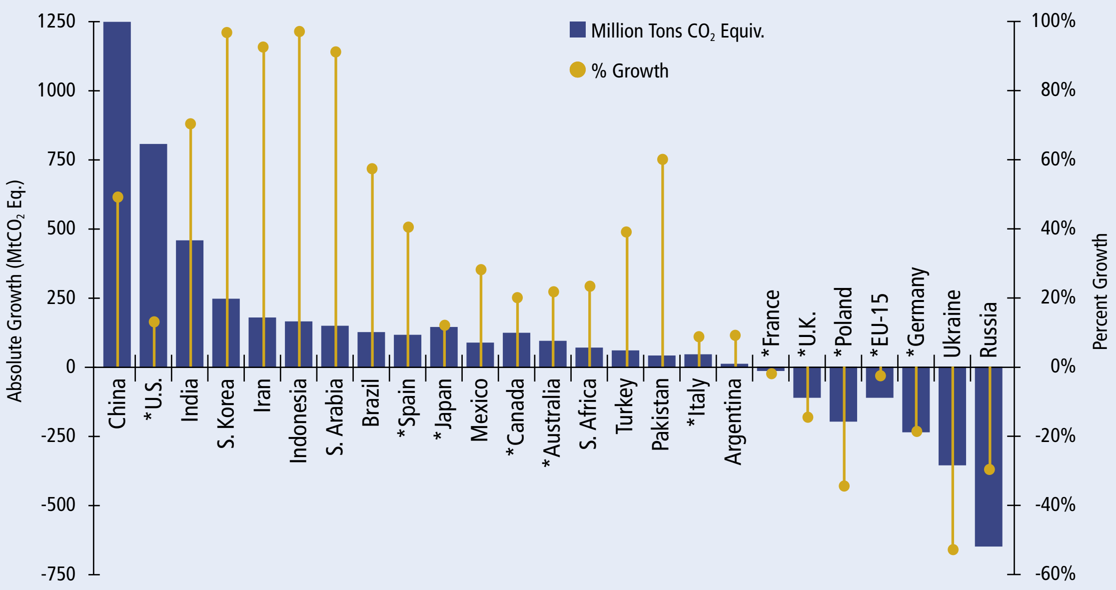
The decomposition analysis shows the importance of population, income, energy intensity, and fuel mix shifts in shaping energy-related emission trends. These factors are discussed in greater depth in Chapters 4 (population) and 5 (energy intensity, fuel mix). It is important to note, however, that the drivers of GHG emissions are more complex and multifaceted than suggested by the decomposition analysis. This report illustrates a range of additional factors that shape emission levels and trends, including natural resource

Figure 2.6. Emission Profiles by Gas and Source



Sources & Notes: WRI, CAIT. Data is from 2000. "LUCF" is land use change and forestry. LUCF is not shown in developed countries because this sector is believed to be a net absorber of CO_2. "Least developed countries" is a subset of "developing countries."

Figure 2.7. GHG Emissions Growth, 1990–2002



Sources & Notes: WRI, CAIT. Countries without asterisks are CO_2 only; countries with asterisks (*) include six GHGs (CAIT-UNFCCC, based on national inventories submitted by Parties to the UNFCCC).

Figure 2.8. Factors Contributing to CO_2 Emissions Growth, 1990–2002

	CO_2 Change 1990–2002		% Contributions to CO_2 Changes				
Country	$MtCO_2$	%	GDP per capita (GDP/Pop)	Population (Pop)	Energy Intensity (E/GDP)	Fuel Mix (CO_2/E)	Non-CO_2 % Changes (1990–2000)
China	1,247	49	122	15	-96	8	21
United States	863	18	23	16	-20	-1	4
India	457	70	55	28	-31	19	20
South Korea	246	97	84	15	12	-15	49
Iran	178	93	44	26	24	-1	46
Indonesia	164	97	44	25	2	26	13
Saudi Arabia	148	91	-7	46	52	0	50
Brazil	125	57	17	21	7	13	10
Spain	98	44	31	6	7	-1	21
Japan	96	9	12	3	0	-7	24
Mexico	87	28	17	22	-12	1	3
Canada	87	20	24	13	-18	0	15
Australia	73	28	31	16	-19	-1	11
South Africa	69	23	-2	28	-2	-1	11
Turkey	59	39	16	25	0	-2	9
Pakistan	40	60	18	38	-1	5	29
Italy	33	8	17	2	-6	-5	4
Argentina	10	9	17	13	-9	-11	9
France	2	0	17	5	-6	-15	-12
United Kingdom	-36	-6	24	3	-20	-13	-32
Poland	-60	-17	35	0	-46	-6	-24
EU-25	-70	-2	21	3	-14	-12	-18
Germany	-127	-13	15	4	-21	-10	-33
Ukraine	-291	-48	-32	-5	40	-51	-35
Russian Federation	-453	-23	-5	-3	-12	-3	-44

Notes: Methodology was adapted from Ang, 2001. See Box 2.1. CO_2 excludes land use change and forestry. For Russia and Ukraine, the time period evaluated is 1992 to 2002, due to lack of energy data in 1990.

endowments (Chapter 8), climatic conditions (Chapter 8), and trade (Chapter 9). A further set of factors influence most of the non-CO_2 emissions, including developments in the agriculture (Chapter 15), waste (Chapter 16), and forestry (Chapter 17) sectors.

Box 2.1. Factors Driving Energy-Related CO_2 Emissions

One approach to understanding energy-related CO_2 emissions is a simple model utilizing four factors: activity levels, structure, energy intensity, and fuel mix. Altering any of these factors—alone or in combination—can influence emissions. By way of illustration, the farther one drives a car (*activity*), the more CO_2 emissions will result. However, fewer emissions will also result if the car is more energy efficient (*energy intensity*), and emissions might be avoided entirely if the car is operating on a zero-carbon fuel (*fuel mix*).

Equation A

$$CO_2 = \overbrace{\frac{\text{GDP}}{\text{Person}} \times \text{Population}}^{\text{Activity}} \times \overset{\text{Energy Intensity}}{\overset{\downarrow}{\frac{\text{Energy}}{\text{GDP}}}} \times \overset{\text{Fuel Mix}}{\overset{\downarrow}{\frac{CO_2}{\text{Energy}}}}$$

Equation A represents these dynamics at the economy-wide level. An additional factor not represented directly is *structure*. For example, a structural change away from heavy industry (high energy inputs) toward commercial activities (e.g., financial or insurance, with low energy inputs) will reduce emissions, even if all other factors remain unchanged over time. Similarly, a shift from domestic production to imports of energy-intensive goods represents structural change. There are no specific national-level indicators to denote structure. Rather, structural changes are part of the energy intensity factor (which decreases when there is structural change away from industry and toward services, for instance).

Isolating the degree to which the discrete variables in Equation A are driving energy-related CO_2 emissions is done through a technique called decomposition analysis.* Decomposition analysis identifies and quantifies the contribution of each factor toward changes in the aggregate indicator over a specific time period (CO_2 changes from 1990 to 2002, in this case). Factors can have compounding or offsetting effects on changes in emissions. Relatively small changes in factors can result in a large change in emissions when all the factors change in the same direction. On the other hand, large changes in one factor can be offset by opposing changes in other factors, resulting in only a small change in emissions.

This decomposition model only accounts for energy-related CO_2 emission changes. In some cases, overall GHG changes are significantly influenced by increases or decreases in non-CO_2 gases. For that reason, the final column in Figure 2.8 shows changes in non-CO_2 emissions. Finally, *percentage* changes such as those shown in the table should be evaluated in the context of absolute shifts. This effect can be seen in the second column of Figure 2.8.

* The approach to decomposition analysis employed in this paper follows the methodology of Ang (2001).

Implications for International Climate Cooperation

Focus on the largest countries, developed and developing. Because global emissions are concentrated among a small number of political entities, these entities are by definition crucial to achieving the environmental objective of the Climate Convention. A regime that does not establish adequate GHG mitigation incentives and/or obligations within these political entities—through domestic initiatives, international agreements, or both—will fail environmentally. Given the diversity of large emitting countries, it is simply not possible to adequately address the climate change problem without engaging both developed and developing countries. However, the specific incentives and obligations within an agreement are likely to differ by country due to a variety of factors, such as economic structure and development level.

Along these lines, it is often said that successful climate agreements must be "global." This is only true insofar as this term is shorthand for engaging the largest emitters. Successful mitigation agreements need not be global, in the sense of engaging all countries. The least developed countries and small island developing states, most of which have negligible emissions, are not critical to GHG mitigation efforts.

The strong concentration of emissions among a relatively small number of countries might suggest possible changes in the structure of international climate negotiations with respect to mitigation actions. Alternative institutional models might be explored that engage the major emitting countries as a group, either within or outside the U.N. Climate Convention.

CHAPTER 3

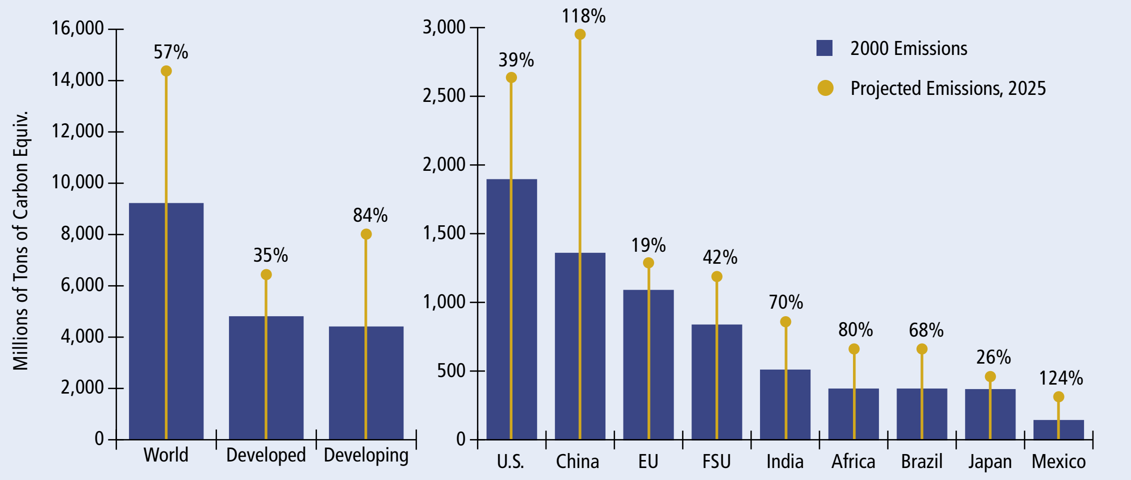
Emissions Projections

The central challenge of international climate change policy is to limit future emissions. Projections of long-term emissions growth depend heavily on assumptions about such critical factors as economic and population trends and the rate of technology development and diffusion. The IPCC has developed four "families" of scenarios incorporating different sets of assumptions.[15] Under these scenarios, global GHG emissions are projected to grow 39 to 89 percent by 2025, and 63 to 235 percent by 2050, depending on the underlying assumptions.[16] As with the decomposition analysis presented earlier, GDP and population are the strongest determinants of emissions trends in most scenarios. The wide range in projections reflects both differing assumptions, for instance with respect to future policy choices, and substantial uncertainties, particularly regarding economic forecasts.

Among the most widely cited emissions projections are those developed by the Energy Information Administration (EIA) of the U.S. Department of Energy.[17] Under EIA's mid-range or "reference case" scenario for CO_2 from fossil fuels, combined with estimates of future non-CO_2 emissions, global emissions are projected to rise 57 percent over the period from 2000 to 2025 (Figure 3.1). Projections from the International Energy Agency suggest similar future outcomes.[18] While growth is projected in all regions, there are significant differences, as shown in Figure 3.1:

- Among industrialized countries, projected increases to 2025 are relatively modest for the EU (19 percent) and Japan (26 percent), and higher for the United States (39 percent).
- The fastest growth until 2025 is projected in developing countries, whose collective emissions are projected to rise 84 percent (compared to 35 percent growth for industrialized countries). By 2025, the developing country share of global emissions is projected to be approximately 55 percent (compared to 48 percent in 2000).
- Among developing countries, the largest relative growth until 2025 is forecast for Mexico (124 percent) and for China (118 percent). China is projected to surpass the United States as the world's largest emitter.

Figure 3.1. Projected Emissions of GHGs in 2025



Sources & Notes: Projections are based on EIA, 2003 (reference case, CO$_2$ from fossil fuels) and POLES (non-CO$_2$ gases) (EC, 2003). GHGs do not include CO$_2$ from land use change. "FSU" is former Soviet Union.

Because emission projections require estimating factors such as population, economic growth, and technological change, they are inherently uncertain. Uncertainties are especially acute in developing country economies, which tend to be more volatile and vulnerable to external shocks. The large uncertainties in national-level projections are reflected in Figure 3.2. For Mexico, for example, one scenario envisions a 68 percent emissions growth by 2025, while another suggests a 215 percent increase. Particularly in large countries, these uncertainties amount to huge quantities of CO$_2$ emissions. In China, for example, the difference between the low (50 percent increase) and high (181 percent increase) estimates amounts to 1,025 MtC, a quantity that exceeds the *combined* current emissions of India, South Korea, Mexico, South Africa, and Brazil. The differences between low- and high-growth estimates are much smaller for industrialized countries, in part because economic growth is more stable and thus uncertainties are smaller.

Figure 3.2. Uncertainty in Future CO$_2$ Emissions

	Projected Growth, 2000–2025 (%)		
Country	**Low Growth Estimate**	**High Growth Estimate**	**% Point Difference**
India	73	225	152
Mexico	68	215	147
China	50	181	131
Brazil	84	165	81
South Korea	43	117	74
Former Sov. Union	37	109	72
Japan	4	46	42
EU-15	-1	39	40
United States	20	52	32
World	**33**	**93**	**60**

Sources & Notes: Scenarios are drawn from EIA, 2004; POLES (EC, 2003); and IEA, 2004c. EU here includes Switzerland and Norway. Figures exclude CO$_2$ from international bunker fuels and land use change and forestry.

Furthermore, past projections have a weak success record. Figure 3.3 compares past projections with actual emissions for the year 2000. Projections were made in 1995 by the EIA, and include reference, low, and high scenarios.[19] In the countries and regions listed, none of the actual emissions in 2000 were even within the high-low range projections from a mere five years earlier. With the exception of the U.S. case, the EIA projections were all overstatements of eventual emissions. Thus, while the range of projections is larger in developing countries, even in industrialized countries it seems that projections often do not encompass the full spectrum of plausible outcomes.

Implications for International Climate Cooperation

Policy changes are needed in the near term to slow and reverse emission trends. As noted in Chapter 1, keeping the global average temperature from rising more than 2° C (3.6° F) will require worldwide emissions to peak around 2015 and subsequently decline by 40 to 45 percent by 2050 compared to 1990 levels.[20] Beyond this timeframe, additional reductions will also be needed. While uncertainty in future projections is pervasive, all forecasts examined here suggest very large increases in worldwide GHG emissions over the coming decades, meaning that significant increases in global atmospheric temperatures are very likely over this century. Significant delay in abatement efforts will either require steeper abatement in later years or lead to severe physical impacts from climate change.[21]

Policy changes in the near term, on the other hand, could begin to shift investment patterns in a manner that moves toward a lower carbon future, and avoids some of the most adverse impacts. As suggested in Chapter 2, policy changes within the largest-emitting countries are most important. To promote national-level policy change, international cooperation is likely to be needed, given that countries resist acting alone in response to a global-scale problem like climate change.

A one-size-fits-all approach to international cooperation is unlikely to succeed. In particular, fixed emission "caps" in developing countries may be impracticable. As discussed in Chapter 2, a successful international climate regime will need to encompass all major emitters, including developing countries. In response to their historical responsibility and financial and technological capabilities, most industrialized and transition countries have adopted fixed (i.e., absolute) emission targets under the Kyoto Protocol. A key future challenge is enabling participation of other major emitting countries, including developing countries.

Emissions in many developing countries, however, are growing at a rapid, unpredictable pace, which creates daunting challenges for Kyoto-style "caps" on national emissions.[22] Formulating caps given such large uncertainties can have detrimental environmental and economic consequences. Achieving a fixed level of emissions at some future year might be very easy under conditions of low economic growth and industrial stagnation but exceedingly difficult if economic growth were instead robust (even if, in this latter case, growth meant that additional resources would be available to fund mitigation efforts). Thus, fixed emission targets would entail widely varying levels of effort, depending on prevailing socio-economic dynamics (especially GDP growth) in any particular country.

Figure 3.3. Accuracy of Emission Projections

Comparing Past Projections to Actuals, 2000

Country	1995 Projected Emissions for 2000 (MtCO$_2$)			Actual 2000 Emissions	
	Reference	Low	High	MtCO$_2$	% Ref
United States	5,390	5,283	5,492	5,787	7
EU-15	4,232	4,071	4,481	3,442	-19
Japan	1,374	1,213	1,590	1,138	-17
For. Soviet Union	2,968	2,821	3,122	2,338	-21
Mexico	421	381	473	364	-14
China	3,459	3,081	3,855	2,861	-17

Sources & Notes: Projections for 2000 were made in 1995, by EIA (1995). Actual emissions are from EIA (2004). EIA (1995) did not include projections for India and other developing countries not shown here. "% Ref" means the percent difference between the "reference case" and actual emissions. "EU-15" includes other OECD countries in Western Europe. CO$_2$ data includes fossil fuels only.

For example, had China adopted a fixed emissions target in Kyoto, it probably would have been based, at least implicitly, on the kinds of "reference case" emission projections shown in Figure 3.3 (e.g., a modest deviation below the "business-as-usual" projection). The result could have been environmentally detrimental to the Kyoto Protocol. China's projections, as it turned out, were wildly off the mark over the five-year period from 1995 to 2000. Emissions in 2000 were almost 600 MtCO$_2$ lower than EIA's reference case, and more than 200 MtCO$_2$ below EIA's "low" projection. If China were permitted to trade its surplus emission allowances, along the lines established under the Kyoto Protocol, these allowances would have created significant amounts of "hot air," and might have effectively weakened the targets of other countries, which could use them to offset their own rising domestic emissions without pursuing domestic emissions reduction strategies.

More broadly, emission projections as well as cross-country differences in other indicators examined in this report, suggest that a one-size-fits-all approach, whereby all countries adopt the same form of commitments, is unlikely to successfully advance international cooperation on climate change.

Per Capita Emissions

As described in the preceding chapter, countries with large populations, large economies, or both tend to be the largest emitting countries. Under such circumstances, focusing only on absolute emission levels only gives a partial understanding of the greenhouse gas picture. Accordingly, this chapter examines GHG emissions *per capita*.

Only a handful of the countries with the largest *total* emissions also rank among those with the highest per capita emissions (Figure 4.1). Among the 25 major emitters, *per capita* emissions vary widely, with Australia, the United States and Canada having the highest per capita emissions (ranking 4th, 6th, and 7th globally). Their per capita emissions are more than twice those of the EU (37th globally), six times those of China (99th globally), and 13 times those of India (140th globally). When all countries are ranked on a per capita basis, the upper tiers show considerable diversity (Figures 4.1 and 4.2):

- Four of the five highest per capita emitters are the gulf states of Qatar, United Arab Emirates, Kuwait, and Bahrain, largely the result of small populations producing highly GHG-intensive commodities for export.
- A number of small-island states rank relatively high, including Trinidad & Tobago (10th), Antigua & Barbuda (12th), Singapore (18th), Palau (23rd), and Nauru (24nd). Some of these countries are industrialized (despite their non-Annex I status under the UNFCCC), with high population densities (but low total populations). Some are also producers of energy-intensive exports.
- Several economies in transition with significant fossil fuel resources also rank relatively high, including Estonia (14th), the Czech Republic (17th), Turkmenistan (19th), and Russia (22th).
- Some advanced developing economies have per capita emissions commensurate with those of many industrialized countries. Singapore ranks higher than most EU members. South Korea has the same per capita emissions as the United Kingdom, Taiwan's match the EU average, and South Africa's are just slightly below.

In general, there is a relatively strong relationship between *emissions* per capita and *income* per capita, with wealthier countries having higher emissions per capita. This is due to higher rates of consumption and more energy-intensive lifestyles, although other

Figure 4.1. Emissions Per Capita, 2000

Country	GHGs (Tons CO_2 Equiv.)	(Rank)	CO_2 Only (Tons)	(Rank)
Qatar	67.9	(1)	60.0	(1)
United Arab Emirates	36.1	(2)	25.2	(3)
Kuwait	31.6	(3)	26.8	(2)
Australia	25.6	(4)	17.3	(7)
Bahrain	24.8	(5)	20.6	(4)
United States	24.5	(6)	20.4	(5)
Canada	22.1	(7)	17.1	(8)
Brunei	21.7	(8)	13.7	(10)
Luxembourg	21.0	(9)	19.2	(6)
Trinidad & Tobago	19.3	(10)	16.7	(9)
New Zealand	18.9	(11)	8.6	(32)
Antigua & Barbuda	18.5	(12)	4.9	(62)
Ireland	17.3	(13)	10.9	(18)
Estonia	16.6	(14)	11.3	(17)
Saudi Arabia	16.4	(15)	13.4	(11)
Belgium	14.5	(16)	12.2	(14)
Czech Republic	13.9	(17)	12.1	(15)
Singapore	13.9	(18)	13.1	(12)
Turkmenistan	13.8	(19)	7.8	(40)
Netherlands	13.5	(20)	10.9	(19)
Finland	13.3	(21)	10.9	(20)
Russia	13.2	(22)	10.6	(21)
Palau	12.9	(23)	12.7	(13)
Nauru	12.8	(24)	11.4	(16)
Denmark	12.5	(25)	9.7	(27)
Germany	12.3	(27)	10.4	(22)
United Kingdom	11.1	(32)	9.4	(30)
South Korea	11.1	(33)	9.9	(26)
EU-25	10.5	(37)	8.5	(34)
Japan	10.4	(39)	9.5	(29)
Poland	9.8	(43)	7.8	(41)
Ukraine	9.7	(44)	6.3	(47)
South Africa	9.5	(46)	7.9	(39)
Spain	9.4	(47)	7.5	(44)
Italy	9.2	(48)	7.7	(42)
France	8.7	(50)	6.2	(48)
Argentina	8.1	(52)	3.9	(70)
Iran	7.5	(60)	5.3	(56)
Turkey	5.3	(75)	3.3	(78)
Mexico	5.2	(76)	3.9	(71)
Brazil	5.0	(83)	2.0	(100)
China	3.9	(99)	2.7	(88)
Indonesia	2.4	(122)	1.4	(111)
Pakistan	2.1	(131)	0.8	(132)
India	1.9	(140)	1.0	(120)
Developed	**14.1**		**11.4**	
Developing	**3.3**		**2.1**	
World	**5.6**		**4.0**	

Notes: Countries shown are the top 25 per capita emitters, plus other countries among the top 25 *absolute* emitters. Countries not among the top 25 absolute emitters are shown in italics. Emission figures exclude CO_2 from international bunker fuels and land use change and forestry.

factors such as energy endowments (Chapter 8), trade (Chapter 9), population density, and geography also influence a country's per capita emissions.

As with total emissions, per capita figures can vary considerably depending on which gases are considered. The gap in per capita emissions between wealthy and less wealthy countries generally widens when only energy-related CO_2 emissions are considered. For instance, when counting only energy-related CO_2, compared to all gases, the per capita emissions of China, India, and Brazil drop 31, 47, and 60 percent, respectively, while in the EU, the United States and Japan, they drop only 19, 17, and 9 percent. The major influences here are CH_4 and N_2O emissions from agriculture, which comprise a larger share of GDP in developing countries than in developed countries (see Chapter 15). Counting CO_2 from land-use change also has a dramatic effect on per capita emissions, as it represents an estimated one-third of all emissions from developing countries, whereas developed countries may be net absorbers. There are significant uncertainties, however, in country-level estimates of CO_2 from land-use change (see Chapter 17).

As illustrated in the decomposition analysis in Chapter 2, population growth—either through higher birth rates or immigration—can be a significant driver of GHG emissions growth (Figure 2.8, p.15). This is particularly the case in developing countries, but also in "new world" industrialized countries such as the U.S., Canada, and Australia. In other countries, such as Japan, European nations, and Economies in Transition (EITs), population has been relatively stagnant and thus has had little influence on absolute emissions. However, in South Africa, population growth was by far the largest contributor to emissions growth since 1990.

Accordingly, examining per capita emission trends serves to nullify the effect of population growth. Figure 4.3 compares absolute and per capita emission changes from 1990 to 2002 for the U.S. and EU. For the U.S., CO_2 emissions growth was 18 percent in absolute terms but only 2 percent in per capita terms. For the EU, on the other hand, the effect of population growth is not especially large, as absolute CO_2 emissions declined 2 percent compared to a 5 percent decline in per capita terms. As a result, the gap between the EU and U.S. in terms of CO_2 growth is significantly narrower when analyzed from a per capita perspective (7 percentage point difference rather than 20 percentage points). Similar examples can be seen with other countries and regions. With respect to population growth, the "new world" industrialized countries—such as the U.S., Canada, Australia, and New Zealand—actually appear more comparable to developing countries than to the EU and Japan (Figure 4.4).

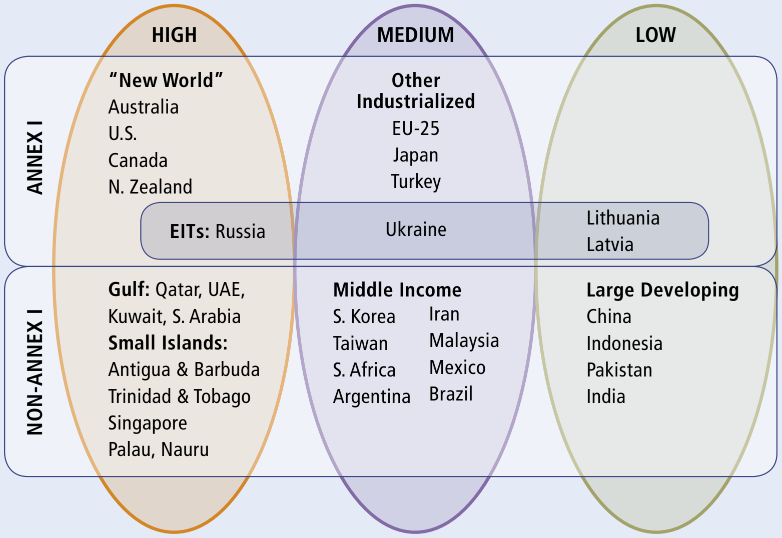
Implications for International Climate Cooperation

International agreements predicated on equal per capita emission entitlements are unlikely to garner consensus. Since the 1980s, a number of proposals have been advanced to address the problem of global climate change by equalizing emissions per capita across countries.[23] These approaches have received considerable support from a range of governments and NGO groups. While the operational details of these proposals often differ, they tend to share the method of allocating emission allowances to countries in proportion to population size (either immediately, or after some period of gradual convergence from present levels), while total allowable emissions globally contract over time. To the extent that these proposals require similar obligations for countries with similar per capita emission levels, they are unlikely to garner widespread support. Those countries with large populations and relatively low levels of economic development would receive apparent benefits, whereas other countries with small populations, high emissions, or both, could be significantly burdened. Absent significant adjustments, such proposals cannot take into account national circumstances faced by Parties, an established principle within the UNFCCC.[24]

However, it is important to note that the implementation of virtually any national or international climate change policies is likely to have the effect of promoting a convergence in per capita emission levels over time. Considering that over the long term net emissions must fall to zero, convergence is a corollary of climate protection.

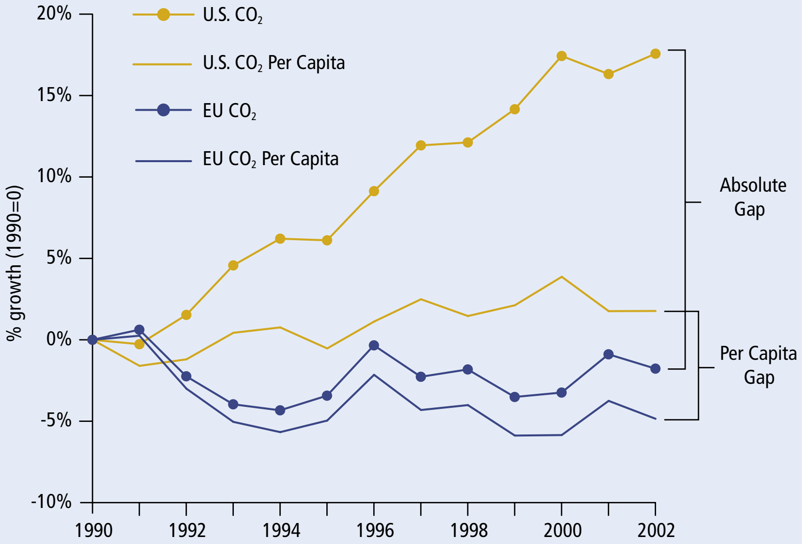
Differentiated per capita GHG emission targets would reduce the effects of population growth on the commitments of Parties. Though not widely discussed in climate policy debates, population growth, as shown, can have a significant effect on the capacity of countries to achieve similar near-term emission

Figure 4.2. GHG Emissions per Capita: Selected Country Groupings
Top 25 emitting countries, plus selected other high per capita emitters



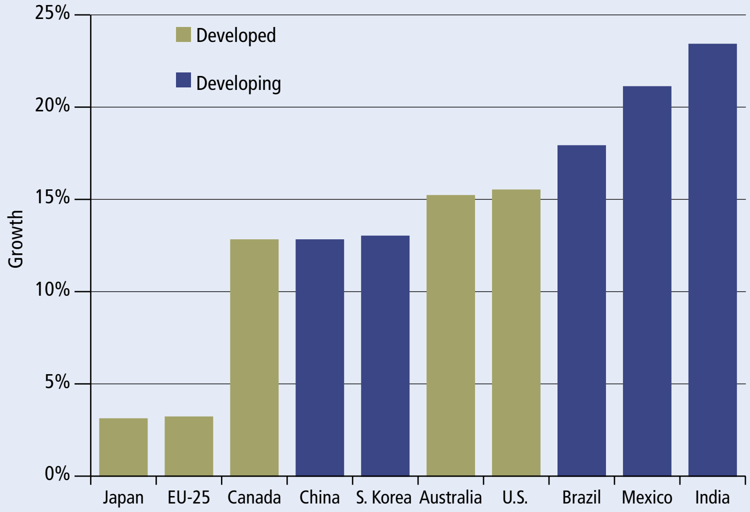
Sources & Notes: WRI, CAIT. "High" GHG per capita countries are those with values from 12.8 to 67.8 tCO_2 eq./person. "Medium" countries are those with values 5.0 to 12.8 tCO_2 eq./person. "Low" values are those countries from 0 to 5.0 tCO_2 eq./person. Figures are for 2000, and include the six GHGs. CO_2 from land use change and forestry and international bunkers are not included.

Figure 4.3. Influence of Population in CO_2 Trends, 1990–2002
EU-25 v. United States



Source: WRI, CAIT.

Figure 4.4. Population Growth, 1990–2002
Selected developed and developing countries



Source: WRI, CAIT.

limits. For instance, under the Kyoto Protocol the United States, Japan, Canada, and the EU initially agreed to emission limitations of similar magnitude (ranging from -6 to -8 percent below 1990 levels), creating the perception of similar levels of stringency. Yet, the United States and Canada are growing countries, and this growth in population plays a major role—along with many other factors—in the relative difficulty of achieving targets.

If governments seek to adopt a new round of fixed emission limitations, particularly among industrialized countries, this population factor might warrant more attention. For instance, emission targets might be framed in terms of emissions per capita, rather than absolute emissions. This would eliminate population growth as a relevant factor in achieving (or not achieving) a national target.

To be sure, the purpose of such an approach would primarily be to address the likely misperceptions associated with adopted emission targets. Invariably, governments, observers, and the media tend to attach value judgments to target levels, which is one reason for the similarity of targets adopted by the major industrial powers in Kyoto. As a practical matter, population growth is reasonably predictable and varies little from year-to-year. Thus, it could easily be implicitly built into absolute emission targets. Yet, this might convey a false sense of disparity across countries. At least in part, this could be remedied by adopting country-by-country targets in per capita terms, which would be simple and more easily comparable across countries.

CHAPTER 5

Emissions Intensity

Emissions intensity is the level of GHG emissions per unit of economic activity, usually measured at the national level as GDP.[25] Intensities vary widely across countries, owing to a variety of factors that are explored in this chapter. GHG intensities for the major emitters, as well as recent trends, are shown in Figure 5.1. Table 3 shows carbon intensity and its constituent factors—energy intensity and carbon content of fuels—for the top 25 emitting countries.

Intensity Levels and Trends

Not surprisingly, emission intensities vary widely across countries. Among the major emitters, GHG intensity varies almost seven-fold—from 344 tons per million dollars GDP in France, to 2,369 tons in Ukraine. France—with relatively low energy intensity, and very low carbon intensity, owing to its reliance on nuclear power—generates only 1.5 percent of global CO_2 emissions while producing 3.3 percent of global GDP. Ukraine—with high coal consumption and one of the world's most energy-intensive economies—generates 1.4 percent of global CO_2 emissions from only 0.5 percent of global GDP. As the country data suggests, however, intensity levels are unconnected with the size of a country's economy or population. A large or wealthy country may have a low GHG intensity, and vice-versa.

Like absolute and per capita emission levels, relative emission intensities vary depending on which gases are included. The inclusion of non-CO_2 gases boosts all countries' intensity levels, but in significantly different proportions. Aggregate CO_2 intensities are similar for developing and developed countries, while GHG intensities (using all six GHGs) in developing countries are about 40 percent higher, on average, than those in developed countries. Likewise, reported intensity levels depend on how GDP is measured. GDP may be expressed in a national currency, U.S. dollars, international dollars (using purchasing power parity conversions), or other common currency. Further, currencies may be inflation-adjusted to different base years. (To facilitate international comparisons, figures here use GDP measured in purchasing power parity expressed in constant 2000 international dollars.)

Historically, emissions intensities fell between 1990 and 2002 for most countries, including three-fourths of the major emitters (Figure 5.1 and Table 3).[26] Among the top 25 emitters, carbon intensity dropped

Figure 5.1. Emissions Intensity Levels and Trends
Top 25 GHG Emitting Countries

	GHG Intensity, 2000	% Change, 1990–2002	
Country	Tons of CO_2 eq. / $mil. GDP-PPP	Intensity (CO_2 only)	GDP
Ukraine	2,369	-6	-50
Russia	1,817	-5	-26
Iran	1,353	17	64
Saudi Arabia	1,309	45	32
Pakistan	1,074	4	55
China	1,023	-51	205
South Africa	1,006	-3	27
Poland	991	-43	47
Australia	977	-16	51
Turkey	844	-2	42
Indonesia	799	22	62
Canada	793	-15	40
India	768	-9	87
South Korea	729	-2	100
United States	720	-17	42
Brazil	679	17	35
Argentina	659	-18	33
Mexico	586	-9	41
Spain	471	5	37
Germany	471	-29	22
EU-25	449	-23	27
United Kingdom	450	-29	32
Japan	400	-6	16
Italy	369	-10	20
France	344	-19	24
Developed	**633**	**-23**	**29**
Developing	**888**	**-12**	**71**
World	**715**	**-15**	**36**

Notes: GHG intensity includes emissions from six gases. GHG intensity and CO_2 intensity exclude CO_2 from international bunker fuels and land use change and forestry. GDP is measured in terms of purchasing power parity (constant 2000 international dollars).

an average 15 percent, helping to drive a global decline of a commensurate amount. The most striking decline was in China, where intensity dropped 51 percent over the 12-year period. However, preliminary data for 2003 and 2004 shows that this trend is reversing, with emissions growing at twice the rate of economic output.[27] Carbon intensity rose significantly from 1990 to 2002 in Saudi Arabia, Indonesia, Iran, and Brazil.[28]

Drivers of Emissions Intensity

Chapter 2 identified population and GDP as major determinants of a country's emissions and changes in its emissions over time. Emissions intensity[29]—the level of greenhouse gas emissions per unit of economic output—is a composite indicator of two *other* major factors contributing to a country's emissions profile, namely energy intensity and fuel mix (Equation B).

Equation B

$$\overset{\text{Carbon Intensity}}{\overset{\downarrow}{\frac{CO_2}{GDP}}} = \overset{\text{Energy Intensity}}{\overset{\downarrow}{\frac{\text{Energy}}{GDP}}} \text{ X } \overset{\text{Fuel Mix}}{\overset{\downarrow}{\frac{CO_2}{\text{Energy}}}}$$

Following on Equation A in Box 2.1, CO_2 emissions intensity is a function of two variables. The first variable is *energy intensity*, or the amount of energy consumed per unit of GDP. This reflects both a country's level of energy efficiency and its overall economic structure, including the carbon content of goods imported and exported. An economy dominated by heavy industrial production, for instance, is more likely to have higher energy intensity than one where the service sector is dominant, even if the energy efficiencies within the two countries are identical. Likewise, a country that relies on trade to acquire (import) carbon-intensive goods will—when all other factors are equal—have a lower energy intensity than those countries that manufacture those same goods for export.

Energy-intensity levels are not well correlated with economic development levels (Table 3). Transition economies, such as Russia and Ukraine, tend to have the highest energy (and carbon) intensities. Intensities in developing countries tend to be somewhat higher than in industrialized countries, owing largely to the fact that developing countries generally have a higher share of their GDP coming from energy-intensive manufacturing industries, such as basic metals. Industrialized countries, on the other hand, have greater shares of their economies comprised of lower-carbon service sectors.

The second component of emissions intensity is *fuel mix* or, more specifically, the carbon content of the energy consumed in a country (see Chapter 8). Coal has the highest carbon content, followed by oil and then natural gas (Figure 8.5, p.43). Accordingly, if two nations are identical in energy intensity, but one relies more heavily on coal than the other, its carbon intensity will be higher. Figure 5.2 shows the breakdown of fuel mixes for selected countries. Countries vary widely in their use of fuels. Coal dominates in some countries (for example, China and South Africa), gas prevails in others (Russia), while other fuels—like hydropower, biomass, and other renewable sources presumed carbon-neutral—are significant in still other countries (Brazil, India).[30] "Other renewable energy," which includes solar, wind, and geothermal, accounts for no more than 3.5 percent of total primary energy supply in any of the major emitting countries. Fuel mixes, it should be further noted, are highly correlated with countries' natural endowments of coal, oil, gas, and hydropower capacity, a topic addressed further in Chapter 8.

Table 3 highlights the relative contribution of energy intensity and fuel mix to overall carbon intensity changes. In the EU, declining carbon intensity reflects reductions in both energy intensity and carbon content (for example, the switch from coal to gas in the U.K.). In the United States, declines stem almost entirely from reduced energy intensity. In some cases, the two factors counterbalance one another. In India, for instance, the increased carbon content of fuels has nearly entirely offset the effect of reduced energy intensity.[31] South Korea's case is virtually the opposite: the switch to lower carbon fuels has nearly offset a sizable increase in energy intensity. Globally, the decline in overall carbon intensity stems more from reduced energy intensity than from changes in fuel mix.

Using the decomposition analysis introduced in Chapter 2, Figure 2.8 (p.15) shows in more detail the relative effects of energy intensity and fuel mix in shaping *absolute* emission trends. In several countries, it can be seen that declines in intensity were accompanied by significant increases in GDP, leading to increases in absolute CO_2 levels. The most notable case is China, where the effect of significant intensity declines was more than offset by substantial GDP growth. Likewise, the U.S. decline in carbon intensity (17 percent) was offset by increases in population and GDP.

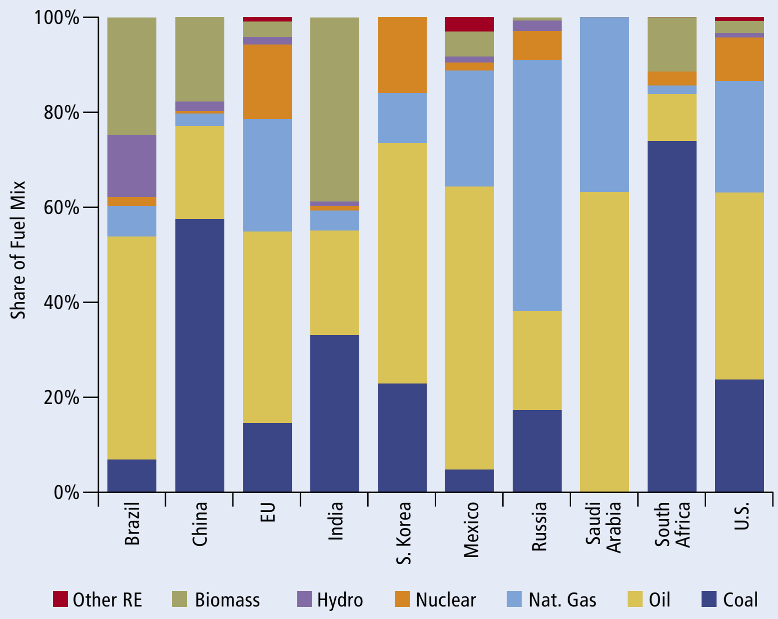
When non-CO_2 gases are considered, additional factors beyond energy intensity and fuel mix affect emissions intensities and trends. For instance, CH_4 and N_2O emissions from agricultural sources might be influenced significantly by commodity prices and shifts in international livestock and grain markets. Land-use change and forestry emissions might also be influenced by domestic and international forces unrelated to the factors discussed above.

