Chapter 1

Introduction

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Author(s):	CLAs:	David Victor, Dadi Zhou	
	LAs:	Essam Hassan Mohamed Ahmed, Pradeep Kumar Dadhich, Jos Olivier, Hans-Holger Rogner, Kamel Sheikho, Mitsutsune Yamaguchi	
	CAs:	Giovanni Baiocchi, Linda Wong	
	REs:	Arnulf Grübler, Alik Muvundika	
Chapter Science Assistant:	Songli Zhu		
Remarks:			
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Chapter 1: Introduction

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Executive Summary

Since the first IPCC assessment report (IPCC, 1990), the quantity and depth of scientific research on climate change mitigation has grown enormously. In tandem with scholarship on this issue, the last two decades have seen relatively active efforts around the world to design and adopt policies that control ("mitigate") the emissions of pollutants that affect the climate. Those policies have been local, national and international in scope. They have included market-based approaches such as emission trading systems along with regulation and voluntary initiatives; they encompass many diverse economic development strategies that countries have adopted with the goal of promoting human welfare and jobs while also achieving other goals such as mitigating emissions of climate pollutants. International diplomacy—leading to agreements such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol—has played a substantial role in focusing attention on mitigation of GHGs.

The field of scientific research in this area has evolved in parallel with actual policy experience allowing, in theory, insights from each domain to inform the other. Since the 4th assessment report (AR4) of IPCC (2007a) (2007b) there have been numerous important developments in both the science and practical policy experience related to mitigation. There is growing insight into how climate change mitigation policies interact with other important social goals from the local to the national and international levels. There is also growing practical experience and scholarly research concerning a wide array of policy instruments. Scholars have developed much more sophisticated information on how public opinion influences the design and stringency of climate change mitigation policies.

Meanwhile, events in the world have had a large impact on how scientific researchers have seen the scale of the mitigation challenge and its practical diplomatic outcomes. A worldwide economic recession beginning around 2008 has affected patterns of emissions and investment in the world economy and in many countries has affected political priorities on matters related to climate change mitigation.

The present chapter identifies six conclusions. First, efforts at mitigation must begin with assessments of the trends in total emissions of greenhouse gases (GHGs) as well as the factors that affect those emissions. Since AR4, global GHG emissions have continued to grow and reached an all time high of 50.1 billion tonnes (gigatonnes or Gt) of carbon dioxide equivalents (CO2-eq). On a per-capita basis, emissions from industrialized countries that are listed in Annex I of the UNFCCC are on average nearly 4 times higher than those from developing countries. However, since AR4 total emissions from countries not listed in Annex I have overtaken total emissions from the Annex I industrialized countries. Treating the 27 members of the EU as a single country, about ten large countries—from the industrialized and developing worlds—account for 70% of world emissions. [1.3; high agreement, robust evidence] The driving forces for emissions include population, income, the structure of the economy, individual and societal behaviour, patterns of consumption, investment decisions, the state of technology, availability of energy resources, and induced effects, e.g. anthropogenic land use conversion, forest, peat and other land emissions in changing climatic conditions. These factors affect the choice of fuels as well as the overall efficiency of the energy system. In nearly all countries it is very likely that the main short-term driver of changes in the level of emissions is the overall state of the economy. It is likely that there is a large role for climate policies focused on controlling emissions. [1.3; high agreement, robust evidence]

Second, national governments are addressing climate change in the context of other national priorities, such as energy security and alleviation of poverty. Thus it is very likely that actual progress in controlling emissions is larger than it may seem when analysts focus just on policies that governments have identified as "climate change-related." In nearly all countries the most important driving forces for climate policy are not solely the concern about climate change. [1.2 and 1.4; medium agreement, medium evidence]. Studies on policy implementation show that improvements to climate mitigation and adaptation programs as well as other possible responses such as geoengineering—for example through capacity-building—need to engage these broader national priorities. Despite the variety of existing policy efforts and the existence of the UNFCCC and the Kyoto Protocol, GHG emissions have grown at about twice the rate in the recent decade (2000-2010) than any other decade since 1970. [1.3.1; high agreement, robust evidence]

Third, it is virtually certain that the current trajectory of global annual and cumulative emissions of GHGs is inconsistent with widely discussed goals of limiting global warming at 1.5 to 2 degrees Celsius above the pre-industrial level. [1.2.1.6 and 1.3.3; medium agreement, robust evidence] Existing models suggest it is very unlikely that the goal of stabilizing warming at 2 degrees at least cost is practically feasible unless international cooperation that involves all countries were to begin almost immediately and a wide array of cost-effective low emission technologies were available. It is exceptionally unlikely that meeting the more aggressive goal of stabilizing warming at 1.5 degrees Celsius is feasible [1.3.3; high agreement, robust evidence]

Fourth, it is likely that deep cuts in emissions will require a diverse portfolio of policies and technologies as well as human behaviour. It is very likely that there are many different development trajectories capable of substantially mitigating emissions, and it is virtually certain that the ability to meet those trajectories will be constrained if particular technologies are removed from consideration. It is virtually certain that the most appropriate policies will vary by sector and country, suggesting the need for flexibility rather than a singular set of policy tools. In most countries the actors that are relevant to controlling emissions aren’t just national governments. Many diverse actors participate in climate policy from the local to the global levels—including a wide array of nongovernmental organizations representing different environmental, social, business and other interests. [1.4; medium agreement, robust evidence]

Fifth, policies to mitigate emissions are extremely complex and arise in the context of many different forms of uncertainty. While there has been much public attention to uncertainties in the underlying science of climate change—a topic addressed in detail in IPCC’s Working Group 1 and 2 reports—it is virtually certain that profound uncertainties arise in the socioeconomic factors addressed here in Working Group 3. Those uncertainties concern the development and deployment of technologies, average rates of economic growth and the distribution of benefits and costs within societies, emission patterns, and a wide array of institutional factors such as whether and how countries cooperate effectively at the international level. For the most part, these uncertainties and complexities multiply those already identified in climate science by Working Groups 1 and 2. The pervasive complexities and uncertainties suggest it is very likely that there is a need to emphasize policy strategies that are robust over many criteria, adaptive to new information, and able to respond to unexpected events. [1.2; medium agreement, medium evidence]

Sixth, scholars have developed more sophisticated techniques for assessing risks. They have also focused research on risk management strategies, drawing attention to the interactions between mitigation and other kinds of policy responses such as adaptation to climate change and possible deployment of geoengineering technologies as a last resort in case the dangers of extreme climate change appear quickly [chapter 2; low agreement, medium evidence]. In that context it is very likely that adaptation to climate change should be viewed as a complement to mitigation policies, not a substitute [1.4; high agreement, limited evidence]. There is rising scholarly attention to the role of adaptation in light of the GHGs already loaded into the atmosphere and virtually certain to be emitted in the future.

1.1 Introduction

Working Group 3 of the IPCC is charged with assessing scientific research related to the mitigation of climate change. “Mitigation” is the effort to control the fundamental human sources of climate change and their cumulative impacts, notably the emission of pollutants that can affect the planet’s energy balance, and to enhance GHG sinks. Because mitigation lowers the likely effects of climate change as well as the risks of extreme impacts, it is part of a broader policy strategy that includes adaptation to climate impacts—a topic addressed in more detail in IPCC’s Working Group 2. There is a special role for international cooperation on mitigation policies because most climate pollutants have long atmospheric lifetimes and mix throughout the global atmosphere. The effects of mitigation policies on economic growth, innovation and spread of technologies and other important social goals are also matters of international concern because nations are increasingly inter-linked through global trade and economic competition.

This chapter introduces the major issues that arise in mitigation policy and also frames the rest of the Working Group III volume. First we focus on the main messages since the publication of AR4 in 2007 (section 1.2). Then we look at the historical and future trends in emissions and driving forces, noting that the scale of the mitigation challenge has grown enormously since 2007, raising questions about the viability of widely-discussed goals such as limiting climate warming to 2 degrees Celsius since the pre-industrial period (section 1.3). Then we look at the conceptual issues—such as sustainable development, green growth, and risk management—that frame the mitigation challenge and how those concepts are used in practice (section 1.4). Finally, we offer a roadmap for the rest of the volume (section 1.5).