GDP Changes and Projections

Emissions intensities, at least with respect to energy and industrial emissions, are influenced primarily by shifts in energy intensity, economic structure, and fuel mix. It follows that emission intensities are not directly correlated with changes in activity levels (GDP and population). Even in the event of major GDP changes, changes in intensity levels may be modest. Absolute emission levels, on the other hand, are most strongly influenced by GDP shifts (Chapter 2). When GDP rises, emissions also tend to rise correspondingly. This correlation is illustrated in Figure 5.3 for South Korea, where the effect of the 1998 Asian financial crisis is clearly apparent. GDP and CO_2 moved in tandem while carbon intensity was less affected. Because of this correlation, projections of carbon intensity tend to exhibit less uncertainty than absolute emission forecasts.

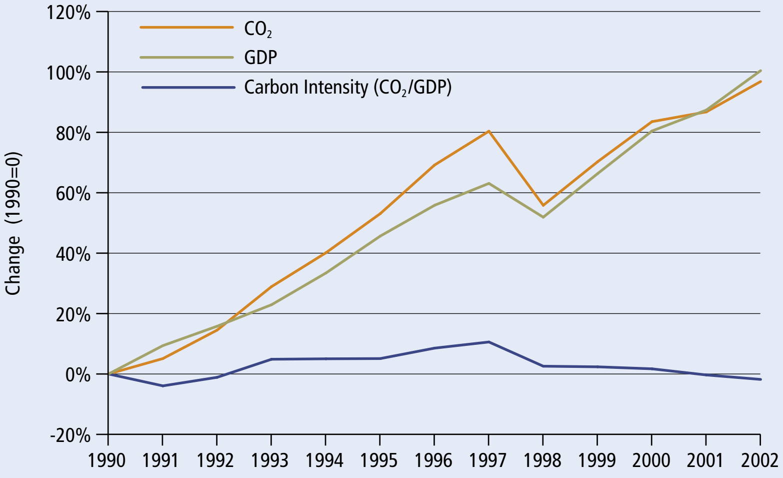
In several countries, declines in emissions intensity were accompanied by significant increases in GDP, leading to increases in absolute CO_2 levels. China and the U.S. are notable cases.

Figure 5.2. Fuel Mix in Energy Supply, 2002
Relative shares, selected major GHG emitters



Source: WRI, based on IEA, 2004b.

Figure 5.3. South Korea: Relationship Between CO_2 and GDP, 1990–2002



Sources & Notes: WRI, CAIT. CO_2 includes fossil fuels and cement only.

This conclusion, however, may not hold in some instances. First, intensity projections may be less certain for countries whose national emissions profile includes large shares of non-CO_2 gases or LUCF-related emissions. As discussed above, these emissions are likely to be shaped by a different set of factors, many of which are difficult to predict. In general, non-CO_2 gases and LUCF-related emissions are not as strongly correlated with GDP.[32]

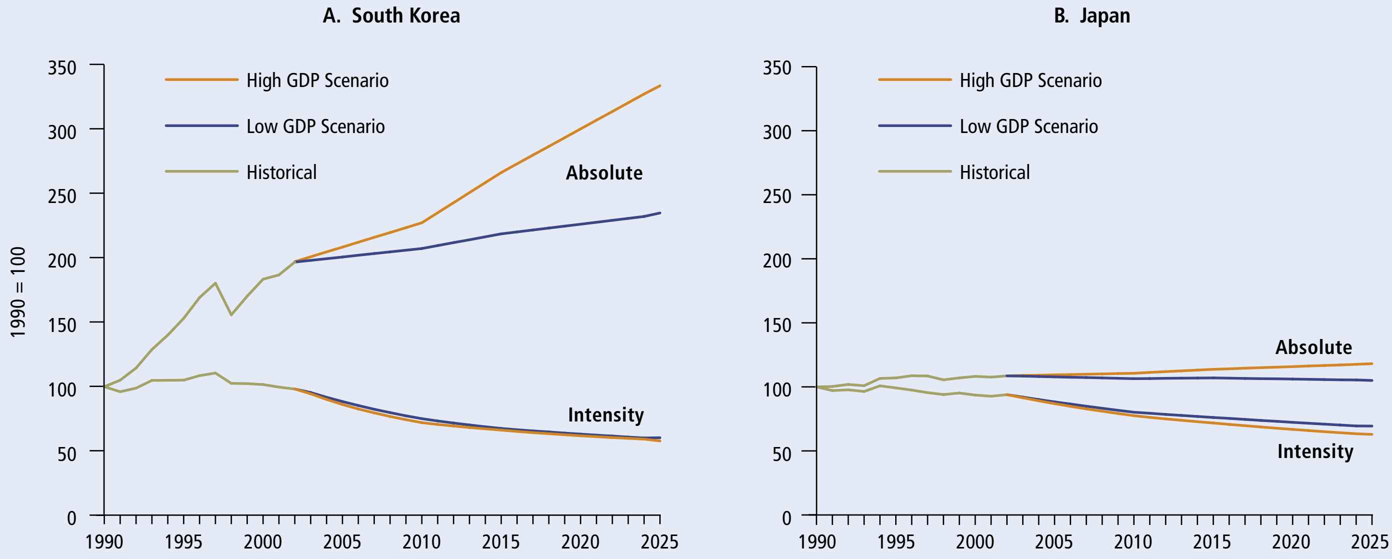
Second, the uncertainty reduction benefits of intensity indicators may be less apparent for mature, developed economies. A simplified illustration can be made using projections from the United States EIA. Figure 5.4 shows projections in terms of absolute emissions and emissions intensity for Japan, a mature economy, and nearby South Korea, a rapidly developing economy. For each country, projections include the EIA "high" and "low" growth scenarios. It is of course possible, if not likely, that all of the projections turn out to be significantly off the mark, as discussed in Chapter 3. Nevertheless, the perceived "uncertainty" gap (i.e., difference between high and low) for absolute emissions is very large for South Korea, whereas the intensity gap is relatively small. In other words, according to the EIA, future emissions (in absolute terms) are highly uncertain in South Korea, whereas intensity is less so. For Japan, emissions are expected to grow between 5 and 18 percent by 2025. While not especially large, this uncertainty is not insignificant. What is notable, however, is that the uncertainty for Japan's intensity does not seem to be much less than for absolute emissions.

Implications for International Climate Cooperation

Emission targets, measured in **intensity** ***terms, can reduce cost uncertainty.*** Uncertainty is perhaps the most significant problem associated with target setting, and perhaps GHG mitigation in general. Not unjustifiably, governments tend to be unwilling to adopt commitments when it is unclear what kinds of policies and costs are implicit in those commitments. Framing a target in carbon intensity terms, as illustrated above, tends to reduce that uncertainty and, accordingly, may be a more attractive option than fixed targets. However, the reduced cost uncertainty comes at the expense of greater environmental uncertainty. Furthermore, the benefits of reduced uncertainty are likely to be much greater for developing countries than for developed countries, as discussed above.

For developing countries, a high proportion of emissions may come from non-CO_2 gases and land-use change and forestry. When these emissions are factored into intensity targets, the benefits of reduced uncertainty tend to be lower, since these emissions are less tied to economic activity levels than CO_2 from fossil fuels. The case of Argentina's proposed target illustrates this phenomenon. In 1999, Argentina sought to adopt a "dynamic" emission target under the Kyoto Protocol.[33] However, CH_4 and N_2O from agriculture accounted for more than 40 percent of Argentina's GHG emissions. Future agricultural emissions would be influenced more by the international livestock and grain market than domestic GDP. Accordingly, Argentina chose not to propose a simple "intensity" target. Instead, Argentina suggested a complex indexing methodology tailored to their particular circumstances.[34]

Figure 5.4. **Absolute (CO_2) v. Intensity (CO_2/GDP) Forecasts, 1990–2002**



Sources & Notes: WRI, based on projections from EIA, 2005b. Includes only CO_2 from fossil fuels.

GHG targets, measured in intensity terms, may introduce complexities and reduce transparency. Intensity targets would make international climate negotiations (and domestic policy-making) more complex, especially if they are being adopted by many countries. Countries might try to adopt both different percentage reduction commitments (as in Kyoto) *and* different GDP adjustment provisions, as the Argentine case illustrates. Negotiations might become exceedingly complex, to the point that non-specialists, or indeed anyone other than climate negotiators themselves, would have difficulty understanding proposed commitments.[35]

The case of the Bush Administration's GHG intensity target helps illustrate the potential for confusion with this approach. The target—an 18 percent reduction in GHG intensity over the 2002 to 2012 timeframe—was introduced as a bold new effort. Yet, in the preceding 10-year period from 1992 to 2002, U.S. GHG emissions intensity had dropped by 18.4 percent[36] and, assuming continued U.S. GDP growth, the target would permit U.S. emissions to rise by 14 percent over the decade.[37] Thus, the Bush Administration's target is essentially a continuation of past trends; one that is likely to result in increases, not reductions, of GHG emissions in absolute terms. This has often been misunderstood or inaccurately reported in the U.S. media. Thus, more than some other metrics, intensity targets may be vulnerable to misperceptions and obfuscation.

Overall, intensity targets represent a trade-off in terms of benefits and drawbacks. In some instances intensity targets would significantly aid in uncertainty reduction, but at the expense of simplicity and transparency. Complexities of intensity targets also extend to other areas, not discussed above, such as interactions with international emissions trading.[38]

Cumulative Emissions

The preceding chapters focused largely on current and future GHG emissions. However, climate change results from the cumulative buildup of GHGs in the atmosphere over time, not emissions in any particular year. Accordingly, the cumulative sum of a country's historical emissions is one indicator that tries to capture the contribution a country has made to the climate change problem.

Country-level estimates of CO_2 emissions from fossil fuels go back as far as 1850.[39] Based on that record, the United States ranks first and the EU second in cumulative emissions. Together, the 25 major emitters today account for 83 percent of current global emissions and 90 percent of cumulative global emissions. Figure 6.1 shows the cumulative emissions for the major emitting countries. All but five of the top 25 current emitters also rank among the top 25 historic emitters.

In most cases, a country's historic share of global emissions differs from its current share. For most industrialized countries, the historic share is higher, in many cases significantly so. The EU, with 16 percent of current fossil fuel emissions, accounts for nearly 27 percent of cumulative emissions. For the United Kingdom, an early industrializer, the difference is even more pronounced: its historic share is nearly three times its current share. Conversely, the historic share for many developing countries is sharply below their current share of global emissions. China and India's cumulative shares (7.6 percent and 2.2 percent, respectively, since 1850) are only half their current shares. Overall, developing countries, which generate 41 percent of current fossil fuel emissions, have contributed only 24 percent of cumulative emissions.

Historic contribution can be assessed in different ways, including the following:

- The *cumulative emissions* approach weighs all historic emissions equally, regardless of when they occurred. A ton of CO_2 emitted in 1850 has the same "value" as a ton of CO_2 emitted in 2005.
- An alternative approach assesses a country's contribution to increased atmospheric CO_2 *concentrations*. By taking into account the decay of GHGs over time, this approach estimates a country's share of emissions presently in the atmosphere.
- A third approach attempts to measure a country's contribution to the increase in global average *temperature* (approximately 0.6° C, globally, above pre-industrial levels).[40]

Figure 6.1. Cumulative CO_2 Emissions, 1850–2002

Country	% of World	(Rank)
United States	29.3	(1)
EU-25	26.5	(2)
Russia	8.1	(3)
China	7.6	(4)
Germany	7.3	(5)
United Kingdom	6.3	(6)
Japan	4.1	(7)
France	2.9	(8)
India	2.2	(9)
Ukraine	2.2	(10)
Canada	2.1	(11)
Poland	2.1	(12)
Italy	1.6	(13)
South Africa	1.2	(14)
Australia	1.1	(15)
Mexico	1.0	(16)
Spain	0.9	(20)
Brazil	0.8	(22)
South Korea	0.8	(23)
Iran	0.6	(24)
Indonesia	0.5	(27)
Saudi Arabia	0.5	(28)
Argentina	0.5	(29)
Turkey	0.4	(31)
Pakistan	0.2	(48)
Developed	**76**	
Developing	**24**	

Source: WRI, CAIT.

While the scientific certainty underlying these alternative methodologies varies significantly,[41] the relative results they yield are quite similar for most countries (Table 4). For several countries, the calculated share of historic contribution is nearly identical in all three approaches.

When CO_2 from land-use change is also taken into account, the picture changes considerably. Looking at data for all emissions since 1950 (earlier country-level estimates for land use-related emissions are not available[42]), the historic share for most industrialized (and some developing) countries drops sharply (Figure 6.2 and Table 5). The United States' cumulative contribution, for instance, drops from 26.6 percent to 16.7 percent. The most dramatic increases in historic share are for tropical countries with large forest sectors. Brazil and Indonesia, with 0.9 percent and 0.6 percent of cumulative fossil fuel emissions, respectively, jump to 6.1 percent and 7.2 percent, respectively, with the inclusion of CO_2 from land-use change. Overall, the developing country share of cumulative emissions since 1950 rises from 29 to 49 percent. As discussed in Chapter 17, however, this is in part due to the fact that periods of rapid deforestation in (present-day) developed countries pre-dates 1950, and thus is not reflected in the available data.

A second major factor influencing the calculation of historic contribution is the time period chosen. Going back only to 1990, the baseline year for emission targets in the UNFCCC and the Kyoto Protocol, yields very different results than going back a century-and-a-half (Figure 6.3 and Table 6). The historic share for developed countries drops from 76 percent to 61 percent, while the share for developing countries rises by a commensurate amount.

Implications for International Climate Cooperation

Data constraints will likely prevent international climate agreements based on cumulative emissions or "responsibility." The relevance of historical responsibility for climate change is noted in the Climate Convention and generally acknowledged to be an important factor in shaping response strategies that are widely acceptable. This concept has also become noteworthy since, in the run-up to the 1997 Kyoto Protocol negotiations, the Government of Brazil advanced a specific proposal that would have apportioned GHG emissions targets according to each (Annex I) country's historical responsibility for the global temperature increase.[43] Although this proposal did not prevail, the topic has continued to be studied under the UNFCCC.[44]

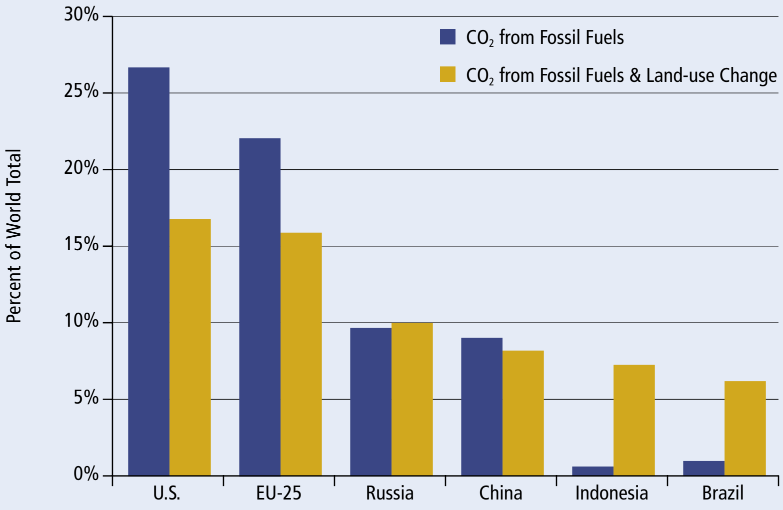
Proposals that rely on historical emissions prior to 1990, however, are unlikely to garner widespread support, in part due to data constraints. As shown above, the country-level contributions to climate change are extremely sensitive to two factors: (1) the time period chosen and (2) inclusion of LUCF (and non-CO_2)

emissions. Even if countries could agree on which time period to adopt, no official country-level data exists prior to 1990. Unofficial data for CO_2 from fossil fuels extends back to the 1800s.[45] However, the certainty of data covering such distant time periods is likely to be disputed. Historical data is also geographically biased, as earlier data is more likely to be available for European countries. Equally significant is the absence of virtually any country-level data for non-CO_2 gases and LUCF prior to 1990. The one country-level dataset that is available for LUCF covers only 1950 to 2000, and it is understood to be highly uncertain (see Chapter 17). The lack of LUCF data in historical responsibility calculations will have highly varying effects at the country level.

Two major factors may influence assessments of a country's contribution to climate change: the time period analyzed and the gases and sources included.

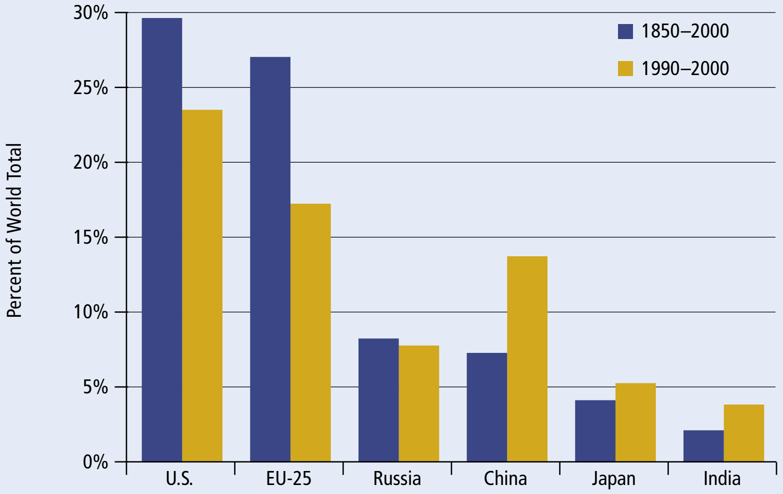
This is not to suggest that the concept of historical responsibility is irrelevant, only that it is unlikely that this concept can form the core of an agreement, or could be assessed in a manner reliable enough to be the basis for legal obligations. It should also be noted that other factors, unrelated to data issues, have also led to political objections pertaining to proposals to base the international climate change regime on historical emissions, including concerns over equity and the potential lack of required action by some Parties.

Figure 6.2. **Cumulative CO_2 Emissions, 1950–2000**
With and without land-use change & forestry



Sources & Notes: WRI, CAIT. CO_2 from fossil fuels includes CO_2 from cement manufacture.

Figure 6.3. **Cumulative CO_2 Emissions, Comparison of Different Time Periods**



Sources & Notes: WRI, CAIT. CO_2 includes emissions from fossil fuels and cement manufacture.

Socioeconomic Development

GHG emissions can only be understood properly within the broader socioeconomic context. Such a context gives a sense not just of emissions, but the degree to which countries have the financial and institutional capacity to address the causes and consequences of climate change. Similarly, an understanding of different levels of development provides a sense of the context within which climate change competes for political attention. In particular, in many countries other issues are likely to take greater priority over considerations of GHGs in many policy-making spheres. For these reasons, this chapter examines the major emitters across a range of non-emissions issues.

Perhaps the most striking aspect of the major GHG emitting countries is the disparity in development levels. One measure of development, which provides a clear picture of the disparity, is per capita income figures (Figures 7.1 and 7.2). Figure 7.3 depicts the relationship between income and emission levels. In 2002, annual per capita income among the top emitting countries ranged from over $34,000 in the United States (4th globally) to under $2,000 in Pakistan (138th globally).[46] Other measures of a country's capacity to address climate change or other complex social challenges include life expectancy, educational achievement, and quality of governance (for example, political stability, level of corruption). As might be expected, the disparities in these measures largely mirror those for per capita income, although there are exceptions (Table 7).

Certain patterns and observations are notable:

- China and India, the world's largest countries, have per capita incomes that are six to eight times lower than those in industrialized countries when measured in purchasing power parity.[47] Some 550 million people in these two countries (16 percent of China's population and 35 percent of India's) subsist on less than $1 a day.[48]
- Per capita income is lower in the two largest EITs (Russia and Ukraine) than in several advanced developing countries (Argentina, Brazil, South

Figure 7.1. Income Per Capita, Top 25 GHG Emitting Countries

			% Growth, 1980–2002	
Country	**2002 $PPP**	**(Rank)**	**Average Annual**	**Total**
United States	34,557	(4)	2.0	54
Canada	28,728	(7)	1.7	45
Australia	27,256	(11)	1.9	52
Germany	26,141	(13)	1.7	46
France	26,090	(14)	1.7	44
Japan	25,788	(15)	2.0	56
Italy	25,453	(17)	1.7	46
United Kingdom	25,139	(18)	2.2	62
EU-25	22,917	(21)	2.1	57
Spain	20,777	(25)	2.3	67
South Korea	16,570	(33)	6.1	270
Saudi Arabia	11,994	(43)	-2.9	-47
Argentina	10,664	(46)	-0.6	-12
Poland	10,299	(48)	3.2	46
South Africa	9,750	(51)	-0.6	-13
Mexico	8,662	(59)	0.6	13
Russia	7,993	(61)	-2.2	-24
Brazil	7,480	(64)	0.4	9
Iran	6,277	(73)	1.1	28
Turkey	6,145	(76)	1.9	51
Ukraine	4,719	(97)	-5.1	-47
China	4,379	(100)	8.2	468
Indonesia	3,057	(118)	3.4	111
India	2,572	(121)	3.5	115
Pakistan	1,941	(138)	2.2	63
Developed	**22,254**		**0.9**	**23**
Developing	**3,806**		**1.9**	**50**
World	**6,980**		**1.3**	**32**

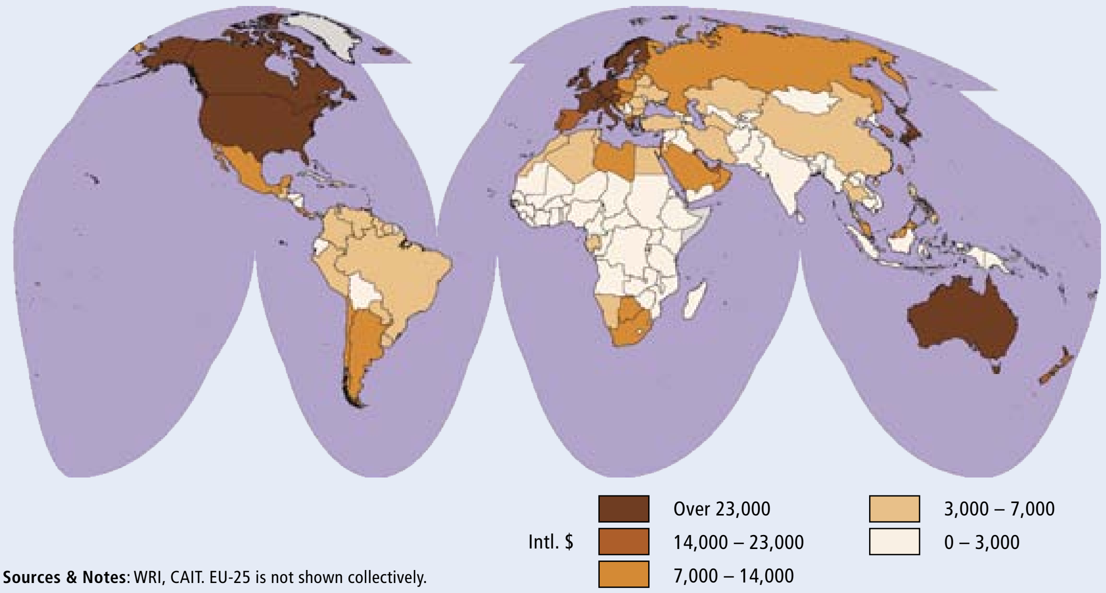
Notes: GDP is measured in terms of purchasing power parity (constant 2000 international dollars). Growth figures for Poland, Russia, and Ukraine are from 1990, due to lack of GDP data in 1980.

Korea, Mexico, and South Africa). On the governance scale, Russia and Ukraine likewise rank lower than many developing countries among the major emitters.

- South Korea stands well above most other developing countries on health, literacy, and governance measures. South Korea's economic development levels exceed those of several industrialized countries, including some EU members.
- South Africa, while ranking relatively high on governance, is well below all other major emitters in life expectancy (49 years), largely as a result of its AIDS epidemic.
- Four developing countries among the major emitters—India, Indonesia, Iran, and Pakistan—rank in the lower half globally on life expectancy, literacy, and governance measures.

Per capita income is on the rise for most countries, in some cases dramatically. For most developed countries among the major emitters, per capita income rose between 40 and 60 percent from 1980 to 2002. By far the largest gains among the major emitters were in China and South Korea (468 percent and 270 percent, respectively). India and Indonesia experienced gains exceeding 100 percent. For most other middle-income developing countries, however, income was almost stagnant; over the period from 1980 to 2002, incomes in Brazil and Mexico grew only 9 and 13 percent, respectively. Per capita incomes fell in five of the major emitters: 12 percent in Argentina, 13 percent in South Africa, 24 percent in Russia, and 47 percent in Saudi Arabia and Ukraine.[49]

Figure 7.2. Income Per Capita, 2002 *($ per person, measured in purchasing power parity)*



Sources & Notes: WRI, CAIT. EU-25 is not shown collectively.

On the whole, per capita income has grown faster in percentage terms in developing countries (50 percent) than in developed countries (23 percent). These figures, however, may be misleading because developing country growth is from a much smaller base. As a result, the *absolute* income gains in developing countries were much lower than in developed countries. Measured in 2000 U.S. dollars, incomes in developing countries grew by under $500 (from $880 to $1,318) from 1980 to 2002, while developed country incomes grew by almost $4,000 (from $16,703 to $20,561), or 8 times more. Thus, even as incomes rise rapidly in developing countries, the absolute income gaps between rich and poor continue to widen. This dynamic is expected to continue (Figure 7.4).

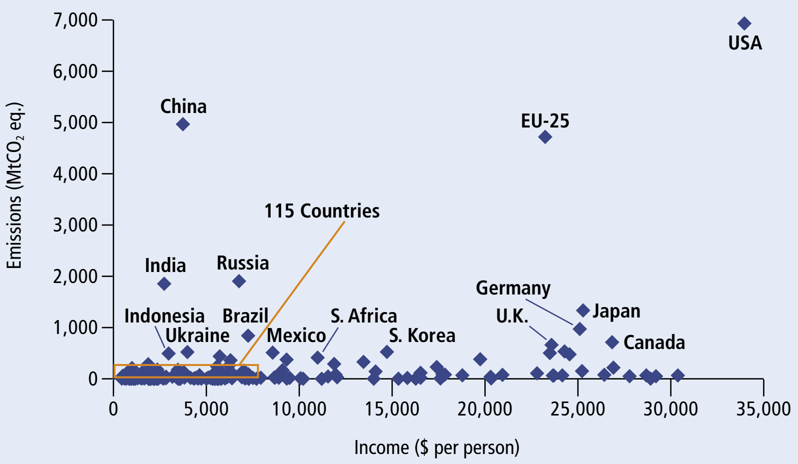
A cause and consequence of low levels of socioeconomic development is lack of access to modern energy services. A full one-third of the developing country population—over 1.5 billion—lacks access to electricity (Figure 7.5). Four of the major GHG emitters have major electricity access deficits, with India alone accounting for almost 600 million people. About half of the developing world—2.4 billion people—rely on traditional forms of biomass for cooking and heating.[50] It follows that without commercial energy services, modern conveniences like refrigeration are often unobtainable.

Similar disparities characterize transport. Figure 7.6 shows motor vehicle ownership, with the U.S. and Europe having one vehicle for every one or two persons. A second tier includes South Korea, Argentina, Russia, and Mexico. India and China, by contrast, have on the order of 10-12 vehicles for every 1,000 people, although vehicle use in these countries is growing rapidly. Differing levels of motorization, like electrification, help explain large per capita emissions disparities discussed in Chapter 4, as well as disparities at the sector level, discussed in Part II.

Implications for International Climate Cooperation

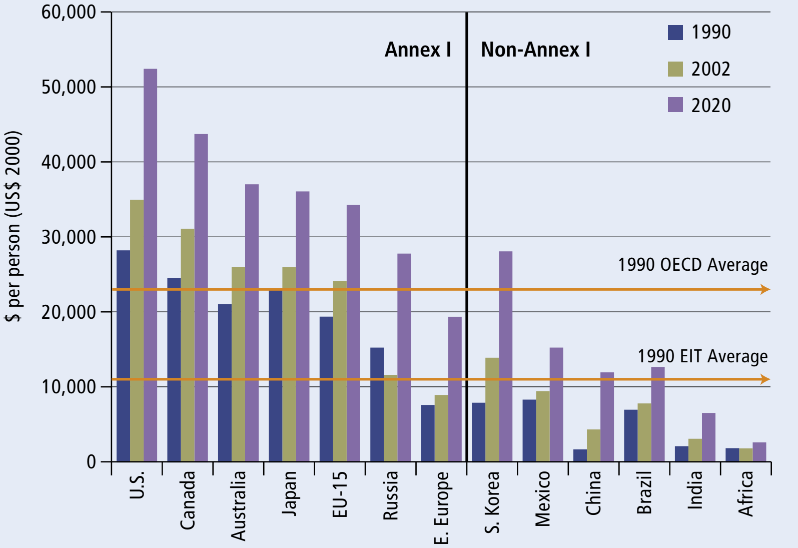
The Climate Convention recognizes the need for advancing economic and social development, particularly for developing country Parties, noting that "economic development is essential for adopting measures to address climate change."[51] The Convention also notes that "Parties should protect the climate system ... in accordance with their common but differentiated responsibilities and *respective capabilities*."[52] The issues discussed in this chapter will thus likely be a part of future decision-making. But exactly how is not clear.

Figure 7.3. Income Per Capita and GHG Emissions



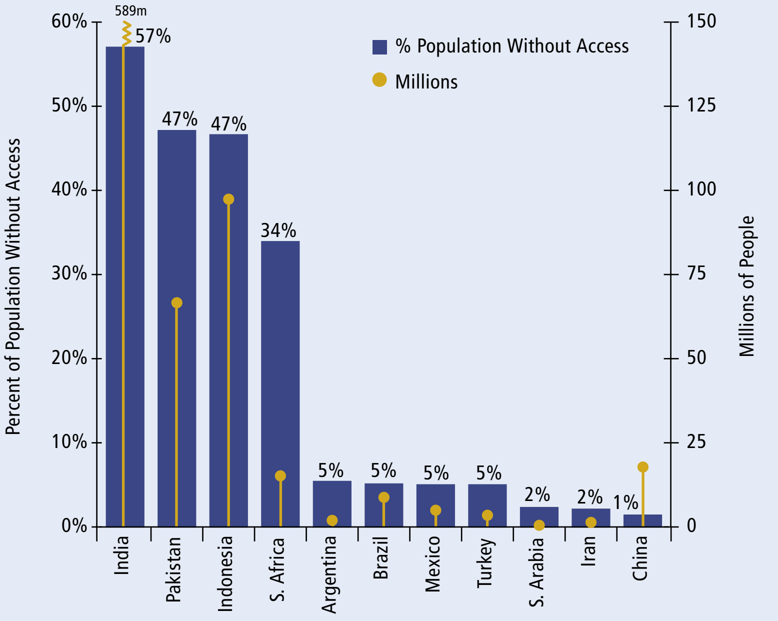
Sources & Notes: WRI, CAIT. Data is for 2000. There are several countries not shown, such as Luxembourg, with per capita incomes that exceed $35,000 per year.

Figure 7.4. Projected Income Relative to Historical Levels



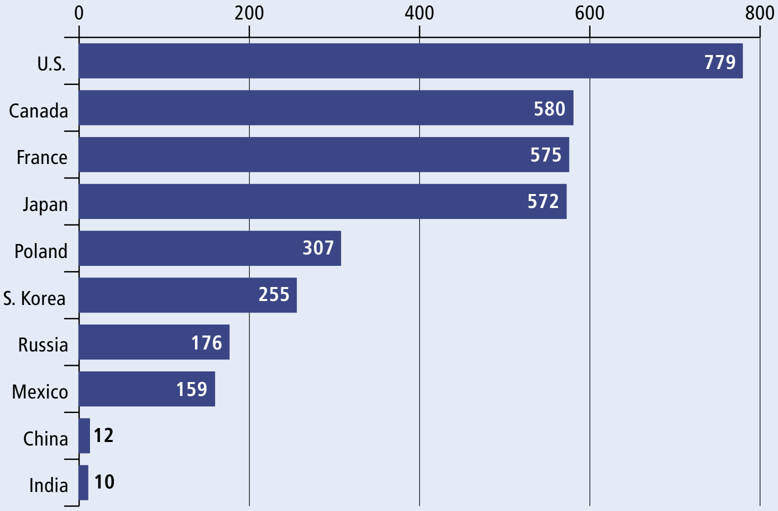
Sources & Notes: EIA, 2005b. OECD and EIT averages reflect only those countries included in Annex I of the Climate Convention (e.g., Mexico and S. Korea are excluded from OECD).

Figure 7.5. Access to Electricity



Sources & Notes: WRI, 2005c, based on data from IEA, 2002. Countries shown are the top 25 GHG emitters with populations lacking access to electricity.

Figure 7.6. Motor Vehicles per 1,000 People



Sources & Notes: World Bank, 2005. Data ranges from 1997–2000.

Review memberships of Convention and Protocol Annexes. Annex I of the Convention (and Annex B of the Kyoto Protocol) includes primarily developed countries and transition economies, whereas Annex II includes only the wealthier developed countries. Since these Annexes were agreed upon in the early 1990s, the national circumstances of many Parties have changed significantly, as has the membership of the OECD. Present Annex memberships correspond neither to any memberships in international organizations nor any particular indicators of social or economic development. Indeed, as shown in Figure 7.4, some non-Annex I countries (including some not shown) already have income levels that approach or exceed those that non-Annex I countries had when the Annex memberships were determined.

Given that these Annexes largely define which rights and obligations adhere to which Parties, membership (or lack thereof) has a major bearing on the evolution of the climate change regime. Depending on how the regime evolves in the period after Kyoto's first commitment period (that is, after 2012), it may be necessary to modify existing Annexes or create additional ones.

Institutional and technical capacity will influence the degree to which countries can reliably formulate, implement, and comply with climate commitments. Since the adoption of the Kyoto Protocol, a wide range of proposals have been made for a successor agreement. Different options implicitly require different levels of capacity.[53] Adopting legally binding emission caps, for instance, presupposes significant institutional, financial, and technical capacity that may not exist in many developing countries. New laws and regulations that cover the entire economies of some countries may be needed. Parties must have the ability to exercise regulatory control over their private and public entities, and must apply appropriate sanctions in cases of noncompliance. Kyoto-style targets require quantitative precision, and thus high-quality monitoring tools and robust national GHG inventories, developed in accordance with international standards. This is a major challenge, since to date, almost all developing countries have reported difficulty in compiling their emissions inventories under the UNFCCC.[54] As suggested by the Convention, Parties should adopt commitments that are at least somewhat commensurate with their present or anticipated future capacities.[55] Along these lines, additional efforts to enhance developing country capacities are needed, so that these countries will be in a position to make significant contributions to the objectives of the Climate Convention.

Successful GHG mitigation approaches, particularly those pertaining to developing countries, are likely those that are supportive of development needs and mitigative capacity. Many developing countries must deal with extreme poverty and major social challenges, and climate change is likely to continue to rank low as a political priority in those countries. Accordingly, successful international climate change initiatives will likely be those that can mitigate GHGs while also helping countries meet their development aspirations. Such a "sustainable development policies and measures" approach is examined in depth in a companion publication entitled *Growing in the Greenhouse: Protecting the Climate by Putting Development First* (Box 7.1).

Box 7.1. Sustainable Development Policies and Measures (SD-PAMs)

The SD-PAMs concept involves identifying policies and measures that are aimed first and foremost at national development priorities, while finding low-carbon routes to achieve them (Winkler et al., 2002). The existence of SD-PAMs, or at least of potential synergies between climate policy and sustainable development, is widely recognized, as is the desirability of finding these synergies. For instance, Brazil's embrace of biofuels in the transport sector had little to do with climate change, but this strategy has offset more than 400 $MtCO_2$ over the past few decades.

A companion report to this publication, *Growing in the Greenhouse: Protecting the Climate by Putting Development First*, examines case studies of actual and potential SD-PAMs that would enhance development prospects while limiting GHG emissions. The report also suggests that integrating SD-PAMs within an international climate agreement is, rather than a threat to development, an opportunity for developing countries to participate in global efforts to combat climate change while advancing their own priorities.

Sources: Winkler et al., 2002; Bradley and Baumert, 2005.

Capacity building assistance is needed to help engage some of the larger developing countries. Lack of capacity or low levels of development cannot alone be a reason for doing little or nothing on climate change. As discussed in Chapter 2, the engagement of the large-emitting countries is essential to accomplishing the Climate Convention objective. This holds true even for those major emitters that have other more pressing priorities, such as India, South Africa, and Indonesia. The challenge instead is determining the appropriate strategies in these countries—and in developed country assistance programs, including capacity building—for slowing and eventually reversing GHG emission growth. Although there are over 100 countries that have both low income and emission levels (Figure 7.3), ensuring that these countries are engaged in mitigation efforts seems less critical to achieving the objective of the Climate Convention.

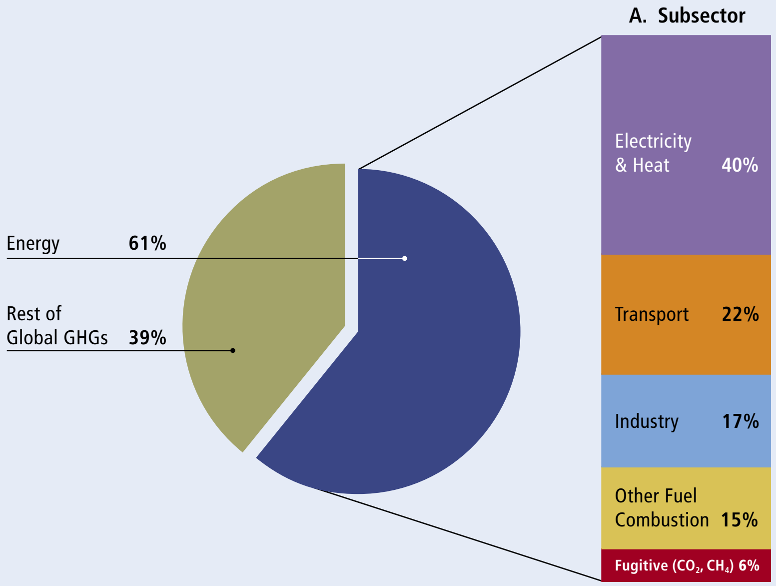
CHAPTER 8

Energy and Fuels

As discussed in Chapters 2 and 5, energy fuel mix and energy intensity (shaped by economic structure and energy efficiencies) play important roles as drivers of CO_2 emissions. Within a broader context, this chapter examines the energy sources that emit CO_2, focusing on production, consumption, and reserves of the main fossil fuels.

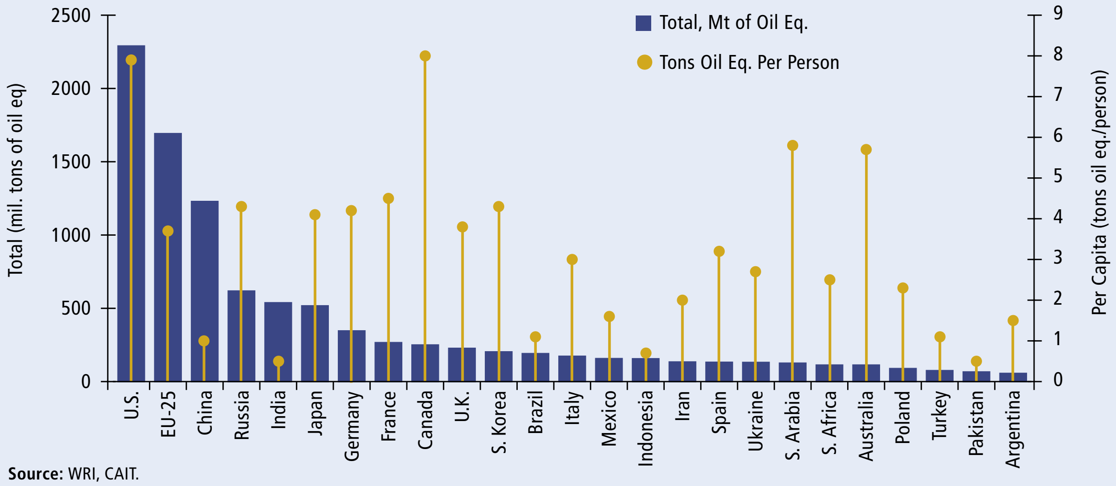
Levels of emissions are highly correlated with levels of energy use, in large part because 61 percent of total GHGs (and almost 75 percent of all CO_2) stem from energy-related activities, with the large majority coming from fossil fuel combustion (Figure 8.1). These emissions result from electricity and heat generation, transport, industry, other fuel combustion, and fugitive emissions (for example, from oil and gas extraction)—most of which are examined in detail in Part II of this report. Figure 8.2 shows energy consumption in the top 25 GHG emitting countries, in both absolute and per capita terms. These 25 countries are all within the top 30 energy-consuming countries. Together, this group accounts for 85 percent of global energy consumption, with the 10 largest users accounting for over 70 percent. The United States, EU-25, and China, are the largest consumers at 22, 17, and 11 percent, respectively.