1.2 Main messages and changes from previous assessment

Since AR4 there have been many developments in the world economy, emissions and policies related to climate change. Here we review what has changed because that helps to define the challenges and opportunities that arise for the current report.

1.2.1 Lessons learned since AR4

Since AR4 there have been changes, broadly, in two areas. First, there have been large changes in the economic and political context within which governments and various actors have tried to address the climate issue. Second, there have been changes in the scientific assessment of climate change mitigation and adaptation. Those broad changes have been reflected, in particular, in six major ways.

FAQ 1.1. What exactly is climate change mitigation?

The Framework Convention on Climate Change (UNFCCC), in its Article 1, defines *climate change* as: ‘a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods’.

Climate Change Mitigation is an activity with the purpose to reduce emissions of greenhouse gases (GHG) in the atmosphere at levels lower than would otherwise occur. The ultimate goal of mitigation (per Article 2 of the UNFCCC) is preventing dangerous anthropogenic interference with the climate system.

1.2.1.1 Sustainable Development and other Goals

Addressing climate change has become one element in an effort to broaden the concept of economic growth. Often called “sustainable development,” “green growth,” “green economy,” or other terms, these varied new approaches aim to harmonize economic growth with other goals such as environmental protection and justice (World Commission on Environment and Development, 1987; UNDP, 2009; ADB et al., 2012; BRICS, 2012; OECD, 2012; United Nations, 2012) Over the last two decades, climate change has become a key (but not sole) environmental challenge of sustainable development (see chapter 4). In many respects, these concepts are not new as they reflect the effort in the social sciences over the last century to develop techniques for measuring and responding to the many positive and negative externalities that arise as economies evolve—concepts discussed in more detail in chapter 3 of this volume.

All countries in varied ways have made great efforts on sustainable development and addressing climate change. Their efforts cover all major mitigation measures, such as energy conservation and efficiency improvement, development of low carbon energy sources, protecting and increasing forests and other carbon sinks, and reducing greenhouse gases emission from particular sectors such as industry and transport. For example, China has declared many policy strategies that centrally advance green and low carbon development. It has set a national energy efficiency target of decreasing energy intensity (emissions per unit of GDP) of 20% between 2006-2010. (The actual achievement was 19.1 %.) A new target (16% reduction in energy intensity from 2011 to 2015) is now in force, along with the goal of reducing carbon intensity by 17% over the same time (Hu and Rodriguez Monroy, 2012; Paltsev et al., 2012). The practical effects of these policy goals are evident in many places. For example, by the end of 2011, wind power installed capacity in China reached 65 GW, ranking the first in the world; the country has doubled its hydro-power capacity during 2006-2010; and more nuclear reactors are being planned and under construction than in the rest of the world combined (Xie, 2009; Guo, 2011; Ye, 2011).

Many other countries are also playing leading roles in developing and deploying new energy technologies—driven by sustainable development strategies that emphasize the interconnection of many different policy goals such as energy and food security, local pollution control and climate change. For example, the Government of India launched the Jawaharlal Nehru National Solar Mission (JNNSM) to encourage the needed regulatory frameworks, human resource capacity and investment in solar energy technologies with the goal of making solar power competitive with conventional grid power by 2022. India has added more than a Gigawatt of solar capacity in less than three years since the launch of the mission (Government of India, 2009).

Just as many developing countries have taken steps, many industrialized countries have also adopted important policies. The European Union has implemented an Emission Trading Scheme (ETS) which covers about half of the EU's emissions, along with an array of regulations in other sectors (e.g., buildings) where emissions are not included in the ETS. Since AR4 the EU has expanded the ETS to cover aviation. The U.S. has adopted new regulatory standards on fuel economy and other types of end-use efficiency as well as labeling programs; many U.S. states have also adopted their own state regulations to advance complementary goals. The governments of Australia and Japan have adopted carbon tax, as has the Canadian province of British Columbia—and all of these governments have devoted at least a portion of the tax revenues to activities that will mitigate emissions.

Some countries also made significant progress in protecting and improving carbon sinks. Brazil launched the program for preventing and controlling the deforestation and forest fires in the Amazon area, with advanced remote sensing and meteorological satellite technologies, combined with administrative, economic and legal instruments. As a result, the CO_2 emissions related to land use and forestry in Brazil have decreased to 1.26 billion tons of CO_2 in 2005 from the highest 1.84 billion tons of CO_2 in 1995 (FRB, 2010). It remains difficult, however, to disentangle the role of policies from other factors that affect incentives for deforestation (Assunção et al., 2012).

While there are many areas of tangible progress from countries integrating the many goals that lead to sustainable development there are also many challenges. Per capita energy consumption and emissions of some developing countries is still far lower than that of developed countries, suggesting that as economies converge that emissions will rise (Olivier et al., 2012). Current investment in low carbon technologies is insufficient to offset the emissions increases associated with projected economic growth in both developed and developing countries. In the face of other development needs, high upfront investment costs of may low carbon technologies pose a challenge to developing countries. .

Overall, the evidence suggests that while efforts to define and implement "sustainable development," "green growth" and other efforts to organize economies around multiple social goals that include management of environmental externalities have led to a diverse array of climate change mitigation policies, the totality of the global effort remains inconsistent with widely discussed goals for protecting the climate.

FAQ 1.2. What causes GHG emissions?

Anthropogenic GHGs come from combustion of fossil fuels in energy conversion systems like boilers in electric power plants, engines in aircraft and automobiles, and in cooking and heating within homes and businesses. While most GHGs come from fossil fuel conversion, a substantial part also comes from other activities like agriculture, deforestation, industrial processes and municipal waste.

1.2.1.2 The World Macroeconomic Situation

Shortly after the publication of AR4 in 2007, the world encountered a severe and deep financial crisis (Sornette and Woodard, 2009). The crisis which spread rapidly in the fall of 2008 destabilized many of the largest financial institutions in the US, Europe and Japan, and shocked public confidence in the global financial system and wiped out an estimated $25 trillion in value from the world's publicly traded companies, with particularly severe effects on banks (IMF, 2009; Naudé, 2009). The effects of the crisis are evident in economic growth—shown on Figure 1.1. The year 2009 witnessed the first contraction in global GDP since the Second World War (Garrett, 2010). International trade of goods and services had grown rapidly since the turn of the millennium - from 18% of world GDP in 2000 to 28% in 2008 (WTO, 2011). The crises caused global trade to drop to 22% in 2009 before rebounding to 25% in 2010.

The effects of the recent economic crisis have been concentrated in the advanced industrialized countries that have remained somewhat decoupled from the rest of the global economy (Te Velde, 2008; Lin, 2008; ADB, 2009, 2010) While this particular crisis has been large, studies have shown that these events often recur, suggesting that there is pervasive over-confidence that policy and investment strategies can eliminate such cyclic behaviour (Reinhart and Rogoff, 2011).

Although Figure 1.1 reveals that developing countries were generally not directly affected by the melt-down of financial institutions in the industrialized world the contagion of recessions centred on the OECD has spread, especially to countries with small, open and export-oriented economies. The crisis has also affected foreign direct investment (FDI) and official development assistance (ODA) (IMF, 2009, 2011).