Figure 8.1. GHGs from Energy



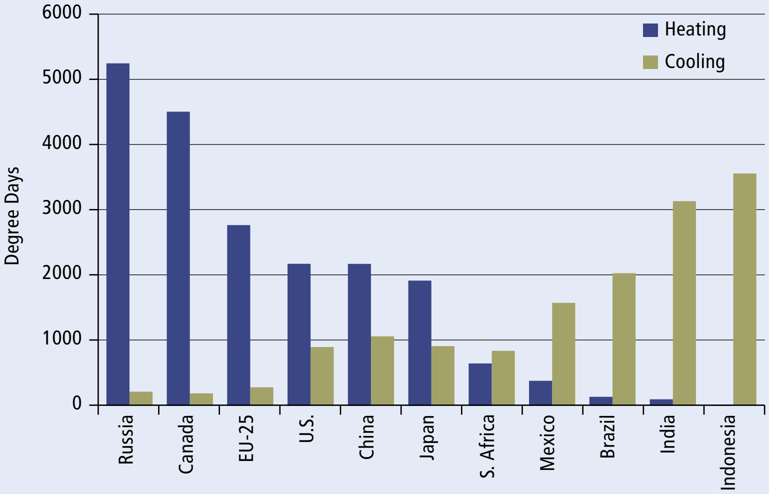
Sources & Notes: See Appendix 2.A for sources and sector definition. Absolute energy-related emissions, estimated here for 2000, are 25,611 $MtCO_2$.

Figure 8.2. Energy Consumption, Total and Per Capita, 2002
Top 25 GHG emitters



Source: WRI, CAIT.

Figure 8.3. Heating and Cooling Degree Days



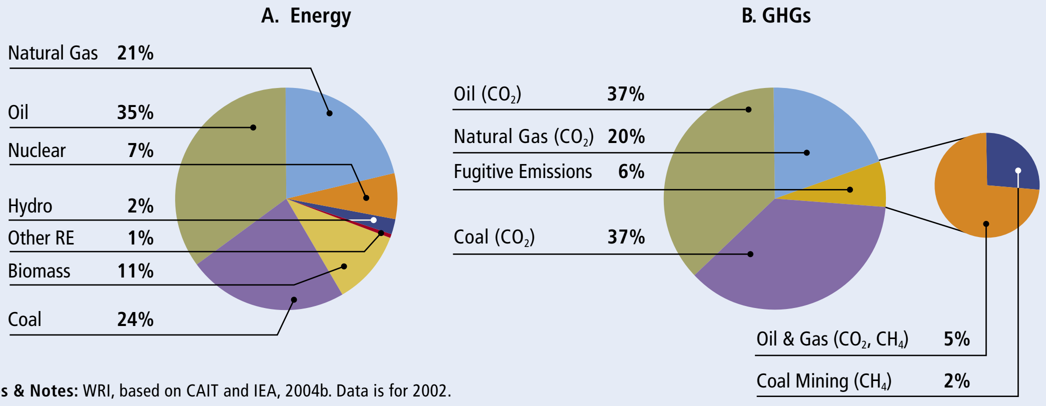
Sources & Notes: WRI, CAIT. The "degree-day" is a measure commonly used to evaluate demand for heating and cooling services. The measure is based on departures from an average temperature of 18°C (65°F), a base temperature considered to have neither heating nor cooling requirements. For underlying methodologies, see WRI (2003).

As with emissions, per capita energy disparities are large. The largest per capita energy consumers are Canada, the U.S., and Australia, while India, Brazil, and China use energy at only a fraction of the rate of the industrialized countries. There are also disparities among industrialized countries; for example, per capita consumption in Japan and the EU is about half the U.S. level.

Many of the cross-country differences can be explained by the same factors discussed in Chapters 2 and 5, namely economic structure and energy efficiency. More significantly, levels of economic development shape energy use. As discussed in Chapter 7, many developing countries lack access to electric power and modern transportation. Developing countries also have lower penetration rates for many energy-consuming appliances, such as refrigerators, televisions, computers, and air conditioners. Still other cross-country differences are explained by "natural factors" such as climatic conditions, land area, population densities, and natural resource endowments.[56] These factors influence energy use through differential heating and cooling needs, transportation requirements, and energy technology choices. The concept of heating and cooling "degree days," for instance, shows that heating and cooling demands are significantly higher in some countries (Figure 8.3).[57]

Across fuels, oil constitutes the most commonly used energy fuel, at 35 percent of global primary energy use, followed by coal (24 percent), natural gas (21 percent), and other non-fossil sources that do not emit GHGs directly.[58] These figures, along with the shares of GHG emissions from different fuels, are shown in Figure 8.4. Differences between energy use and GHG shares are explained by differences in efficiencies and the carbon content of the fuels. Coal, the highest carbon fuel, has a carbon content that is 34 percent higher than oil and 75 percent higher than gas (Figure 8.5). The remainder of this chapter examines the fuels that contribute to climate change in more detail. Figures 8.5 to 8.9 provide basic information about coal, oil, and gas, including carbon content, reserves, consumption levels, projected growth, and trade.

Figure 8.4. World Primary Energy Consumption and GHG Emissions *(by fuel)*



Sources & Notes: WRI, based on CAIT and IEA, 2004b. Data is for 2002.

Coal

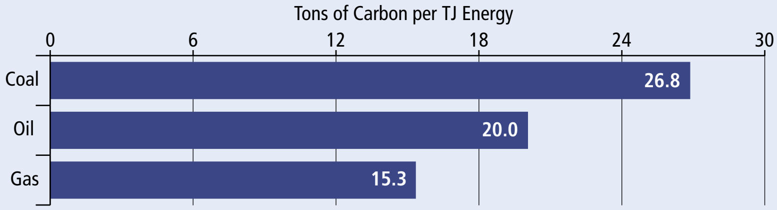
The top 25 GHG emitting countries collectively account for 93 to 94 percent of global coal consumption, production, and known reserves (Table 8). Coal mining and use is highly concentrated. Five countries account for more than three-quarters of worldwide consumption (Figure 8.10). Six countries—the United States, Russia, China, India, Australia, and South Africa—contain 81 percent of global coal reserves and account for an equal share of coal production. Globally, coal reserves are significantly larger than other fuels. At current prices and consumption rates, present reserves will not be depleted until the year 2168.[59]

Future growth in coal consumption is expected to be significant, though not as fast as growth in oil and gas (Figure 8.8). IEA projects that coal consumption will more than double by 2030, with China and India alone accounting for 68 percent of this increase.[60]

Unlike oil and to some extent natural gas, most coal is consumed domestically. Exceptions include Japan, Europe, South Korea, and Taiwan, which are significant importers. Conversely, Australia, South Africa, and Indonesia are leading exporters.[61] Despite being bulky and expensive to transport, higher grade coal (such as coking coal for steel making) is relatively amenable to transport.[62] Overall, only 17 percent of total world coal production is traded across national borders (Figure 8.9). Increased seaborne trade in coal is expected in the coming decades.[63]

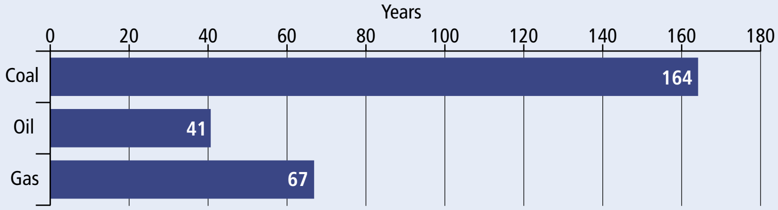
Electricity and heat account for 70 percent of coal consumption; industry accounts for the second largest share (16 percent) (Figure 8.11-A).

Figure 8.5. Carbon Content of Fossil Fuels



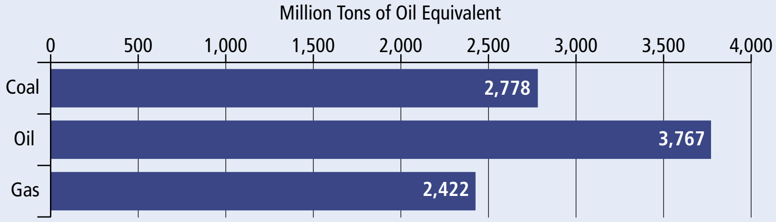
Sources & Notes: IPCC, 1997. The carbon emissions factor for coal is based on anthracite coal. There are slightly different carbon contents for other grades of coal, such as coking (25.8), bituminous (25.8), and lignite (27.6).

Figure 8.6. Reserves to Production (R/P) Ratios, 2004



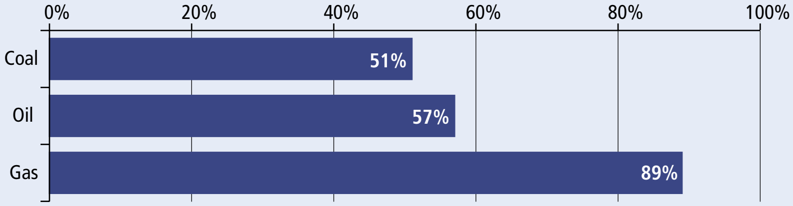
Sources & Notes: BP, 2005. An R/P ratio is the reserves remaining at the end of the year divided by the production in that year. The result is the length of time that those remaining reserves would last if production were to continue at that level.

Figure 8.7. Global Fossil Fuel Consumption, 2004



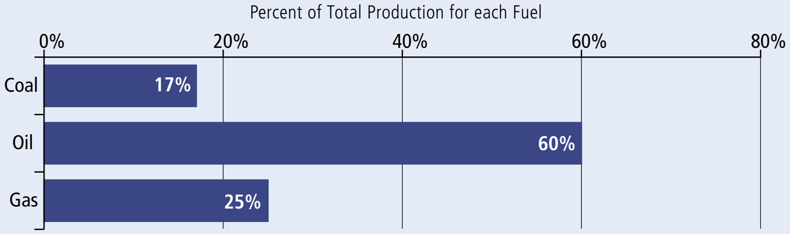
Source: BP, 2005.

Figure 8.8. Projected Growth in Energy Demand, 2002–2030



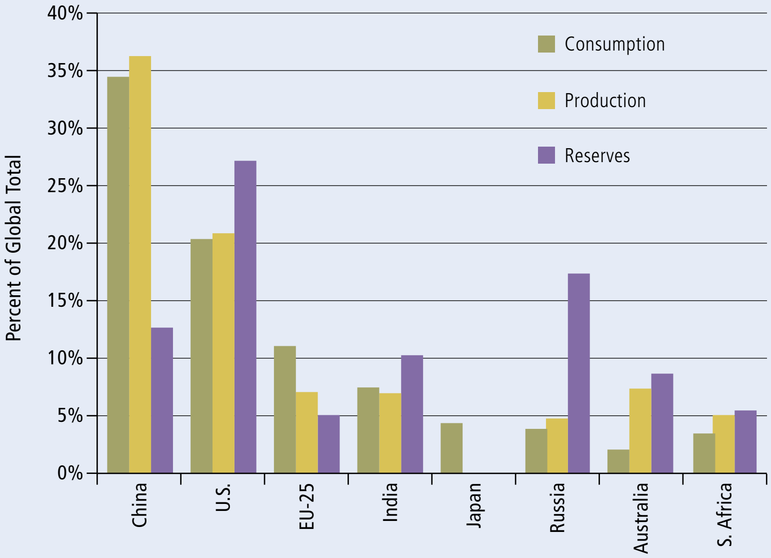
Source: IEA, 2004c.

Figure 8.9. Shares of Fossil Fuel Traded



Sources & Notes: WRI, based on BP, 2005 (oil and gas); IEA, 2004b (coal). Shares are total production for a fuel divided by the amount of that fuel traded internationally. Figures are based on data from 2004 (oil and gas) and 2002 (coal).

Figure 8.10. Coal Consumption, Production, and Reserves, 2004



Sources & Notes: BP, 2005. Countries shown are the top five consumers, plus selected others with large reserves. Countries are ordered according to consumption. See also Table 8. Total global coal consumption, production, and reserves in 2004 are 2,778, 2,732, and 448,464 million tons of oil equivalent, respectively.

Oil

Together, the top GHG emitting countries account for 84 percent of oil consumption, 58 percent of production, and 48 percent of known oil reserves (Table 9). Oil reserves are highly concentrated; OPEC countries account for 74 percent of global reserves.[64] Almost an equal amount of known reserves (72 percent) are concentrated in just seven countries—Saudi Arabia, Iran, Iraq, United Arab Emirates, Kuwait, Venezuela, and Russia. Of these, only Russia is among the top 15 GHG emitting countries (Figure 8.12). Although global reserves of oil are widely disputed, the most recent estimates from BP suggest that, at current prices and consumption rates, just over 40 years of reserves remain.[65] Improved extraction technologies and new discoveries may extend reserve estimates. On the other hand, if expected increases in consumption—57 percent by 2030—are realized, demand may put continued upward pressure on oil prices (Figure 8.8).

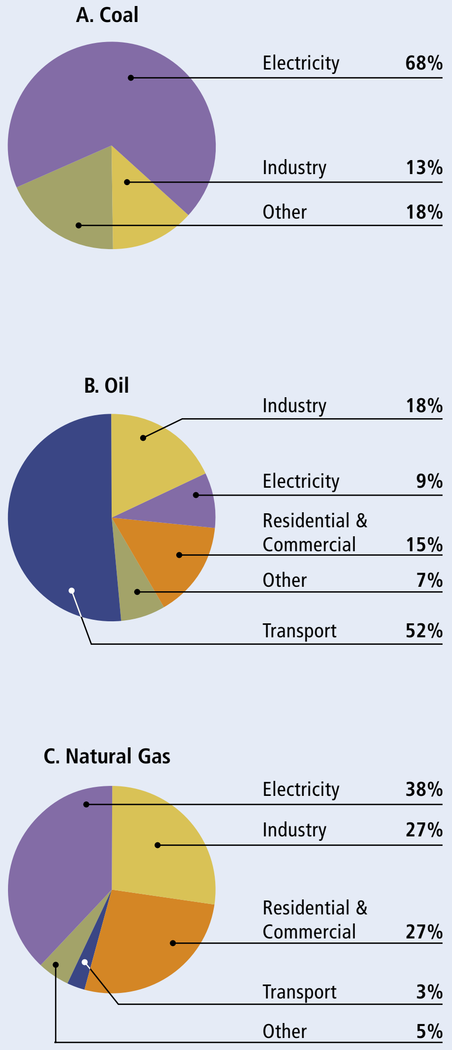
Oil consumption is less geographically concentrated than other fuels. This is primarily due to two factors: (1) oil's dominance in the transport sector, and (2) its tradability. First, in the transport sector, oil maintains nearly complete dominance, accounting for 96 percent of global energy consumption in the sector.[66] Overall, transport represents about 52 percent of the total world oil consumption (Figure 8.11-B). Industry accounts for an additional 18 percent, and residential and commercial activities (such as heating) collectively account for about 15 percent. In developing countries, however, oil is used in greater proportions for electricity generation and industry, with transport accounting for only 40 percent of the total.[67]

Second, oil is the most heavily traded fossil fuel, with about 60 percent[68] of global production being moved across borders through a well-developed global transit network of tanker fleets (Figure 8.9). The hub of world trade is the Middle East, accounting for 46 percent of world crude exports in 2004.[69] Total volume of world trade in oil is expected to double by 2030, with exports increasing most from the Middle East.[70]

Natural Gas

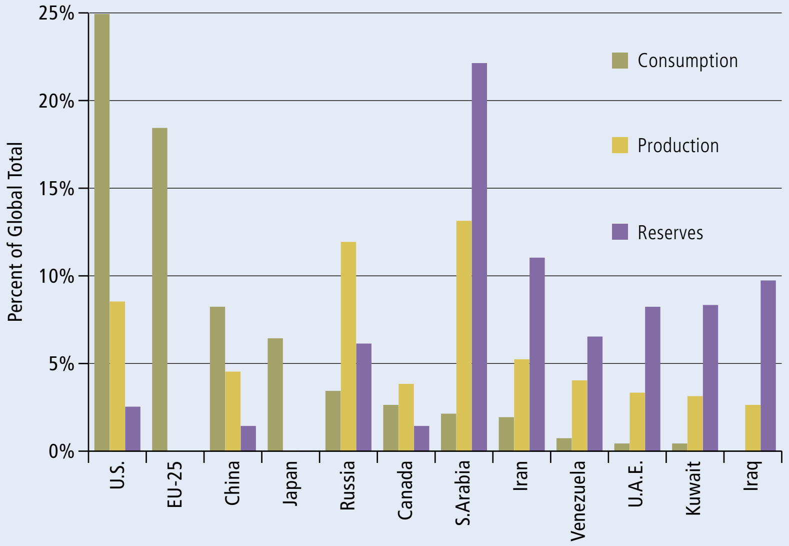
With respect to natural gas, the top 25 GHG emitters account for 84 percent of global consumption, 76 percent of production, and 59 percent of gas reserves (Table 10). As with oil, natural gas reserves are highly concentrated; 69 percent of known gas reserves are in just seven countries—Russia, Iran, Qatar, Saudi Arabia, the United Arab Emirates, the United States, and

Figure 8.11. Fossil Fuel Consumption by Sector and Fuel, 2002



Sources & Notes: WRI, based on IEA, 2004b. Residential and commercial includes agriculture. Other includes energy transformation and energy industries (e.g., oil and gas extraction).

Figure 8.12. Oil Consumption, Production, and Reserves, 2004



Sources & Notes: BP, 2005. Countries shown are the top five consumers, plus selected others with large reserves. Countries are ordered according to consumption. See also Table 9. Total global oil consumption, production, and reserves in 2004 are 3,767, 3,868, and 161,900 million tons, respectively.

Nigeria. Russia, Iran, and Qatar alone account for 56 percent (Figure 8.13). More than half of all production and consumption takes place in the U.S., Russia, and EU-25, with the remainder widely dispersed geographically. If gas production continued at the current pace, about 67 years of known reserves are extractable at current prices and technologies. However, among the fossil fuels, growth in natural gas use is expected to increase the fastest, with the IEA projecting 89 percent growth by 2030 (Figure 8.8).

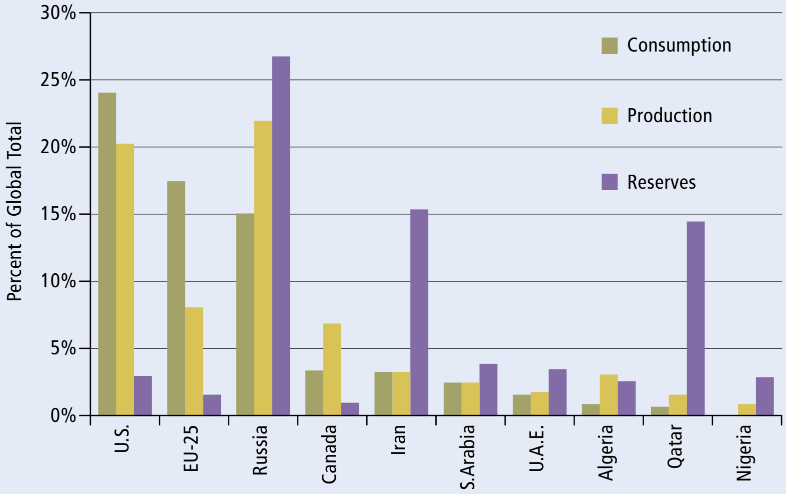
Unlike oil, most gas is consumed domestically, although exports and imports are significant and growing. In 2004, 25 percent of global gas production was traded across borders (Figure 8.9).[71] Trade in gas is primarily regional—mainly in North America and Europe—with about three-fourths of the total trade moving via pipeline.[72] The remainder of trade is via tanker transport of liquefied natural gas (LNG), predominantly in the Asia-Pacific and Middle East regions, where LNG infrastructure is more developed.[73] Global trade in gas is expected to triple by 2030, with most of the increase coming from growing LNG trade.[74]

Electricity and heat production account for about 38 percent of natural gas consumption, while the industrial and other sectors (primarily residential and commercial) account for about 27 and 35 percent respectively (Figure 8.11-C).

Implications for International Climate Cooperation

To date, international cooperation on climate change has not been focused directly on energy or specific energy fuels. In the future, international cooperation may likewise be fuel-neutral, although initiatives might be oriented around particular fuel-specific activities that are especially emissions-intensive, or

Figure 8.13. Natural Gas Consumption, Production, and Reserves, 2004



Sources & Notes: BP, 2005. Countries shown are the top five consumers (excluding individual EU members), plus selected others with large reserves. Countries are ordered according to consumption. See also Table 10. Total global gas consumption, production, and reserves in 2004 are 2,420, 2,422, and 161,574 million tons of oil equivalent, respectively.

that offer unique abatement opportunities. These could include initiatives to address coal-bed methane, sequester CO_2 in association with enhanced oil recovery, and phase-out certain gas flaring practices.[75] In addition, the interplay between the different fuels is likely to have significant implications for cooperative efforts.

Coal is used primarily for power generation, and there are immense reserves remaining in the largest emitting countries, including the U.S., China, Russia, and India. If emissions from coal use continue unabated from power generation, then the objective of the UNFCCC is unlikely to be met. International cooperation on climate change may need to pursue one or both of the following options: switch away from coal toward lower-carbon natural gas or renewables, or capture and sequester CO_2 emitted from coal plants. Both will require significant technology transfer and high capital investment costs. Some advanced coal technologies, it should be noted, are not conducive to climate protection. Emerging coal-to-liquids technologies, in particular, would enable coal to be consumed as a transport fuel (after liquification), which would increase the carbon intensity of transport.

Concerning oil, present consumption patterns, largely driven by transport, are weakly correlated with reserves, and those global reserves are heavily concentrated in the politically volatile Middle East. These two factors suggest a possible constellation of interests on the part of oil-importing countries to reduce dependence on oil. In other words, concerns about security of supply and rising future costs—along with associated issues related to external debt and balance of payments—are compelling reasons to pursue measures promoting energy efficiency and alternative fuels (for example, biofuels). For instance, the Biofuels Initiative launched by UNCTAD aims to assist developing countries in boosting their renewable energy potential through fuels—such as bioethanol, biodiesel and biogas—derived from agricultural crops. Such initiatives, especially if bolstered by significant financial and technical resources, could yield large energy security and poverty-reduction benefits while limiting GHG emissions.

Natural gas, the least carbon-intensive fossil fuel, is conducive to a wide variety of uses, ranging from power generation to industry to residential use. To the extent that natural gas consumption rises in step with the other fuels, gas is unlikely to be an important part of climate protection strategies. On the other hand, if gas can be used more strategically to substitute for coal use, it can provide identical energy services with 40 percent fewer CO_2 emissions, making it a key potential variable in climate protection. Natural gas has other advantages over coal as well. It can be used more efficiently than coal in many end-use applications, such as power generation (increasing the CO_2 savings), and can substitute for oil in transport, either compressed or through conversion to liquids. Furthermore, it may offer a promising pathway to hydrogen technologies. The potential for gas to play a role in climate change mitigation suggests global gas strategies may warrant further attention.

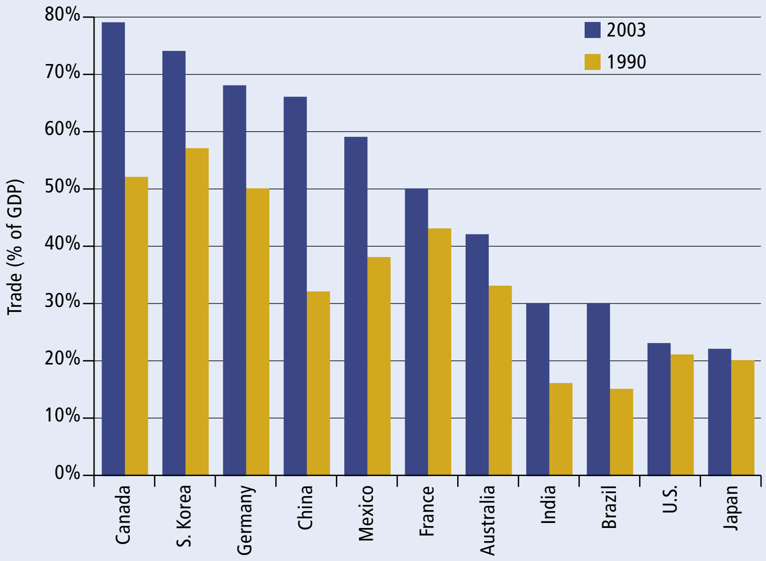
International Trade

Global trade in mining products (such as energy fuels, discussed in Chapter 8), manufactured goods, and agricultural products has increased remarkably over the past few decades. Since 1960, global trade has grown twice as fast as GDP, accounting for about 25 percent of world GDP in 1960 and about 50 percent in 2003.[76] Accordingly, the share of national economies comprised of imports and exports has in most cases increased dramatically over the past few decades. For instance, as of 2003, trade accounted for 66 percent of China's GDP (34 percent exports and 32 percent imports), compared to 32 percent in 1990 and 15 percent in 1980.[77]

Many of the top GHG emitting countries are now highly integrated into the world economy through imports and exports of goods and services (Figure 9.1). Among the most integrated are Canada, South Korea, and Germany, where trade (imports and exports) accounts for 78, 74, and 68 percent of GDP, respectively.[78] The countries in which trade accounts for smaller shares of GDP include Japan, the U.S., Brazil, and India, where trade is between 22 and 30 percent of GDP.[79]

These trends have implications for understanding GHG emissions, given that trade flows include many products that are GHG-intensive. GHGs, discussed throughout this report, are generally measured at the *point of emissions*. Emissions data primarily reflect national production rather than consumption patterns. Certain traded goods—such as motor vehicles and household appliances—contribute to GHG emissions primarily through their use (post-manufacture). For these products, the prevailing GHG accounting system does not pose significant controversy, as the emissions are attributed to the user. On the other hand, some traded products—such as some chemicals—contribute significant GHG emissions during the manufacturing process itself. Products manufactured in China and exported to Japan, for instance, may have "embedded" emissions associated with the manufacturing process. These emissions, under prevailing methodologies, will be attributed to the producer (exporter) country. Thus, emissions may appear misleadingly low for countries that import large quantities of emission-intensive goods, such as chemicals or aluminum. Conversely, for countries that

Figure 9.1. **Trade and National Economies**
Selected countries



Sources & Notes: World Bank, 2005. Trade's share of GDP is the sum of the GDP shares for imports and exports (and therefore could exceed 100%). Data for Canada, Australia, and the U.S. is from 2002.

help satisfy, through exports, the market demand in other countries, emissions may appear unduly high.

Figure 9.2 shows how CO_2 emissions would change, for selected countries, if they were instead assessed in terms of consumption of manufactured goods, using the methodology developed by Ahmad (2003). The largest net outflows of CO_2 come from Russia, China and Canada, where consumption-based accounting reduces emissions by 16, 12, and 11 percent respectively. Emissions also decline in India and Australia. By contrast, Japanese, French, and South Korean emissions would be 17, 15, and 10 percent higher, respectively, when viewed through the lens of consumption rather than production. Emissions in Germany, the U.S., Brazil, and the United Kingdom also increase under this methodology. For industrialized countries as a whole, the results show a net increase in emissions when measured through consumption of about 5 percent.[80] Accordingly, as a whole, emissions from developing countries decline when adjusted for consumption and production.

These figures include only trade in energy-intensive manufactured goods. Similar issues arise for international trade in fossil fuels. As discussed in Chapter 8, cross-border flows of energy fuels are significant, especially for oil. Production-related GHG emissions—such as from gas flaring, gas venting, refining, and other transformation processes—are likewise significant and, under normal GHG accounting practices, are routinely attributed to the exporting rather than importing country. As with manufactured goods, industrialized countries are net energy importers.[81] Although the bulk of energy-related emissions occur in the importing country (through combustion), industrialized countries avoid significant quantities of emissions by importing—compared to the hypothetical scenario where all energy consumption is from domestic sources.[82] It follows that exporting-country emissions are higher due to their role in satisfying demand in other countries.

National-level effects of energy trade can sometimes be significant, as the cases of Norway and Canada illustrate. While 90 percent of Norway's oil and gas production is exported, the emissions associated with these exports constitute 35 percent of Norway's total energy-related emissions.[83] Thus, increased demand

Figure 9.2. **CO_2 Emissions from Production and Consumption**

	Domestic Production	Exports	Imports	Domestic Consumption	Difference (Cons. less Prod.)	
Country		——— $MtCO_2$ ———			$MtCO_2$	%
United States	5,421	289	552	5,684	263	5
China	3,068	463	102	2,708	-360	-12
Russia	1,440	256	24	1,208	-232	-16
Japan	1,100	102	289	1,287	187	17
Germany	866	193	254	927	61	7
India	672	74	24	623	-49	-7
United Kingdom	536	110	123	549	13	2
Canada	493	155	101	439	-54	-11
South Korea	364	75	113	402	38	10
France	355	86	139	408	53	15
Australia	279	47	31	263	-16	-6
Brazil	258	24	32	266	8	3

Sources & Notes: Ahmad, 2003. Data ranges from 1993 to 1998, and includes only CO_2 from fossil fuels.

in Europe for Norwegian oil and gas has significant impacts on Norway's emissions. Similarly, increases in Canadian exports of oil and gas (which constitute over half of domestic production) put upward pressure on Canada's emissions.[84]

Overall, the degree to which emissions differ under the alternative accounting methodologies depends in significant part on the volume and mix of traded products for individual countries. Additional information about trade flows in particular sectors—such as electricity, steel, aluminum, chemicals, and others—can be found in Part II of this report.

Implications for International Climate Cooperation

There are good reasons, such as clarity and simplicity, for basing GHG accounting on emissions within national borders. It would be practically infeasible to develop, refine, and implement a comprehensive new system of emissions accounting based on consumption rather than production. Such an approach would be complex, controversial, and probably not transparent to the broader policy community and public. Furthermore, a consumption-based system may have its own substantive shortcomings. For example, it is debatable whether producers of GHG-intensive products should be absolved of responsibility for production-related emissions on the grounds that the products were consumed elsewhere.

Nevertheless, examining the role of trade and changes in international markets can enhance the overall understanding of the forces driving national emissions patterns, and may also be relevant for domestic and international policy-making. For instance, production and consumption differences may be an additional factor to be considered in differentiating future emission targets. At the very least, failure to acknowledge the trade effects on emissions may create political challenges for particular policies or proposals that, implicitly or explicitly, attach value judgments to national emissions levels, such as through cross-country comparisons. In some cases, it may be that special treatment is warranted to address inequities arising from the inability of prevailing measurement systems to account for trade-related effects. For example, following the U.S. announcement that it would not become party to the Kyoto Protocol, the government of Canada suggested that its "clean energy exports" to the U.S. ought to merit special consideration under the Protocol's accounting rules.

Other possibilities also exist. Partnerships between importers and exporters, perhaps in particular carbon-intensive sectors or products, could help address the issues raised above. Likewise, policy approaches might be developed that create incentives for producers to consider the downstream effects of the fuels or emissions-intensive products they produce (value-chain analysis).

PART II. SECTOR-BASED DATA AND INDICATORS

Sectoral Emissions and International Cooperation

Greenhouse gas emissions come from almost every aspect of society, spanning transportation, agriculture, space heating, and many other activities. The GHG Flow Diagram, introduced in Chapter 1 (Figure 1.3, p. 4) shows the extent of these activities, and the relative contributions from particular sectors, end-uses, and gases. Part II of this report discusses sector and end-use data in greater detail, and the possible implications for international climate regimes.

There are two reasons for examining GHG data from a sectoral perspective. First, the analysis helps illuminate which sectors—and which activities, fuels, and processes within sectors—are contributing most to the buildup of GHGs in the atmosphere. Understanding emissions in this manner can help policymakers and investors focus on the areas of critical importance. Shaping policy and investment priorities in light of the relative contributions of different sectors is likely to bring about a more effective and efficient response to climate change.

Second, sectoral considerations may play an important role in future international climate change agreements. The 1997 Kyoto Protocol covers only about 28 percent of worldwide GHGs, mainly those from Canada, Europe, Japan, and Russia. For the period beyond Kyoto's 2008–2012 timeframe, many Parties to the UNFCCC are seeking to engage a broader set of countries in worldwide GHG mitigation efforts. To do this, a range of sectoral initiatives or agreements may be helpful. Several sectoral models are outlined in Box 10.1, some of which are already being used in the context of the Kyoto Protocol. Future international climate agreements may likewise benefit from using a combination of these approaches in their treatment of sectors. Other forms of sectoral cooperation, structured either on a bilateral or plurilateral basis, might also characterize the post-Kyoto climate regime.

There are many possibilities for sector-based agreements or initiatives. Rather than explore these in depth, Part II of this report examines more broadly which sectors might be appropriate for or conducive to international cooperation, and why. Figure 10.1

Box 10.1. Forms of International Sectoral Cooperation

Sector-specific parameters could be built into the international climate regime in a variety of ways, including:

1. **Sector-Only Model.** Development of multiple sector agreements and initiatives that, when taken collectively, cover a significant share of total emissions. Agreements might be separate from one another, although linkages between them might also be created, for example, through offset and emissions trading mechanisms.
2. **Carve-Out Model.** Development of a comprehensive agreement, which would exclude particular sectors that would be the subject of separate consideration.
3. **Complementary Model.** Development of a comprehensive agreement, which would coexist with particular sector agreements that would separately apply, or be integrated within a comprehensive agreement.
4. **Product Model.** Similar to any of the above models, but the agreements or initiatives would be based on reducing the emissions associated with widely traded products, such as commodities or appliances.
5. **Sector-Baseline Model.** Development of a comprehensive agreement—but probably covering only emissions from developed countries—that would coexist with sectoral agreements pertaining to developing countries. Developing countries might be required to generate some amount of reductions (sectorally or nationally),[85] or an agreement might generate reductions through incentives such as a credit-trading system.[86]

The Kyoto Protocol uses several of the above models. The Protocol uses a *carve-out* approach for international bunkers (aviation and marine) and for gases covered under the Montreal Protocol on Substances that Deplete the Ozone Layer. A *complementary* approach is taken in the land-use change and forestry sector, where the Protocol and subsequent actions by the Parties specify which emissions and absorptions are included, and what additional accounting safeguards are required. Finally, the Kyoto Protocol includes the Clean Development Mechanism. The CDM, while not a sectoral mechanism, employs a baseline approach for generating emissions at the project level.

lists seven criteria used to evaluate the suitability of different sectors for sectoral cooperation; each is described below and explored within specific sector contexts in the remainder of Part II (Chapters 11-17). Whether a sectoral initiative or agreement is appropriate is likely to depend substantially on these criteria, but also some others not listed, such as competitiveness between rival firms and technological potential to achieve emissions reductions within a particular sector.

The seven criteria shown in Figure 10.1 are used to evaluate sectors and subsectors using a combination of available data, literature review, and solicited expert opinion. The evaluation involves analyzing GHG emissions, the nature of the emitting sources, the quality of emissions data, as well as production, trade, and other sectoral data. Precise proxies for the different criteria are not available in every case, and quantitative precision is not possible. Accordingly, a qualitative assessment is used to convey the inclination of each sector toward a sectoral approach for each of the criteria. This is done by applying one of three relative grades: "+" (positive), no score, or "–" (negative). A "+" grade is used in cases where available evidence strongly indicates appropriateness or conduciveness to a sectoral approach, consistent with the rationale for each criterion. A "–" grade is assigned in cases where the evidence suggests barriers to sectoral cooperation. No grade is assigned in cases where evidence is mixed, ambiguous, or the criterion is irrelevant. The remainder of this chapter explains the criteria in more depth and summarizes the sector-specific findings from Chapters 11-17.

GHG Emissions

The first criterion is the share of global GHG (or CO_2) emissions encompassed by a particular sector. This factor does not relate directly to whether a particular sector is conducive or otherwise appropriate for sectoral cooperation, but it does point to the issue of environmental significance and therefore the importance of sectors in terms of policy and priority. The largest sectors are, in order, electricity & heat, industry, land-use change and forestry, agriculture, buildings, and transport (Figure 10.2, p.57). Future growth is expected to be most rapid in electricity and transport (see Figure 11.2).

The share of emissions will of course depend on the definition and boundaries of a particular sector, and here there are virtually unlimited possibilities. For instance, a sector could be defined as (1) *transport* (encompassing all transport modes); or (2) as *road* transport, *air* transport, *international air* transport, or some combination of these. Sectors could include direct (on-site) emissions or also indirect emissions (e.g., from public electricity and heat consumption). In some cases, sectors might encompass a small number of emitting processes or end products (for example, cement manufacture); in other cases thousands of processes or products might be aggregated together (for example, chemical manufacture). Definitions adopted here are described in the endnote that begins each chapter in Part II; more detail is provided in Appendix 2. It also should be noted that some sectors examined in Part II are not mutually exclusive; electricity (and heat in particular) is treated both as a discrete sector and a component of other power-consuming activities. In addition, sectors examined in Part II do not cover 100 percent of global emissions.

International Exposure

Sectors that are greatly exposed to international competition may be more appropriately targeted for sectoral cooperation. One of the main rationales for advancing sectoral cooperation as a means to broaden participation in the climate regime is to address concerns pertaining to international competitiveness and leakage, whereby emission reductions in one location are offset by unintended increases elsewhere (Box 10.2). Certain forms of sectoral cooperation might promote a more level regulatory playing field within a given sector, thereby keeping governments from shielding that sector domestically, which they may be likely to do with economy-wide (such as Kyoto-style) targets.

These concerns, shared by many Parties, are particularly acute when international agreements, such as the Kyoto Protocol, do not include major emitting countries. International exposure is assessed here by evaluating international trade and investment flows (including those associated with multinational corporations), through which emissions may shift to countries that afford comparative advantages for production. Sectors with a high degree of trade and investment flows may indicate appropriateness for a sectoral approach.

Subsectors that are especially exposed to international competition are those that produce widely traded products or materials. Of the areas examined here, this includes motor vehicles, aircraft, steel, chemicals, and aluminum. These subsectors tend to be characterized by a significant amount of international trade as well as cross-border investment, and, in some cases, a strong presence of multinational corporations.

Concentration of Actors

Sectors with fewer actors are likely to be more conducive to international sectoral initiatives. Cooperation tends to be easier if the relevant actors are fewer, and can be readily identified and brought to the table in a coordinated manner. This criterion is evaluated by assessing the number of companies or firms responsible for the majority of economic activity within each sector, including multinational corporations. The concentration of emissions across *countries* is also a relevant consideration for this criterion. Almost half of global cement emissions, for example, come from a single country, China. High concentration, or relatively small numbers, of significant firms or countries may suggest that a sector is conducive to a sectoral approach. Conversely, low concentration or disperse activity may suggest barriers to sectoral approaches.

Figure 10.1. Criteria for Evaluating Sectors

Criterion	Evaluation Indicator(s)	Grading (+ / –)
GHG Emissions	Share of global total; trends	
International Exposure	▪ Scale of trade flows ▪ Scale of international investment ▪ Role of multinational corporations	High international exposure may suggest appropriateness (+) for a sectoral approach.
Concentration of Actors	Number of emitting sources (companies, countries) or product producers	High concentration may suggest conduciveness (+) to sectoral approach; low concentration may suggest a barrier (–)
Uniformity of Products/Processes	Number of distinct products, processes, and end products	High uniformity may suggest conduciveness (+) to sectoral approach; low uniformity may suggest a barrier (–)
Government Role	Regulations, subsidies, and other requirements	Existing regulations may suggest receptivity (+) to sectoral cooperation; Government protections may be evidence of constituencies that would be a barrier (–) to sectoral approach
GHG Measurement Issues	Measurement errors; degree of uncertainty.	Measurement challenges suggest appropriateness (+) of sectoral approach
GHG Attribution Issues	Trade in energy-intensive raw materials; diffuse production/consumption patterns.	Attribution difficulty may suggest appropriateness (+) of sectoral approach

Note: No grade is assigned in cases where evidence is ambiguous or the criterion is not relevant.

With respect to this criterion, actors tend to be concentrated in industry subsectors such as steel, cement, and aluminum. Producers of motor vehicles and aircraft are also relatively few, although the use of these products (where most emissions occur) is widely dispersed. Key actors in other sectors (and subsectors)—like electricity, chemicals, buildings, agriculture, and waste—tend to be dispersed, either across countries, firms, or domestic jurisdictions (for example, state and local actors).

Uniformity of Products/Processes

Sectors may produce diverse or uniform products, or may employ diverse or similar production processes. Sectors characterized by uniformity may be more conducive to sectoral initiatives, since abatement techniques or efficiency improvements are more easily transferred between like products and processes. Sectors producing uniform products may likewise be conducive to internationally harmonized policy approaches such as efficiency standards, technology standards, or performance benchmarks. This criterion is assessed by examining the number of distinct products, processes, and end products that exist within a sector or subsector. High uniformity of products and processes may indicate opportunities for sectoral approaches; on the other hand, low uniformity may signal a barrier to sectoral approaches.

Box 10.2. Leakage and International Competitiveness

Many countries—including those already covered by the Kyoto Protocol's emission controls—are concerned about jobs and loss of economic output caused by restricting GHG emissions. In particular, the concern is that agreements that do not cover all major emitters may lead to cross-border "leakage," whereby industries shift their production to countries that do not have emission limits. This phenomenon could be exacerbated by the increased incidence of cross-border investment and trade (Chapter 9).