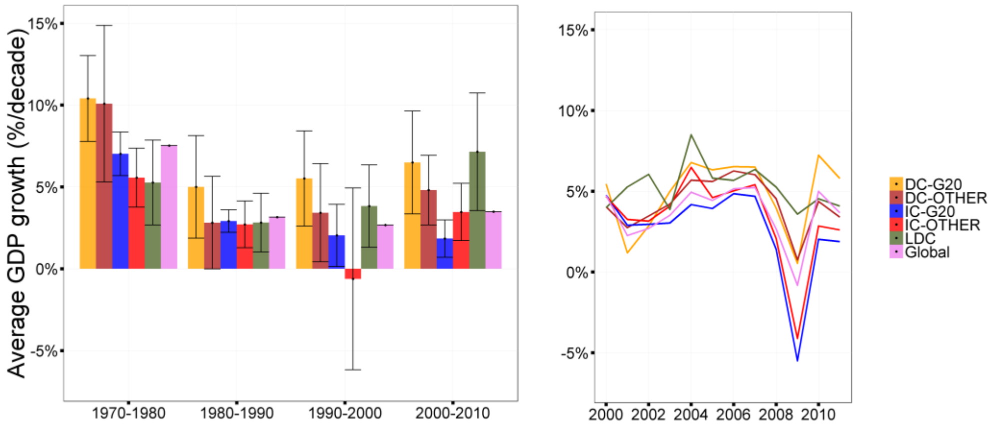


Figure 1.1. Annual real growth rates of real GDP by decade (left panel) and since 2000 (right panel) for large developing countries that are members of the G20 (DC-G20), large industrialized countries that are G20 members (IC-G20), other countries that are not G20 members and the least developed countries (LDC) as defined by the UN. Estimates weighted by economic size and variations to one standard deviation shown. Growth rates averaged by decade and weighted by size of the economy; also shown the variation to one standard deviation. Sources: Real (PPP converted) growth rates from World Bank, with coverage gaps filled with IMF, Penn World Tables and IEA-OECD.

The continued growth of developing economies, albeit at a slower pace than before the crisis, helps to explain why global commodity prices, such as for oil, have quickly rebounded as well (see Figure 1.2). Among the many implications of high and volatile commodity prices are continued concerns about the availability and security of energy and food supply, especially in the least-developed countries. Those concerns have also reshaped, to some degree, how problems such as global climate change are viewed in many countries and societies. Where climate change mitigation has linked to these broader economic and energy security concerns it has proven politically easier to mobilize action; where they are seen in conflict the economic and security priorities have often dominated (Chandler et al. 2002; IEA 2007; ADB 2009).

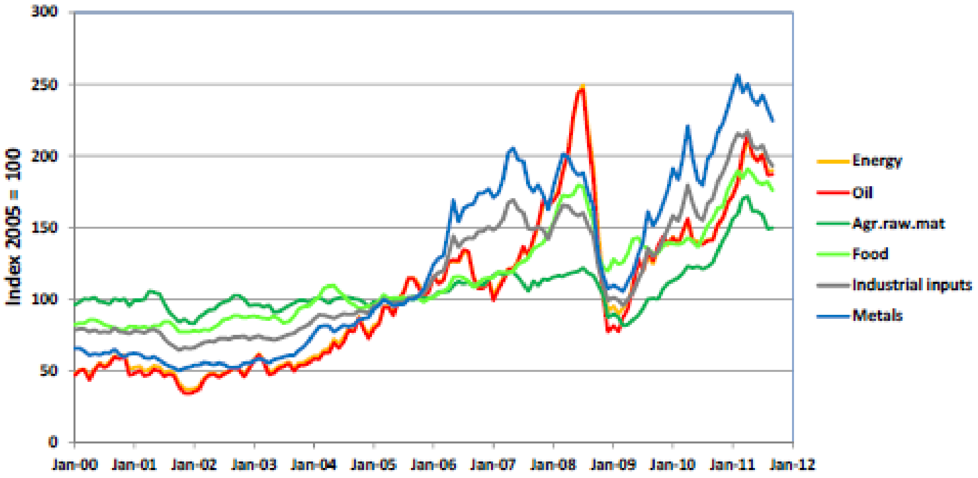


Figure 1.2. Price indices of selected commodities. Source: (Index Mundi, 2011). [Author Note: this is a placeholder for a figure that will show price indices of oil, [metal/steel/ore], concrete, ethanol, coal, and food [composite/corn?] since 1970 (main figure) and since 2000 (inset). [Author note to reviewers: this figure to be redrawn and simplified in parallel with SOD.]

The implications of these macroeconomic patterns are many, but at least five are germane to the challenges of climate change mitigation:

- First, the momentum in global economic growth has shifted to the emerging economies—a pattern that was already evident in the 2000s before the crisis hit. Although accelerated by the recent financial crisis, this shift in production, investment and technology to emerging economies is a phenomenon that is consistent with the expectation that in a globalized world economy capital resources will shift to emerging economies where they can be used with greatest marginal productivity (Zhu, 2011; Lamy, 2011). With that shift has been a consequent shift in the growth of greenhouse gas emissions.
- Second, much of this shift has arisen in the context of globalization in investment and trade, leading to higher emissions that are 'embedded" in traded goods and services, suggesting the need for additional or complementary accounting systems that reflect the ultimate consumption of manufacturing goods that cause emissions rather than just the geographical place where emissions occurred during manufacturing (Houser et al. 2008; Davis and Caldeira 2010; Peters, Davis, and Andrew 2012; Peters et al. 2011).
- Third, economic troubles affect political priorities. As a general rule, hard economic times tend to focus public opinion on policies that yield immediate economic benefits that are realized close to home (Kahler and Lake, 2013). Long-term goals, such as global climate protection, suffer unless they are framed to resonate with these other, immediate goals. Chapter 2 of this volume looks in more detail at the wider array of factors that affect how humans perceive and manage risks that are spread out over long time horizons.
- Fourth, economic slowdown may also reduce the rate of technological progress that contributes to addressing climate change, such as in energy efficiency (Bowen et al., 2009). The crisis also has accelerated shifts in the global landscape for innovation (Gnamus, 2009). The largest emerging economies have all built effective systems for innovation and deployment of new technologies—including low emission technologies. This "technology transfer" now includes "South-South" exchanges of technology although a central role remains for "North-South" technology transfer as part of international agreements on climate change and other topics (see also chapters 5 and 16).
- Fifth, commodity prices remain high and volatile despite sluggish economic growth in major parts of the world economy. High costs for food have amplified concerns about competition between food production and efforts to mitigate emissions, notably through the growing of bioenergy crops (see Chapter 11 Bioenergy Annex). High prices for fossil fuels along with steel and other commodities affects the cost of building and operating different energy systems, a topic to which we now turn.

1.2.1.3 The Availability, Cost and Performance of Energy Systems

The purpose of energy systems—from resource extraction to refining and other forms of conversion to distribution of energy services for final consumption—is to provide affordable energy services to fuel economic and social development. The choice of energy systems depends on a wide array of investment and operating costs, the relative performance of different systems, infrastructures and lifestyles. These choices are affected by many factors--notably price and performance—and the assessment of different energy options depends critically on how externalities, such as pollution, are included in the calculations.

Following a decade of price stability at low levels, since 2004 energy prices have been high and volatile (see Figure 1.2). Those prices have gone hand-in-hand with substantial geopolitical consequences that have included a growing number of oil importing countries focusing on policies surrounding energy security (e.g., (Yergin, 2011). Some analysts interpret these high prices as a sign of imminent “peak production” of exhaustible resources with subsequent steady decline while others have argued that the global fossil and fissile resource endowment is plentiful (Rogner, 2012). Concerns about the scarcity of resources have traditionally focused on oil (Aleklett et al., 2010), but more recently the notions of peak coal (Heinberg and Fridley, 2010), peak gas (Laherrère, 2004) and peak uranium (EWG, 2006) have also entered the debate (see Chapter 7.4). Two opposing trends have been observed since 2004 - low investment in exploration and extraction capacity of conventional oil and gas combined with unexpected surges in demand (driven by large and fast growing emerging economies).

Just as AR4 was going into publication, sustained high prices had encourage a series of technological innovations that have created the possibility of large new supplies from unconventional resources (e.g., oil sands, shale oil, extra-heavy oil, deep gas, coal bed methane (CBM), shale gas, gas hydrates). By some estimates, these unconventional oil and gas sources have pushed the “peak” out to the second half of the 21st century” (IIASA, 2012), and they are a reminder that “peak” is not a static concept. These unconventional sources have raised a number of important questions and challenges, such as their high capital intensity, high energy intensity (and cost), large demands on other resources such as water for production and other potential environmental consequences. Consequently there are many contrasting view points about the future of these unconventional resources (e.g. (Hirsch et al., 2005; Smil, 2011; IEA, 2012a; Rogner et al., 2012; Jordaan, 2012).

The importance of these new resources is underscored by the rapid rise of unconventional shale gas supplies in North America—a technology that had barely any impact on gas supplies in 2000 and by 2010 accounted for one-fifth of North American gas supply with exploratory drilling elsewhere in the world now under way. This potential for large new gas supplies—not only from shale gas but also coal-bed methane, deep gas, and other sources—could lower emissions where gas competes with coal if gas losses and additional energy requirements for the fracturing process can be kept relatively small. (A modern gas-fired power plant emits about half the CO_2 per unit of electricity than a comparable coal-fired unit.) In the United States, 49% of net electric power generation came from coal in 2006, and by 2011 that share had declined to 43% and is expected to decline further(EIA, 2013a; b). Of course, total U.S. emissions are affected by a wide range of other factors as well, including fuel economy regulations, replacement by renewable energy sources and the overall state of the economy. Worldwide, however, most projections still envision robust growth in the utilization of coal, which already is one of the fastest growing fuels with total consumption rising 50% between 2000 and 2010 (IEA 2011c). The future of coal hinges, in particular, on large emerging economies such as China and India as well as the diffusion of clean coal technologies.

An option of particular interest for mitigating emissions is carbon dioxide capture and storage (CCS), which would allow for the utilization of coal while cutting emissions. Without CCS or some other advanced coal combustion system, coal would be the most emission intensive of all the major fossil fuels yet, as we discuss below, consumption of coal is expanding rapidly. Thus since AR4 CCS has figured prominently in many studies that look at the potential for large cuts in global emissions (IEA 2010a; IEA 2011a; IIASA 2012). However, CCS still has not attracted much tangible investment. By mid-2012 there are eight large-scale projects in operation globally and a further eight under construction. The total CO_2 emissions avoided by all 16 projects in operation or under construction are about 36 million tonnes a year by 2015 (Global CCS Institute, 2012). The implementation of large-scale CCS systems generally requires extensive funding and an array of complementary institutional arrangements such as legal frameworks for assigning liability for long-term storage of CO2. Since AR4 studies have underscored a growing number of practical challenges to commercial investment in CCS (IEA 2010b).

Over the period since AR4 innovation and deployment of renewable energy supplies has been particularly notable (IEA 2011a; IIASA 2012). The IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (IPCC, 2011) provides a comprehensive assessment of the potential role of renewables in reducing GHG emissions. Globally wind electricity generating capacity has experienced double-digit annual growth rates since 2005 with an increasing share in developing countries. While still being only a small part of the world energy system, renewable technology capacities, especially wind but also solar and geothermal, are growing so rapidly that their potential for large scale growth is hard to assess but could be very large (IEA 2011a; IIASA 2012). Renewable energy potentials exist not only for stationary users via electricity but also for transportation through biofuels. Renewable energy technologies appear to hold great promise, but like all major sources of energy they also come with an array of concerns. Many renewable sources of electricity are variable and intermittent, which can make them difficult to integrate into electric grids at scale (see chapter 8 in (IPCC, 2011). Some biofuels are contested due to fears for food security and high lifecycle greenhouse gas emissions of some fuel types (see chapter 11 in (Delucchi, 2010; IPCC, 2011). Other concerns are financial since nearly every major market for renewable energy has relied heavily on a variety of policy support such as subsidies, leading many analysts to explore whether and how these energy sources will continue to be viable for investors if subsidies are curtailed.

Since AR4 there have also been substantial advances in the technological possibilities for making energy systems more efficient and responsive. The use of energy efficient devices, plant and equipment has been legislated in many jurisdictions (RISØ, 2011). Energy networks with integrated information and communication technology (ICT) that enable greater energy efficiency and flexibility in energy use and the integration of variable and intermittent renewable energy sources are increasingly tested in many municipalities. This interconnection offers the promise of energy systems—especially in electricity where the potential for pervasive use of ICT is often called a “smart grid”—that integrate demand response with supplies, allowing for smooth and reliable operation of grids even with fluctuating renewable supplies (EPRI, 2011). Innovations of this type may also interact with behavioural changes that can have large effects on emissions as well.

A central challenge in shifting to clean energy supplies and to creating much more efficient end-use of energy is that many energy technologies require large capital costs with long time horizons. Thus even when such technologies are cost-effective they may face barriers to entry if investors and users are not confident that needed policy and market support will not be reliable. Innovations in financing—for example, mechanisms that allow households to lease solar panels rather than pay the full cost up front—can play a role in addressing such issues, as can public schemes to fund initial deployment of new technologies. Such arrangements are part of a broader effort often called “market transformation” that, if implemented well, can lead to new trajectories for deployment of technologies that otherwise would face many barriers to entry (IEA, 2010c).

Since AR4, a large number of governments have begun to explore the expansion or introduction of nuclear power. They have also faced many challenges in the deployment and management of this technology. Countries with active nuclear power programmes have been contemplating replacing aging plants with new builds or expanding the share of nuclear power in their electricity mix for reasons of economics, supply security and mitigation climate change. In addition, more than 20 countries currently that have never had commercial reactors have launched national programmes in preparation for the introduction of the technology and several newcomer countries have entered contractual arrangements with vendors (IAEA, 2011). After the Fukushima accident, an event that forced Japan to review its energy policy substantially, the future patterns in nuclear power investment are more difficult to parse. Some countries have scaled back nuclear investment plans or ruled out new build (e.g., Switzerland, Belgium); some, notably Germany, have decided to close existing reactors. Several countries preparing the introduction of nuclear power have extended the time frame for the final go-ahead decisions, only few in a very early stage of preparation for the introduction stopped their activities altogether. In other countries, including all the countries that have been most active in building new reactors (e.g., China, India, Russia, Finland, and South Korea), there aren’t many noticeable results from Fukushima and the investment in this energy source is accelerating, despite some scale-back in the wake of Fukushima (IEA, 2012a). These countries’ massive investments in nuclear were much less evident, especially in China, India and South Korea, at the time of AR4. The Fukushima accident has also increased investment in deployment of new, safer reactor designs such as so-called “Generation III” reactors.

1.2.1.4 International institutions and agreements

For more than two decades formal intergovernmental institutions have existed with the task of promoting coordination of national policies on the mitigation of emissions. In 1992 diplomats finalized the United National Framework Convention on Climate Change (UNFCCC), which entered into force in 1994. The first session of the Conference of the Parties (COP) to that Convention met in Berlin in 1995 and outlined a plan for new talks leading to the Kyoto Protocol in 1997, which entered into force in 2005. The main regulatory provisions of the Kyoto Protocol concerned numerical emission targets for industrialized countries (listed in Annex B of the Treaty) during the years 2008 to 2012. When AR4 concluded in 2007, diplomats were in the early stages of negotiations for possible amendment or replacement of the Kyoto treaty following the expiration of the original regulatory goals in 2012. Those negotiations had been expected to finish at the COP 15 meeting in Copenhagen in 2009, but a wide array of disagreements made that impossible. Instead, talks continued while, in tandem, governments made an array of “Copenhagen pledges” concerning the policies they would adopt to mitigate emissions and other related actions on the management of climate risks; some of those pledges are contingent upon actions by other countries. The 86 countries that adopted these pledges account for the vast majority (78%) of world emissions (UNFCCC, 2012a; b). If fully implemented the pledges might reduce emissions in 2020 about one-tenth below the emissions level that would have existed otherwise—not quite enough to return emissions to 2005 levels and far from what is probably needed to stabilize warming at the widely discussed goals of 1.5 or 2 degrees.