In its review of this issue in the context of the Kyoto Protocol, the IPCC concluded that "relocation of some carbon-intensive industries to non-Annex I countries and wider impacts on trade flows in response to changing prices may lead to leakage in the order of 5–20 percent."[87] In other words, the worst case (20 percent leakage) suggests that a 5 percent reduction in GHG output in the industrialized world leads to a 1 percent increase in the developing world. This would be significant, although not highly damaging environmentally. Potential leakage can also be further minimized, according to the IPCC, through international emissions trading and internationally coordinated actions at the sector level.[88]

In some specific sectors, such as energy-intensive industries, leakage may be higher than the IPCC suggests. In other instances, leakage may be positive; that is, cleaner technology development in some countries might generate "spillover benefits," as those technologies are disseminated to other countries not covered by emission controls.[89] Overall, the extent of likely emissions leakage and loss of competitiveness is disputed, and models produce inconsistent results. Many factors shape competitiveness and foreign direct investment decisions, including labor costs and skills, market size, political stability, income levels, physical infrastructure, and a wide range of government policies (for example, tax, financial, and investment policies) are typically the main considerations. Energy prices or future climate change policy will also be a factor, although probably more so where there are significant restrictions on CO_2 emissions within energy-intensive sectors, such as steel or chemicals, where products are readily traded across borders.

Certain industry subsectors, such as chemicals, machinery, and food, include a huge range of products. Similarly, the drivers and sources of emissions in the buildings, agriculture, and land-use sectors are diverse and scattered. On the other hand, many emissions are associated with relatively uniform products, processes, and technologies, including cement, unwrought metals (for example, steel and aluminum), motor vehicles, aircraft, gas flaring, and waste processing.

Government Role

Governments often intervene in, privilege, or shelter different sectors to advance or protect particular interests or those of the public at large. This criterion is evaluated by examining the nature and extent of government interventions in particular sectors. Public ownership of industries, regulation, subsidies, and trade protections are examples of such interventions. Whether the government role is conducive (+) or a barrier (–) to sectoral agreements usually depends on the type of intervention within particular sectors. National governments are more likely to have vested political and economic interests in sectors in which they have intervened through public ownership, subsidies, or trade protections, and thus may be less likely to cede control to multinational agreements. Accordingly, sectors in which governments are significant stakeholders may not be good candidates for sectoral agreements, and may be more disposed to frameworks that preserve greater national autonomy. Such sectors might include electricity, forestry, agriculture, and waste. Provision of public services or protection of vested interests is commonplace in these areas.

Conversely, particular patterns of government regulation within countries could provide a model for multinational cooperation, so long as those regulations have not created entrenched constituencies. For instance, government-established efficiency standards in motor vehicles, appliances, and buildings may be comparable across international lines, and thus might form the basis of international harmonization in these areas. It may also be the case that agreements in sectors lacking significant government involvement or active constituencies are less likely to meet with political resistance or efforts to protect autonomy.

GHG Measurement Issues

Certain sectors and activities present significant challenges concerning the measurement and understanding of emissions. For example, emissions from the land-use change and forestry (LUCF) sector have proven difficult in this regard. Imprecise emissions measurements are problematic for policy instruments such as emissions trading systems that are predicated on detailed and accurate GHG inventories. As such, uncertainties in certain sectors may undermine the effectiveness of certain policy tools within comprehensive agreements, and therefore signal the appropriateness of more tailored sectoral approaches. In addition to the LUCF sector, challenges associated with GHG measurement are prevalent in agriculture, waste, and aviation.[90]

GHG Attribution Issues

Even where measurement is relatively certain, some sectors and activities present unique challenges concerning the attribution of emissions to particular countries or other actors. This issue tends to arise where emissions occur in international territory (for example, aviation and seaborne shipping) or where there is a high degree of international trade in emissions-intensive products (as discussed in Chapter 9). For countries with transit hubs or energy-intensive exports, the prevailing national GHG accounting systems may yield unfavorable results and therefore pose political challenges. Chemicals, steel, and aluminum are sectors that may warrant special sectoral treatment to address inequities in this regard. As noted in Box 10.1, a sectoral approach has already been initiated for emissions from international bunker fuels, which are not covered under the Kyoto Protocol.

Sectoral Summary and Implications for International Cooperation

By making assessments across a range of sectors and criteria, this report begins to identify the sectors that are relatively conducive to international cooperation—and those that are not. Figure 10.2 summarizes the results of the analysis for the sectors treated in Chapters 11-17. Areas that score particularly well overall include subsectors of transport and some industry subsectors. By contrast, electricity and heat and agriculture scored relatively poorly across the range of factors considered. Other sectors had mixed results.

It is important to note, however, that favorable scores do not necessarily indicate that sectoral agreements are feasible, desirable, or likely. A wide range of subjective factors not examined here are likely to play an important role in determining whether governments or companies address climate change along transnational sectoral lines. Furthermore, one criteria among those examined may play a dominant role, offsetting the conduciveness of other criteria.

For transport (Chapter 12), both motor vehicles (9.9 percent of global GHGs) and aircraft (1.6 percent) are characterized by a small number of actors (manufacturers), a high degree of international exposure, and relatively few differentiated products. International air travel has the added issue of difficulty in attributing emissions. These factors suggest cooperative ventures in either or both subsectors may be potentially fruitful; indeed, it is already clear that international air travel calls for special sectoral consideration. International cooperation in these areas could focus, for example, on establishing carbon efficiency or energy efficiency standards.

For the industry subsectors examined (Chapter 13), steel (3.2 percent of global GHGs), cement (3.8 percent), and aluminum (0.8 percent) have relatively high concentrations of actors and international exposure (though less so for cement), and relatively narrow product/process mixes. These factors, along with some trade-related attribution challenges, suggest areas where international cooperation may be helpful. Overall, aluminum and steel scored the highest, followed by cement. There is a range of possibilities with respect to the form of cooperation, such as common efficiency benchmarks or CO_2-intensity reductions. By contrast, chemicals scored poorly, owing largely to the huge diversity of actors and processes, which would be difficult to coordinate for a common purpose or to align within a single technology standard, efficiency standard, or other policy approach.

For land-use change and forestry (Chapter 17), the central challenge relates to GHG accounting. Emissions and absorptions are hard to measure and subject to large uncertainties. Emission absorptions that are claimed from particular policies or measures are reversible (for example, through subsequent land clearing). For these reasons, integrating this sector into a more comprehensive agreement, such as the Kyoto Protocol, has proven challenging. Due to quantification difficulties, a policy-based (qualitative) approach to mitigation might be more effective than quantitative approaches, such as emission targets and trading systems. Likewise, because emissions are concentrated in a relatively narrow band of tropical countries, geographically tailored initiatives might more effectively address CO_2 mitigation in this sector.

Figure 10.2. Summary of Sector Analysis

Sector	Share of Global GHG Emissions	International Exposure	Concentration of Actors	Uniformity of Products/Processes	Government Role	GHG Measurement Issues	GHG Attribution Issues
Electricity & Heat	24.6%		–	+	–		
Transport	13.5%						
Motor Vehicles	*9.9%*	+	+	+	+		
Aviation	*1.6%*	+	+	+		+	+
Industry	21.1%						
Chemicals	*4.8%*	+	–	–			+
Cement	*3.8%*		+	+			
Steel	*3.2%*	+	+	+			+
Aluminum	*0.8%*	+	+	+			+
Buildings	15.4%		–	–	+		
Agriculture	14.9%		–	–	–	+	
Land-Use Change & Forestry	18.2%			–	–	+	
Waste	3.6%		–	+	–	+	

Notes: Sectors shown do not comprise 100 percent of global emissions, nor are all sectors mutually exclusive. See Appendix 2. A "+" grade suggests high appropriateness or conduciveness for international sectoral cooperation. A "–" grade suggests a barrier to international sectoral cooperation. No grade means evidence is mixed, ambiguous, or not relevant.

For other sectors such as electricity and heat (Chapter 11), buildings (Chapter 14), agriculture (Chapter 15), waste (Chapter 16), and a range of industry subsectors, the conditions seem less appropriate or amenable to international sectoral cooperation. The reasons, however, differ across sectors, ranging from the lack of international exposure (electricity), diverse product/process mixes (industry, agriculture), and heavy governmental interventions or vested domestic interests (electricity, agriculture, waste).

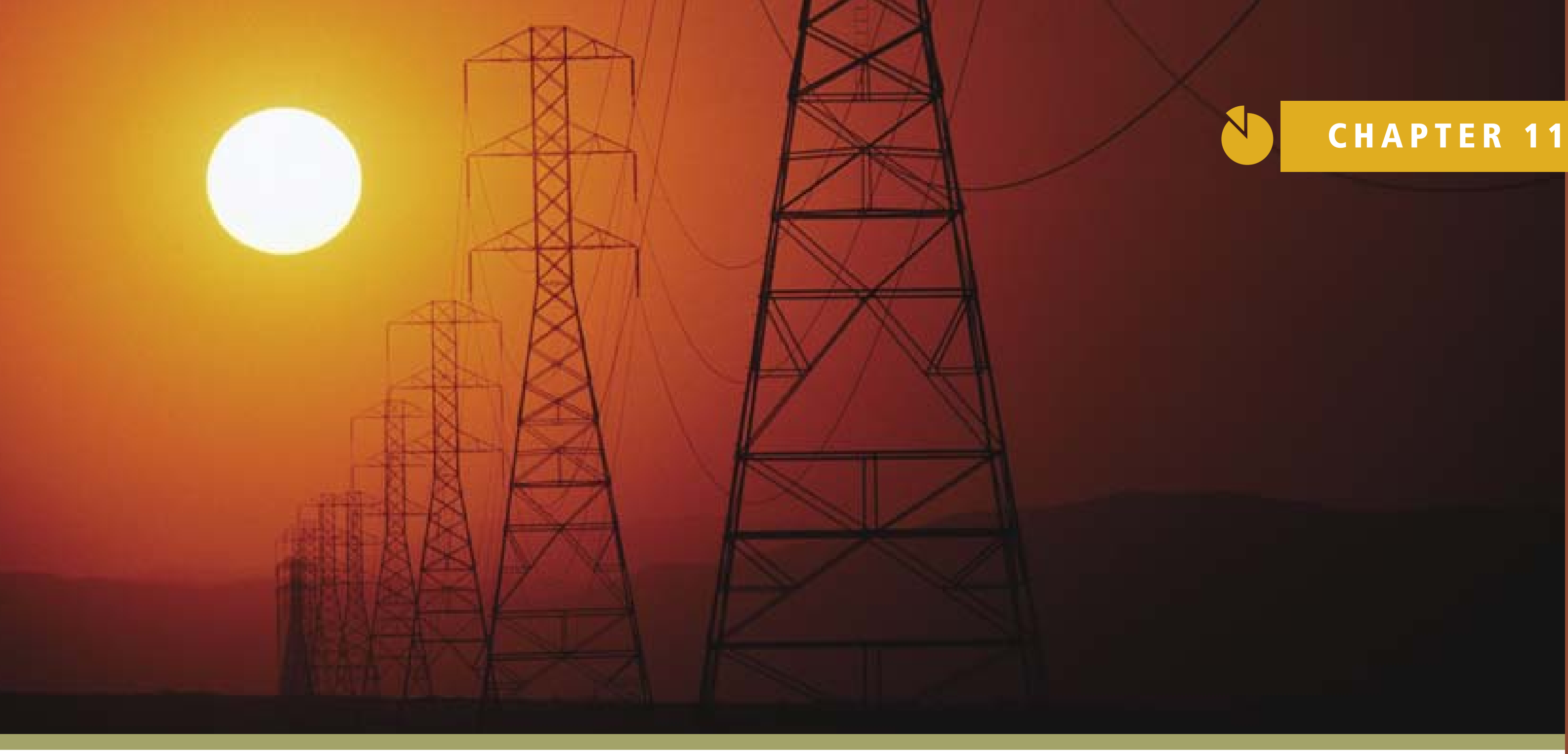
Aggregating the most attractive sectors—such as steel, cement, aluminum, motor vehicles, and aircraft—suggests a coverage of about 20 percent of world emissions. Adding LUCF could increase this to closer to 35 or 40 percent. It may be possible to increase this share by redefining sectors or identifying traded products for which the conditions of cooperation are more promising. For example, focusing attention on fertilizer production and use would cut across both industry (chemicals) and agriculture (soils) sectors. Similarly, it could be possible to identify a range of specific products—such as home appliances—that could be the subject of agreements (for example, energy efficiency standards), much as motor vehicles or aircraft might. Such initiatives would impact residential emissions indirectly through reduced electricity consumption.

The results here help illuminate both the perceived successful and unsuccessful aspects of the Kyoto Protocol.

Overall, however, the findings suggest that a "sector-by-sector" approach to international cooperation on climate change is unlikely to be adequate or feasible. Rather, comprehensive agreements (covering most sectors and gases), with special provisions or supplementary agreements for specific sectors offer greater promise. The results here also help illuminate both the perceived successful and unsuccessful aspects of the Kyoto Protocol. One of the characteristics of the Protocol that fostered consensus was that it did *not* adopt a sectoral approach that intruded upon sensitive domestic policy terrain. Rather, national emission targets were agreed upon, with governments free to achieve their targets in any way they deemed appropriate, including using regulatory approaches crafted to their own national circumstances.

On the other hand, the Kyoto Protocol has not been able to easily accommodate certain sectors. As noted, emissions from international bunker fuels are carved out of the Protocol. Most emissions from land-use change and forestry (Chapter 17) are included, but due to the enormous accounting and technical challenges associated with this sector, rulemaking has been fraught with complexity and controversy. The LUCF findings here suggest that international cooperation in this sector is especially challenging, regardless of whether it is treated in a comprehensive agreement or a special sectoral agreement.

The Kyoto Protocol likewise has not secured the participation of the United States, Australia, and developing countries within its GHG mitigation provisions. One reason is that some key sectors in these countries are heavily exposed to international cooperation, thus creating a perception that participation will result in loss of jobs and economic output. As illustrated here, there is a relatively narrow band of sectors where this issue arises (covering a minority of emissions). Nevertheless, advancing international cooperation on climate change may benefit from tailoring sectoral approaches in particularly sensitive areas. The sector-specific analysis in the remaining chapters provides additional perspective.



Electricity and Heat

Emissions

Electricity and heat[91] account for about 25 percent of global GHG emissions, making it the largest sector. This is equivalent to 32 percent of global CO_2 emissions and 43 percent of CO_2 emissions from energy-related sources. Within this sector, electricity generation accounts for the largest share, at 68 percent of the sector and 17 percent of global GHG emissions. Heat (including combined heat and power) amounts to about 5 percent of worldwide emissions, and other energy industries[92] account for roughly 3 percent (Figure 11.1).

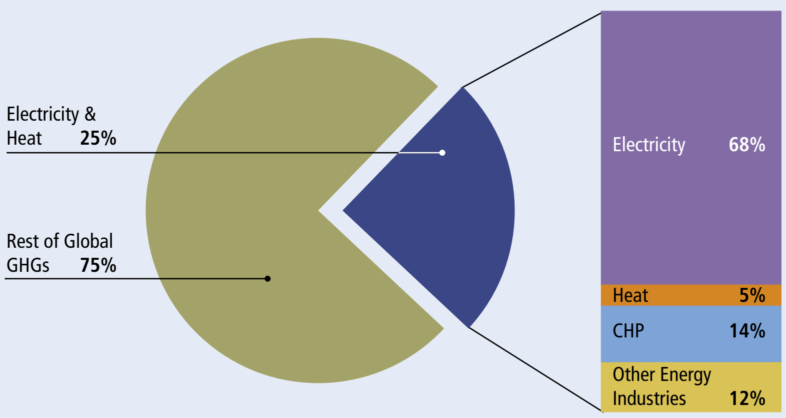
More than 40 percent of all electricity is consumed in buildings, either residential (23 percent) or commercial and public (19 percent, collectively).[93] (The main uses within buildings are discussed in Chapter 14.) Industry accounts for a further 35 percent of all electricity use. About 9 percent of electricity is consumed in energy production and processing (for example, refineries), with an equal amount lost in transmission and distribution (transmission and distribution losses are significantly higher in developing countries). Relatively small amounts are consumed in agriculture (2.3 percent of total) and transport (1.4 percent, mostly from rail). With respect to fuel types, coal powers 38 percent of global electricity supply. Gas, nuclear, and hydropower follow with shares of 20, 17, and 16 percent, respectively (Figure 11.4).

Residential and industry sectors dominate public heat consumption, at 39 and 33 percent of the global total, respectively.[94] Smaller amounts come from energy production and processing (9 percent), other buildings (8 percent), and distribution losses (7 percent). In terms of fuel sources, most heat is generated by gas (53 percent) and coal (36 percent).

Figure 11.5 shows electricity and heat-related CO_2 emissions of the top emitting countries, in both absolute and per capita terms. Together, these countries account for 88 percent of global emissions from this sector, with the 10 largest emitters accounting for 81 percent. The United States, China, and the EU-25 are by far the largest emitters (25, 16, and 14 percent, respectively, of the global total for this sector). The largest per capita emitters, in order, are Australia, the U.S., Saudi Arabia, and Russia.

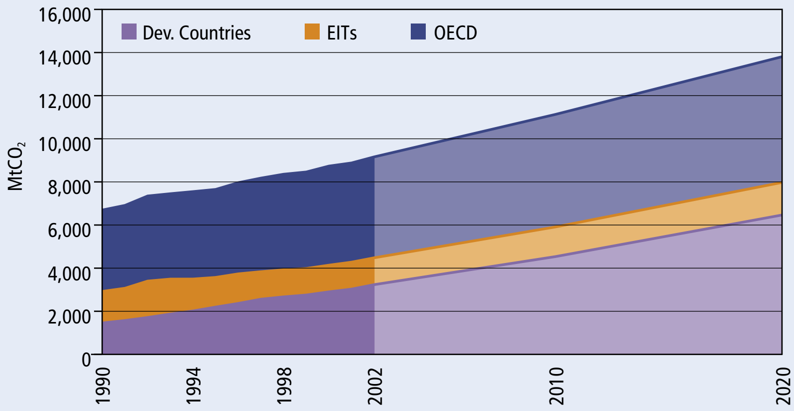
The notable cross-country differences are explained by a variety of factors, discussed in Part I of this report. First, different levels of affluence and access to

Figure 11.1. GHGs from Electricity and Heat



Sources & Notes: IEA, 2004a. See Appendix 2.A for sources and sector definition. Absolute emissions in this sector, estimated here for 2000, are 10,269 $MtCO_2$.

Figure 11.2. GHGs from Electricity and Heat, Trends and Projections



Source: IEA, 2004b,c.

electricity result in large consumption and emissions disparities. Second, power generation efficiencies are higher in some countries than others.[95] Third, fuel mixes for power generation vary significantly across countries, as shown in Figure 11.6.

To some extent, these variances stem from government decisions that favor exploitation of domestic energy resources for electric power generation. Countries with large coal resources—like Australia, the United States, India, China, and South Africa—have tended to exploit those resources, resulting in higher CO_2 emissions. For other countries, like Brazil, hydropower potential has been exploited, resulting in relatively low emissions. Likewise, countries like France that made decisions decades ago to invest in nuclear energy are likely to have lower electricity emissions. For countries with large oil reserves (and production), such as Saudi Arabia, oil is used in domestic power generation despite the fact that oil is the least efficient fossil fuel for electricity generation.

Few countries have large fractions of their power generated from non-hydro renewables (for example, geothermal and wind). Among the major emitters, Indonesia (5.8 percent) and Spain (3.8 percent) have the largest shares of non-hydro renewables.[96] Among countries not ranked in the top 25 emitters, Costa Rica, Denmark, Iceland, and the Philippines are notable in that they all have shares exceeding 15 percent of their national totals.

At the global level, emissions from electricity and heat are growing faster than any other sector, and are projected to keep growing at high rates. From 1990 to 2002, emissions from electricity and heat rose fastest in the developing Asian economies, growing 120 percent or more in South Korea, China, India, and Indonesia (Figure 11.3). In these same countries, growth by 2020 is expected to approach or exceed an additional 100 percent. Emissions since 1990 grew by a modest 8 percent in Europe, and declined in Russia and Ukraine. Increases of about 25 percent are projected in the United States and the European Union (without taking into account the impact of the EU's emissions trading scheme, which began in January 2005).

Sector Context

Electricity and heat provide vital and enabling services, playing a dominant role in the economic life of industrialized and many other countries. The importance of this sector has, to a large degree, shaped its characteristics, including the level of government involvement and international exposure. Government intervention remains heavy in electricity and heat generation, despite liberalization and international investment trends, discussed below. In most countries, electricity and heat production for public consumption is either publicly owned or a regulated enterprise. This is due to the public benefits associated with power and heat, linkages to economic and national security issues, as well as the natural monopoly characteristics of transmission and distribution services.

The electricity and heat sector has a low overall level of international exposure. Trade plays only a minor role, with just over 3 percent of world electricity production traded across borders, and virtually no trade in heat.[97] This is due partly to the requirement of geographic contiguity, which inherently limits trade in this sector. Other factors are also significant, such as governmental preferences to exploit domestic resources (discussed above) and limited cross-border electric transmissions systems. Most electricity trade is within Europe and North America.[98] Although actual trade flows are small, some African countries are heavily reliant on electricity imports.

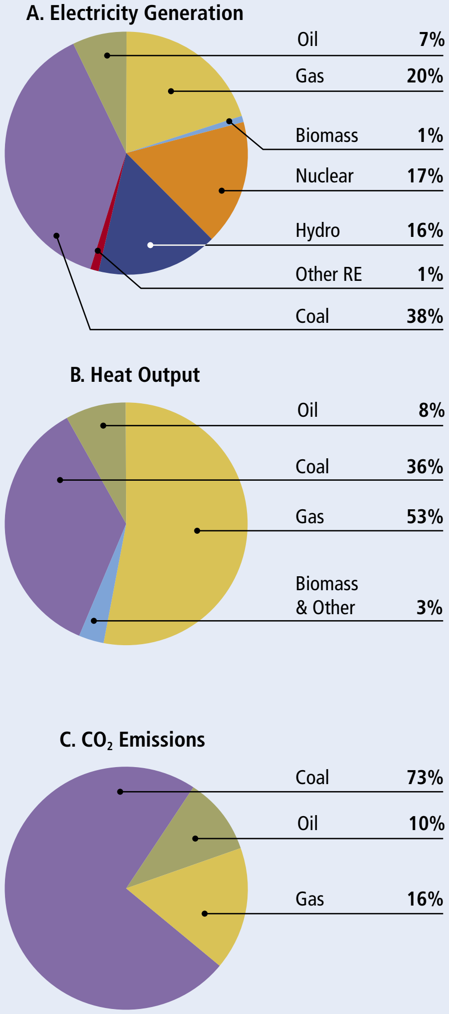
Because electric transmission systems are not deeply integrated internationally, sales of electric power in most countries are not exposed to international competition. Due to trends in liberalization and regulatory restructurings, however, power companies have been expanding their international investment portfolios. More than 20 U.S. power companies have established assets in other countries that are liberalizing their power sectors, such as the United Kingdom, Argentina, Australia, and Chile.[99] Government-owned Electricité de France generates and distributes electricity in 19 countries.[100] Other companies are focusing more exclusively on overseas investment. The U.S.-based AES Corporation, for instance, operates 113 electric power facilities in 17 countries, employing

Figure 11.3. CO_2 from Electricity and Heat

		% Change	
Country	**% of World 2002**	**1990–2002**	**Projected 2002–2020***
United States	24.7	26	23
China	15.8	147	104
EU-25	14.0	1	26
Russia	8.6	-17	18
India	5.4	119	83
Japan	4.7	24	–
Australia	2.0	53	19
South Korea	1.8	203	–
Canada	1.8	39	–
Mexico	1.7	75	65
Indonesia	1.1	120	149
Brazil	0.5	80	133
World	**100.0**	**66**	**51**

Notes: Growth rates for Russia are from 1992 (not 1990). *Projections are drawn from IEA (2004c). The projected figure for the U.S. includes Canada; Australia includes New Zealand. "–" signifies no data.

Figure 11.4. Electricity and Heat
Shares by fuel

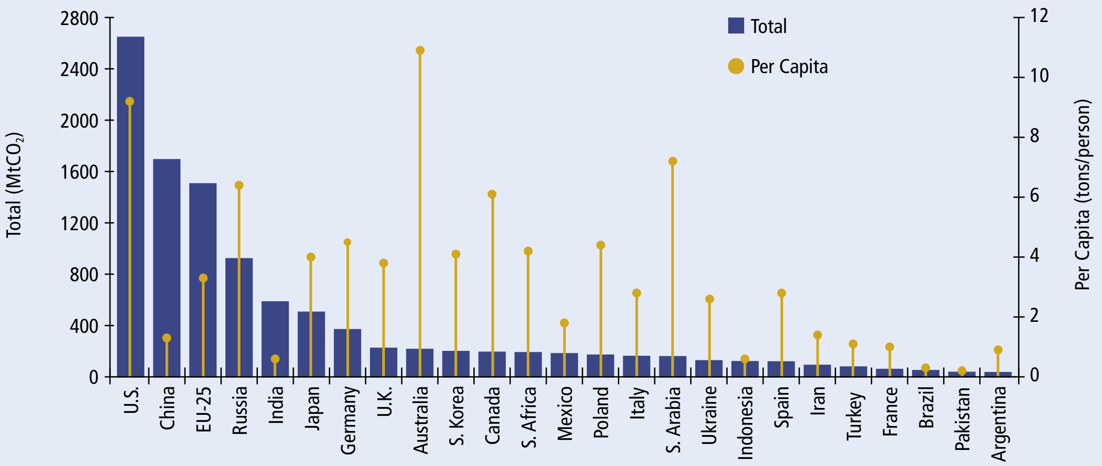

A. Electricity Generation

B. Heat Output

C. CO_2 Emissions

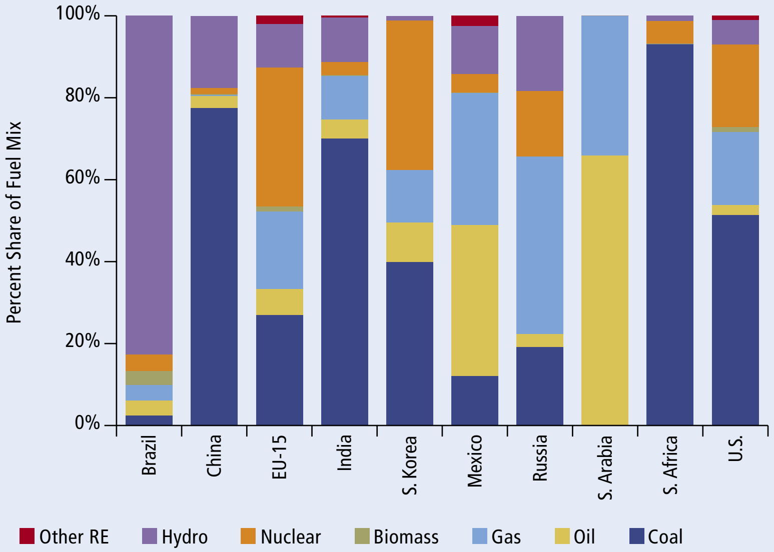
Sources & Notes: WRI, based on IEA, 2004a,b. Electricity generation and heat output are based on gigawatt hours and terajoules, respectively. CO_2 emissions include electricity and heat.

Figure 11.5. CO$_2$ from Electricity and Heat, Total and Per Capita, 2002
Top 25 GHG emitters



Source: WRI, CAIT.

Figure 11.6. Fuel Mix in the Electricity Sector, 2002
Relative shares, selected major GHG emitters



Sources & Notes: WRI, based on IEA, 2004b. Shares are based on gigawatt hours of generation.

30,000 people.[101] Still other companies are regionally focused. The South African utility Eskom, for example, has operations in other African countries, and seeks to become the pre-eminent African energy-related service company.[102]

In terms of uniformity, the electricity and heat sector has mixed characteristics. On one hand, electricity itself is almost completely fungible; the end product is the same regardless of the fuels and processes used to generate it. Similarly, the components of generating technologies, such as turbines, are fungible and may offer large advantages for harmonization. The number of basic fuels used to produce electricity is also relatively small. However, technologies used to generate electricity can vary widely. Advances in technology can also take long periods to achieve full potential, as large electricity plants tend to have operating lives of many decades.

Emissions from the electricity and heat sector are dominated by fuel consumption. Practices for estimating emissions from these processes are well understood and estimates are easily calculated when fuel consumption data is available. Consequently, there is little difficulty in measuring emissions from this sector. Large hydroelectric power dams are an exception, particularly in tropical countries where CH$_4$ emissions may be significant.[103] Attribution likewise does not present large challenges, since most (but not all) emissions occur when fuels are combusted, not when they are extracted or refined. However, regional trade may present some potential attribution controversy, as emissions associated with electricity trade would tend to be allocated only to the producer country.

CHAPTER 12

Transport

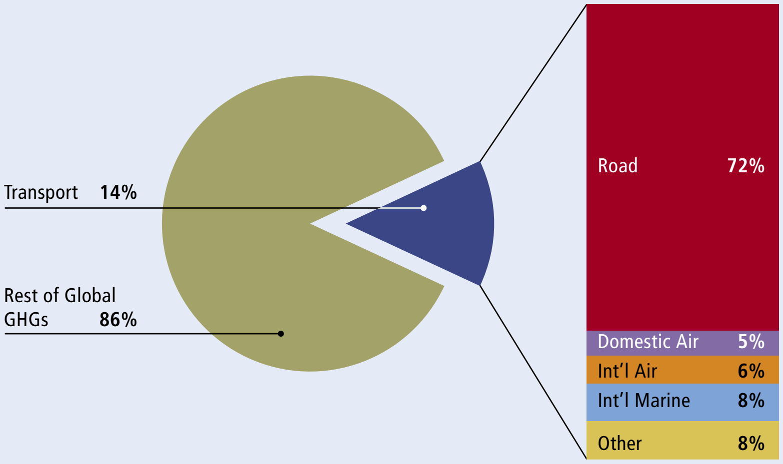
Emissions

Transport[104] accounts for about 14 percent of global GHG emissions, making it a major contributor to global climate change (Figure 12.1). This is equivalent to 18 percent of global CO_2 emissions and 24 percent of CO_2 emissions from energy-related sources. Within this sector, road transport, at 72 percent of the sector and 10 percent of global GHG emissions, accounts for the largest share. Aviation (domestic and international) amounts to about 12 percent of transport emissions, and 2 percent of overall GHGs.

With respect to energy sources, transport is dominated by oil, which amounts to 96 percent of energy supply and 97 percent of emissions (Figure 12.3). Gas accounts for about 3 percent, and biomass 0.5 percent (with 68 percent of biomass used in transport coming from one country, Brazil).

Figure 12.4 shows transport-related CO_2 emissions of the top emitting countries, in both absolute and per capita terms. Together, these countries account for 87 percent of global emissions from this sector, with the five largest emitters accounting for two-thirds of the global total. The United States far outranks all other countries, with 35 percent of global emissions, about twice the EU's total and seven times the emissions of the next highest country, Japan. The U.S., Australia, and Canada are prominent in their high per capita emissions. As with electricity, cross-country differences in transport emissions owe largely to wide variations in per capita consumption patterns, discussed in Chapter 7. The predominant mode of

Figure 12.1. GHGs from Transportation



Sources & Notes: IEA, 2004a. See Appendix 2.A for sources and Appendix 2.B for sector definition. Absolute emissions in this sector, estimated here for 2000, are 5,743 $MtCO_2$.

transport in China's urban areas, for instance, is public transit, cycling, and walking, whereas in the U.S. and Europe, automobiles are predominant.[105]

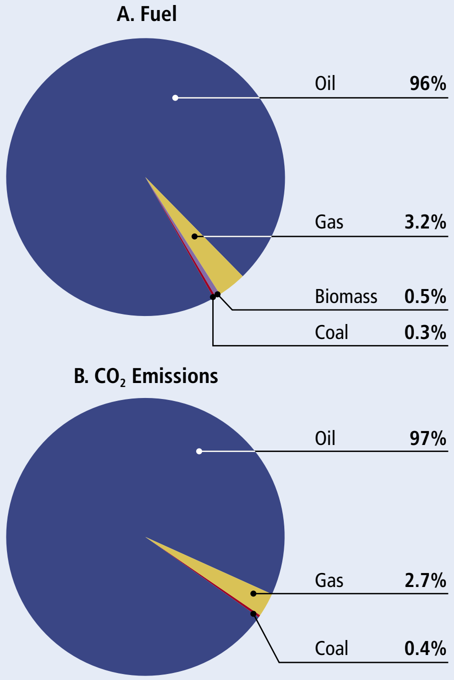
In some countries, transport is the fastest growing source of GHG emissions. From 1990 to 2002, transport-related emissions grew 20–25 percent in most industrialized countries, but much faster in many developing countries (Figure 12.5). The fastest growth was in South Korea, Indonesia, and China, where transport emissions doubled. Among major emitters, CO_2 from this sector declined only in Russia and Ukraine.

By 2020, the IEA expects global transport emissions to increase by 50 percent.[106] Increases of about 30 percent are projected in developed countries (Figure 12.5). Much higher increases are projected in developing countries, including China (143 percent), India (67 percent), Indonesia (122 percent), Mexico (71 percent), and the Middle East (68 percent).

Sector Context

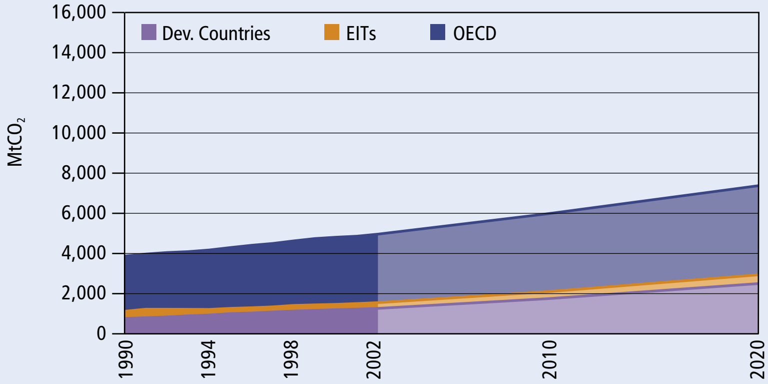
The transport sector—and motor vehicles in particular—is notable for its high concentration of actors and significant international integration. Motor vehicle production—which includes passenger cars, light commercial vehicles, heavy duty trucks, and buses—is concentrated among relatively few countries and companies (Figures 12.6 and 12.7). Production is dominated by the U.S., EU-25, and Japan, with China rapidly increasing its production levels. Over the 5-year period from 1999 to 2004, China's vehicle production increased more than 175 percent, approaching half of Japanese levels by 2004. South Korea, Canada, and Brazil also have significant vehicle production. At the company level, five multinational automakers—General Motors, Ford, Toyota, Volkswagen, and DaimlerChrysler—produce about half of all motor vehicles (Figure 12.7). Major auto companies are largely headquartered in the United States, Japan, Europe, and South Korea. Virtually all manufacturers, however, have assembly and production facilities in multiple countries. Joint ventures are also common among major manufacturers, particularly in developing countries.

Figure 12.3. Transportation *(shares by fuel)*



Sources & Notes: WRI, based on IEA, 2004a,b.

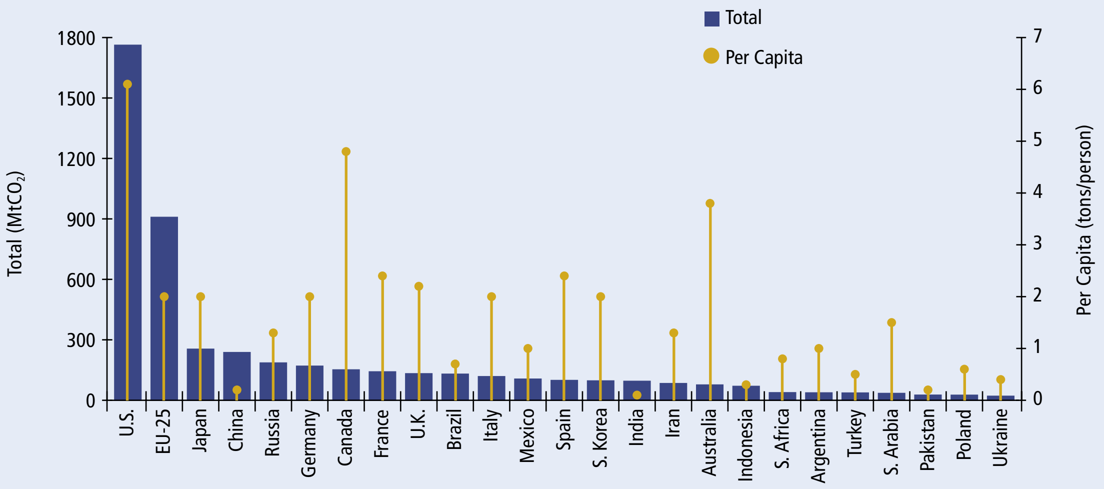
Figure 12.2. GHGs from Transportation, Trends and Projections



Sources: IEA, 2004b,c.

Motor vehicles, parts, and related accessories are heavily traded products. In 2003, world trade in automotive products reached $724 billion, amounting to 10 percent of all global trade.[107] A significant portion of this trade is regional, within Europe (37 percent)

Figure 12.4. **CO_2 from Transportation, Total and Per Capita, 2002**
Top 25 GHG emitters



Source: WRI, CAIT.

Figure 12.5. **CO_2 from Transportation**

		% Change	
Country	**% of World 2002**	**1990–2002**	**Projected 2002–2020***
United States	35.5	24	30
EU-25	18.3	23	31
Japan	5.1	20	–
China	4.8	101	143
Russia	3.7	-29	49
Canada	3.0	21	–
Brazil	2.6	60	77
Mexico	2.1	21	71
South Korea	1.9	120	–
India	1.9	15	92
Australia	1.5	23	29
Indonesia	1.4	109	122
World	**100.0**	**40**	**50**

Notes: CO_2 from international bunker fuels is not included. Growth rates for Russia are from 1992 (not 1990). *Projections are drawn from IEA (2004c). The projected figure for the U.S. includes Canada; Australia includes New Zealand. "–" signifies no data.

Figure 12.6. **Motor Vehicle Production**

	Vehicle Production	
Country	**Millions 2004**	**% Change since 1999**
EU-25	18.3	0
U.S.	12.0	-8
Japan	10.5	6
China	5.1	177
France	3.7	15
S. Korea	3.5	22
Canada	2.7	-11
Brazil	2.2	64
Mexico	1.6	1
India	1.5	85
Russia	1.4	18
Poland	0.6	4
Indonesia	0.4	346
Argentina	0.3	-15
World		**14**

Sources & Notes: OICA, 2000; OICA, 2005. Vehicles include passenger cars, light commercial vehicles, heavy-duty trucks, and buses.

Figure 12.7. Leading Motor Vehicle Manufacturers

	Total Vehicles, 2004		
Company (& other brands)	**Millions**	**% World**	**Country(s) of Origin**
General Motors (Opel, Vauxhall)	8.1	12.6	U.S., Germany
Toyota	6.8	10.6	Japan, U.S.
Ford (Volvo, Jaguar)	6.6	10.4	U.S., Germany
Volkswagen Group (VW, Audi)	5.1	7.9	Germany, Spain, China
DaimlerChrysler (Evobus)	4.6	7.2	U.S., Germany
PSA Peugeot Citroën	3.4	5.3	France, Spain
Honda	3.2	5.0	Japan, U.S.
Nissan	3.2	5.0	Japan, U.S.
Hyundai-Kia	2.8	4.3	South Korea
Renault-Dacia-Samsung	2.5	3.9	France, Spain
Fiat-Iveco-Irisbus	2.1	3.3	Italy, Brazil
Suzuki-Maruti	2.0	3.1	Japan, India

Sources & Notes: OICA, 2005. Vehicles include passenger cars, light commercial vehicles, heavy duty trucks, and buses.

and within North America (13 percent).[108] Trade flows between Europe and North America, as well as between Asia and North America, are also significant.

The EU-15, Japan, and the U.S., are the largest exporters, with export product values of $125, $103, and $69 billion, respectively, in 2003.[109] Some developing countries are increasingly producing automobiles for export, often through joint ventures with major automakers. The share of domestic output that is exported from Mexico, for instance, is 60 percent.[110] The largest importers are the United States, EU-15, and Canada, with import product values of $181, $67, and $49 billion, respectively.[111] The share of domestic consumption that is imported is often very large, such as in large EU countries (30–67 percent), Australia (52 percent), and the U.S. (32 percent).[112] Other countries consume primarily domestically manufactured cars, with imports constituting a small share; this includes Japan (3 percent), South Korea (6 percent), and India (5 percent).[113]

Uniformity is high for all transport products. Most automobiles, trucks, and buses are produced on assembly lines, with similar production methods employed by different firms. Furthermore, while vehicle models may vary widely, the number of propulsion technologies involved is very small. All road vehicles use one of a few major types of internal combustion engine, fueled by gasoline, diesel, or natural gas.

Governments play a significant role in the transport sector, but not as fundamental as with electricity. Interventions tend to be oriented around safety and fuel efficiency regulations—particularly in developed countries—and transportation infrastructure like roads, highways, seaports, and airports. Existing national fuel efficiency regulations may provide a pathway for coordinated action at the sectoral level.

Difficulty in attributing emissions to countries depends on the mode of transport. Ground transport is relatively easy to attribute. Although there some exceptions, such as in Europe, emissions almost always occur within the same national boundaries where fuels are purchased.[114] Emissions for *international* transport, however, nearly all occur in or over international territory, raising ambiguities concerning attribution, as discussed in more detail below.

SECTOR SPOTLIGHT: *Aviation*

Aviation, as noted above, represents approximately 12 percent of CO_2 emissions from transport when international flights are included (and about 1.6 percent of the world GHG total).[115] Emissions from international flights are more than half of overall air emissions.[116] Air travel—and associated CO_2 emissions—have grown at tremendous rates over the past few decades. Since 1960, passenger traffic has grown at about 9 percent per year, though the rate has slowed in recent years as the industry has matured.[117] Looking ahead, passenger and freight traffic are expected to grow at rates well in excess of GDP growth.[118]

The global warming effect of aviation is larger than suggested by the numbers and emissions trends discussed above, which are based on fossil fuel consumption. The climate impacts of air travel are amplified when ozone-producing NO_X emissions, contrail formation, water vapor release, and other high-altitude effects of aircraft use are accounted for. Most of these effects are characterized by high levels of uncertainty, and are difficult to account for. The IPCC estimates that, although aircraft accounted for only 2 percent of anthropogenic emissions in 1992, they produced an estimated 3.5 percent of total radiative forcing from human activities.[119] IPCC projections suggest that radiative forcing from aircraft may increase by a factor of nearly four by 2050, accounting for 5 percent of total radiative forcing from human activities.[120]

Figure 12.8 shows the breakdown of total and international air emissions from the top 10 countries in this subsector. Although all the countries shown are within the top 25 overall emitters, some countries with large international aviation emissions are not among the top overall emitters. Hong Kong, the Netherlands, Thailand, and Singapore rank 8, 9, 11, and 12 respectively in this category, mainly because they are large air transit hubs.

Figure 12.8. CO_2 from Aviation, 2002

	Total Air			International Air		
Country	**% World**	**(Rank)**	**% Change from 1990**	**% World**	**(Rank)**	**% Change from 1990**
United States	37.2	(1)	7	14.3	(2)	31
EU-25	20.3	(2)	49	30.3	(1)	59
Japan	5.0	(3)	42	6.0	(5)	59
United Kingdom	4.9	(4)	54	6.1	(4)	65
Russia	4.5	(5)	–	8.3	(3)	–
Germany	3.3	(6)	25	5.9	(6)	48
France	3.1	(7)	69	4.1	(7)	52
China	2.8	(8)	611	0.8	(27)	442
Canada	2.4	(9)	19	0.8	(24)	3
Spain	2.0	(10)	75	2.3	(13)	137
World			**38**			**38**

Source: Calculations based on IEA, 2004a.

Aviation emissions, as suggested above, are measured at the point of refueling and do not depend on subsequent destinations or nationalities of passengers, or high-altitude effects. Accordingly, attributing aviation emissions to particular countries is controversial, and for this reason emissions in this sector are excluded from the Kyoto Protocol. Parties to the Climate Convention have requested assistance in dealing with air emissions from the International Civil Aviation Organization (ICAO), although no formal agreements have been reached.

While measurement and attribution of emissions are more problematic for aviation than for motor vehicles, the two subsectors have otherwise similar characteristics. Aviation products are highly uniform, as nearly all medium and large commercial aircraft rely on jet engine propulsion. Production is highly concentrated. Nearly all jet aircraft are manufactured by five companies, operating primarily in North America and Europe. Boeing Corporation, headquartered in the United States, and Airbus S.A.S, headquartered in France, manufacture almost all large (100+ seat) commercial jet aircraft. Smaller jet aircraft, including regional corporate jets, are manufactured mainly by Bombardier (Canada), Embraer (Brazil), and Gulfstream, a division of General Dynamics (United States). According to industry sources, these manufacturers accounted for nearly all of the approximately 16,000 jet aircraft in service worldwide in 2003.[121] Industry forecasts project demand for almost 24,000 new jet aircraft through 2023.[122]

Given the high concentration of actors, it is not surprising that cross-border trade is significant. The U.S. exports 40 percent of its production of aircraft, nearly half of which go to developing countries.[123] Other significant producers, such as France, Germany, Canada and the United Kingdom, export over 50 percent of their domestic aircraft production.[124]

CHAPTER 13

Industry

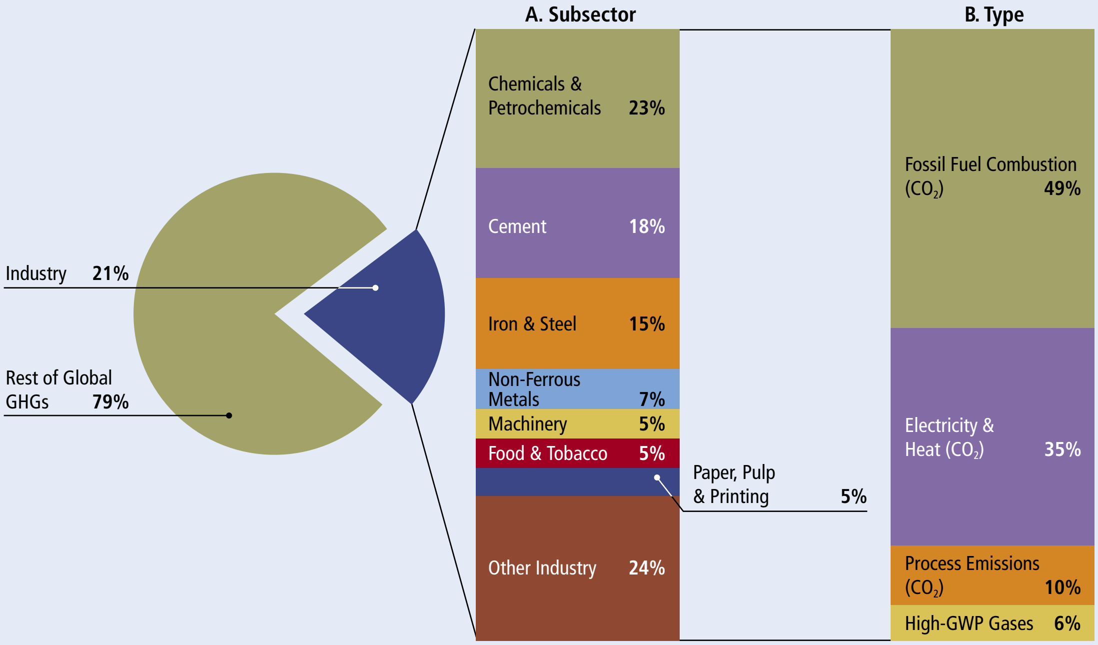
Emissions

GHG emissions associated with manufacturing and construction industries[125] represent approximately 21 percent of world GHG emissions (Figure 13.1). This figure includes direct fossil fuel combustion (49 percent), indirect CO_2 emissions from electricity and heat consumption (35 percent), and CO_2 and non-CO_2 emissions from industrial processes (16 percent). Within the industry sector, (1) chemicals and petrochemicals (23 percent), (2) cement (18 percent), and (3) iron and steel (15 percent) account for the largest shares of sector-wide emissions.

Figure 13.3 shows industry-related CO_2 emissions of the top emitting countries, in both absolute and per capita terms. Together, these countries account for 85 percent of global emissions from this sector, with the five largest emitters accounting for 62 percent of the global total. This sector is unusual in that a majority of global emissions come from developing countries, with China having the largest share (22 percent). However, in per capita terms, industrialized country emissions are still four times higher than developing countries.

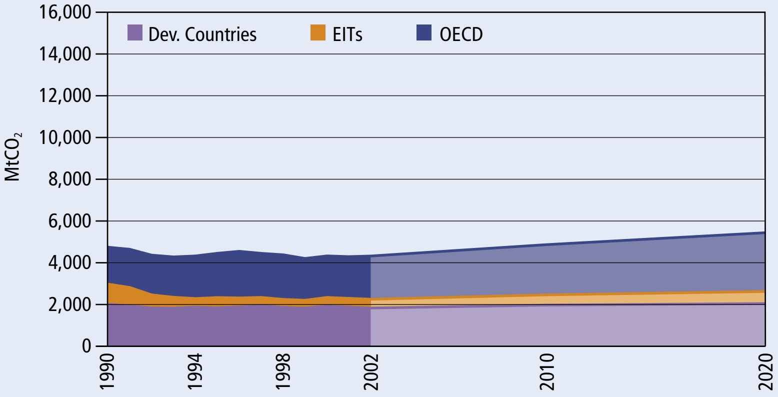
In terms of trends, this sector has declined as a relative share of many countries' national emissions totals since 1990, as evidenced by the relatively modest growth rates, some of which are negative. Industry emissions have declined since 1990 in Mexico (-26 percent), Russia (-22 percent), Australia (-18 percent), EU-25 (-15 percent), and the U.S. (-10 percent). Growth has been significant in India, China, Brazil, and South Korea, but slower than in other major sectors (Figure 13.4).

Figure 13.1. GHGs from Industry



Sources & Notes: CAIT, IEA, 2004a, Hendriks, 1999. See Appendix 2.A for sources and Appendix 2.B for sector definition. Absolute emissions in this sector, estimated here for 2000, are 8,856 $MtCO_2$.

Figure 13.2. GHGs from Industry, Trends and Projections

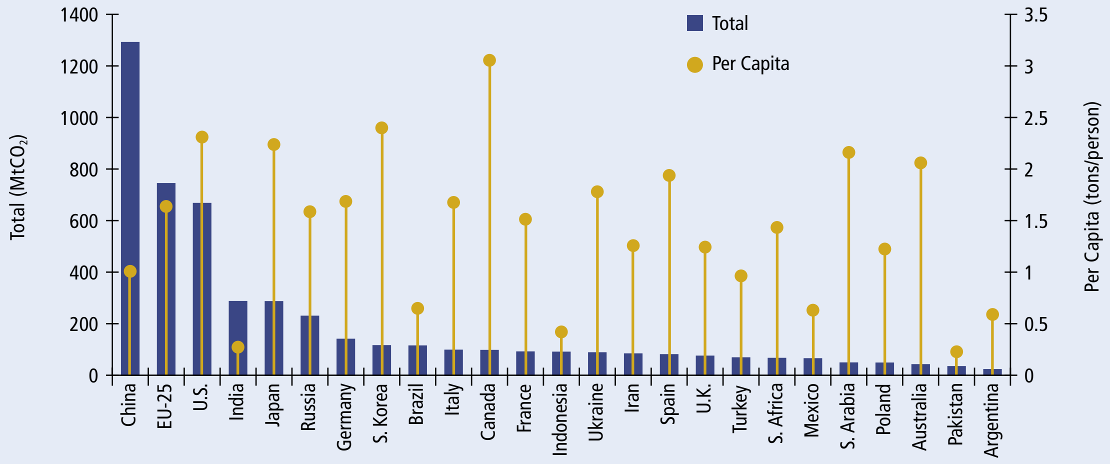


Source: IEA, 2004b,c.

Sector Context

The industry sector is notable for the sheer diversity of activities, processes, and technologies. This is a sharp contrast to electricity and heat, where the end product is homogeneous, and transport, where the technologies are relatively uniform. In addition to chemicals, cement, steel, and aluminum (which are discussed in more detail below), other significant contributors to industry emissions include food and tobacco, pulp and paper, and machinery. Naturally, given the lack of uniformity in the manufacturing and industry sector, there are a large number of diverse actors operating in a multitude of regulatory contexts.

Figure 13.3. **CO_2 from Industry, Total and Per Capita, 2002**
Top 25 GHG emitters



Sources & Notes: WRI, based on IEA, 2004a and CAIT. CO_2 emissions are from direct fossil fuel combustion and cement manufacture. Emissions from public electricity and heat are not included here.

The industry sector is also characterized by a high degree of trade and international competition. Manufactured goods account for 75 percent of all global trade.[126] And while developed and developing countries have large disparities in consumption patterns, described throughout this report, they often are competitive in key industrial sectors. As the emission trends suggest, the industrial sectors of many developed countries have been in decline, with gradual loss of output and employment (substituted by service sector growth). Greater detail is provided below for specific industry subsectors. Not coincidentally, manufacturing output has risen more significantly in developing countries, with particularly astonishing growth in China.

Figure 13.4. **Direct CO_2 Emissions from Industry**

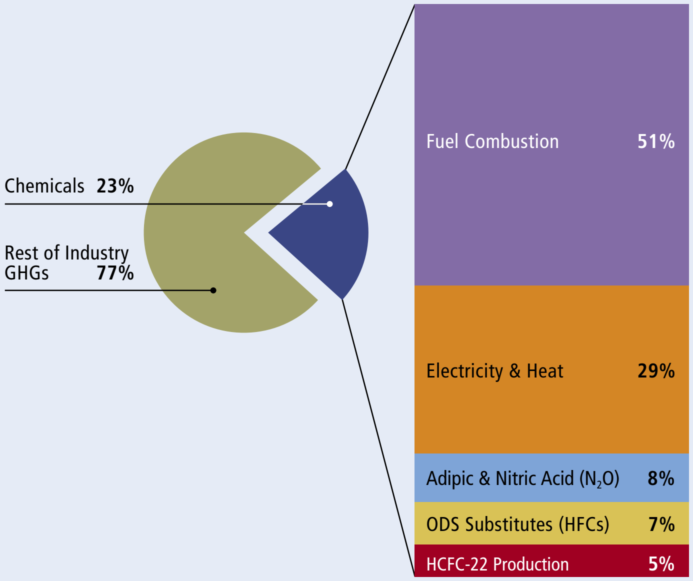
		% Change	
Country	**% of World 2002**	**1990–2002**	**Projected 2002–2020***
China	24.7	21	22
EU-25	14.2	-15	4
United States	12.8	-10	12
India	5.5	49	65
Japan	5.5	2	–
Russia	4.4	-19	44
South Korea	2.2	77	–
Brazil	2.2	61	65
Canada	1.8	3	–
Indonesia	1.7	152	54
Mexico	1.2	-26	49
Australia	0.8	-18	21
World	**100.0**	**18**	**26**

Notes: This table combines IPCC Source/Sink Categories 1A2 (manufacturing & construction) and 2 (industrial processes). Growth rates for Russia are from 1992 (not 1990). *Projections are drawn from IEA (2004c) and include only CO_2 from fossil fuels. The projected figure for U.S. includes Canada; Australia includes New Zealand. "–" signifies no data.

SECTOR SPOTLIGHT: *Chemicals and Petrochemicals*

Chemical manufacture is the second largest energy-consuming manufacturing sector in the world,[127] and accounts for almost 5 percent of global GHG emissions (Figure 13.5). The most notable attribute of the chemicals sector is the diversity of products and production processes. As defined here, this industry includes fertilizers, pesticides, pharmaceuticals, plastics, resins, synthetic rubber, refrigerants, paints, solvents, soaps, perfumes, and synthetic fibers, as well as chemicals derived from fossil fuels, such as ethylene, propylene, and butylene.[128] GHG emissions in the chemicals sector pertain to the direct production and use of chemicals, and include direct (on-site) CO_2 emissions from fossil fuel combustion, indirect emissions from electricity consumed during production, and release of non-CO_2 gases from various industrial processes. Emissions pertaining to some chemicals may derive more from use than manufacture (e.g., HFCs).

Figure 13.5. GHGs from Chemicals and Petrochemicals



Sources & Notes: CAIT, IEA, 2004a,b. See Appendix 2.A for sources and Appendix 2.B for subsector definition. Absolute emissions in this subsector, estimated here for 2000, are 2,013 $MtCO_2$.

Chemical production is highly concentrated geographically, with the EU-25, United States, Japan, and China accounting for three-quarters of global chemical production (Figure 13.6). Corporate presence is also geographically concentrated (Figure 13.7). Of the 30 largest chemical companies, all but two are headquartered in the EU, United States, or Japan.[129]

However, because of the diversity of products, there is overall a low concentration of actors in this subsector. The 15 leading chemical companies worldwide shown in Figure 13.7 account for less than 20 percent of global sales, and often operate in very different markets, such as pharmaceuticals, petrochemicals, and basic and consumer chemicals. Small and medium-size enterprises, which may have a single facility producing a single product, are common. The EU, for instance, has 31,000 chemical enterprises, 96 percent of which have fewer than 250 employees.[130]

Some companies shown are amongst the largest in the world. German companies BASF and Bayer have operations in 74 and 61 countries, respectively, while U.S.-based Dow Chemical and Dupont each operate in 32 countries.[131] Accordingly, there is considerable cross-border investment in this sector, in part by large transnational corporations. Overall foreign direct investment in chemicals in 2002 reached $420 billion, more than a doubling since 1990, and a 20 percent share of FDI in manufacturing (the largest sector).[132] Almost 100 percent of this investment came from industrialized countries, which were also recipients of 80 percent of this investment.[133]

The international trade in chemicals has increased steadily over the past two decades, with double digit annual

Figure 13.6. Chemical Production, 2004

Country	% of World
EU-25	33.0
United States	23.4
Japan	10.4
Asia, excl. Japan & China	10.3
China	7.7
Brazil	2.7
Switzerland	2.1
Canada	1.6
Mexico	0.8
Rest of World	7.9

Sources & Notes: CEFIC, 2005. World market shares are based on value of sales, including domestic and exports. Data for Mexico is for 2003.

growth rates.[134] An estimated 30 percent of chemical production is traded across borders.[135] In 2003, chemicals constituted about 15 percent of all manufacturing exports, with a world trade value of about $800 billion (about 40 percent of which is intra-Europe).[136] Because of the diversity of products, many countries are both significant importers and exporters.

The largest importers are the U.S. (13 percent of world total), EU-15 (11 percent), and China (6 percent).[137] The largest exporters are the EU-15 (22 percent), U.S. (12 percent), Japan (5 percent), and Switzerland (4 percent).[138] Trade raises some challenges related to attribution of emissions, as chemicals traded may already have undergone GHG-intensive production processes prior to export.

Figure 13.7. Leading Chemical Companies, 2003

Company	Sales ($US billions)	Country of Origin
Pfizer	52.5	United States
GlaxoSmithKline	39.0	UK
BASF	37.7	Germany
Dow Chemical	32.6	United States
Bayer	32.3	Germany
Merck	30.9	U.S. / Germany
Novartis AG	28.2	Switzerland
DuPont	27.0	United States
AstraZeneca	21.4	UK
Shell	20.8	UK/Netherlands
ExxonMobil	20.2	United States
Total/Arkema	20.2	France
Mitsubishi Chemical	16.6	Japan
BP	15.5	UK
Akzo Nobel	14.7	Netherlands

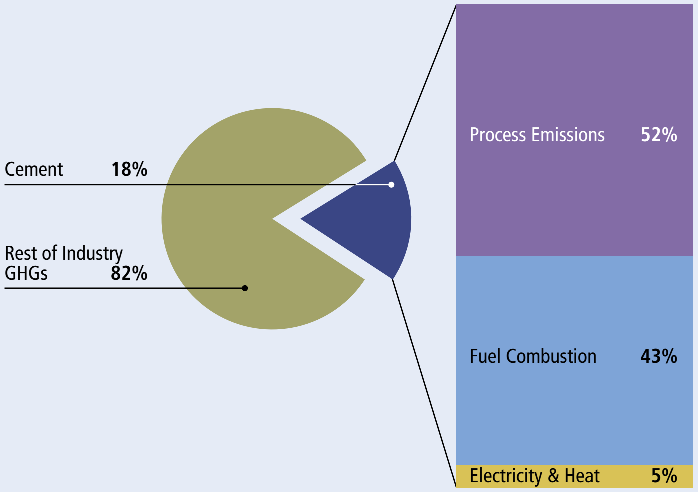
Sources & Notes: CEFIC, 2005; company reports; http://www.hoovers.com. Sales data for Pfizer, Glaxo, Merk, Novartis, and AstraZenica is from 2004.

SECTOR SPOTLIGHT: *Cement*

GHG emissions associated with cement manufacturing account for approximately 3.8 percent of global GHG emissions, and 5 percent of global CO_2. Cement amounts to about 18 percent of all manufacturing emissions, with CO_2 emitted at a variety of points in the production process, including (1) the chemical process of making clinker (a key component of cement); (2) the direct, on-site burning of fossil fuels; and (3) indirect emissions from electricity consumed during the cement production process (Figure 13.8). Although the energy-related emissions depend on the fuels used (both for direct energy use and electricity purchases), chemical process emissions do not. Generally about half of cement emissions come from the chemical process and 40 percent come from direct fossil fuel combustion, with the remainder coming from electricity purchases and on-site transport.[139]

Collectively, the top 12 cement-producing countries account for about 81 percent of the world total (Figure 13.9). China is by far the largest producer, accounting for 43 percent of the world total in 2004. In Europe, Japan, and Australia, cement production (and

Figure 13.8. GHGs from Cement Manufacture



Sources & Notes: CAIT, IEA, 2004a. See Appendix 2.A for sources and Appendix 2.B for subsector definition. Absolute emissions in this subsector, estimated here for 2000, are 1,588 $MtCO_2$.

Figure 13.9. Cement Manufacture, 2004

Country	Production (mil. tons)	% of World	% change since 1999
China	850	42.5	48
EU-25	214	10.7	-3
India	110	5.5	22
United States	97	4.8	10
Japan	69	3.5	-14
South Korea	60	3.0	25
Russia	46	2.3	62
Brazil	38	1.9	-6
Egypt	35	1.8	50
Mexico	35	1.8	19
Thailand	35	1.8	38
Turkey	34	1.7	-1
World	**2,000**		**25**

Sources & Notes: USGS, 2004; USGS, 2005. Individual EU member states not shown. Countries not among the top 25 absolute emitters are shown in italics.

Figure 13.10. Leading Cement Companies, 2003

Company	World Market Share (%)	Country of Origin
Lafarge	5.5	France
Holcim	5.0	Switzerland
Cemex	4.3	Mexico
HeidelbergCement	2.5	Germany
Italcementi	2.1	Italy
Taiheiyo	1.6	Japan

Source: Freedonia Group, 2004a.

related emissions) is stagnant or declining. The fastest growth is in East and South Asia. Cement emissions in the U.S. and Middle East are also rising significantly.

The cement sector employs a limited set of production processes and produces a limited range of products. Production processes range from "wet" to "dry" with intermediate variations, characterized by the amount of moisture content used during blending.[140] The main ingredient in cement is clinker—derived from limestone, iron oxide, silicon dioxide and aluminum oxide—and cement products are distinguished by the ratio of clinker to other additives.[141]

In terms of international exposure, the cement sector is mixed. Cement is not conducive to international trade, given the abundance of limestone and other primary materials, along with the high density and low value of cement. Less than 6 percent of global cement production is exported across borders;[142] accordingly, emissions attribution presents little difficulty.

However, cross-border investment in the cement sector is significant and growing. In particular, the sector is increasingly characterized by the presence of large, multinational firms. The growth of multinationals and foreign direct investment is also leading to a gradual increase in concentration of actors in the sector. Figure 13.10 shows the leading cement manufacturing companies. The six leading multinational companies account for an estimated 21 percent of global cement production.[143] LaFarge and Holcim, the two largest, operate in 75 and 70 countries, respectively. Factoring in China (about 43 percent of global cement production) and some other developing countries, however, suggests a sector with a much lower degree of concentration of actors. China has some 5,000 cement manufacturing facilities, many of which are rural township enterprises with low production levels.[144] There are nevertheless trends toward more private ownership, foreign investment, and consolidation, including the development of large Chinese cement conglomerates.[145]

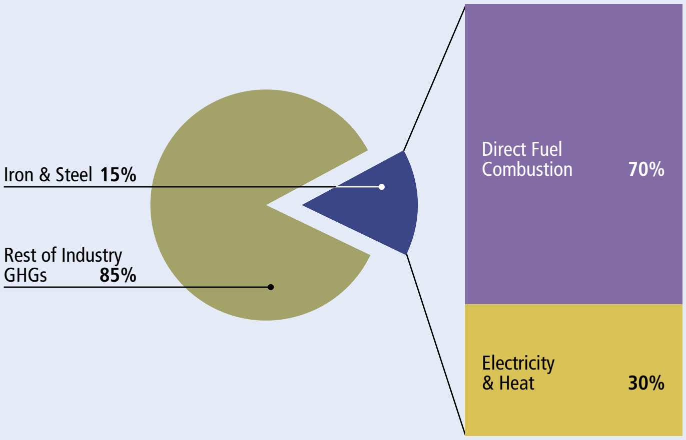
Collectively, the top 12 cement-producing countries account for about 81 percent of the world total. China is by far the largest producer, accounting for 43 percent of the world total in 2004.

SECTOR SPOTLIGHT: *Steel*

The iron and steel industry is the largest energy-consuming industry sector in the world.[146] CO_2 is emitted at a variety of points in the steel-making process, including the on-site combustion of fuels and indirect emissions from electricity and heat consumed during the production process. Taking all emissions into account, iron and steel accounts for an estimated 4.1 percent of total world CO_2 emissions, and about 3.2 percent of all GHGs.[147] Steel amounts to about 15 percent of all manufacturing emissions, with about 70 percent of emissions coming from direct fuel use and the remaining coming indirectly from electricity and heat (Figure 13.11).

Steel production techniques do not vary widely globally, and are now dominated by only two processes: integrated steel mills that use either a blast furnace-open hearth or blast furnace/basic oxygen furnace, and mini-mills that use scrap in electric arc furnaces.[148] However, there are a range of steel products, including ingots, semi-finished products, hot-rolled and cold-finished products, tubes, wire, and unworked castings and forgings, which have a wide variety of manufacturing and construction applications.

Figure 13.11. CO_2 from Iron and Steel



Sources & Notes: IEA, 2004a,b. See Appendix 2.A for sources and Appendix 2.B for subsector definition. Absolute emissions in this subsector, estimated here for 2000, are 1,319 $MtCO_2$.

Figure 13.12 presents steel production data for the leading countries. The 12 countries shown represent 90 percent of the worldwide totals. China, EU-25, and Japan are the three largest steel producers (55 percent of the global total). China's steel sector has grown at about 25 percent annually over the past few years[149] and, according to the Chinese Iron and Steel Association, is facing overinvestment and potential excess capacity.[150] Crude steel capacity, as well as production, has more than doubled since 2001 in China.[151]

In terms of both trade and investment, the iron and steel sector has gradually become more internationalized over the past few decades. Figure 13.13 lists the world's leading steel companies, ranked by production. Newly formed Mittal Steel, the world's most global steel producer, has steel-making capacity in 14 countries, including South Africa, Algeria, Kazakhstan, Trinidad and Tobago, as well as North America and Europe.[152] Other companies, such as Nippon Steel, POSCO, and most Chinese companies, do not have overseas production operations, and instead rely on trade to disseminate their products. Collectively, the top 25 steel-making companies account for roughly 42 percent of global production in 2004.[153] While the sector is characterized by many large companies, there are also a large number of small steel producers.[154]

The share of steel traded across international borders has increased steadily from 22 percent in the mid-1970s to about 37 percent in 2003.[155] This amounts to a trade product value of about $180 billion, or 2.5 percent of all global trade.[156] The largest net steel importers in 2003 were China and the U.S., at about 11 and 4 percent of world steel trade, respectively.[157] The largest exporters were Japan, Russia, and Ukraine, which accounted for 8 to 9 percent each.[158] The volume of steel trade, however, is expected to decline globally in 2005 and beyond, largely due to new production capacity located near consumption centers.[159] Chinese steel imports, in particular, have declined significantly since 2003, due to expanded domestic capacity. The steel industry's trade volume raises some difficulties in attributing emissions to specific countries, since exported products embody significant amounts of CO_2 emissions.

Figure 13.12. Steel Production, 2004

Country	Production (mil. tons)	% of World	% change since 1999
China	273	25.8	120
EU-25	193	18.3	10
Japan	113	10.7	21
United States	99	9.4	2
Russia	66	6.2	27
South Korea	48	4.5	16
Ukraine	39	3.7	41
Brazil	33	3.1	32
India	33	3.1	34
Turkey	21	1.9	43
Mexico	17	1.6	9
Canada	16	1.5	1
World	**1,057**		**34**

Sources & Notes: IISI, 2004; IISI, 2005. Individual EU member states not shown.

Figure 13.13. Leading Steel Companies, 2004

Company	Production (mil. tons)	% of World	Country of Origin
Arcelor	47	4.4	Luxembourg
Mittal	43	4.1	U.K., Netherlands
Nippon Steel	32	3.1	Japan
JFE	32	3.0	Japan
POSCO	30	2.9	South Korea
Shanghai Baosteel	21	2.0	China
US Steel	21	2.0	United States
Corus Group	19	1.8	United Kingdom
Nucor	18	1.7	United States
ThyssenKrupp	18	1.7	Italy
Riva Acciao	17	1.6	Italy
Int.'l Steel Group	16	1.5	United States
Gerdau	15	1.4	Brazil
Sumitomo	13	1.2	Japan
EvrazHolding	12	1.2	Russia

Source: IISI, 2005.

SECTOR SPOTLIGHT: *Aluminum*

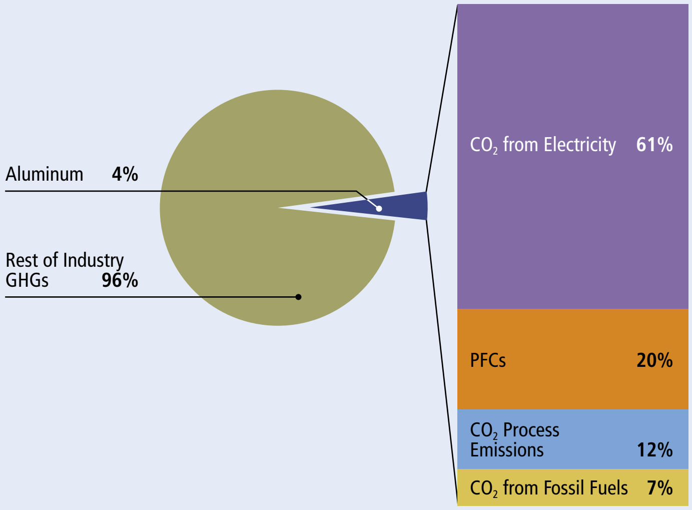
GHG emissions associated with aluminum production account for approximately 0.8 percent of global GHG emissions, which amounts to about 4 percent of all manufacturing emissions.[160] Greenhouse gases are emitted at a variety of points in the production process, including (1) fossil fuel use in the refining of bauxite (the raw material input used to produce alumina); (2) electricity consumption in the smelting process (where alumina is reduced to aluminum metal); (3) and PFC and CO_2 emissions due to chemical processes in the smelting process (Figure 13.14). Additional emissions, not factored in here, may arise from the mining of bauxite and production of a diverse array of final aluminum products, such as foils, cans, construction materials, and automotive components.[161]

Aluminum production processes and technologies do not vary widely. Most of the emissions occur in the smelting process, which requires large amounts of electricity—typically about 15,000 kilowatt hours per ton of metal produced.[162] This collectively amounts to about 2.4 percent of global electricity consumption.[163] There are only two basic smelting technologies—Söderberg and pre-bake. The phasing in of newer technologies that are variants of the pre-bake technology (Point Fed and Centre Worked Prebake plants, which now predominate) results in substantial reductions in PFC emissions.[164]

Secondary aluminum production from recycled scrap aluminum fills some 40 percent of global aluminum demand.[165] By re-melting aluminum scrap, GHG emissions are reduced more than 95 percent relative to primary aluminum production.

Like many other commodities and manufactured goods, production is dominated by a small number of countries, with 12 countries representing 82 percent of global production (Figure 13.15). China, Russia, EU-25, Canada, and the United States account

Figure 13.14. GHGs from Aluminum Manufacture



Sources & Notes: IEA, 2004a,b. See Appendix 2.A for data sources Appendix 2.B for subsector definition. Absolute emissions in this subsector, estimated here for 2000, are 324 $MtCO_2$.

Figure 13.15. Aluminum Production, 2004

Country	Production (1,000 tons)	% of World	% change since 1999
China	6,100	21.1	141
Russia	3,600	12.5	14
EU-25	2,851	9.9	4
Canada	2,640	9.1	10
United States	2,500	8.7	-34
Australia	1,880	6.5	9
Brazil	1,450	5.0	16
Norway	1,250	4.3	23
South Africa	820	2.8	19
Venezuela	600	2.1	5
World	**28,900**		**22**

Sources & Notes: USGS, 2004; USGS, 2005. EU data is based on 2003 figures. Countries not among the top 25 absolute emitters are shown in italics.

for 61 percent of total production. More than other commodities, however, aluminum production is dominated by a small number of companies, mostly multinationals. The ten leading companies produce 55 percent of the world's aluminum, with Alcan, Alcoa, and Rusal constituting one-third of global production (Figure 13.16). The 26 companies that comprise the International Aluminium Institute collectively account for 80 percent of global production.[166]

The aluminum sector is perhaps the most internationalized industry sector, in terms of both trade and investment. An estimated 45 percent of global production is exported as unwrought aluminum, with significant additional trade volumes for aluminum products.[167] The top two manufacturers, Alcan and Alcoa, each operate in more than 25 countries and have a majority of their employees working outside their home countries.[168] The international character of the aluminum sector, along with the strong concentration of multinational corporate actors, may contribute to the fact that this sector has already adopted voluntary climate change targets (Box 13.1).

Figure 13.16. Leading Aluminum Companies, 2004

Company	Primary Aluminum (1,000 tons)	% of World	Country of Origin
Alcan	3,382	11.7	Canada
Alcoa	3,376	11.7	United States
Rusal	2,671	9.2	Russia
Norsk Hydro	1,720	6.0	Norway
BHP Billiton	1,260	4.4	Netherlands
SUAL Holding	920	3.2	Russia
Comalco	837	2.9	United Kingdom
Chinalco	761	2.6	China
Dubai Alum. Co.	540	1.9	UAE
Aluminium Bahrain	525	1.8	Bahrain

Sources & Notes: Data obtained from company annual reports and websites. Alcan includes Picheney. Comalco is a division of Rio Tinto. Figures for Aluminium Bahrain are for 2003 and are derived from USGS estimates. Rusal is the Russian Aluminium Joint Stock Co. Chinalco is the Aluminum Corp. of China Ltd.

Box 13.1. The Global Aluminum Climate Change Initiative

The International Aluminium Institute (IAI) has developed a voluntary initiative on key issues related to sustainability, including climate change. The initiative is global in scope, covering IAI's 26 member companies, which collectively account for 80 percent of global primary aluminum production.

Key climate change targets include an 80 percent reduction in PFC emissions per ton of aluminum produced and a 10 percent reduction in smelting energy usage per ton of aluminum produced. Both targets apply to the industry as a whole and are to be reached by 2010 (using a 1990 base year). The IAI has a team of experts that advise and assist member companies, as well as report on the overall results.

For several reasons, this sector is unique in positioning itself at the global level to play a leadership role in climate protection. First, technological options are available to substantially reduce PFC emissions. IAI surveys show that participants have already reduced PFC emissions per unit of production in 2003 by 73 percent compared to 1990 levels. Second, aluminum is conducive to recycling, which avoids 95 percent of emissions compared to primary manufacture. Indeed, most aluminum ever produced is still in use, as the metal can be recycled and re-used continuously without deterioration in quality. Third, aluminum can replace higher density materials in transport, leading to energy efficiency improvements (and CO_2 reductions) through lighter-weight vehicles. As part of its sustainability initiative, the industry will monitor aluminum shipments for use in the transport sector. The IAI believes it is possible that aluminum will become "climate-change positive" in 20 years on a life-cycle basis.

Sources: International Aluminium Institute, 2004, 2005a,c.

CHAPTER 14

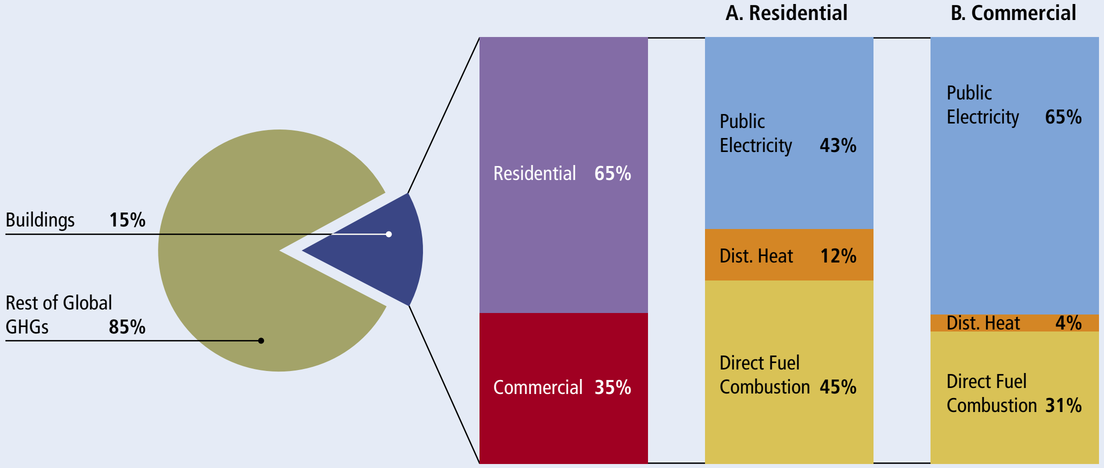
Buildings

Emissions

The buildings sector[169] encompasses both residential and commercial (including institutional) buildings. The sector accounts for 15.3 percent of global GHG emissions, including 9.9 percent for commercial buildings and 5.4 percent for residential; CO_2 accounts for nearly all emissions (Figure 14.1). Emissions from the building sector are predominantly a function of energy consumption for diverse purposes that can be organized into three broad categories: public electricity use, direct fuel combustion, and district heating.

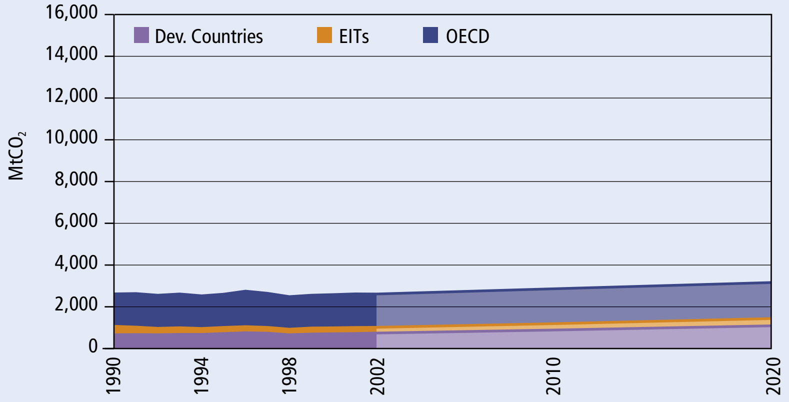
Public electricity use includes lighting, appliance use, refrigeration, air conditioning, and to some

Figure 14.1. CO_2 from Building Use



Sources & Notes: IEA, 2004a. See Appendix 2.A for data sources Appendix 2.B for sector definition. Absolute emissions in this sector, estimated here for 2000, are 6,418 $MtCO_2$.

Figure 14.2. **CO_2 from Building Use, Trends and Projections**



Source: IEA, 2004b,c.

extent space heating and cooking. These activities account for 65 percent of commercial building emissions and 43 percent of residential building emissions. Globally, the building sector is responsible for more electricity consumption than any other sector, 42 percent,[170] so to a significant extent, this sector implicates the electricity sector at large (see Chapter 11). Direct fuel consumption results primarily from space heating with modest contributions from food preparation (gas-driven cooking) as well as gas-driven air conditioning and refrigeration systems. This source accounts for 45 and 31 percent of emissions in residential and commercial buildings, respectively. District heating includes centrally operated heating (and sometimes cooling) systems that service entire cities or other large areas. Emissions arising from production of construction materials (e.g., steel, aluminum), including manufacture of appliances, are not included here.

Building sector emissions may be either *direct* (on-site), such as emissions from fuels combustion, or *indirect*, such as emissions from public electricity use and district heat consumption. Certain activities such as cooking, air conditioning, space heating and refrigeration may generate either direct or indirect emissions depending on the technology used.

The building sector encompasses a diverse set of end-use activities, which have different implications in terms of emissions reductions. Space heating, space cooling, and lighting, which together account for a majority of building energy use in industrialized countries, depend not only on the energy efficiency of temperature control and lighting systems, but also on the efficiency of the buildings in which they operate.[171] Building designs and materials have a significant effect on the energy consumed for a select set of end uses. On the other hand, building design does not affect the energy use of cooking or appliances, though these end uses are nonetheless attributed to the building sector. Appliance efficiency matters more for some end uses than for others. Water heating and refrigeration each account for significant shares of building energy use since they are in constant use. By contrast, cooking, and small appliances (including computers and televisions) generally account for only small percentages of building energy consumption, owing to their intermittent use.[172]

Emissions from the building sector vary widely by country in both absolute and per capita terms (Figure 14.3), and depend greatly on the degree of electrification, the level of urbanization, the amount of building area per capita, the prevailing climate, as well as national and local policies to promote efficiency. In addition, building sector emissions vary by composition (Figure 14.4), reflecting different space heating needs and carbon intensities in the electricity sector (Chapter 11). For example, building emissions in Australia and South Africa consist almost completely of electricity use due to the predominance of coal used for electricity production, while the electricity shares of emissions in France and Brazil are much lower, due to their reliance, respectively, on nuclear and hydropower. District heat use is concentrated in the transition economies of Russia, Ukraine, and Poland, as well as in Scandinavian countries.

There is an important correlation between building emissions and socioeconomic development levels (Chapter 7). In general, building emissions are higher in industrialized countries, both in per capita terms (Figure 14.3) and as a percentage of total country emissions (Figure 14.5) with variances due to climate, fuel mix and other factors. Thus, development has an important effect on emissions from the building sector, implying that building efficiency becomes more significant as countries become more prosperous.