At this writing, diplomatic talks are focused on the goal of adopting a new agreement that would be in effect by 2020 (UNFCCC, 2012c). In tandem, governments have also made a number of important decisions such as to extend the Kyoto Protocol’s regulatory obligations at least to 2020 (Höhne et al., 2012; UNEP, 2012).

The growing complexity of international diplomacy on climate change mitigation, which has been evident especially since AR4 and the Copenhagen meeting, has led policy makers and scholars alike to look at many other institutional forms that could complement or even partially replace the UN-based process. Proposals exist within the Montreal Protocol on Substances that Deplete the Ozone Layer to regulate some of the gases that have replaced ozone-destroying chemicals yet have proved to have strong impacts on the climate. A wide array of other institutions has become engaged with the climate change issue. The G8—the group of Canada, France, Germany, Italy, Japan, Russia, the UK, and the US that convenes regularly to address a wide array of global economic challenges—has repeatedly underscored the importance of limiting warming to 2 degrees and implored its members to take further actions. In the context of climate change negotiations, Brazil, Russia, India, China and South Africa—the so-called “BRICS” countries—have met as a group in efforts to coordinate policies and negotiating strategies. The G20, a much broader group of economies that has played a major role in international economic cooperation ever since the Asian financial crisis of the late 1990s, has put climate change matters on its large agenda, including with active efforts to reform fossil fuel subsidies and to implement green growth strategies. The UN, itself, has a large number of complementary diplomatic efforts on related topics, such as the “Rio+20” process. Many other institutions are now actively addressing particular aspects of climate change mitigation, such as the International Renewable Energy Agency - IRENA (which focuses on renewable energy), varied institutions such as the International Atomic Energy Agency - IAEA (focused on nuclear power), International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) (both focusing on emissions from bunker fuels) and many others with expertise in particular domains. The International Energy Agency (IEA) is now extensively engaged in analyzing how developments in the energy sector could affect patterns of emissions (e.g., IEA 2011c). Looking across these many different activities, international institutions that have engaged the climate change topic are highly decentralized rather than hierarchically organized around a single regulatory framework (Keohane and Victor, 2011). Since AR4 research on decentralized international institutions has risen sharply (Raustiala and Victor, 2004; Alter and Meunier, 2009; Zelli et al., 2010; Johnson and Urpelainen, 2012), building in part on similar concepts have emerged in other areas of research on collective action (e.g., (McGinnis, 1999).

Since the completion of the last IPCC assessment report there has been a sharp increase in scholarly and practical attention to how climate change mitigation could interact with other important international institutions such as the World Trade Organization (WTO) (see also Chapter 13 of this volume) (Brewer, 2010). Relationships between international trade agreements and climate change have been a matter of long standing interest in climate diplomacy and are closely related to a larger debate about how differences in environmental regulation might affect economic competitiveness as well as the spread of mitigation and adaptation technology (Gunther et al., 2012). A potential role for the WTO and other trade agreements also arises because the fraction of emissions embodied in internationally traded goods and services is rising with the globalization of manufacturing and rising trade in embodied emissions (see 1.2.1.2 above). Trade agreements might also play a role in managing (or allowing the use of) trade sanctions that could help enforce compliance with mitigation commitments—a function that raises many legal questions as well as numerous risks that could lead to trade wars and an erosion of political support that is essential to the sustainability of an open trading system (Bacchus et al., 2010). For example, Article 3 of the UNFCCC requires that “[m]easures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade.”

Since the IPCC AR4 in 2007 the scholarly community has analysed the potentials, design and practices of international cooperation extensively. A body of research has emerged to explain why negotiations on complex topics such as climate change are prone to gridlock (e.g., see (Murase, 2011; Victor, 2011; Yamaguchi, 2012). There is also a large and vibrant research program by political scientists and international lawyers on institutional design, looking at issues such as how choices about the number of countries, type of commitments, the presence of enforcement mechanisms, schemes to reduce cost and increase flexibility, and other attributes of international agreements can influence their appeal to governments and their practical effect on behaviour (see e.g., the comprehensive reviews and assessment on these topics by Hafner-Burton, Victor, and Lupu (2012) as well as earlier research of Abbott et al. (2000); and Koremenos, Lipson, and Snidal (2001)). Much of that research program has sought to explain when and how international institutions, such as treaties, actually help solve common problems. Such research is part of a rich tradition of scholarship aimed at explaining whether and how countries comply with their international commitments (e.g., (Downs et al., 1996; Simmons, 2010). Some of that research focuses on policy strategies that do not involve formal legalization but, instead, rely more heavily on setting norms through industry organizations, NGOs and other groups (e.g., (Vogel, 2008; Buthe and Mattli, 2011). The experience with voluntary industry standards has been mixed; in some settings these standards have led to large changes in behaviour and proved highly flexible while in others they have little or no impact or even divert attention (Rezessy and Bertoldi, 2011).

One of the many challenges in developing and analysing climate change policy is that there are long chains of action between institutions such as the UNFCCC and the ultimate actors whose behaviour is affected, such as individuals and firms. We note that there have been very important efforts to engage the business community on climate mitigation as well as adaptation to facilitate the market transformations needed for new emission technologies and business practices to become widespread(WEF, 2009; UN Global Compact and UNEP, 2012).

1.2.1.5 Understanding the roles of emissions other than fossil fuel CO_2

Most policy analysis has focused on CO_2 from burning fossil fuels, which comprise about 60% of total global greenhouse gas emissions in 2010 (including forest-related emissions). However, the UNFCCC and the Kyoto Protocol cover a wider array of warming substances—including methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). Nitrogen trifluoride (NF_3) was added as a GHG under the Kyoto Protocol for its second commitment period. This large list was included, in part, to create opportunities for firms and governments to optimize their mitigation efforts across different substances. The effects of different activities on the climate varies because the total level of emissions and the composition of those emissions varies. For example, at current levels the industrial and power sectors have much larger impacts on climate than agriculture (Figure 1.3). Moreover, a pulse of today's average emissions from industrial or power sector sources leads initially to partially offsetting effects as emissions cause some cooling (due to aerosols that interact with clouds to reflect sunlight back to space) while the overall long term effect is warming due to long-lived carbon dioxide. By contrast, current emissions from agriculture have about one-quarter the total effect over twenty years and the warming effects that do follow are dominated by relatively short-lived methane and longer-lived nitrous oxide (see Working Group I, chapter 8 on Anthropogenic and Natural Radiative Forcing such as figure 8.34). [Author note to reviewers: WG1 info is preliminary from SOD.] A variety of studies have shown that allowing for trading across these different gases will reduce the overall costs of action; however, many studies also point to the complexity in agreeing on the correct time horizons and strategies for policy efforts that cover gases with such different properties (Reilly et al., 2003; Ramanathan and Xu, 2010; Shindell et al., 2012). In addition to the gases regulated under the Kyoto Protocol, many of the gases that deplete the ozone layer—and regulated under the Montreal Protocol on Substances that Deplete the Ozone Layer—are also strong greenhouse gases (Velders et al., 2007).

In addition to the UNFCCC/Kyoto gases, other short-lived climate pollutants (SLCPs) have come under scrutiny (e.g. (UNEP, 2011; Shindell et al., 2012; Victor et al., 2012). Those include tropospheric ozone (originating from air pollutant emissions of nitrogen oxides and various forms of reduced carbon) and aerosols (such as black carbon and organic carbon and secondary such as sulphates) affect climate forcing (see Chapter 8, Section 8.2.2). This remains an area of active research, not least because some studies suggest that the climate impacts of short-lived pollutants like black carbon (soot) could be much larger or smaller (Ramanathan and Carmichael, 2008); Working Group I, chapters 7 and 8). Such pollutants could have a large role in mitigation strategies since they have a relatively swift impact on the climate—combined with mitigation of long-lived gases like CO_2 such strategies could make it more easily feasible to reach near-term temperature goals (Ramanathan and Xu, 2010). Not all short-lived pollutants cause warming. Studies that have estimated global average effects of different sources pollution sources suggest that aerosols, at present, currently have a net cooling effect. In particular, aerosol emissions from the industrial and power sectors and large-scale biomass burning contribute to cooling, whereas black carbon from road transport and residential biofuel contributes to global warming (Unger et al., 2010).