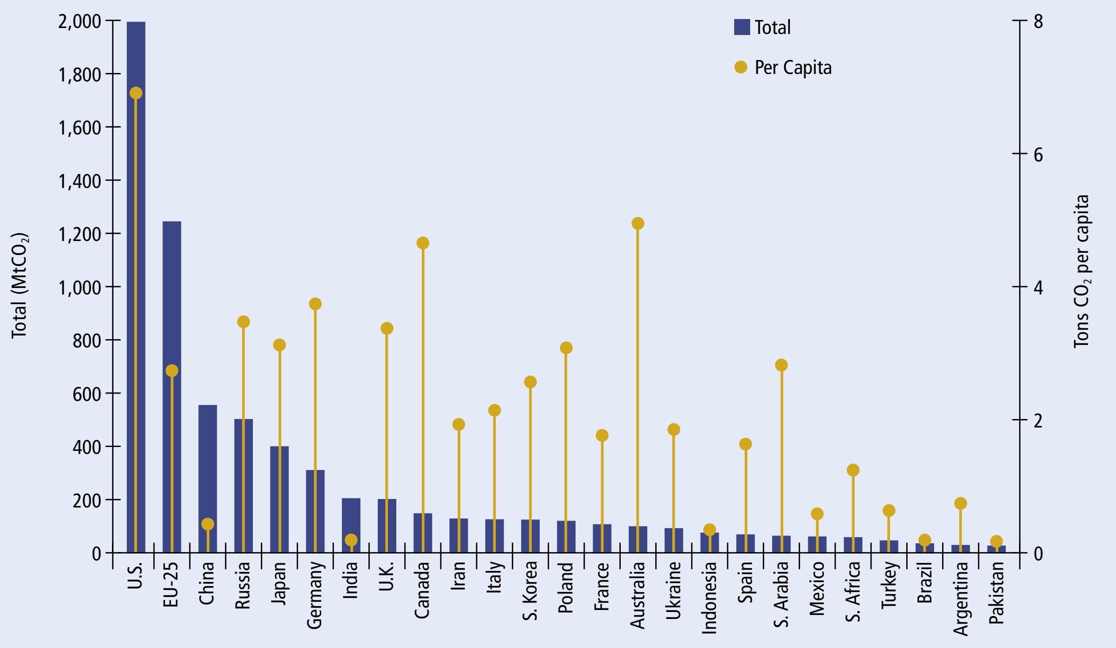
In the development context, it is important to distinguish between new building construction and existing building stock. New construction can more easily incorporate efficient materials and technologies, and owing to the long life cycle of buildings, is a strong indicator of future emissions trends.[173] New construction is projected to grow by 7 percent annually in China and 5 percent annually in India and Southeast Asia, compared to only 2 percent in the United States, Western Europe and Japan.[174] Building efficiency directly impacts at least half the emissions from end uses (space heating, cooling and light combined) in the building sector. Therefore, the importance of building sector emissions is especially significant in key developing countries, owing both to projected shifts in sectoral composition and rapid new construction with attending opportunities to employ efficient materials and best practices.

Sector Context

Analysis of the building sector produces mixed conclusions, owing to the diversity of influences and end uses that the sector embodies. International trade and a small number of multinational corporations play a significant role in the production and distribution of most building appliances, including cooking appliances, lighting, heating, and cooling systems. However, the opposite is true for building construction, which is dominated by small local firms. Many materials essential to building efficiency, such as cement and timber, are not heavily traded (aluminum and steel are notable exceptions), and building practices and materials vary widely depending on available resources, customs, and prevailing climate.

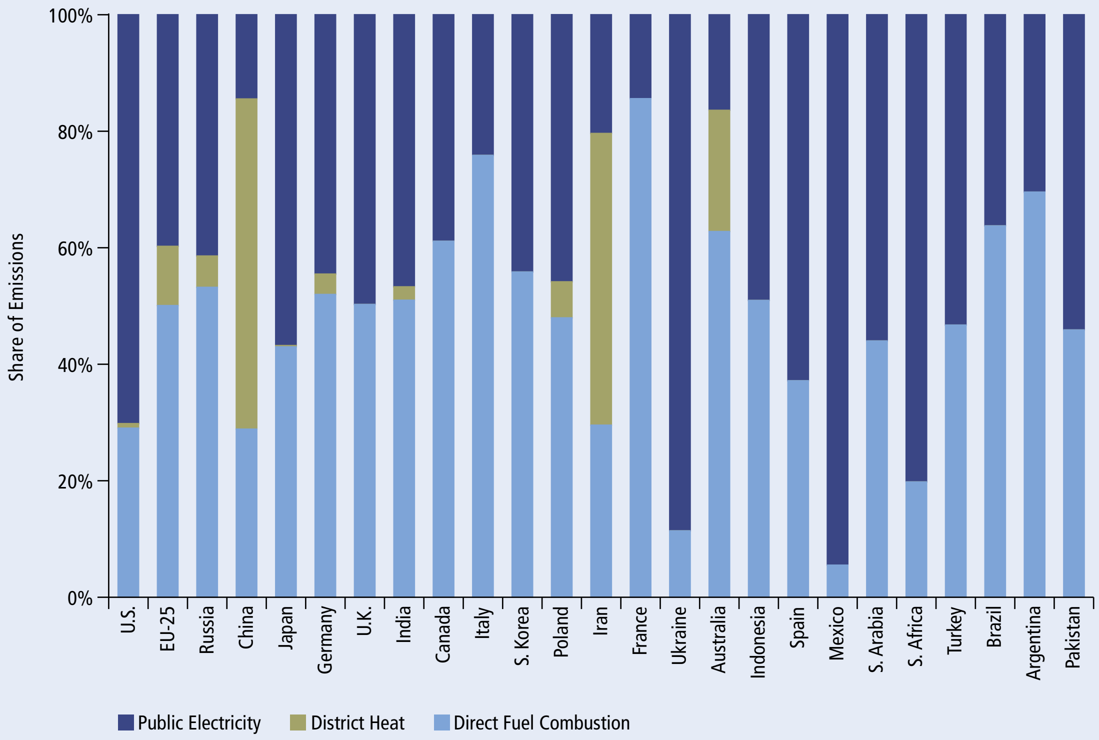
One consistent quality in the building sector is that it is subject to a high degree of regulation. Building codes often influence material use, and appliance standards, both mandatory and voluntary, have a significant effect on energy efficiency. Regulatory regimes, to the extent that they exist, may therefore provide a pathway to improve efficiency for both building construction and a variety of building appliances. Furthermore, government operations in commercial buildings often constitute a significant share of total building use, as government activity at all levels is building-dependent. By choosing energy efficient designs and materials for their own use, governments can thus exert significant influence over the building sector as a whole.

Figure 14.3. CO_2 from Building Use, Total and Per Capita, 2002
Top 25 GHG emitters



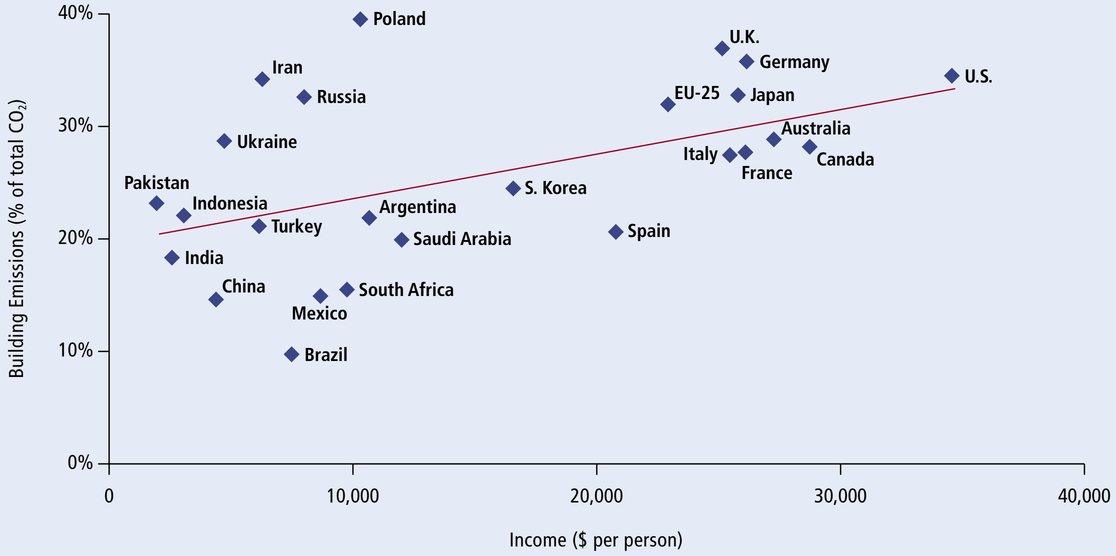
Sources: IEA, 2004a,b.

Figure 14.4. **Relative Shares of CO_2 Emissions from Building Use, 2002**
Top 25 GHG emitters



Source: IEA, 2004a,b.

Figure 14.5. **Correlation of Socioeconomic Development and Building Sector Emissions, 2002**
Top 25 GHG emitters



Sources & Notes: WRI, based on CAIT, IEA 2004b. The red trend line depicts the best fit correlation between per capita income and share of building emissions. Total CO_2 excludes emissions from land-use change and forestry and from international bunker fuels.

CHAPTER 15

Agriculture

Emissions

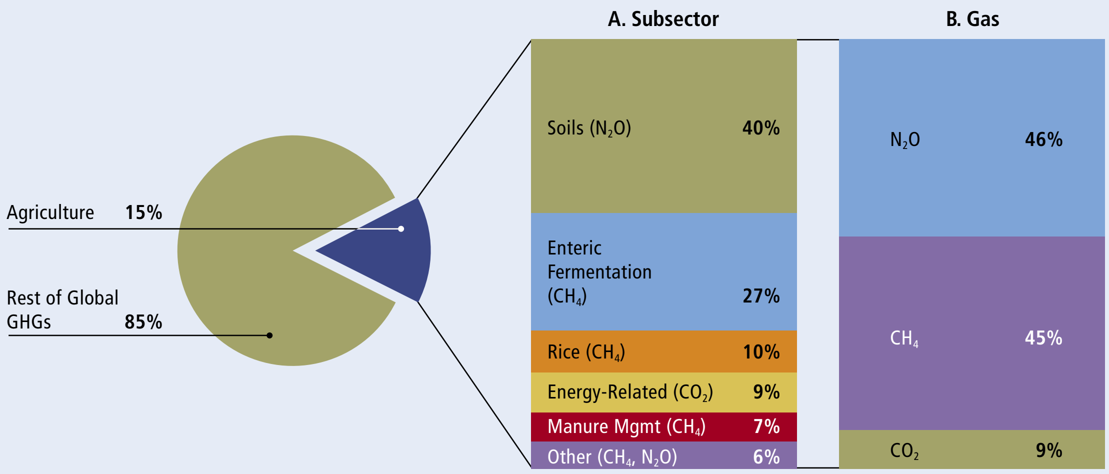
Emissions from agricultural activities[175] account for about 15 percent of global GHG emissions (Figure 15.1). This amount is divided roughly evenly between CH_4 and N_2O (about 45 percent each), with CO_2 from fossil fuel combustion and electricity use accounting for the remaining share. At the activity level, the largest agricultural source is soils management (40 percent of the sector total), where emissions result from particular tillage and cropping practices, such as fertilizer application.[176] The second largest source is methane emissions from livestock (27 percent of the agriculture total), which is a byproduct of the normal digestive process of cattle and other livestock. Other important agriculture sources are wetlands rice cultivation (CH_4) and manure management (CH_4). Agriculture also contributes to CO_2 through land clearing and the burning of biomass. Due to data limitations and classifications, however, these latter contributions are not readily quantifiable, or are included in the land-use change sector (Chapter 17).

Figure 15.3 and Table 11 show GHG emissions from agriculture for the major GHG-emitting countries. Together, these countries account for 72 percent of global emissions from agriculture. China and India, the two largest emitters, together account for 29 percent of the global total. The United States, EU-25, and Brazil together account for another 25 percent. All other countries individually constitute less than 2 percent of the world total.

Sector Context

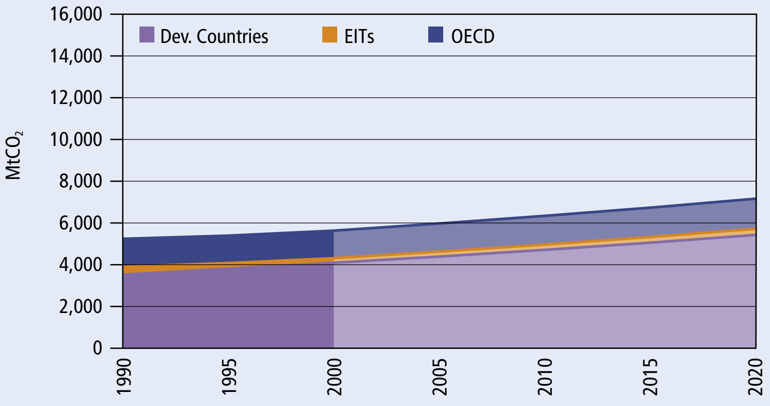
Agriculture's importance to national economies differs greatly across countries (Figure 15.4). In India, China, and Indonesia, agriculture constitutes between 15 and 23 percent of GDP, and is a source of employment for half to two-thirds of the workforce. In industrialized countries, by contrast, agriculture is between 1 and 4 percent of GDP and

Figure 15.1. GHGs from Agriculture



Sources & Notes: EPA, 2004. See Appendix 2.A for data sources Appendix 2.B for sector definition. Absolute emissions in this sector, estimated here for 2000, are 6,205 $MtCO_2$.

Figure 15.2. GHGs from Agriculture, Trends and Projections

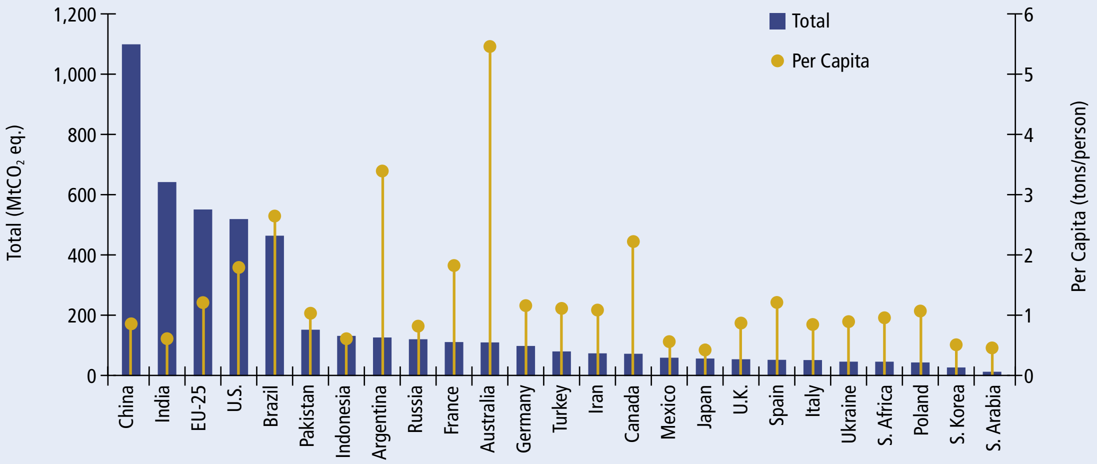


Source: EPA, 2004.

the workforce. Agriculture production is highly decentralized, consisting of loosely organized individuals and small interests, with few multinational companies involved in production. Likewise, agriculture techniques and processes vary greatly, not only by crop or livestock type, but according to local ecosystems, soil quality, labor availability, and custom. However, certain agricultural practices such as cropping techniques (for example, no-till), crop switching, and irrigation practices may be transferable.

Agricultural products are heavily traded. In 2003, world trade in agricultural products totaled $674 billion, amounting to 9 percent of all global trade.[177] The level of trade in agriculture leads to difficulties in attribution of responsibility, since food consumption in importing countries is indirectly responsible for agriculturally based emissions in food exporting countries. In addition, emissions measurement in the agriculture sector is problematic. Methodologies rely on estimates of crop harvests, levels of irrigated land, and numbers of livestock. The accuracy of these indicators and their emission factors are often uncertain, especially for developing countries with sizable agriculture production.

Figure 15.3. **CO_2 from Agriculture, Total and Per Capita, 2000**
Top 25 GHG emitters



Sources & Notes: WRI, based on CAIT and IEA, 2004a. CO_2 emissions are from direct fossil fuel combustion only.

Figure 15.4. **Agriculture and the National Economy**
Selected major emitters

Country	% of GDP	% of workforce
India	23	59
Indonesia	17	47
China	15	66
Argentina	11	9
Russia	6	10
South Africa	4	9
Mexico	4	20
S. Korea	4	9
Australia	3	4
France	3	3
United States	2	2
Japan	1	4

Sources & Notes: World Bank, 2005; CAIT-V&A 1.0. Data is from 2001 and 2002.

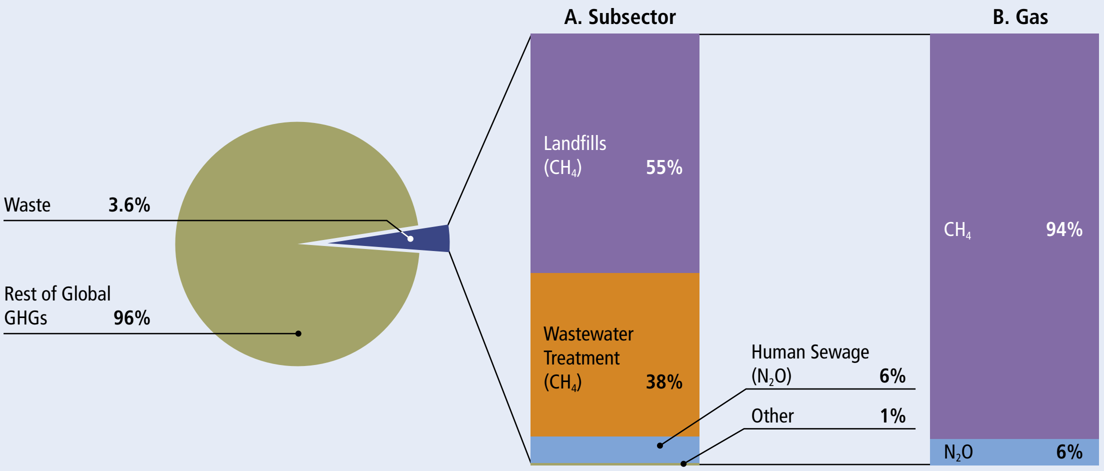
CHAPTER 16

Waste

Emissions

Emissions from waste[178] account for just under 4 percent of global GHG output (Figure 16.1). The largest source of emissions from this sector is landfilling of solid waste, which emits CH_4. Emissions here result from anaerobic decomposition of organic matter. These emissions can also be captured as natural gas and channeled to productive purposes. Handling and treatment of wastewater, which also emits CH_4, is the second largest source. A small share of waste emissions also comes from N_2O from treatment of human sewage. Overall, CH_4 accounts for a vast majority of emissions from this sector, at more than 90 percent. It

Figure 16.1. GHGs from Waste



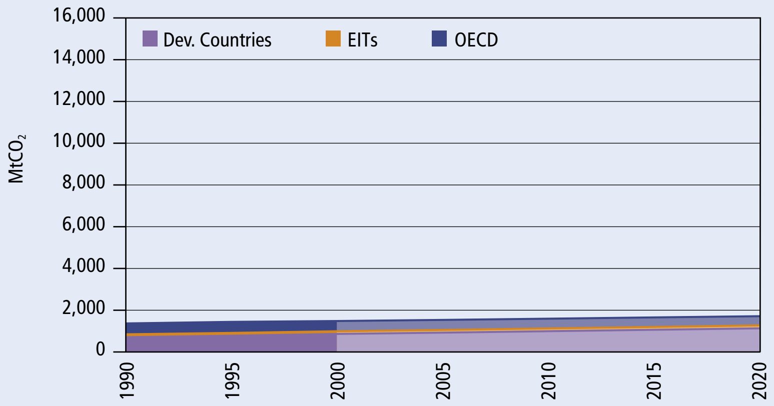
Sources & Notes: EPA, 2004. See Appendix 2 for sector definitions and data sources. Absolute emissions in this sector, estimated here for 2000, are 1,484 $MtCO_2$.

should be noted, however, that data uncertainties are likely to be high in this sector, as with agriculture and LUCF. Data from the waste sector is also less complete than others in terms of country coverage. Figure 16.3 shows GHG emissions from waste for the major GHG-emitting countries. The largest shares come from the United States and EU.

Sector Context

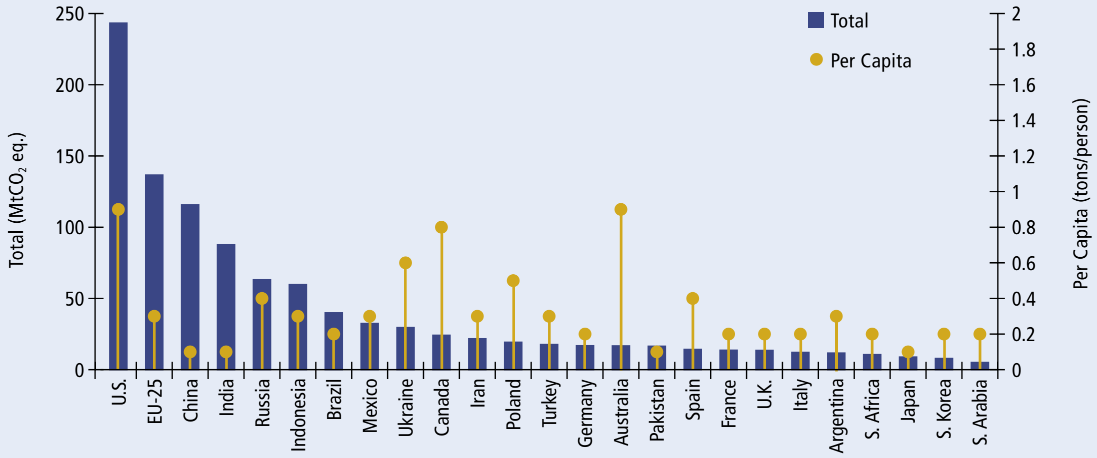
Waste disposal is typically a public sector function, often at the local or municipal level. This includes the operation of solid waste disposal sites as well as treatment facilities for industrial and residential wastewater. Accordingly, international competition and trade are not significant factors, nor are concerns over attribution, and actors tend to be dispersed at the local level.

Figure 16.2. GHGs from Waste, Trends and Projections



Source: EPA, 2004.

Figure 16.3. GHGs from Waste, Total and Per Capita, 2000
Top 25 GHG emitters



Source: WRI, CAIT.

CHAPTER 17

Land-use Change and Forestry

Emissions

An estimated 18 percent of global GHG emissions (and 24 percent of CO_2 emissions) are attributable to land use change and forestry (LUCF)[179] (Figure 17.1). This contribution is the largest for any single sector, with the exception of electricity and heat. Estimates reflect the CO_2 flux (emissions and sink absorptions) from the following activities: land clearing for permanent croplands (cultivation) or pastures (no cultivation), abandonment of croplands and pastures (with subsequent regrowth), shifting cultivation,[180] and wood harvest (industrial and fuelwood).[181] The largest source is deforestation driven by the conversion of forest to agricultural lands, primarily in developing countries (Figure 17.2).

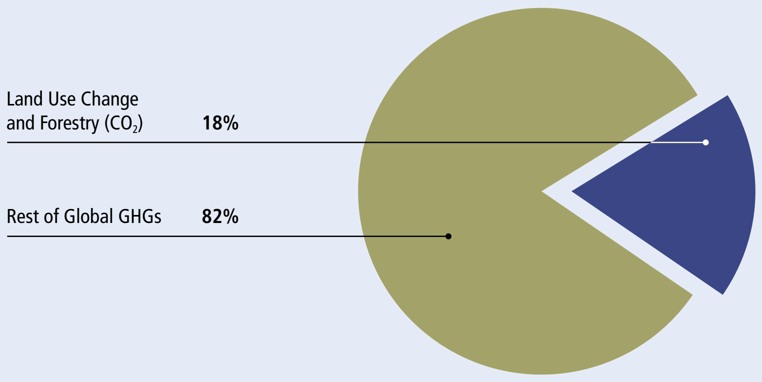
Emissions and absorptions from LUCF have several unique characteristics. First, the pattern of emissions and absorptions across countries is unlike any other sector (see Figure 17.3). Most countries have very small fluxes, either slightly positive or slightly negative (that is, sequestering more CO_2 than they emit in this sector). A majority of LUCF emissions come from tropical countries;[182] estimates by Houghton (2003a) suggest that the largest sources are Indonesia and Brazil, with 34 percent and 18 percent, respectively, of the global total. Some countries that are not among the largest overall GHG emitters account for significant shares of the global total from land-use change and forestry. They include Malaysia, Myanmar, and the Democratic Republic of Congo. For developing countries collectively, CO_2 from LUCF constitutes an estimated one-third of total emissions (see Chapter 2).

Industrialized countries, on the other hand, are presently believed to be net *absorbers* of CO_2. This is due to land clearing in North America and Europe prior to the 20th century. During these periods, deforestation emitted significant quantities of CO_2, while today's forests are absorbing CO_2 through natural regrowth. Thus, the profile of emissions across countries has changed significantly over time. Estimates for 1875 show North America, Europe, and the former Soviet Union contributing more than two-thirds of global LUCF emissions during that time period.[183]

Second, a unique characteristic of the sector is that emissions and absorptions of CO_2 in the terrestrial biosphere depend on complex interactions between the carbon cycle, nutrient cycles, and the hydrological cycle.[184] Each of these can be influenced by human activities, though it can be difficult to discern what effects are said to be "human induced."

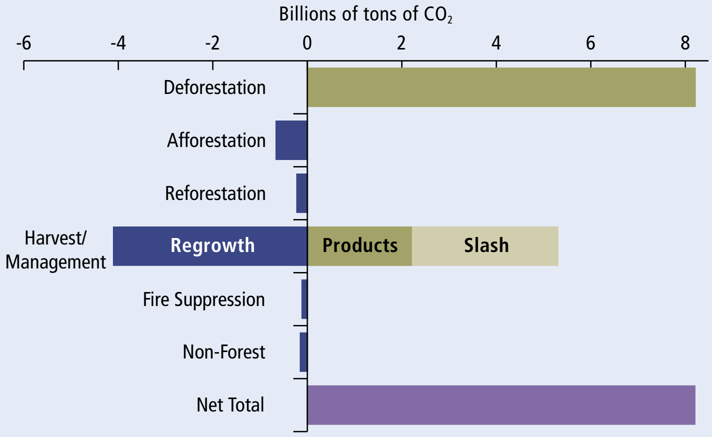
Third, and related, emissions data from the land-use change and forestry sector are subject to extraordinary uncertainties.[185] The IPCC estimates that, during the 1990s, global LUCF emissions aver-

Figure 17.1. CO_2 from LUCF



Sources & Notes: CAIT, based on Houghton, 2003a. See Appendix 2 for sector definitions and data sources. Absolute emissions in this sector, estimated here for 2000, are 7,619 $MtCO_2$.

Figure 17.2. Annual Emissions and Absorptions from Land-Use Change Activities, *Global estimates for the 1990s*



Sources & Notes: Houghton, 2003b. Deforestation and reforestation in tropical countries include only the net effect of shifting cultivation. For afforestation, areas of plantation forests are not generally reported in developed countries (this estimate includes only China's plantations). Fire suppression is probably an underestimate, as it includes the U.S. only (similar values may apply elsewhere). Non-Forests include CO_2 from agricultural soils, but only resulting from cultivation of new lands.

aged 1.6 gigatons (GtC) per year ±0.8 GtC.[186] The 1.6 GtC figure amounts to 20 percent of global CO_2 emissions.[187] Taking uncertainties into account, CO_2 from LUCF may be as little as 0.8 GtC (12 percent of world emissions) or as high as 2.4 GtC (28 percent), a difference of a factor of three. Estimates used here, based on Houghton and Hackler (2002) and Houghton (2003b), amount to 2.2 GtC per year (26 percent of CO_2 in the 1990s), which is in the upper range of IPCC estimates. This sector also includes emissions and removals of CH_4 and N_2O, although there are no reliable global estimates of the influence of these gases on the LUCF sector.[188]

Uncertainties increase further for national-level figures, where estimates are uncertain on the order of ±150 percent for large fluxes, and ±180 $MtCO_2$ per year for estimates near zero.[189] A comparison of the data presented here with the official data submitted by governments to the UNFCCC helps illustrate the uncertainties (Figure 17.4). In some cases, the two sources are close in their estimate (for example, Mexico and some small countries). However, for large emitters and absorbers, the estimates are significantly different, most notably in Indonesia, Brazil, and the United States. In some cases, such as China, India, and Argentina, the data submitted by governments show a negative source (that is, a net sink) of CO_2, whereas other sources report a positive emissions source.

A final characteristic of LUCF is that absorptions, by definition, are reversible. If a forest absorbs CO_2 during a given year, those absorptions may be returned to the atmosphere in any subsequent year. This reversal may be due to human drivers, such as deforestation, or natural causes such as fires or forest die off. The non-permanence of claimed emission reductions in this sector poses technical and legal challenges within policy-making contexts.

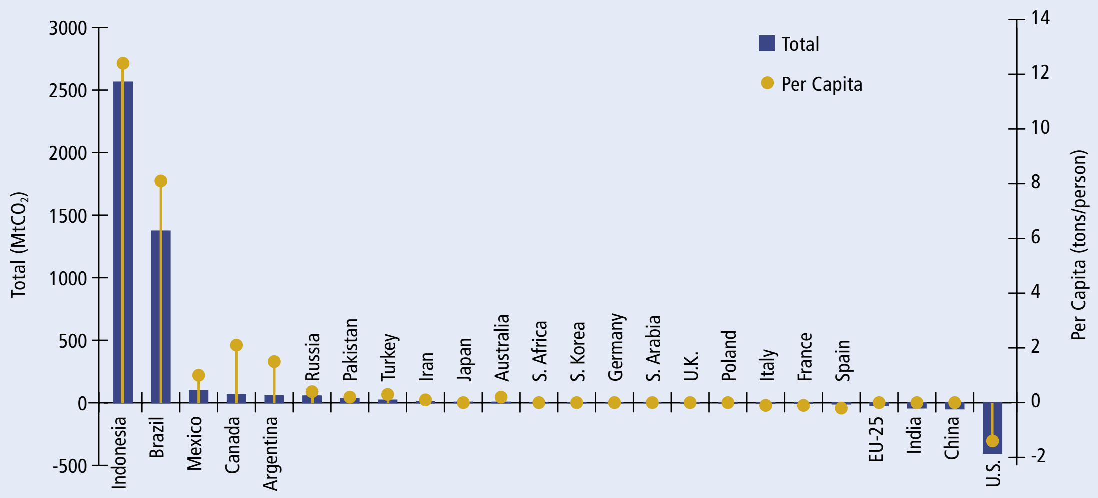
Sector Context

The land-use change and forestry sector, more than others, is difficult to characterize at the global level. The circumstances in tropical countries, for instance, have little in common with those in industrialized countries other than some ecosystem characteristics.

In the developing world, this sector is closely connected with poverty and human development, including through agriculture and energy use (biomass). The practice of converting forest land to agricultural land, noted above, is widespread. Likewise, wood energy—usually in the form of fuelwood or charcoal—is the most important source of energy for 2 billion people, mostly the poor that lack access to modern energy services.[190] In numerous other ways, forests directly influence livelihoods in developing countries, notably through eco-tourism and harvesting of forest products—such as timber, rubber, coconuts, bamboo, and palm oil—for both local use and export.

The degree to which different forces, such as those described above, are driving worldwide CO_2 emissions in this sector is not well known, in part because of measurement uncertainties noted previously. However, the available evidence suggests that there are a diffuse set of processes, products, and actors that contribute to forest degradation and consequent CO_2 emissions, though as noted above emissions seem to be concentrated in relatively few countries.

Figure 17.3. CO$_2$ from Land-Use Change, Total and Per Capita, 2000
Top 25 GHG emitters

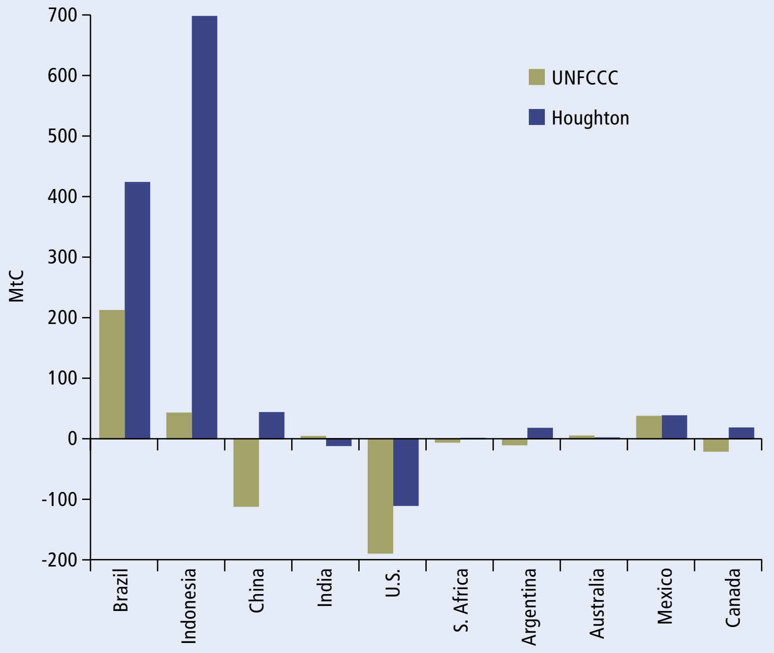


Source: WRI, CAIT (based on Houghton, 2003a).

Government intervention in the forest sector is high. Generally, forests are viewed as a sector to be managed by governments, and in many cases the government itself owns most forested lands.[191] Since the 1990s, however, more governments in both the developed and developing worlds are privatizing forest resources as a means of improving economic performance and raising revenue.[192] Privatization takes many forms, including transferring land ownership, concessions and leases, volume permits or standing timber sales, outsourcing, and community-based approaches.[193] One consequence of this trend is increased ownership and administration of forests by local communities. As characterized by the FAO, "[i]n general, policy and regulatory functions remain with central governments, while the private sector and civil society are taking charge of operations."[194] However, it should be noted that regulatory effectiveness may be weak, as illegal logging and noncompliance with forestry law is not uncommon, particularly in certain tropical countries.

The forestry sector, like agriculture, is both local in nature but also subject to international trade. This primarily takes the form of international demand for forest products[195]—including roundwood, sawnwood, pulp, and paper—although it is not clear to what degree this demand is the primary driver of CO$_2$ emissions in this sector (compared to say, forest clearing for agriculture). Forest products are estimated to contribute to about 1.2 percent of world GDP, and 3 percent of international merchandise trade.[196] Trade volumes are expanding, with the largest importers for these products being Europe, the U.S., and China.[197] The relationship between international trade and sustainable forest management has led to a variety of responses, such as certification of forest management, product labeling, and a range of trade-related measures.[198]

Figure 17.4 Comparisons of LUCF Estimates



Sources & Notes: Houghton, 2003a; CAIT-UNFCCC. UNFCCC data is taken from national communications (developing countries) and national inventories (industrialized countries). Estimates from U.S., Canada, and Australia are for 2000; Mexico is from 1990, and others are from 1994.

Endnotes

[1] This section draws largely on IPCC, 2000a; IPCC, 2001a,b; den Elzen and Meinshausen, 2005.

[2] Such an emissions reduction would achieve a 2° C target with a probability exceeding 85 percent. The reduction figure excludes emissions from land-use change and forestry. Significant climate damages may still be associated with a 2° C increase in global temperatures. See den Elzen and Meinshausen, 2005.

[3] Author calculations, based on Marland et al., 2005 and Houghton, 2003a.

[4] Author calculations, based on Marland et al., 2005 and Houghton, 2003a.

[5] Author calculations, based on BP, 2005.

[6] Author calculations, based on BP, 2005.

[7] Activities related to land-use change and forestry could also be included here (for example., land clearing). However, the data in this sector does not permit a more detailed analysis.

[8] Measured in carbon dioxide equivalent units, using 100-year global warming potentials from IPCC (1996).

[9] Official GHG inventories submitted by Parties to the UNFCCC are used only sparingly. The primary reason is that UNFCCC data has very limited geographic and temporal coverage.

[10] Most analyses of GHG emissions focus solely on CO_2 from fossil fuel combustion because it is the largest source, and because the data record is the longest, most comprehensive, and most precise. The figures here are more inclusive.

[11] Cement emissions here refer to emissions resulting from the chemical process of cement manufacture. See Chapter 13.

[12] Author calculations, based on BP, 2005. According to BP, China's total primary energy consumption increased 34 percent over the 2003 to 2004 period.

[13] Author calculations, based on BP, 2005. Global growth over the two-year period is estimated at 2.4 billion tons CO_2, with China's increase estimated at 1.3 billion tons.

[14] These figures differ from those in Figure 2.8 because of the inclusion of all gases. Coverage of six gases for the 1990 to 2002 period is not possible for most countries due to lack of data.

[15] IPCC, 2000a.

[16] IPCC, 2000a.

[17] EIA, 2003.

[18] IEA, 2004c, includes a reference case projection for world emissions in 2030 that is 62 percent above 2002 levels. Emissions are projected to grow 41 percent by 2020.

[19] EIA, 1995.

[20] *See supra*, note 2.

[21] *See e.g.*, IPCC, 2001b.

[22] For a discussion, see Kim and Baumert, 2002.

[23] *See e.g.*, Agarwal et al., 1999; Meyer, 2000.

[24] UNFCCC, 1992. Art. 3.2.

[25] Emission intensities can also be fashioned for some sectors (discussed in Part II), such as CO_2 per kilowatt hour of electricity generation or CO_2 per ton of steel produced.

[26] An analysis of GHG intensities over the 1990 to 2002 period, which would include all gases, is not possible for most countries due to lack of non-CO_2 data for the period after 2000.

[27] Author calculations, based on BP (2005) suggest increases in CO_2 emissions of 17.6 percent in 2003 and a further 14.9 percent in 2004. Reported GDP growth rates in China are in the 8 to 9 percent range.

[28] In Brazil, the rapid increase reflects at least in part the recent effort to diversify the electricity mix, moving from large hydropower to natural gas.

[29] *Greenhouse gas* intensity is the ratio of all GHG emissions per unit of gross national product. *Carbon* intensity reflects only the portion of total GHG emissions arising from fossil fuel combustion. It captures the majority of emissions in most cases and can be more accurately calculated.

[30] In reality, both hydropower (WCD, 2000) and biomass use (see Chapter 17) may entail significant emissions.

[31] Some of these shifts may be a result of data deficiencies. In some countries (e.g., India and Nepal), for instance, energy consumption may be shifting away from traditional fuel use (such as biomass) toward commercial fuel use (fossil fuels). Energy use increases may be overstated because there is a tendency for traditional fuel use to not be captured in some energy data, whereas commercial energy use is captured.

[32] Using available data, statistical correlations were estimated for (1) changes in emissions of non-CO_2 gases and changes in GDP, and (2) changes in emissions of CO_2 from fossil fuels and changes in GDP. The linear correlation measure for (1) was 0.29 (360 data points). The correlation for (2) was 0.49 (370 data points).

[33] Bouille and Girardin, 2002.

[34] Bouille and Girardin, 2002.

[35] Kim and Baumert, 2002.

[36] Updated WRI calculations, based on WRI, 2003b.

[37] WRI, 2003b.

[38] Kim and Baumert, 2002.

[39] Marland et al., 2005. CO_2 emission estimates for the period prior to 1850 are available, but for only a few countries.

[40] Methodologies for concentrations and temperature indicators follow a simple methodology that was applied in the original Brazilian Proposal and was recommended as the preliminary default by the UNFCCC expert group (UNFCCC, 2002). For more information, see WRI, 2005b.

[41] Uncertainties are found in precisely attributing temperature increases to change in concentrations, and to attributing concentration changes to changes in cumulative emissions. See Aldy et al., 2003; UNFCCC 2002; WRI, 2005b for details.

[42] Regional estimates, however, extend back to 1850. Houghton and Hackler, 2002.

[43] *See e.g.*, UNFCCC, 1997; La Rovere et al., 2002.

[44] UNFCCC, 2002a.

[45] Marland et al., 2005.

[46] GDP figures are measured in terms of purchasing power parity, in constant 2000 international dollars. World Bank, 2005.

[47] Disparities are significantly larger when income is compared using market exchange rates. Comparisons are visible in CAIT.

[48] UNDP, 2003.

[49] This figure for Ukraine, however, is from 1990 to 2000 due to lack of GDP estimates for earlier periods.

[50] IEA, 2004c. Figure pertains to 2002.

[51] UNFCCC, 1992, Art. 3.4.

[52] UNFCCC, 1992, Art. 3.1. Emphasis added.

[53] *See* Willems and Baumert, 2004.

[54] UNFCCC, 2002b: at ¶ 161 Problems reported include lack of quality data, lack of technical and institutional capacity, and problems related to methodologies.

[55] *See e.g.*, Jacobson and Brown Weiss, 1997: 100-01 (discussing as a "crucial factor" a country's "administrative capacity," which has numerous dimensions, including skill, financial support, legal authority, and access to information).

[56] For a discussion, see WRI, 2005b. For more in-depth analysis, see Neumayer (2002) and Schipper et al. (2000).

[57] The "degree-day" is a measure commonly used to evaluate demand for heating and cooling services. The measure is based on departures from an average temperature of 18 °C (65 °F), a base temperature considered to have neither heating nor cooling requirements. For underlying climatic data sources and methodologies, see WRI (2003).