Table 1.1: Implications of GWP choice for mitigation strategy. Table shows the main geophysical properties of the major Kyoto gases and the implications of the choice of time horizon (20, 100 or 500 years) on the share of weighted total emissions for 2010. NF3 is included but contributes much less than 0.1%. Note that CO2 is removed by multiple processes and thus has no single lifetime, although the bulk of the net removal is consistent with an approximate 100 year life time. We show CF4 as one example of the class of perfluorocarbons (PFCs) and HFC-134a and HFC-23 as examples of hydroflurocarbons. All other industrial fluorinated gases ("F-gases") are summed. Emissions reported in JRC/PBL (2012)(2011) using GWPs reported in IPCC's second, fourth and fifth assessment report (IPCC, 1995, 2007c, 2013). The fourth report was used for GWP-500 data. Geophysical properties of the gases drawn from IPCC Working Group 1, Appendix 8.A, Table 8.A.1—preliminary data)

	Geophysical properties		**GWP-weighted share of global GHG emissions (2010)**			
Kyoto gases	Average atmospheric lifetime (yrs)	Instantaneous forcing (W/m2/ppb)	SAR (Kyoto) 100 years	20 years	100 years	500 years
CO_2	various	1.375 x 10^{-5}	76%	52%	73%	88%
CH_4	12.2	3.63 x 10^{-4}	16%	42%	20%	7%
N_2O	121	3.03 x 10^{-4}	6.2%	3.9%	5.5%	3.5%
HFC-134a	13.4	0.159	0.5%	0.9%	0.4%	0.2%
HFC-23	222	0.176	0.4%	0.3%	0.4%	0.5%
CF_4	50,000	0.1	0.1%	0.1%	0.1%	0.2%
SF_6	3,200	0.575	0.3%	0.2%	0.3%	0.5%
NF_3	500	0.21	not applicable	0.0%	0.0%	0.0%
other F-gases	various	various	0.7%	0.9%	0.8%	0.4%

Starting with the first assessment report, the IPCC has calculated global warming potentials (GWPs) to convert climate pollutants into common units over 20, 100 and 500 year time horizons (chapter 2, IPCC First Assessment Report 1990). In the Kyoto Protocol, diplomats chose the middle value—100 years—despite the lack of any published conclusive basis for that choice (Shine, 2009). That approach emphasizes long-lived pollutants such as CO_2, which are essential to stopping climate warming over many decades to centuries. As shown in Table 1.1, when GWPs are computed with a short time horizon the share of short-lived gases, notably methane, in total warming is much larger and that of CO_2 becomes proportionally smaller. The uncertainty in the GWPs of non-CO_2 substances increases with time horizon and for GWP100 the uncertainty is larger than 50% (IPCC, 2013). If policy decisions are taken to emphasize SLCPs as a means of altering short-term rates of climate change rises then alternative GWPs or other metrics may be needed (IPCC, 2009; Fuglestvedt et al., 2010; Victor et al., 2012). Additional accounting systems—for example to include soot, which is not presently part of the Kyoto Protocol—may also be needed.

1.2.1.6 Emissions Trajectories and Implications for Article 2

Chapter 1 of the AR4 concluded that, without major policy changes, the totality of policy efforts do not put the planet on track for meeting the objectives of Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) (IPCC, 2007a). Since then, emissions have continued to grow—a topic we examine in more detail below. Article 2 of the UNFCCC describes the ultimate objective of the Convention. It states:

> "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the

> climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

The above goal was based, in part, on earlier diplomacy (e.g., Noordwijk Declaration on Atmospheric Pollution and Climate Change (1989). Interpreting the UNFCCC goal is difficult. The first part of Article 2, which calls for stabilization at levels that are not "dangerous," requires examining scientific climate impact assessments as well as normative judgments—points that are explored in detail in the IPCC Working Group 2 report. The second part of Article 2 is laden with conditions whose interpretation is even less amenable to scientific analysis. In light of the enormous variations in vulnerability to climate change across regions and ecosystems, it is unlikely that scientific evidence will conclude on a single such goal as "dangerous." Variations in what different societies mean by "dangerous" and the risks they are willing to endure further amplify that observation. Article 2 requires that societies balance a variety of risks and benefits—some rooted in the dangers of climate change itself and others in the potential costs and benefits of mitigation and adaptation.

Since the publication of AR4 a series of high-level political events have sought to create clarity about what Article 2 means in practice. For example, the Bali Action Plan, adopted at COP 13 held in Bali, Indonesia, in December 2007, cited AR4 as a guide for negotiations over long-term cooperation to manage climate change. At the L'Aquila G8 Summit in 2009, five months before the COP15 meeting in Copenhagen, leaders "recognized the broad scientific view that the increase in global average temperature above pre-industrial levels ought not to exceed 2°C," and they also supported a goal of cutting emissions at least 80% by 2050. Later that year, an COP 15, delegates "took note" of the Copenhagen Accord which recognized "the scientific view that the increase in global temperature should be below 2 degree Celsius," and later meetings arrived at similar conclusions (Decision1/CP.16). Ever since the 2009 Copenhagen Conference the goal of 1.5 degrees has also appeared in official UN documents, and some delegations have suggested that a 1 degree target be adopted. Some scholars suggest that these goals can create focal points that facilitate policy coordination, although there is a variety of perspectives about whether these particular goals are playing that role, in part because of growing evidence that they will be difficult to attain (Schneider and Lane, 2006; National Research Council of the National Academies, 2011; Victor, 2011; Helm, 2012).

At present, emissions are not on track for stabilization let alone deep cuts (see section 1.3 below). This reality has led to growing research on possible extreme effects of climate change and appropriate policy responses. For example, Weitzman (2009) raised the concern that standard policy decision tools such as cost-benefit analysis and expected utility theory have difficulty dealing with climate change decisions, owing to the uncertain probability of catastrophic impacts. Partly driven by these concerns, the literature on geoengineering options to manage solar radiation and possibly offset climate change along with technologies that allow removal of CO2 and other climate-altering gases from the atmosphere has been increasing exponentially (see chapter 6.9). Geoengineering schemes to alter the planet's radiation balance have attracted particular attention because they have potentially high leverage on climate, creating as well possibly many risks that are difficult if not impossible to forecast and raising many challenges for the design of effective regulatory mechanisms (Rickels et al. 2011; Gardiner 2010; IPCC 2012; Keith, Parson, and Morgan 2010).

1.2.2 New challenges for the AR5

These six shifts since AR4 create challenges for the AR5 assessment. For example, the flexibility of viewing mitigation as part of a broader array of sustainable development goals has encouraged analysts to look more closely at the factors that have (and could) encourage countries to adopt policies that mitigate emissions. Policies are pursued for a reason with many reinforcing benefits (known as "co-benefits"), making it hard to assign costs and benefits to any single policy in isolation.

The plethora of international institutions working on matters related to climate has inspired social scientists to look at how these institutions might interact—including where they might conflict—rather than focusing just on the global UN-based organizations dedicated to the task of managing climate issues. That insight has also led to many model-based assessments of future emissions, mitigation and climate impacts that reflect a likely real-world "muddling through" policy rather than optimal global design—a topic addressed in more detail in chapter 6 of this volume. Rising awareness of the importance of pollutants beyond fossil fuel CO_2—including short-lived pollutants such as black carbon—require analysts and governments to look much more carefully at policy strategies and their effects over different time horizons. And the evidence that the world is not on track to stabilize warming at 2 degrees Celsius means that analysts have had to consider a number of alternative goals, and the costs of inaction relative to the costs of accelerated policy action.

The full report that follows offers much more detail on these main areas where the scientific understanding has shifted since AR4. Over the rest of this chapter we set the scene with information about the patterns of emissions (and their causes) and the main challenges for mitigation.

1.3 Historical, Current and Future Trends

Since AR4 there have been new insights into the scale of the mitigation challenge and the patterns in emissions. Notably, there has been a large shift in industrial economic activity toward the BRICS countries—especially China—that has affected those nations' emission patterns. Many countries have adopted policies to encourage shifts to lower GHG emissions from the energy system, such as through improved energy efficiency and greater use of renewable technologies (e.g., biofuels and wind). While mitigation of CO_2 emissions from fossil fuels has been limited, in many countries around the world there are substantially stronger incentives to limit short-lived pollutants like black carbon (soot) and methane—in part because these other pollutants are also linked to many local environmental ills and thus the local benefits from mitigation are more immediate and apparent (UNEP, 2011; Shindell et al., 2012). In addition to national policy efforts, a large array of mitigation actions have also been planned and orchestrated by local governments, including cities that are working in concert on climate change issues through partnerships such as the C40, and there is some evidence that these efforts are intensifying (see chapter 15) (UNFCCC, 2011) paragraph 7).

1.3.1 Review of four decades of greenhouse gas emissions

While there are several sources of data, the analysis here relies on the EDGAR data set (JRC/PBL, 2012)[see WG3 Annex II Methods and Metrics for a complete delineation of emission categories]. We focus here on all major direct greenhouse gases (GHGs) related to human activities—including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). We also examine various ozone-depleting substances (ODS), which are regulated under the Montreal Protocol due to their effects on the ozone layer but also act as long-lived GHG: chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and halons. (Due to lack of comparable data we do not here examine soot, cooling aerosols and NF_3.) For the analyses that follow we use 100-year GWPs because they are widely used by governments, but we are mindful that other time horizons and other global warming metrics also merit attention (see section 1.2.1.5 above).

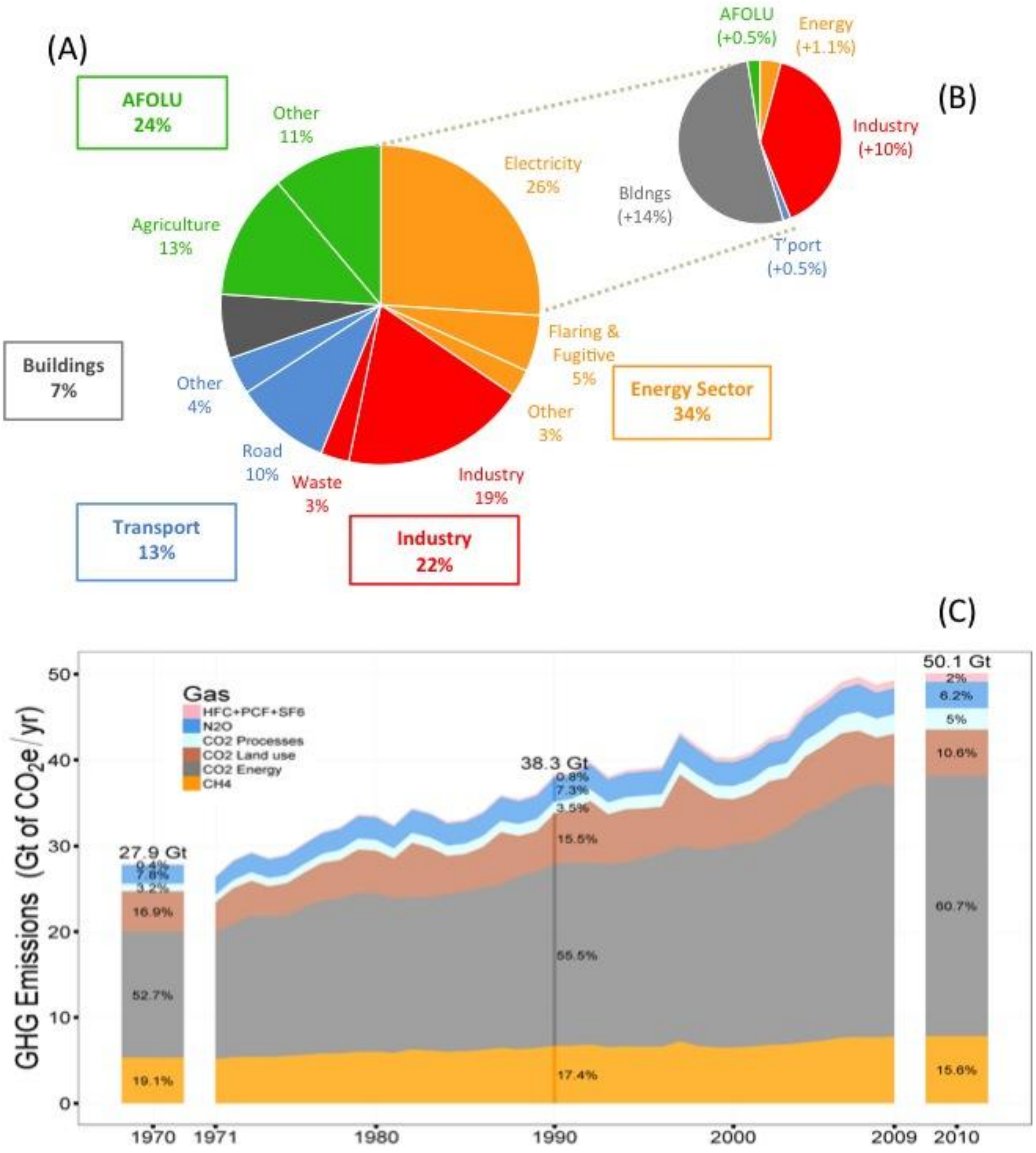


Figure 1.3. Panel A: Allocation of GHG emissions in 2010 across the five sectors examined in detail in this report. Panel B: Allocation of emissions due to electricity consumption as "indirect" emissions to the main end-use sectors discussed in this report. (Emissions from the power sector are ultimately linked to activities in these other sectors, notably industry and buildings.) Panel C: Emissions by gas since 1970. Sources: (JRC/PBL, 2011). Emissions weighted with 100-year GWPs as used in the Kyoto Protocol (i.e. values from the second IPCC report) and, in general, sectoral and national/regional allocations as recommended by the 1996 IPCC guidelines (IPCC, 1996). Notes: "electricity" is public and self-produced and includes heat; "other energy sector" includes refineries, coal mining, oil and gas production. "Industry" includes coke ovens, blast furnaces and non-combustion CO_2 from limestone use and from non-energy use of fuels, N_2O from chemicals production and include an about 2% share of emissions from F-gases: HFCs, PFCs and SF_6; "Waste" includes wastewater; "Transport" includes international shipping and aviation; "FOLU" includes forest related emissions and CO_2 from peat decomposition and peat fires.

Looking at the total source of greenhouse gases and weighting with 100-year GWPs (Table 1.1), at present CO_2 contributes 76%; CH_4 about 16%, N_2O about 6% and the combined F-gases about 2%. By sector, the largest sources were the sectors of energy (68%, mainly CO_2 fossil fuel use), and agriculture (11%, mainly CH_4 and N_2O). Other sources of greenhouse gases include CO_2 from biomass burning (11%, mostly forest and peat fires and post-burn decay in non-Annex I countries), and industrial sources such as CO_2 from cement production (3%, of which half originated in China).

Following the breakdown in sectors discussed in this report (Chapters 7 to 11),Figure 1.3 looks at emissions over time by gas and sector. Figure 1.4 looks at those patterns over time according to different groups of countries, which reveals the effects of periodic economic slowdowns and contractions on emissions and also shows the growing role for embodied emissions due to the increasing world trade of manufactured goods (see section 1.2.1.2 above). In effect, developed countries (Annex B) are importing large embodied emissions from developing countries (non-Annex B). Figure 1.4 shows that, globally, emissions of all greenhouse gases increased by about 75% since 1970.

Overall, per-capita emissions in the developed world are roughly flat over time and remain about six times larger than those from developing countries, although the latter have been rising steadily for the last decade. There is huge variation within these categories as some very low income countries have extremely low per-capita emissions while some developing countries have per-capita emissions comparable with those of some industrialized nations. Box 1.1 explores some special issues that affect the least developed countries.