[58] Some hydropower installations, it should be noted, can result in significant emissions of greenhouse gases, particularly dams in tropical countries. See WCD, 2000.

[59] BP, 2005.

[60] IEA, 2004c: 169.

[61] Author calculations, based on IEA, 2004b and BP, 2005. Australia's share of exports is about 30 percent of the world total; Japan's share of imports is about 25 percent of the world total.

[62] Bosi and Riey, 2002: 13. Coking coal represents almost 30 percent of world trade in coal, but less than 15 percent of coal production. IEA, 2004b.

[63] IEA, 2004c: 169.

[64] Author calculations, based on BP, 2005.

[65] Author calculations, based on BP, 2005.

[66] Author calculations, based on IEA, 2004b.

[67] Author calculations, based on IEA, 2004b.

[68] Author calculations, based on BP, 2005.

[69] Author calculations, based on BP, 2005.

[70] IEA, 2004c: 81.

[71] Author calculations, based on BP, 2005.

[72] Author calculations, based on BP, 2005.

[73] BP, 2005.

[74] IEA, 2004c: 129.

[75] See the U.S.-led Methane to Markets Partnership as a possible nascent example of such an initiative. Information available online at: http://www.methanetomarkets.org/.

[76] World Bank, 2005. Exports and imports each represented 12 percent shares of GDP in 1960, and 24 percent shares in 2002. The pace of trade growth relative to GDP growth has increased since 1990. See WTO (2004) regional tables pertaining to trade and GDP developments.

[77] World Bank, 2005.

[78] World Bank, 2005. Based on most recent year, 2002 or 2003.

[79] World Bank, 2005. Based on most recent year, 2002 or 2003.

[80] Ahmad, 2003: 21.

[81] BP, 2005.

[82] Bosi and Riey, 2002. Industrialized countries here refer to the IEA countries (identical to OECD, but excluding Iceland, Mexico, Poland, and Slovakia). See http://www.iea.org.

[83] Bosi and Riey, 2002: 43. This figure is for 1999.

[84] Bosi and Riey, 2002: 43. Based on data from 1999.

[85] *See* Baumert and Goldberg, 2005.

[86] On sectoral crediting mechanisms, see e.g., Samaniego and Figueres, 2002; Bosi and Ellis, 2005.

[87] *See* IPCC, 2001c: 10, 11, 542-43.

[88] *See* IPCC, 2001c: 10, 11, 542-43.

[89] For a comprehensive examination of leakage and spillover effects, see Sijm et al., 2004.

[90] Aviation measurement problems pertain less to emissions than *radiative forcing*. See Chapter 12.

[91] "Electricity & Heat," as used here, corresponds to IPCC Sector/Source category 1A1 (IPCC, 1997). Contents are described in Appendix 2.A. It includes electric power and heat plants (primarily but not exclusively public plants) and "other energy industries."

[92] "Other energy industries" includes emissions from fuel combusted in petroleum refineries and in fossil fuel extraction (IEA, 2004).

[93] Author calculations, based on IEA, 2004b.

[94] Author calculations, based on IEA, 2004b.

[95] For example, in an examination of 15 OECD countries, estimated coal-fired electricity generation efficiency ranged from 33.1 percent (United States) to 43.5 percent (Denmark) in 2000. Phylipsen et al., 2003.

[96] Author calculations, based on IEA, 2004b.

[97] Author calculations, based on IEA, 2004b.

[98] Bosi and Riey, 2002: 23-24.

[99] This was made possible by the 1992 Energy Policy Act, which liberalized international investment rules for U.S. utilities. *See* EIA, 1997.

[100] EdF, 2005.

[101] AES, 2005.

[102] Eskom, 2004.

[103] WCD, 2000. These emissions are characterized by large uncertainties and poorly developed measurement methodologies. They are usually unaccounted for in GHG emissions inventories and statistics.

[104] "Transport," as used here, pertains to IPCC Source Category 1A3, but also includes a small amount of energy-related CO_2 emissions from indirect sources (1A1), mainly electricity for rail transport. *See* Appendix 2.B.

[105] Ng and Schipper, 2005.

[106] Author calculations, based on IEA, 2004c.

[107] WTO, 2004: 101.

[108] WTO, 2004: 137.

[109] WTO, 2004: 140. The EU figure includes only extra-EU-15 exports. Including intra-EU trade, the product value is $371 billion.

[110] Author calculations, based on UNIDO, 2005. The calculations include ISIC classes 3410, 3420, and 3430.

[111] WTO, 2004: 140.

[112] Author calculations, based on UNIDO, 2005. EU countries sampled are Italy, Spain, U.K., France, and Germany.

[113] Author calculations, based on UNIDO, 2005.

[114] There are non-trivial impacts of international road traffic in Europe. This includes some gravitation toward purchasing fuels in low-priced countries, which has only a small impact in large countries, but a significant impact in some smaller countries like Luxembourg. In addition, roughly 10 percent of all trucking in continental Europe represents international transit traffic.

[115] Under IPCC Guidelines (IPCC, 1997), emissions from international aviation are not counted against national emission totals and are not classified under national emissions from transport.

[116] Author calculations, based on IEA, 2004a.

[117] IPCC, 1999: 3.

[118] IPCC, 1999: 3.

[119] IPCC, 1999: 8. This figure reflects projected growth in all other sectors as well.

[120] IPCC, 1999: 8.

[121] E-mail correspondence with Michael Metcalf, President of International Society of Transport Aircraft Trading, February 11, 2005.

[122] Airbus 2004; Embraer, 2004.

[123] Author calculations, based on UNIDO, 2005. Based on ISIC class 3530, 2001 data; includes spacecraft.

[124] Author calculations, based on UNIDO, 2005. Based on ISIC class 3530, 1999-2002 data; includes spacecraft.

[125] "Industry," as used here, covers *energy*-related CO_2 emissions from direct sources (IPCC Source Category 1 A 2) as well as *industrial process*-related GHG emissions (IPCC Source Category 2). Where possible, indirect CO_2 emissions from electricity and heat are also included in this sector definition. *See* Appendix 2.B.

[126] WTO, 2004: 101. This figure includes all manufactured goods, including automobiles, discussed in Chapter 10.

[127] Phylipsen, 2000: 43.

[128] The sector definition corresponds with ISIC Rev.3 division 24 (Manufacture of chemicals and chemical products). ISIC, see http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=2&Lg=1. *See also*, ICCA, 2002.

[129] CEFIC, 2005. The two are SABIC (Saudi Arabia) and Sinopec (China).

[130] CEFIC, 2005.

[131] UNCTAD, 2004: 279.

[132] UNCTAD, 2004: 302, 303.

[133] UNCTAD, 2004: 302, 303.

[134] WTO, 2004: 127.

[135] ICCA, 2002.

[136] WTO, 2004: 127.

[137] WTO 2004: 129.

[138] WTO 2004: 129.

[139] Holcim, 2004.

[140] Hendriks et al., 2004.

[141] Price et al., 1999.

[142] Watson et al., 2005, citing U.N. Commodity Trade Statistics. Author calculations based on UNIDO (2005) suggest even smaller amounts of trade (covering ISIC classes 2694 [cement, lime and plaster] and 2695 [articles of concrete, cement and plaster]).

[143] Freedonia Group, 2004a.

[144] Xuemin, 2004; Soule et al., 2002.

[145] Xuemin, 2004; Soule et al., 2002.

[146] OECD/IEA, 2001b.

[147] OECD/IEA, 2001b, citing De Beer et al. (1999), estimated global iron and steel emissions in 1995 at 1442 $MtCO_2$, amounting to 7 percent of global CO_2. Our estimate for 2000 is less, at 1320 $MtCO_2$. One possible reason for the discrepancy is that some gas byproducts of iron and steel production (namely, coke oven gas, blast furnace gas, and oxygen steel furnace gas) are recovered and used outside the steel-making process (for example, in certain power plants). Because we account for "end use" emissions, emissions from those gas byproducts are not counted under iron and steel.

[148] OECD/IEA, 2001b.

[149] China Iron and Steel Association (CISA). Online at: http://www.chinaisa.org.cn/en/stat/stat.htm.

[150] Haoting, 2005.

[151] Mannato, 2005.

[152] Mittal company profile. Online at: http://www.ispat.com/Company/Profile.htm

[153] Author calculations, based on IISI, 2005.

[154] Inferred from IISI, 2005. Top 40 companies represent 53 percent of global production; top 80 percent represent 69 percent.

[155] IISI, 2005: 14. One quarter of this trade is within Europe.

[156] WTO, 2004: 101.

[157] IISI, 2005: 12.

[158] IISI, 2005: 12.

[159] Mannato, 2005.

[160] See Appendix 2.B for more information.

[161] Shares by application are transport (26%), construction (20%), packaging (20%), electrical (9%) and other (26%). IAI, 2002.

[162] IAI, 2005c. *See* "Environment/Aluminum's Lifecycle."

[163] Author calculations, based on IEA, 2004b and IAI, 2005c (see "Environment").

[164] IAI, 2005c. *See* "Production/Smelting/Technology Types."

[165] IAI, 2005c. *See* "Production/Recycling."

[166] IAI, 2005c. *See* "IAI."

[167] John Newman, personal communication, July 20, 2005 (citing U.N. Commodity Trade Statistics). Author calculations based on UNIDO (2005) also suggest similarly large trade flows (covering ISIC class 2720, non-ferrous metals). *See also* Watson et al., 2005.

[168] UNCTAD, 2004: 278-280.

[169] "Buildings," as used here, pertains to IPCC Source Category 1A4a (commercial/institutional) and 1A4b (residential), as well as indirect emissions from *electricity and heat* (category 1A1) consumed in buildings. See Appendix 2.B.

[170] IEA, 2004b.

[171] EIA, 2005a; IEA, 2004d.

[172] EIA, 2005a; IEA, 2004d.

[173] Brown et al., 2005.

[174] Freedonia Group, 2004b.

[175] "Agriculture," as used here, pertains to IPCC Source Category 4, but also includes *energy*-related CO_2 emissions from direct sources (category 1A4) and indirect sources (1A1). *See* Appendix 2.B.

[176] EPA, 2002: §4.1, noting that "N_2O is produced naturally in soils through the microbial process of denitrification and nitrification. A number of anthropogenic activities add nitrogen to the soils, thereby increasing the amount of nitrogen available for nitrification and denitrification, and ultimately the amount of N_2O emitted."

[177] WTO, 2004: 101.

[178] "Waste" pertains to IPCC Source Category 6. *See* Appendix 2.A.

[179] "Land-Use Change and Forestry" pertains to IPCC Source Category 5. *See* Appendix 2.A.

[180] These are farming systems that alternate periods of annual cropping with fallow periods, such as "slash and burn" systems, which use fire to clear fallow areas for cropping.

[181] Houghton 2003a,b. Estimates do not include the indirect or natural effects of climatic change (for example, CO_2 fertilization) or changes in carbon stocks that may result from various forms of management, such as agricultural intensification, fertilization, the trend to no-till agriculture, thinning of forests, changes in species or varieties, and other silvicultural practices.

[182] Houghton, 2003a; IPCC, 2000b: 4.

[183] Author calculations, based on Houghton, 2003a. These emissions amounted to roughly one-quarter of the annual emission levels of tropical countries in the 1990s. Earlier periods of deforestation (e.g., going back to the 16th century in Europe), for which data is not available, may have had higher emissions.

[184] IPCC, 2000b: 3.

[185] Houghton, 2003a; IPCC, 2000b.

[186] A gigaton of carbon (GtC) is equivalent to 1000 MtC, or 3,664 million tons of CO_2 equivalent.

[187] The remainder of CO_2 emissions are 6.3 GtC from fossil fuel combustion and cement manufacture. IPCC, 2000b: 5.

[188] IPCC, 2000b: 4.

[189] Houghton. 2003a.

[190] FAO, 2005: 98.

[191] *See* e.g., FAO, 2005:

[192] FAO, 2005: 42-44.

[193] FAO, 2005: 43.

[194] FAO, 2005: 46.

[195] For definitions of forest products, see http://www.fao.org/waicent/faostat/forestry/products.htm#1.

[196] FAO, 2005: 108.

[197] FAO, 2005: 108.

[198] *See* FAO, 2005: 109-111.

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Appendix 1. CLIMATE ANALYSIS INDICATORS TOOL

The Climate Analysis Indicators Tool (CAIT) is an information and analysis tool on global climate change developed by the World Resources Institute. CAIT provides a comprehensive and comparable database of greenhouse gas emissions data (including all major sources and sinks) and other climate-relevant indicators. CAIT can be used to analyze a wide range of climate-related data questions and to help support future policy decisions made under the Climate Convention and in other forums. Except where noted, all of the data in this report is derived from CAIT. CAIT is accessible free of charge at http://cait.wri.org.

This appendix provides basic information about CAIT, how the tool is used in this report, and caveats about the data. Further information can be found on the CAIT website and in supporting documentation (WRI, 2005a; WRI, 2005b)

Countries and Regions

The CAIT database includes 186 countries, which covers all UNFCCC Parties, except Liechtenstein, Marshall Islands, Micronesia, Monaco (combined with France), San Marino (combined with Italy), and Tuvalu. For these countries, there was inadequate emissions data. Two non-Parties that are members of the UN (Brunei and Iraq) are also included in the database. The EU is also included as a "country" because the European Community (a unit of the EU) is a Party to the Convention. Taiwan (Chinese Taipei), which is neither a UN member nor a Convention Party, is also included in CAIT. This exception is made because Taiwan is a significant source of GHG emissions.

Three categories of regions are also included in CAIT: (1) 8 Geographic regions (for example, sub-Saharan Africa, South America), 17 UNFCCC regions and other organizations (for example, Annex I, G-77/China, OPEC), and (3) user-defined regions, for which customized regions can be created. A full listing of the countries included within each region can be found in WRI (2005b).

Data and Sources

A comprehensive account of the GHG data and sources included in CAIT can be obtained from WRI (2005a). In brief, CAIT includes the "full basket" of GHGs for each country in the world. For a given country, as many as seven GHG data sources may be used (listed in Chapter 1). Efforts have been made by WRI to improve comparability across data sources. CAIT also includes GHG data at the sectoral level. Sectors are based primarily on IPCC (1997) definitions; more detail can be found in Appendix 2. Emission projections included in CAIT are drawn from EIA (2004), EC (2003), IEA (2004c), and IPCC (2000a).

A comprehensive account of the non-GHG related data and sources included in CAIT can be found in WRI (2005b). In brief, non-emissions-related data in CAIT includes population (World Bank, 2005), gross domestic product (World Bank, 2005), energy consumption (World Bank, 2005), electricity production (World Bank, 2005), life expectancy (UNDP, 2004), literacy and school enrollment (UNDP, 2004), aggregated governance indicator (Kaufmann et al., 2003), heating and cooling degree days (WRI, 2003a), fossil fuel reserves (BP, 2005; WEC, 2001), and land area impacted by human activities (WEF, 2001). A wide range of derivative indicators, such as *GDP per capita*, are also generated by CAIT using combinations of data.

Analysis Features

In addition to viewing data and indicators, there are several analysis features in CAIT that enable comparisons between countries and across different indicators. This report made extensive use of these features, which include *compare gases, compare sectors, indicators gases, compare countries, calculate trends,* and *graph trends*.

Appendix 2. SECTORS AND END-USES

The definitions of the sectors and end-uses categories used in this report are in large part a function of what data is available, and how that data can be compiled into meaningful categories. This appendix provides a guide to what data and activities are included in specific sectors and end-use categories.

A. Sector Definitions

Table A2.1 shows datasets that are available at the sectoral level and used in this report (and in CAIT). These sectors pertain to the first column of the GHG Flow Diagram (Figure 1.3). In presenting sector data, the IPCC Common Reporting

Table A2.1. Summary of Sector Contents

Sector	Contents	IPCC Category	Gases	Data Source
Energy		1		
Electricity & Heat[1]	Electricity & heat plants (fossil fuels)			
	- Public plants (electricity, heat, CHP)	1 A 1 a	CO_2	IEA, 2004
	- Autoproducers (electricity, heat, CHP)	1 A	CO_2	IEA, 2004
	Other Energy Industries (fossil fuels)	1 A 1 b,c	CO_2	IEA, 2004
Manufacturing & Construction	Manufacturing & Const. (fossil fuels)	1 A 2	CO_2	IEA, 2004
Transport	Transport (fossil fuels)	1 A 3	CO_2	IEA, 2004
Other Fuel Combustion[2]	Other Sectors (fossil fuels)	1 A 4	CO_2	IEA, 2004
	Biomass Combustion	1 A 5	CH_4, N_2O	EPA, 2004
	Stationary and Mobile Sources	1 A 5	CH_4, N_2O	EPA, 2004
Fugitive Emissions	Gas Venting/Flaring	1 B 2c	CO_2	
	Oil & Natural Gas Systems	1 B 2	CH_4, N_2O	EPA, 2004
	Coal Mining	1 B 1	CH_4, N_2O	EPA, 2004
Industrial Processes	Cement	2 A 1	CO_2	Marland et al., 2005
	Adipic and Nitric Acid Production	2 B 2,3	N_2O	EPA, 2004
	Aluminum	2 C	CO_2	WRI estimate[3]
	Other Industrial non-Agriculture	2	CH_4, N_2O	EPA, 2004
	All F-gases	2	HFCs, PFCs, SF_6	EPA, 2004
Agriculture	Enteric Fermentation (Livestock)	4 A	CH_4	EPA, 2004
	Manure Management	4 B	CH_4, N_2O	EPA, 2004
	Rice Cultivation	4 C	CH_4	EPA, 2004
	Agricultural Soils	4 D	N_2O	EPA, 2004
	Other Agricultural Sources	4	CH_4, N_2O	EPA, 2004
Land-Use Change & Forestry	All	5	CO_2	Houghton, 2003a
Waste	Landfills (Solid Waste)	6 A	CH_4	EPA, 2004
	Wastewater Treatment	6 B	CH_4	EPA, 2004
	Human Sewage	6 B	N_2O	EPA, 2004
	Other	6 D	CH_4, N_2O	EPA, 2004
International Bunkers	Aviation Bunkers	1 A 3a*i*	CO_2	IEA, 2004
	Marine Bunkers	1 A 3d*i*	CO_2	IEA, 2004

Sources: IPCC, 1997; CAIT-UNFCCC.

Notes:

[1] Refers mainly, but not exclusively to electricity and heat (including CHP) produced by entities whose primary activity is to supply the public. Here, this category also includes autoproducers and other energy industries. Autoproducers should ideally be allocated to the sector for which the electricity and/or heat was generated. CO_2 and energy statistics from the IEA do not allow for this. Other energy industries refer to emissions from fuel combusted in association with production and processing (for example, petroleum refineries) of fossil fuels, and is thus not strictly electricity or heat.

[2] Emissions from fuel combustion in (1) commercial and institutional buildings, (2) residential buildings, (3) agriculture, forestry, or domestic inland, coastal and deep-sea fishing, and (4) remaining non-specified emissions.

[3] Estimate is derived from data from USGS (2004), IAI (2005b,c), IPCC (2005), and CAIT.

See Glossary for other terms.

Framework is used to the extent possible. This is the standardized approach used by governments in compiling official national GHG inventories under the UNFCCC (IPCC, 1997). Minor deviations from this approach are sometimes required due to data limitations. For more detail, see WRI (2005a).

The following sectors are included: energy, industrial processes, agriculture, land-use change and forestry, and waste. The energy sector also includes five subsectors (for example, electricity/heat). International Bunkers are shown as a sector, but separately from Energy, in accordance with IPCC Guidelines. All six GHGs are included within their appropriate sectors and subsectors, so far as the data will allow.

All sectors and subsectors here capture only "direct" emissions. Emissions resulting from public electricity consumption (that is, from the grid) in the course of manufacturing, construction, agricultural, or other activities are included only in "electricity and heat." Likewise, emissions released as byproducts of particular industrial processes—such as cement or aluminum manufacture—are categorized under "industrial processes." Emissions from the energy sector pertain only to fuel combustion (for example, fossil fuels, biomass).

B. End-Use / Activity Definitions

Table A2.2 shows the contents of individual end-use/activities used in this report. These end uses appear in the middle column of the GHG Flow Diagram (Figure 1.3), including the sectors and subsectors discussed in Part II of this report.

End-uses/activities described here represent an attempt to aggregate all emissions that pertain to a common "downstream" activity, such as agricultural activities or the manufacture of cement. End-uses deviate from the above-described IPCC sectors in the following respects:

- ***Electricity and Heat*** is distributed to end-uses, rather than treated as a discrete sector. Estimates of CO_2 shares for subsectors and end-uses are based on IEA *Energy Statistics* (IEA, 2004b). Separate allocations were made for electricity, heat, and energy industries.
- ***Industrial Processes***-related emissions are allocated to end uses.
- ***Other IPCC-related sectors*** (for example, transport), where possible, are divided into subsectors (such as road, aviation, rail, ship, and other). This was done for the datasets pertaining to CO_2 from fossil fuel combustion (IEA, 2004a) and non-CO_2 gases (EPA, 2004). Other datasets, such as for CO_2 emissions from cement manufacture (Marland et al., 2005) and for gas flaring (EIA, 2004), already provide data at the end-use level.

Table A2.2. End-Use / Activity Definitions

End Use / Activity	Contents	Gases	Related IPCC Category(s)
Road	Direct fuel combustion	CO_2	Energy: Transport
Air	Domestic air (direct fuel combustion)	CO_2	Energy: Transport, including bunkers
	International air (direct fuel combustion)	CO_2	
Rail, Ship, & Other	Rail (electricity)	CO_2	Energy: Electricity & Heat
	International marine (direct fuel combustion)	CO_2	Energy: Transport, including bunkers
	Pipeline transport, national navigation, and others (direct fuel combustion)	CO_2	
	Pipeline transport (electricity)	CO_2	"
	Non-specified transport (electricity)	CO_2	"
Transmission & Distribution Losses	Distribution losses	CO_2	Energy: Electricity & Heat
	Electrical transmission & distribution.	SF_6	Industrial Processes
Residential Buildings	Direct fuel combustion (on-site)	CO_2	Energy: Other Fuel Combustion
	Electricity and heat consumption (indirect)	CO_2	Energy: Electricity & Heat
Commercial Buildings	Direct fuel combustion (on-site)	CO_2	Energy: Other Fuel Combustion
	Electricity and heat consumption (indirect)	CO_2	Energy: Electricity & Heat
Unallocated Fuel Combustion	Forestry/fishing and other direct fossil fuel combustion not specified elsewhere	CO_2	Energy: Other Fuel Combustion
	Biomass combustion	CH_4, N_2O	"
	Stationary & mobile sources	CH_4, N_2O	"
	Own use in electricity, CHP and heat plants (elect. & heat)	CO_2	Energy: Electricity & Heat
	Pumped Storage (electricity)	CO_2	"
	Nuclear Industry (electricity & heat)	CO_2	"
	Non-specified & other (electricity & heat)	CO_2	"

Table A2.2. End-Use / Activity Definitions *(continued)*

End Use / Activity	Contents	Gases	Related IPCC Category(s)
Iron & Steel	Direct fuel combustion	CO_2	Energy: Manufacturing & Const.
	Electricity and heat consumption (indirect)	CO_2	Energy: Electricity & Heat
Non-Ferrous Metals	Direct fuel combustion (on-site)	CO_2	Energy: Manufacturing & Const.
	Electricity and heat consumption (indirect)	CO_2	Energy: Electricity & Heat
	Aluminum	PFCs	Industrial Processes
	Aluminum[1]	CO_2	Industrial Processes
	Magnesium	SF_6	Industrial Processes
Machinery	Direct fuel combustion	CO_2	Energy: Manufacturing & Const.
	Electricity and heat consumption	CO_2	Energy: Electricity & Heat
Pulp, Paper, & Printing	Direct fuel combustion	CO_2	Energy: Other Fuel Combustion
	Electricity and heat consumption	CO_2	Energy: Electricity & Heat
Food & Tobacco	Direct fuel combustion	CO_2	Energy: Manufacturing & Const.
	Electricity and heat consumption	CO_2	Energy: Electricity & Heat
Chemicals & Petrochemicals	Direct fuel combustion	CO_2	Energy: Other Fuel Combustion
	Electricity and heat consumption	CO_2	Energy: Electricity & Heat
	Adipic and nitric acid	N_2O	Industrial Processes
	ODS Substitutes	HFCs	Industrial Processes
	HCFC-22 production	HFCs	Industrial Processes
Cement Manufacture	Direct fuel combustion	CO_2	Energy: Other Fuel Combustion
	Electricity and heat consumption	CO_2	Energy: Electricity & Heat
	Clinker production	CO_2	Industrial Processes
Other Industry	Transport equipment (direct combustion, electricity, heat)	CO_2	Energy: Manufacturing & Const.
	Mining and quarrying (direct combustion, electricity, heat)	CO_2	Energy: Electricity & Heat
	Wood/wood products (direct combustion, electricity, heat)	CO_2	"
	Construction (direct combustion, electricity, heat)	CO_2	"
	Textile and leather (direct combustion, electricity, heat)	CO_2	"
	Non-metallic minerals excluding cement (direct combustion, electricity, heat)	CO_2	"
	Other & non-specified (direct combustion, electricity, heat)	CO_2	"
	Semiconductors	F-gases	Industrial Processes
	Other industrial non-agriculture	CH_4, N_2O	"
	Other high GWP gases	F-gases	"
Coal Mining & Manufacture	Coal mining	CH_4, N_2O	Energy: Fugitives
	Coal mines (electricity and heat)	CO_2	Energy: Electricity & Heat
	Fuel combustion for the manufacture of hard coal, coke oven coke, and other coal-related fuels	CO_2	"
Oil & Gas Extraction, Refining, Processing	Gas flaring	CO_2	Energy: Fugitives
	Oil & natural gas systems	CH_4	"
	Oil and gas extraction (electricity and heat)	CO_2	Energy: Electricity & Heat
	Electricity and heat (public) consumed in oil refineries, coke ovens and other energy producing plants.	CO_2	"
	Fuel combusted in refineries, gas processing plants, and other energy-producing industries.	CO_2	"
Land-Use Change & Forestry	Land clearing for permanent croplands (cultivation) or pastures (no cultivation), abandonment (with subsequent regrowth), shifting cultivation, and wood harvest.	CO_2	Land-Use Change & Forestry
Energy-Related Agriculture	Direct fuel combustion	CO_2	Energy: Other Fuel Combustion
	Electricity and heat consumption	CO_2	Energy: Electricity & Heat
Agricultural Soils	Fertilizer Application	N_2O	Agriculture
Livestock & Manure	Enteric Fermentation (Livestock)	CH_4	Agriculture
	Manure Management	CH_4, N_2O	"
Rice Cultivation	Rice cultivation	N_2O	Agriculture
Other Agriculture	Miscellaneous Agricultural Processes	CH_4, N_2O	Agriculture

Notes: "F-gases" refers to HFCs, PFCs, and SF_6 collectively. ODS refers to ozone depleting substances.

[1] WRI emissions estimate is derived from data from USGS (2004), IAI (2005b,c), IPCC (2005), and CAIT.

- ***Land-Use Change and Forestry*** includes both emissions and absorptions of CO_2. For this reason, it is not possible to graphically illustrate subsectoral activities in the GHG Flow Diagram (Figure 1.3. Instead, this is done in Figure 17.2 (see Chapter 17).

It is important to note that this report does not assess end use/activity-level emissions using a full lifecycle approach. In particular, "upstream" emissions pertaining to mining, extraction, and processing of fossil fuels and other minerals are not allocated to end uses (such as transport and aluminum production), but to their own end uses. Similarly, transport-related emissions do not include emissions associated with the actual manufacture of motor vehicles or other transport-related equipment, which are included under "Other Industry."

The end-use/activities shown in Table A2.2 can also be aggregated to create broader end-use sectors. This has been attempted in Part II of this report. In particular:

- ***Transport*** (Chapter 12) includes a small amount of electricity (indirect emissions) as well as all direct emissions of fossil fuel combustion associated with transport activities. This sector does not include, however, emissions pertaining to the manufacture of motor vehicles or other transport equipment. Those emissions are contained in Industry.
- ***Industry*** (Chapter 13) includes direct emissions from fossil fuel combustion, indirect emissions from electricity and heat consumption, and emissions from industrial processes (for chemicals, aluminum, and cement). Several additional steps were taken to estimate emissions from two industry subsectors:
    - ***Cement.*** Estimates of direct fossil fuel combustion for cement manufacture and electricity-related emissions (indirect) are estimated by WRI based on IEA (2004a,b) and Hendriks (1999). Industrial process-related emissions (from clinker production) are from Marland et al. (2005).
    - ***Aluminum.*** Industrial process-related CO_2 emissions are estimated based on total world aluminum production (USGS, 2004), CO_2 emission factors (IPCC, 2005), and further information on the relative prevalence of different aluminum production processes (Watson et al., 2005). Energy-related CO_2 emissions are estimated based on national aluminum production statistics (USGS, 2004), CO_2 emission factors (IAI, 2005b,c) and country-level carbon intensity of electricity supply (CAIT, based on IEA). PFC emissions are drawn from EPA (2004).
- ***Buildings*** (Chapter 14) includes direct fossil fuel combustion and indirect emissions attributable to public heat and electricity consumption in residential, commercial, and public buildings.
- ***Agriculture*** (Chapter 15) includes all contents of the IPCC Agriculture sector described in Section A of this appendix, as well as energy-related emissions that can be allocated to agriculture activities (direct fossil fuel combustion and electricity).

In some cases, data limitations prevented a detailed breakdown of end-use activities. For example, detailed data on the relative contribution of different activities in the buildings sector is unavailable at the global level.

Glossary and Abbreviations

Agriculture
This term corresponds to IPCC Source/Sink Category 4, and covers all anthropogenic emissions from this sector except for fuel combustion and sewage emissions, which are covered in energy and waste, respectively.

Agricultural Soils
Emissions and removals of CH_4 and N_2O from agricultural soil/land. These are influenced by irrigation practices, climatic variables, soil temperature and humidity (IPCC category 4D).

Annex I Countries
The industrialized and transition countries listed in this Annex to the Climate Convention. These countries include Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, United States of America.

Autoproducers
Undertakings which generate electricity/heat wholly or partly for their own use, as an activity which supports their primary activity. Autoproducers may be privately or publicly owned.

BAU
Business as usual. A scenario that represents the most plausible projection of the future. BAU typically embodies the notion of what would happen, hypothetically, if climate-friendly actions were not taken.

Bunker Fuels
Fuel supplied to ships and aircraft. In this report, it refers to international bunker fuels, which denotes the consumption of fuel for international transport activities. For the purposes of GHG emissions inventories, emissions from international bunker fuels are subtracted from national emissions totals.

CAIT
Climate Analysis Indicators Tool. See Appendix 1.

CDM
Clean Development Mechanism. A project-based emissions trading system under the Kyoto Protocol that allows industrialized countries to use emission reduction credits from projects in developing countries that both reduce greenhouse gas emissions and promote sustainable development.

CDIAC
Carbon Dioxide Information Analysis Center. A national lab of the U.S. Department of Energy. See: http://cdiac.esd.ornl.gov.

CHP
Combined Heat and Power. Refers to plants that are designed to produce both heat and electricity. Also referred to as co-generation.

Climate Change Convention
See UNFCCC.

CO_2
Carbon dioxide. A naturally occurring gas that is also a byproduct of burning fossil fuels and biomass, other industrial processes, and land-use changes. CO_2 is the principal anthropogenic greenhouse gas affecting the Earth's temperature.

CO_2 equivalent
The amount of CO_2 by weight emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another GHG. Carbon dioxide equivalents are computed by multiplying the weight of the gas being measured (for example, methane) by its estimated global warming potential (see GWP). One unit of carbon is equivalent to 3.664 units of carbon dioxide.

Carbon Intensity
The ratio of CO_2 emissions to activity or output. At the national level, this indicator is shown as CO_2 emissions per unit GDP.

Coal
Includes primary coal products (for example, hard coal and lignite) and derived fuels such as patent fuel, coke oven coke, gas coke, BKB, coke oven gas, and blast furnace gas. Peat is also included in this category.

CH_4
Methane. A colorless, flammable, odorless hydrocarbon that is an important greenhouse gas. All CH_4 data in this report is converted and displayed in CO_2 equivalent units, using global warming potentials in IPCC (1996). CH_4 has a GWP of 21 times that of CO_2 over a 100-year horizon (IPCC, 1996). See GWP.

Degree Day (heating and cooling)
A measure commonly used to evaluate energy requirements for heating or air conditioning. The measure is based on departures from an average temperature of 18°C (65°F), a base temperature considered to have neither heating nor cooling requirements.

Developed Countries
See Annex I Countries. Where noted, the term "developed countries" instead denotes the collective member states of the OECD.

Developing Countries
Those countries not designated in Annex I of the Convention. See Annex I. This group, as used in this report, includes some countries that may be considered industrialized or transitional.

EIA
Energy Information Administration. An independent statistical agency of the U.S. Department of Energy. See: http://www.eia.doe.gov.

EIT
Economy in transition. EITs typically include the countries of Central and Eastern Europe (such as Poland), the former Soviet Union (such as Russia), and Central Asian Republics (such as Kazakhstan).

Energy Use (Consumption)
Energy use refers to apparent consumption, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport. Energy use may also be referred to as energy supply.

Energy Intensity
The ratio of energy consumption (use) to activity or output. At the national level, this indicator is shown as primary energy consumption per unit GDP.

Energy Production
Production of primary energy; that is, petroleum (crude oil, natural gas liquids, and oil from nonconventional sources), natural gas, solid fuels (coal, lignite, and other derived fuels), and combustible renewables and waste as well as primary electricity production (nuclear, hydro, renewables). Production is usually converted into units of oil equivalents.

Enteric Fermentation
CH_4 production from herbivores as a byproduct of enteric fermentation, a digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream. Includes both ruminant (such as cattle, sheep) and non-ruminant animals (such as pigs, horses) (IPCC category 4A).

EPA
U.S. Environmental Protection Agency.
See: http://www.epa.gov.

EU
European Union. Includes either 15 member states (EU-15) or 25 member states (EU-25). For a listing of member countries, see http://cait.wri.org/cait.php?page=notes&chapt=4.

FAO
Food and Agricultural Organization of the United Nations. See: http://www.fao.org.

Flaring (natural gas)
Gas disposed of by burning in flares, usually at the production sites or at gas processing plants. See also Fugitive Emissions.

Former Soviet Union (FSU)
Independent countries comprising the former Soviet Union. Members: Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.

Fugitive emissions
Intentional or unintentional releases of gases from human activities. In particular, they may arise from the production, processing, transmission, storage and use of fuels, and include emissions from combustion only where it does not support a productive activity (such as flaring of natural gases at oil and gas production facilities). See Flaring.

GDP
Gross Domestic Product. The total value of goods and services produced by labor and property located in a given country.

Global Warming Potential (GWP)
An index that allows for comparison of the various greenhouse gases. It is the radiative forcing that results from the addition of 1 kilogram of a gas to the atmosphere compared to an equal mass of carbon dioxide. The data in this report and in CAIT use the GWP estimates in the IPCC Second Assessment Report (IPCC, 1996). Over 100 years, methane has a GWP of 21 and nitrous oxide of 310.

Greenhouse Effect
The effect produced as greenhouse gases allow incoming solar radiation to pass through the Earth's atmosphere but prevent most of the outgoing long-wave infrared radiation from the surface and lower atmosphere from escaping into outer space. This envelope of heat-trapping gases keeps the Earth about 30° C warmer than if these gases did not exist.

GHG
Greenhouse Gas. Any gas that absorbs and re-emits infrared radiation into the atmosphere. The main greenhouse gases include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

GHG Intensity
The ratio of GHG emissions to activity or output. At the national level, this indicator is shown as GHG emissions per unit GDP. This measure is identical to CO_2 intensity, except that non-CO_2 gases may be included here.

HFC
Hydrofluorocarbon. A group of human-made chemicals composed of one or two carbon atoms and varying numbers of hydrogen and fluorine atoms. All HFC data in this report is converted and displayed in CO_2 equivalent units, using global warming potentials in the IPCC Second Assessment Report (1996). Most HFCs have 100-year global warming potentials in the thousands (IPCC, 1996). See GWP.

IEA
International Energy Agency. See: http://www.iea.org.

Industrial Processes
This term corresponds to IPCC Source/Sink Category 2, and covers byproduct or fugitive emissions of GHGs from industrial processes, including all emissions of HFCs, PFCs, and SF_6.

Industrialized Countries
Those countries designated in Annex II of the Convention; namely, members of the OECD, but excluding Mexico and South Korea. See OECD.

Industry
This term corresponds to IPCC Source/Sink Category 1A2, and covers emissions from combustion of fuels in manufacturing and construction industries, including combustion for the generation of electricity and heat. Energy used for transport by industry is not included here. Where noted in this report, this term includes industry-related electricity and heat (indirect) emissions as well as industrial process-related emissions.

IPCC
Intergovernmental Panel on Climate Change. An organization established in 1988 by the World Meteorological Organization and the United Nations Environment Programme. It conducts rigorous surveys of the worldwide technical and scientific literature and publishes assessment reports widely recognized as the most credible existing sources on climate change.

ISIC
International Standard Industrial Classification of all Economic Activities. A standard classification that is widely used internationally in classifying data according to kinds of economic activity in the fields of population, production, employment, gross domestic product, and other economic activities. The major groups and divisions, the successively broader levels of classification, combine the statistical units according to the character, technology, organization, and financing of production. This report utilizes primarily ISIC, Third Revision (Rev.3, 1989). See: http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=2.

Kyoto Protocol
An international agreement adopted by Parties to the Climate Convention in Kyoto, Japan, in December 1997. The Protocol entered into force in 2005. See: http://unfccc.int.

LDC
Least Developed Country. A category of countries (currently 49) deemed by the United Nations to be structurally handicapped in their development process, facing more than other developing countries the risk of failing to come out of poverty as a result of these handicaps, and in need of the highest degree of consideration from the international community in support of their development efforts. For a listing of members, see: http://cait.wri.org/cait.php?page=notes&chapt=4.

LUCF
Land-use change and forestry. This term corresponds to IPCC Source/Sink Category 5, and covers emissions and removals from forest and land-use change activities, including but not limited to (1) emissions and removals of CO_2 from decreases or increases in biomass stocks due to forest management, logging, fuelwood collection, etc.; (2) conversion of existing forests and natural grasslands to other land uses; (3) removal of CO_2 from the abandonment of formerly managed lands (e.g. croplands and pastures); and (4) emissions and removals of CO_2 in soil associated with land-use change and management.

Manure Management
CH_4 and N_2O produced from the decomposition of manure under low oxygen or anaerobic conditions. These conditions often occur when large numbers of animals are managed in a confined area (such as dairy farms, beef feedlots, and swine and poultry farms), where manure is typically stored in large piles or disposed of in lagoons and other types of manure management systems (IPCC category 4B).

Methane
See CH_4.

MtCO₂
Million metric tons of carbon dioxide equivalent. This measure can aggregate different GHGs into a single measure, using global warming potentials (see GWP). One unit of carbon is equivalent to 3.664 units of carbon dioxide.

N₂O
Nitrous Oxide. A GHG emitted through soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning. All N_2O data in this report is converted and displayed in CO_2 equivalent units, using global warming potentials in the IPCC Second Assessment Report (1996). It has a GWP of 310 times that of CO_2 over a 100-year horizon (IPCC, 1996). See GWP.

Non-Annex I Countries
Those countries that are not listed in Annex I of the Climate Change Convention (see Annex I Parties). This group consists primarily of developing countries. For a listing of members, see: http://cait.wri.org/cait.php?page=notes&chapt=4.

Non-CO₂ gases
Refers to the greenhouse gases CH_4, N_2O, HFCs, PFCs, and SF_6.

Natural Gas
A gaseous mixture of hydrocarbon compounds, consisting mainly of methane. Vented or flared gas is excluded.

OECD
Organisation for Economic Co-operation and Development. An international organization consisting of the major industrialized countries. Member states include: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. See: http://www.oecd.org.

OPEC
Organization of Petroleum Exporting Countries. An international organization made up of oil-producing countries that aim to influence world oil prices. Member states include: Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela. See: http://www.opec.org.

Oil
A mixture of hydrocarbons usually existing in the liquid state in natural underground pools or reservoirs.

Petrochemicals
A large group of chemicals derived from a component of petroleum or natural gas. Important petrochemical compounds are alcohols and aldehydes, butylene, butadiene, ethylene, propylene, toluene, styrene, acetylene, benzene, ethylene oxide, ethylene glycol, acrylonitrile, acetone, acetic acid, acetic anhydride, and ammonia. Materials made from the gases include synthetic rubber, polystyrene, polypropylene, and polyethylene. Petrochemicals are widely used in agriculture, in the manufacture of plastics, synthetic fibers, and explosives, and in the aircraft and automobile industries.

PFC
Perfluorocarbon. A group of human-made chemicals composed of carbon and fluorine (CF_4 and C_2F_6). PFCs have no commercial uses and are emitted as a byproduct of aluminum smelting and semiconductor manufacturing. These chemicals are potent GHGs. All PFC data in this report is converted and displayed in CO_2 equivalent units, using global warming potentials in the IPCC Second Assessment Report (1996). See GWP.

PPP
Purchasing Power Parity. An international dollar “currency” for GDP that has the same purchasing power over local GDP as a U.S. dollar has in the United States.

ppmv
Parts per Million by Volume. A unit of concentration for a particular substance (for example, CO_2).

Reserves (or proved reserves)
Estimated quantities of energy sources that analysis of geologic and engineering data demonstrates with reasonable certainty are recoverable under existing economic and operating conditions. The location, quantity, and grade of the energy source are usually considered to be well established in such reserves.

Residential
Refers to fuel, electricity, or heat consumption in households.

Rice Cultivation
The anaerobic decomposition of organic material in flooded rice fields, which produces methane that escapes to the atmosphere by ebullition (bubbling up) through the water column, diffusion across the water/air interface, and transport through the rice plants (IPCC category 4C).

SD-PAMs
Sustainable Development Policies and Measures. An approach to climate protection that builds on sustainable development priorities.

SF_6
Sulfur Hexafluoride. A potent GHG used primarily in heavy industry to insulate high-voltage equipment and to assist in the manufacturing of cable cooling systems. All SF_6 data in this report is converted and displayed in CO_2 equivalent units, using global warming potentials in the IPCC Second Assessment Report (1996). It has a GWP of 23,900 times that of CO_2 over a 100-year horizon (IPCC, 1996). See GWP.

Small Island Developing States (also, Alliance of Small Island States)
A coalition of 42 low-lying and island countries that are particularly vulnerable to sea-level rise and share common positions on climate change. For a listing of members, see: http://cait.wri.org/cait.php?page=notes&chapt=4.

Transformation
This refers to the conversion of primary forms of energy to secondary and further transformation (such as coking coal to coke, crude oil to petroleum products, heavy fuel oil to electricity).

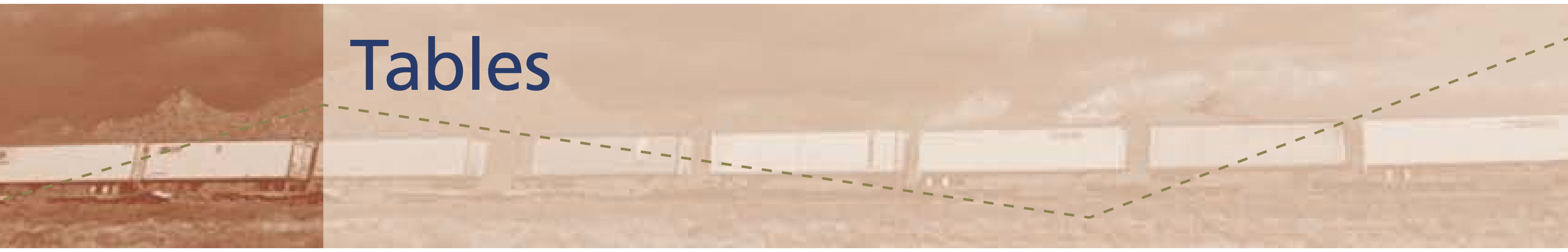
Transport
This term corresponds to IPCC Source/Sink Category 1A3, and covers emissions from the combustion and evaporation of fuel for all transport activity, regardless of the sector. Emissions pertaining to international transport (bunker fuels) are accounted for separately and not included in national totals. Emissions from the manufacture of vehicles or transport-related machinery are not included here. Where noted in this report, this term includes transport-related electricity (indirect) emissions.

UNFCCC
United Nations Framework Convention on Climate Change (Climate Convention, or Convention). A treaty signed at the 1992 Earth Summit in Rio de Janeiro to which nearly all countries of the world have joined. See: http://unfccc.int.

Waste
This term corresponds to IPCC Source/Sink Category 6, and covers emissions from solid waste disposal on land, wastewater, waste incineration, and any other waste management activity. Excludes CO_2 emissions from fossil-based products (incineration or decomposition).

WRI
World Resources Institute. See: http://www.wri.org.

Sources:
UNFCCC (http://unfccc.int/siteinfo/glossary.html);
EIA (http://www.eia.doe.gov/glossary/glossary_main_page.htm);
IEA (http://www.iea.org/Textbase/stats/defs/defs.htm);
World Bank (www.worldbank.org/data/);
IPCC (1997).



Tables

Table 1. 25 Largest Countries: GHG Emissions, Economy, and Population

A. Emissions (6 gases)			B. Gross Domestic Product			C. Population		
Country	**$MtCO_2$ Equiv.**	**% of World**	**Country**	**GDP-PPP$ (billions)**	**% of World**	**Country**	**Millions**	**% of World**
United States	6,928	20.6	EU-25	10,402	22.2	China	1,280	20.7
China	4,938	14.7	United States	9,965	21.3	India	1,049	16.9
EU-25	4,725	14.0	China	5,607	12.0	EU-25	454	7.3
Russia	1,915	5.7	Japan	3,285	7.0	United States	293	4.7
India	1,884	5.6	India	2,698	5.8	Indonesia	212	3.4
Japan	1,317	3.9	Germany	2,157	4.6	Brazil	174	2.8
Germany	1,009	3.0	France	1,552	3.3	Pakistan	145	2.3
Brazil	851	2.5	United Kingdom	1,489	3.2	Russia	144	2.3
Canada	680	2.0	Italy	1,468	3.1	*Bangladesh*	136	2.2
United Kingdom	654	1.9	Brazil	1,305	2.8	*Nigeria*	133	2.1
Italy	531	1.6	Russia	1,151	2.5	Japan	127	2.1
South Korea	521	1.5	Canada	901	1.9	Mexico	101	1.6
France	513	1.5	Mexico	873	1.9	Germany	82	1.3
Mexico	512	1.5	Spain	850	1.8	*Vietnam*	80	1.3
Indonesia	503	1.5	South Korea	789	1.7	*Philippines*	80	1.3
Australia	491	1.5	Indonesia	648	1.4	Turkey	70	1.1
Ukraine	482	1.4	Australia	536	1.1	*Ethiopia*	67	1.1
Iran	480	1.4	*Netherlands*	451	1.0	*Egypt*	66	1.1
South Africa	417	1.2	South Africa	442	0.9	Iran	66	1.1
Spain	381	1.1	Turkey	428	0.9	*Thailand*	62	1.0
Poland	381	1.1	*Thailand*	415	0.9	France	59	1.0
Turkey	355	1.1	Iran	411	0.9	United Kingdom	59	1.0
Saudi Arabia	341	1.0	Poland	394	0.8	Italy	58	0.9
Argentina	289	0.9	Argentina	389	0.8	*Congo, DR*	52	0.8
Pakistan	285	0.8	*Taiwan*	386	0.8	Ukraine	49	0.8
Rest of World	**5,751**	**16.9**	**Rest of World**	**6,195**	**13.2**	**Rest of World**	**1,361**	**22.0**

Notes: $MtCO_2$ eq. is millions of tons of carbon dioxide equivalent. Emissions exclude those from international bunker fuels and land-use change and forestry. Countries not among the top 25 absolute emitters are shown in italics. GHG data is from 2000; other data is from 2002. GDP is measured in terms of purchasing power parity (constant 2000 international dollars).

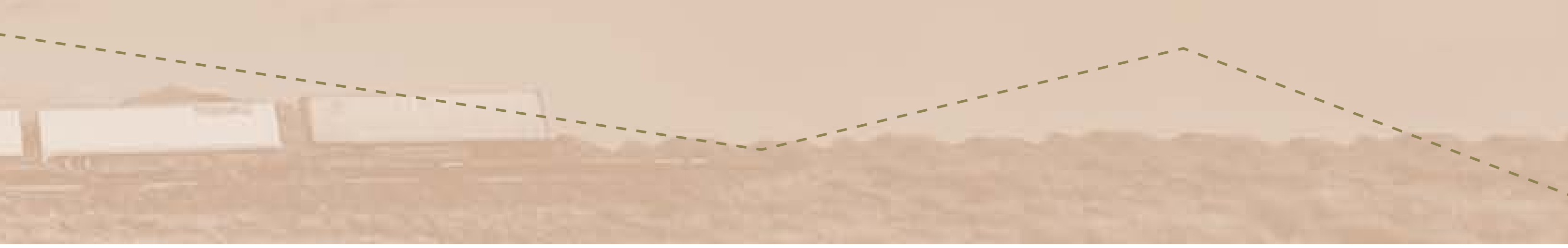


Table 2. **Shares of National Emissions for Different Gas/Source Categories**

Top 25 emitters, each category

	CO$_2$ from Fossil Fuels		CO$_2$ from Fossil Fuels, plus non-CO$_2$ GHGs		CO$_2$ from Fossil Fuels and Land-Use Change, plus non-CO$_2$ GHGs	
Country	**% of world**	**(Rank)**	**% of world**	**(Rank)**	**% of world**	**(Rank)**
United States	24.0	(1)	20.6	(1)	15.8	(1)
EU-25	15.9	(2)	14.0	(3)	11.4	(3)
China	14.4	(3)	14.7	(2)	11.9	(2)
Russia	6.4	(4)	5.7	(4)	4.8	(6)
Japan	5.0	(5)	3.9	(6)	3.2	(8)
India	4.4	(6)	5.6	(5)	4.5	(7)
Germany	3.6	(7)	3.0	(7)	2.5	(9)
United Kingdom	2.3	(8)	1.9	(10)	1.6	(12)
Canada	2.2	(9)	2.0	(9)	1.8	(11)
South Korea	1.9	(10)	1.6	(12)	1.3	(15)
Italy	1.9	(11)	1.6	(11)	1.3	(14)
Mexico	1.6	(12)	1.5	(14)	1.5	(13)
France	1.5	(13)	1.5	(13)	1.2	(17)
South Africa	1.5	(14)	1.2	(19)	1.0	(21)
Iran	1.4	(15)	1.4	(18)	1.2	(19)
Brazil	1.4	(16)	2.5	(8)	5.4	(5)
Australia	1.4	(17)	1.5	(16)	1.2	(18)
Ukraine	1.3	(18)	1.4	(17)	1.2	(20)
Spain	1.3	(19)	1.1	(20)	0.9	(26)
Poland	1.3	(20)	1.1	(21)	0.9	(24)
Indonesia	1.2	(21)	1.5	(15)	7.4	(4)
Saudi Arabia	1.2	(22)	1.0	(23)	0.8	(29)
Taiwan	0.9	(23)	0.7	(28)	0.6	(35)
Turkey	0.9	(24)	1.1	(22)	0.9	(25)
Thailand	0.7	(25)	0.8	(26)	0.8	(31)
Netherlands	0.7	(26)	0.6	(29)	0.5	(37)
Argentina	0.6	(27)	0.9	(24)	0.8	(28)
Venezuela	0.6	(28)	0.7	(27)	0.9	(23)
Malaysia	0.5	(34)	0.5	(33)	2.1	(10)
Pakistan	0.4	(35)	0.9	(25)	0.8	(30)
Myanmar	0.0	(94)	0.3	(48)	1.2	(16)
Developed	**59.0**		**51.9**		**41.4**	
Developing	**41.0**		**47.6**		**59.0**	

Note: Data is for 2000. CO$_2$ from fossil fuels includes CO$_2$ from the chemical process of cement manufacture. LUCF data not available for Ukraine and Taiwan. Countries not among the top 25 absolute emitters are shown in italics.

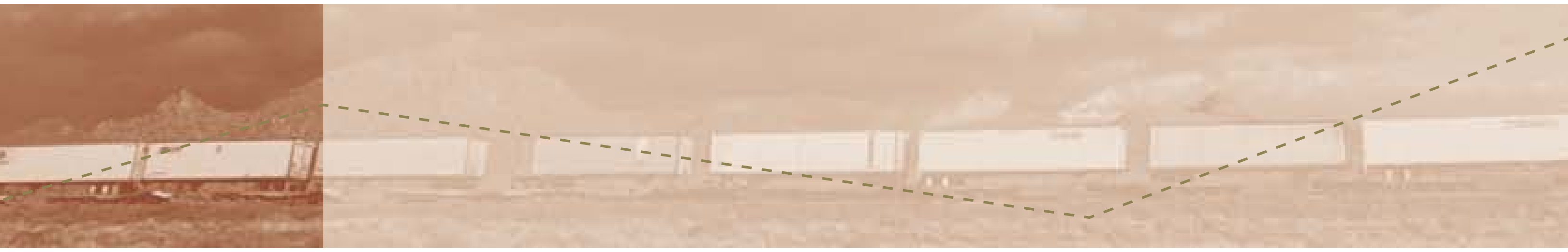


Table 3. Intensity Indicators and Trends, 2002

	Carbon Intensity		Energy Intensity		Fuel Mix	
Country	**Tons of CO$_2$ / \$mil. GDP-PPP**	**% change, 1990–2002**	**Tons of Oil Eq. / \$mil. GDP-PPP**	**% change, 1990–2002**	**Tons of CO$_2$ / Ton of Oil Eq.**	**% change 1990–2002**
Ukraine	1,368	-14	569	-1	2.40	-13
Russia	1,332	-15	537	-13	2.48	-3
Saudi Arabia	1,181	45	481	47	2.45	-1
Iran	899	17	326	19	2.76	-1
South Africa	823	-2	257	-2	3.21	-1
Poland	757	-43	226	-39	3.34	-7
China	675	-51	219	-54	3.08	7
South Korea	633	-2	258	10	2.45	-10
Australia	630	-16	210	-15	2.99	-1
United States	579	-17	230	-16	2.52	-1
Canada	575	-14	278	-15	2.07	0
Indonesia	513	22	241	1	2.13	20
Turkey	489	-2	176	0	2.78	-2
Mexico	453	-9	180	-10	2.52	1
India	410	-9	200	-21	2.05	16
Germany	400	-29	161	-20	2.49	-10
Pakistan	382	4	234	-2	1.63	6
Spain	381	5	155	6	2.46	-1
EU-25	374	-23	163	-13	2.30	-11
Japan	369	-6	157	0	2.35	-6
United Kingdom	363	-29	152	-19	2.39	-12
Argentina	319	-18	145	-8	2.20	-11
Italy	306	-10	118	-5	2.60	-5
Brazil	263	17	146	6	1.80	10
France	244	-19	171	-6	1.43	-14
Developed	**511**	**-23**	**212**	**3**	**2.41**	**-4**
Developing	**549**	**-12**	**224**	**-10**	**2.47**	**5**
World	**529**	**-15**	**218**	**-13**	**2.43**	**-2**

Notes: For Russia and Ukraine, figures cover the 1992–2002 period, due to lack of energy data in 1990. CO$_2$ excludes land use change and forestry and international bunker fuels. "GDP-PPP" is gross domestic product measured in terms of purchasing power parity (constant 2000 international dollars).

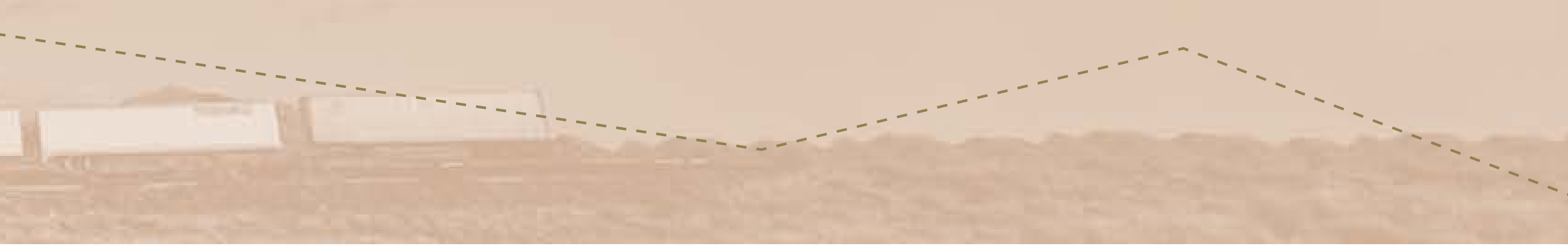


Table 4. Indicators of Historical Contributions to Climate Change, 1850–2002

CO_2 from fossil fuels & cement manufacture

	% of World (Rank)						
Country	**Cumulative**		**Concentration Increase**		**Temperature Increase**		**% change, cum. v. temp**
United States	29.3	(1)	27.8	(1)	29.0	(1)	-1
EU-25	26.5	(2)	23.8	(2)	26.0	(2)	-2
Russian Federation	8.1	(3)	8.3	(4)	8.5	(3)	5
China	7.6	(4)	9.0	(3)	7.5	(4)	0
Germany	7.3	(5)	6.4	(5)	7.1	(5)	-2
United Kingdom	6.3	(6)	5.0	(6)	5.9	(6)	-6
Japan	4.1	(7)	4.4	(7)	4.2	(7)	2
France	2.9	(8)	2.6	(8)	2.8	(8)	-2
India	2.2	(9)	2.5	(9)	2.1	(11)	-3
Ukraine	2.2	(10)	2.2	(10)	2.3	(9)	6
Canada	2.1	(11)	2.2	(11)	2.2	(10)	0
Poland	2.1	(12)	1.9	(12)	2.1	(12)	1
Italy	1.6	(13)	1.7	(13)	1.7	(13)	2
South Africa	1.2	(14)	1.2	(14)	1.2	(14)	1
Australia	1.1	(15)	1.1	(16)	1.1	(15)	0
Mexico	1.0	(16)	1.1	(15)	1.0	(16)	1
Spain	0.9	(20)	1.0	(17)	0.9	(20)	1
Brazil	0.8	(22)	0.9	(19)	0.8	(22)	0
South Korea	0.8	(23)	1.0	(18)	0.7	(23)	-4
Iran	0.6	(24)	0.8	(24)	0.6	(25)	-2
Indonesia	0.5	(27)	0.6	(25)	0.5	(28)	-6
Saudi Arabia	0.5	(28)	0.6	(26)	0.5	(29)	-2
Argentina	0.5	(29)	0.5	(30)	0.5	(27)	2
Turkey	0.4	(31)	0.5	(29)	0.4	(31)	-2
Pakistan	0.2	(48)	0.2	(45)	0.2	(50)	0
Developed	**75.6**		**72.0**		**75.6**		**0**
Developing	**24.4**		**28.0**		**24.4**		**0**

Notes: For information on methodologies, see WRI, 2005b.

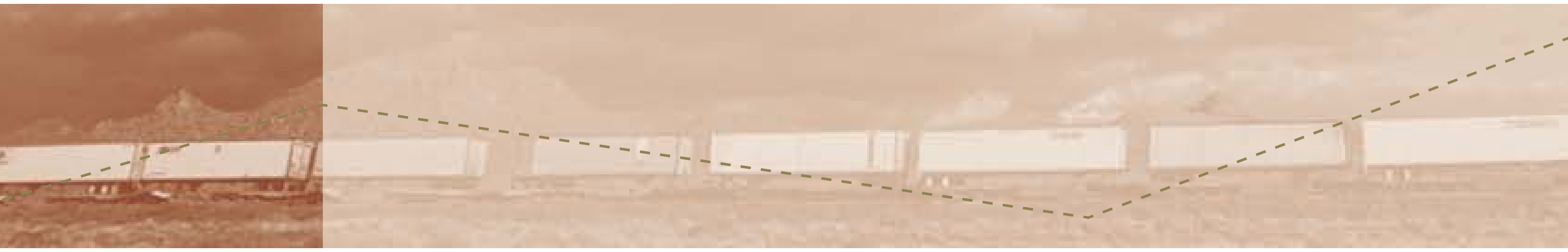


Table 5. Cumulative Emissions and LUCF, 1950–2000

Effect of including land use change & forestry emissions

	% of World (Rank)				
Country	**CO$_2$ from Fossil Fuels**		**CO$_2$ from Fossil Fuels & Land Use Change**		**% Change**
United States	26.6	(1)	16.7	(1)	-37
EU-25	22.0	(2)	15.8	(2)	-28
Russia	9.6	(3)	8.1	(4)	-15
China	9.0	(4)	9.9	(3)	11
Germany	5.9	(5)	4.3	(7)	-28
Japan	4.7	(6)	3.8	(8)	-19
United Kingdom	3.7	(7)	2.7	(9)	-28
Ukraine	2.6	(8)	1.9	(12)	-28
India	2.3	(9)	1.6	(14)	-33
France	2.3	(10)	1.7	(13)	-28
Canada	2.2	(11)	2.0	(10)	-7
Poland	2.0	(12)	1.4	(15)	-28
Italy	1.8	(13)	1.3	(16)	-28
South Africa	1.3	(14)	0.9	(21)	-28
Mexico	1.2	(15)	1.2	(17)	5
Australia	1.2	(16)	0.9	(20)	-18
Spain	1.0	(18)	0.7	(26)	-29
Brazil	0.9	(19)	6.1	(6)	560
South Korea	0.9	(20)	0.7	(25)	-20
Iran	0.8	(23)	0.6	(32)	-21
Saudi Arabia	0.6	(27)	0.4	(38)	-28
Indonesia	0.6	(28)	7.2	(5)	1,165
Argentina	0.6	(29)	0.6	(28)	11
Turkey	0.5	(31)	0.5	(36)	-4
Pakistan	0.2	(46)	0.3	(48)	22
Developed	**71.4**		**51.4**		**-28**
Developing	**28.6**		**48.6**		**70**

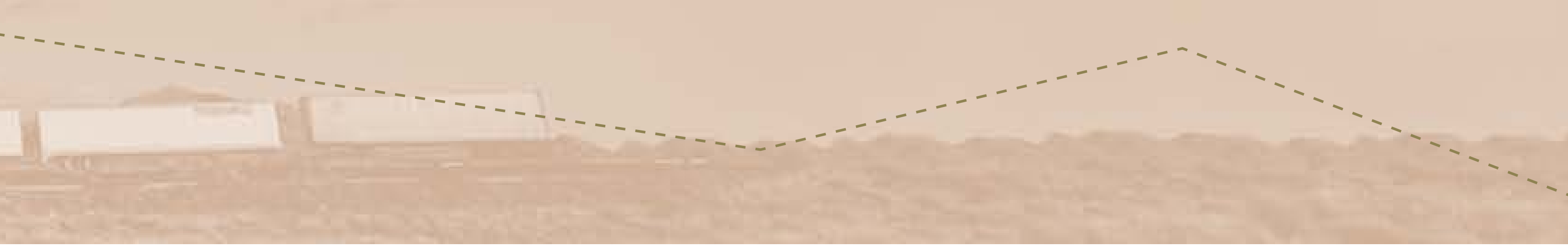


Table 6. Cumulative Emissions and Time Periods
Effect of altering the time period of analysis

	Cumulative CO_2 Emissions from Fossil Fuels				
	% of World (Rank)				
Country	**1850–2002**		**1990–2002**		**% change**
United States	29.3	(1)	23.5	(1)	-20
EU-25	26.5	(2)	17.0	(2)	-36
Russia	8.1	(3)	7.5	(4)	-8
China	7.6	(4)	13.9	(3)	83
Germany	7.3	(5)	4.0	(6)	-46
United Kingdom	6.3	(6)	2.5	(8)	-61
Japan	4.1	(7)	5.2	(5)	26
France	2.9	(8)	1.6	(13)	-44
India	2.2	(9)	3.9	(7)	79
Ukraine	2.2	(10)	1.9	(10)	-12
Canada	2.1	(11)	2.1	(9)	-3
Poland	2.1	(12)	1.5	(15)	-28
Italy	1.6	(13)	1.9	(11)	17
South Africa	1.2	(14)	1.5	(16)	26
Australia	1.1	(15)	1.3	(17)	24
Mexico	1.0	(16)	1.6	(14)	56
Spain	0.9	(20)	1.2	(20)	31
Brazil	0.8	(22)	1.3	(18)	58
South Korea	0.8	(23)	1.7	(12)	127
Iran	0.6	(24)	1.2	(19)	92
Indonesia	0.5	(27)	1.1	(21)	110
Saudi Arabia	0.5	(28)	1.1	(22)	116
Argentina	0.5	(29)	0.6	(30)	16
Turkey	0.4	(31)	0.8	(24)	82
Pakistan	0.2	(48)	0.4	(36)	105
Industrialized	**75.6**		**60.8**		**-20**
Developing	**24.4**		**39.2**		**61**

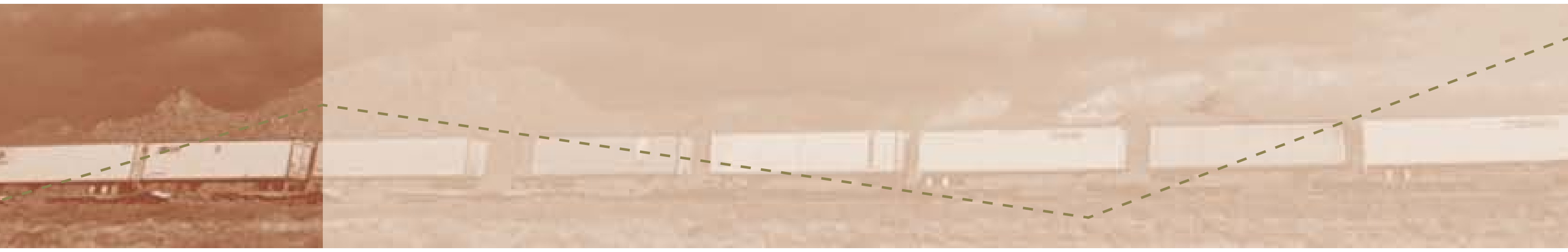


Table 7. Health, Education, and Governance Indicators, 2002

Top 25 GHG emitting countries

Country	Life Expectancy Years	(Rank)	Adult Literacy % of Pop.	(Rank)	Governance Index 0-100 Index	(Rank)
Canada	79	(4)	99	(1)	92	(11)
Australia	79	(6)	99	(1)	92	(10)
Japan	82	(1)	99	(1)	79	(26)
France	79	(9)	99	(1)	83	(20)
Germany	78	(18)	99	(1)	90	(14)
United Kingdom	78	(21)	99	(1)	92	(12)
EU-25	78	(21)	99	(1)	84	(18)
United States	77	(28)	99	(1)	85	(17)
Spain	79	(5)	98	(50)	82	(23)
Italy	79	(11)	99	(45)	73	(30)
Poland	74	(49)	99	(1)	67	(40)
South Korea	75	(38)	98	(47)	66	(43)
Russia	67	(117)	99	(1)	48	(76)
Mexico	73	(56)	91	(91)	52	(72)
Argentina	74	(43)	97	(55)	33	(128)
Ukraine	70	(98)	99	(1)	33	(129)
China	71	(79)	91	(89)	40	(109)
Saudi Arabia	72	(68)	78	(124)	47	(90)
Brazil	68	(113)	86	(101)	49	(74)
Turkey	70	(87)	87	(99)	41	(106)
South Africa	49	(155)	86	(102)	59	(56)
Iran	70	(89)	77	(126)	29	(140)
Indonesia	67	(119)	88	(96)	26	(151)
India	64	(123)	61	(150)	44	(99)
Pakistan	61	(132)	42	(168)	26	(150)
World	**67**		**80**		**51**	

Sources & Notes: Life expectancy and literacy are from UNDP (2004) and governance is a composite index, based on Kaufmann et al. (2002), that captures six interrelated aspects of governance (e.g., political stability, regulatory quality, etc.). Countries are ordered according to their collective ratings of all three indicators (with the highest scoring at the top). The highest possible score here for literacy is 99 percent.

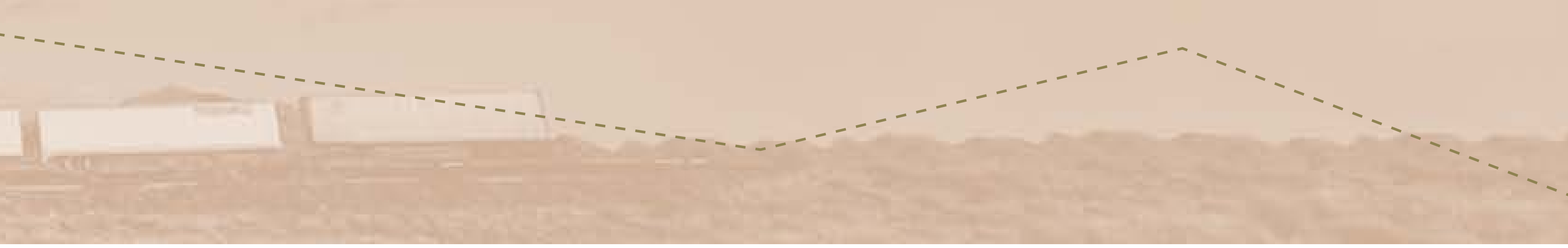


Table 8. Coal Consumption, Production, and Reserves, 2004

	Consumption			Production			Reserves
Country	**Mtoe**	**(Rank)**	**% World**	**Mtoe**	**(Rank)**	**% World**	**% World**
China	957	(1)	34.4	990	(1)	36.2	12.6
United States	564	(2)	20.3	567	(2)	20.8	27.1
EU-25	307	(3)	11.0	191	(4)	7.0	5.0
India	205	(4)	7.4	189	(5)	6.9	10.2
Japan	121	(5)	4.3	1	(32)	—	—
Russia	106	(6)	3.8	128	(7)	4.7	17.3
South Africa	95	(7)	5.0	137	(6)	5.0	5.4
Germany	86	(8)	3.1	55	(10)	2.0	0.7
Poland	58	(9)	2.1	70	(9)	2.6	1.5
Australia	54	(10)	2.0	199	(3)	7.3	8.6
South Korea	53	(11)	1.9	1	(30)	0.1	—
Ukraine	39	(12)	1.4	42	(12)	1.5	3.8
United Kingdom	38	(13)	1.4	15	(16)	0.6	—
Canada	31	(15)	1.1	35	(14)	1.3	0.7
Turkey	23	(17)	0.8	10	(18)	0.4	0.5
Indonesia	22	(18)	0.8	81	(8)	3.0	0.5
Spain	21	(19)	0.8	7	(21)	0.2	0.1
Italy	17	(21)	0.6	—	—	—	—
France	13	(22)	0.4	1	(33)	—	—
Brazil	11	(23)	0.4	2	(29)	0.1	1.1
Mexico	9	(27)	0.3	4	(25)	0.2	0.1
Pakistan	3	(39)	0.1	1	(31)	—	0.3
Iran	1	(47)	—	—	—	—	—
Argentina	1	(49)	—	—	—	—	—
Saudi Arabia	—	—	—	—	—	—	—
Rest of World	**176**		**6.3**	**154**		**5.6**	**6.8**
World	**2,778**			**2,732**			

Sources & Notes: BP, 2005. Mtoe = millions of tons of oil equivalent. "—" signifies no data, small, or zero values. EU-25 production and reserves figures are estimates, based on BP (2005).

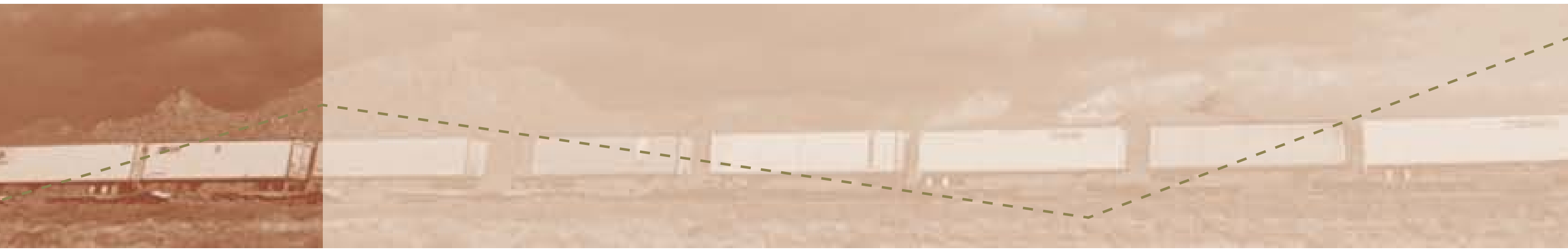


Table 9. **Oil Consumption, Production, and Reserves, 2004**

	Consumption			Production			Reserves
Country	**Mt**	**(Rank)**	**% World**	**Mt**	**(Rank)**	**% World**	**% World**
United States	938	(1)	24.9	330	(3)	8.5	2.5
EU-25	695	(2)	18.4	—	—	—	—
China	309	(3)	8.2	175	(6)	4.5	1.4
Japan	242	(4)	6.4	—	—	—	—
Russia	129	(5)	3.4	459	(2)	11.9	6.1
Germany	124	(6)	3.3	—	—	—	—
India	119	(7)	3.2	38	(24)	1.0	0.5
South Korea	105	(8)	2.8	—	—	—	—
Canada	100	(9)	2.6	148	(9)	3.8	1.4
France	94	(10)	2.5	—	—	—	—
Italy	90	(11)	2.4	5	(46)	0.1	0.1
Mexico	85	(12)	2.3	191	(5)	4.9	1.2
Brazil	84	(13)	2.2	76	(16)	2.0	0.9
United Kingdom	81	(14)	2.1	95	(14)	2.5	0.4
Saudi Arabia	80	(15)	2.1	506	(1)	13.1	22.1
Spain	78	(16)	2.1	—	—	—	—
Iran	73	(17)	1.9	203	(4)	5.2	11.1
Indonesia	55	(18)	1.5	55	(19)	1.4	0.4
Australia	39	(22)	1.0	23	(30)	0.6	—
Turkey	32	(25)	0.8	—	—	—	—
Venezuela	26	(27)	0.7	153	(7)	4.0	6.5
South Africa	25	(28)	0.7	—	—	—	—
Poland	21	(30)	0.6	—	—	—	—
Argentina	19	(32)	0.5	38	(25)	1.0	0.2
Ukraine	17	(33)	0.5	—	—	—	—
UAE	16	(36)	0.4	126	(10)	3.3	8.2
Pakistan	14	(40)	0.4	—	—	—	—
Kuwait	14	(39)	0.4	120	(12)	3.1	8.3
Algeria	11	(43)	0.3	83	(15)	2.1	1.0
Norway	10	(49)	0.3	150	(8)	3.9	0.8
Nigeria	—	—	—	122	(11)	3.2	3.0
Iraq	—	—	—	100	(13)	2.6	9.7
Libya	—	—	—	76	(17)	2.0	3.3
Rest of World	**534**		**14.2**	**698**		**18.1**	**88.7**
World	**3,767**			**3,868**			

Source & Sources: BP, 2005. Mt = millions of tons. "—" signifies no data, small, or zero values. Countries not among the top 25 absolute emitters are shown in italics, and are included here because their oil production accounts for at least 2% of the world total.

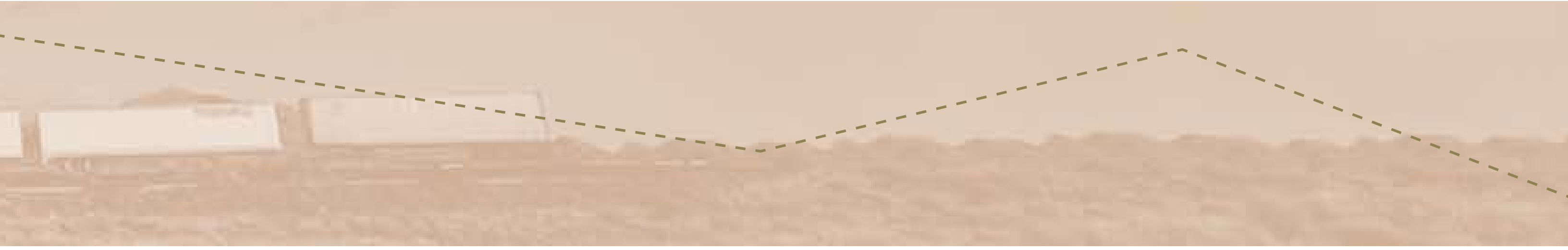


Table 10. Natural Gas Consumption, Production, and Reserves, 2004

	Consumption			Production			Reserves
Country	**Mtoe**	**(Rank)**	**% World**	**Mtoe**	**(Rank)**	**% World**	**% World**
United States	582	(1)	24.0	489	(2)	20.2	2.9
EU-25	420	(2)	17.4	194	(3)	8.0	1.5
Russia	362	(3)	15.0	530	(1)	21.9	26.7
United Kingdom	88	(4)	3.6	86	(5)	3.6	0.3
Canada	81	(5)	3.3	165	(4)	6.8	0.9
Iran	78	(6)	3.2	77	(6)	3.2	15.3
Germany	77	(7)	3.2	15	(31)	0.6	0.1
Italy	66	(8)	2.7	12	(34)	0.5	0.1
Japan	65	(9)	2.7	—	—	—	—
Ukraine	64	(10)	2.6	17	(29)	0.7	0.6
Saudi Arabia	58	(11)	2.4	58	(11)	2.4	3.8
Uzbekistan	44	(12)	1.8	50	(12)	2.1	1.0
Mexico	43	(13)	1.8	33	(19)	1.4	0.2
France	40	(14)	1.7	—	—	—	—
Netherlands	39	(15)	1.6	62	(10)	2.6	0.8
UAE	36	(16)	1.5	41	(15)	1.7	3.4
China	35	(17)	1.5	37	(17)	1.5	1.2
Argentina	34	(18)	1.4	40	(16)	1.7	0.3
Indonesia	30	(19)	1.3	66	(9)	2.7	1.4
Malaysia	30	(20)	1.2	49	(14)	2.0	1.4
India	29	(21)	1.2	27	(21)	1.1	0.5
South Korea	28	(22)	1.2	—	—	—	—
Venezuela	25	(24)	1.0	25	(22)	1.0	2.4
Spain	25	(25)	1.0	—	—	—	—
Pakistan	23	(27)	1.0	21	(25)	0.9	0.4
Australia	22	(28)	0.9	32	(20)	1.3	1.4
Turkey	20	(29)	0.8	—	—	—	—
Algeria	19	(30)	0.8	74	(7)	3.0	2.5
Brazil	17	(31)	0.7	10	(36)	0.4	0.2
Turkmenistan	14	(35)	0.6	49	(13)	2.0	1.6
Qatar	14	(37)	0.6	35	(18)	1.5	14.4
Poland	12	(39)	0.5	4	(46)	0.2	0.1
Norway	4	(51)	0.2	71	(8)	2.9	1.3
Nigeria	—	—	—	19	(26)	0.8	2.8
South Africa	—	—	—	—	—	—	—
Rest of World	**204**		**8.4**	**154**		**6.4**	**10.9**
World	**2,420**			**2,422**			

Sources & Notes: BP, 2005. Mtoe = millions of tons of oil equivalent. "—" signifies no data, small, or zero values. Countries not among the top 25 absolute emitters are shown in italics, and are included here because their gas production and/or reserves account for at least 2% of the world total.

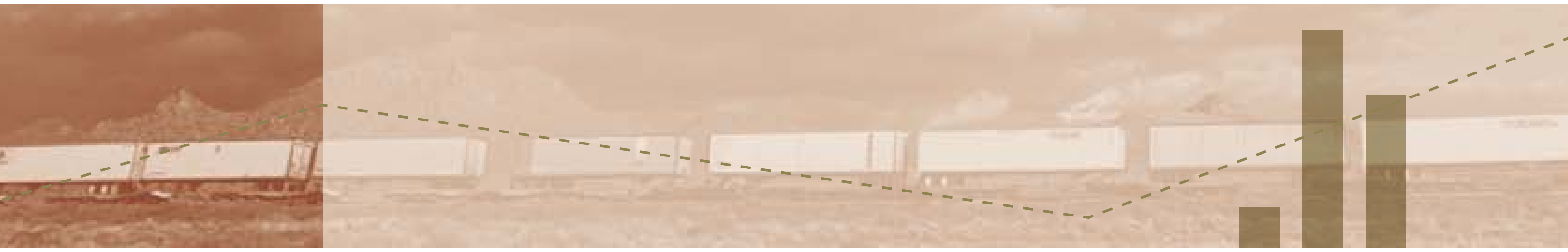


Table 11. GHG Emissions From Agriculture, 2000

	Total Agriculture Emissions		MtCO$_2$ Equivalent		
Country	**MtCO$_2$ eq.**	**% World**	**CO$_2$**	**CH$_4$**	**N$_2$O**
China	1,097	18	88	437	572
India	640	11	0	275	365
EU-25	548	9	71	225	252
United States	517	9	47	162	308
Brazil	461	8	16	250	196
Pakistan	149	2	1	67	82
Indonesia	129	2	6	90	33
Argentina	124	2	7	56	60
Russia	118	2	20	52	45
France	108	2	8	44	56
Australia	107	2	4	76	27
Germany	96	2	6	53	36
Turkey	77	1	8	31	38
Iran	71	1	10	19	42
Canada	70	1	9	23	38
Mexico	56	1	6	46	4
Japan	54	1	20	14	20
United Kingdom	52	1	2	21	29
Spain	50	1	6	23	21
Italy	49	1	8	17	23
South Africa	44	1	4	16	23
Ukraine	43	1	8	20	16
Poland	41	1	14	10	16
South Korea	24	0	10	12	2
Saudi Arabia	10	0	0	2	8
Rest of World	**1,668**	**28**	**41**	**906**	**721**
World	**6,008**		**377**	**2,778**	**2,853**

Notes: Emissions here pertain to IPCC Source Category 4 (CH$_4$ and N$_2$O), but also include CO$_2$ emissions from fossil fuel combustion (category 1A4).

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- To reverse damage to ecosystems. We protect the capacity of ecosystems to sustain life and prosperity.
- To expand participation in environmental decisions. We collaborate with partners worldwide to increase people's access to information and influence over decisions about natural resources.
- To avert dangerous climate change. We promote public and private action to ensure a safe climate and sound world economy.
- To increase prosperity while improving the environment. We challenge the private sector to grow by improving environmental and community well-being.

In all of its policy research and work with institutions, WRI tries to build bridges between ideas and actions, meshing the insights of scientific research, economic and institutional analyses, and practical experience with the need for open and participatory decision-making.