Emissions from the energy sector (mainly electricity production) and from transportation dominate the global trends. Worldwide those emissions have tripled since 1970, and transport has doubled. Since 1990 emissions from electricity and heat production increased by 27% for the group of OECD countries; in the rest of the world the rise has been 64%. Over the same period, emissions from road transport increased by 29% in OECD countries and 61% in the other countries. Present global greenhouse gas emissions stem for one-quarter from electricity and heat production and for one-third from the total energy sector. Industry (including waste) and AFOLU both contribute about one-quarter, with agriculture and other AFOLU (i.e. forests and other land use) each about half of total AFOLU. The transport and buildings sector contribute about 13% and 7%, respectively.

Forest related GHG emissions are due to biomass burning and decay of biomass remaining after forest burning and after logging. In addition, the data shown includes CO_2 emissions from decomposition of drained peatland and from peat fires (Olivier and Janssens-Maenhout, 2012). The forest related figures presented here are in line with the synthesis paper by Houghton et al. (2012) on recent estimates of carbon fluxes from land use and land cover change. This analysis also showed the very large uncertainty in this category of the order of ±50%. In contrast, a synthesis analysis of four global datasets (CDIAC, EDGAR, IEA, EIA) by Andres et al. (2012) showed that global CO_2 emissions from fossil fuel combustion are known to within 10% uncertainty (95% confidence interval) with individual national total fossil-fuel CO_2 emissions ranging from a few per cent to more than 50%. For total CO2 emissions the overall uncertainty range in global total emissions was estimated at ±5% excluding LULUCF and ±10% including them (Andres et al., 2012; Houghton et al., 2012; Olivier et al., 2012). For global emissions of CH_4, N_2O and the F-gases uncertainty estimates of 25%, 30% and 20%, respectively, were assumed (UNEP, 2012).

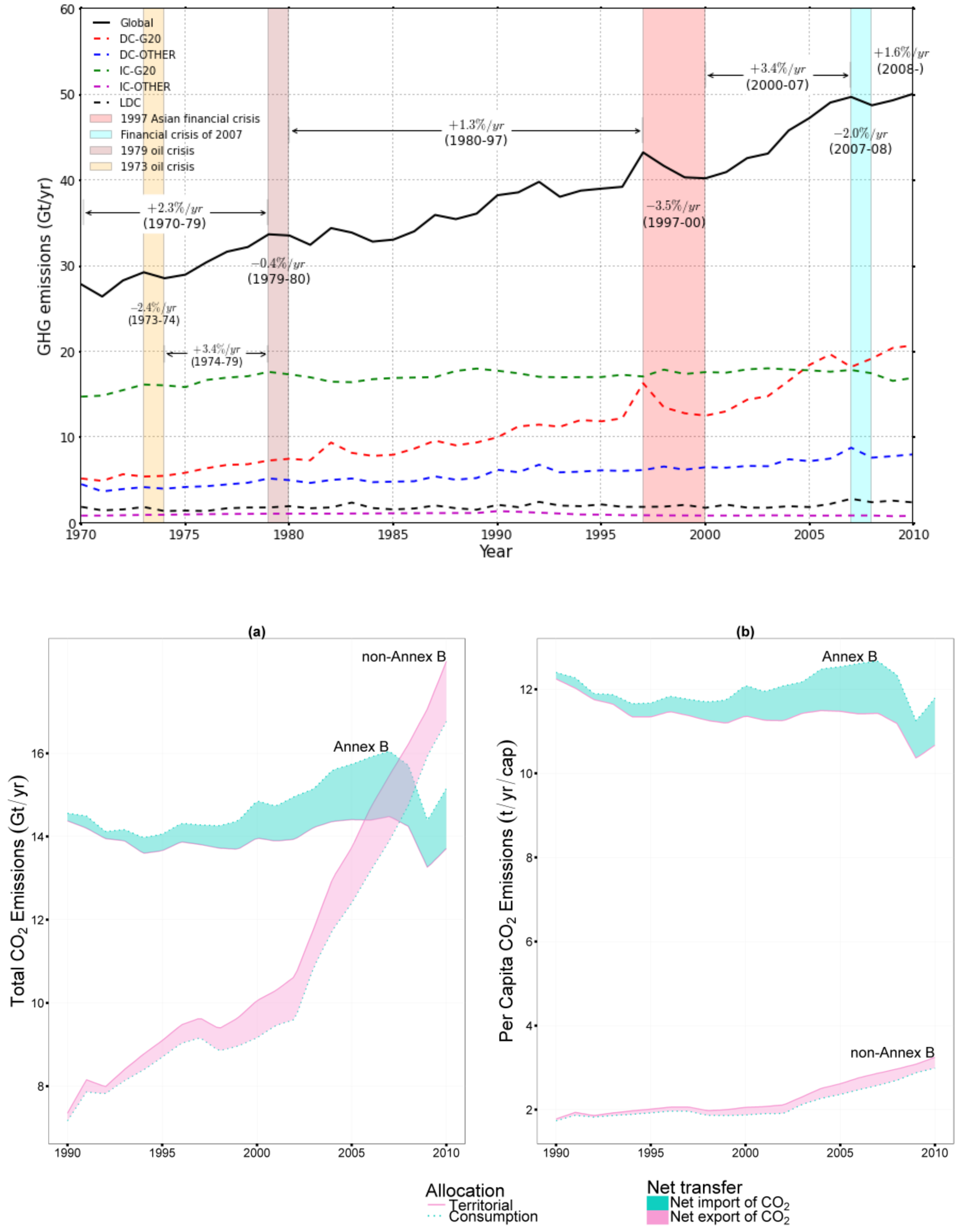


Figure 1.4. Three Perspectives on Global Growth in Emissions. Top panel shows world emissions (total and for the regions shown in figure 1.1) and major economic recessions. Bottom panels show emissions for two broad groupings—the industrialized countries listed in Annex B of the Kyoto Protocol and the other (mainly developing countries) not listed in Annex B. Bottom panels show emissions allocated on the basis of territory (solid line) and ultimately consumption (dotted line). The shaded areas are the trade balance (difference) between Annex B/non-Annex B production and consumption; as the world economy becomes more integrated through trade between these categories of countries the width of the shaded areas grows. Bottom left panel shows total emissions and right per-capita. Sources: IPCC databases and Peters et al (2011).

Box 1.1. Least Developed Countries: mitigation challenges and opportunities

[COMMENTS ON TEXT BY TSU TO REVIEWER: Boxes highlighting further LDC-specific issues are included in other chapters of the report (see chapter sections 1.3.1, 2.1, 6.3.6.6, 7.9.1, 8.9.3, 9.3.2, 10.3.2, 11.7, 12.6.4, 16.8) and a similar box may be added to the Final Draft of chapters, where there is none in the current Second Order Draft. In addition to general comments regarding quality, reviewers are encouraged to comment on the complementary of individual boxes on LDC issues as well as on their comprehensiveness, if considered as a whole.]

The Least Developed Countries (LDCs) consist of 49 countries and over 850 million people, located primarily in Africa and Asia – with 34 LDCs in Africa alone (UNFPA, 2011). These countries are characterised by low income (three-year average gross national income per capita of less than $992), weak human assets index (nutrition, health, school enrolment and literacy), and high economic vulnerability criterion (UNCTAD, 2012a). Despite their continued marginalization in the global economy, these countries' economies grew at about 6% per year from 2000 to 2008, largely stimulated by the strong pull-effect of the Asian emerging economies (Cornia, 2011). However, the global economic downturn and the worsening Eurozone crisis have had an effect on most LCD economies. In 2011, LDCs grew by 4.2%, 1.4 percentage lower than the preceding year, hence mirroring the slowdown of growth worldwide (UNCTAD, 2012a). Many of the traditional domestic handicaps remain as LDC economies continue to be locked into highly volatile external transactions of commodities and low-productivity informal activities, having neither the reserves nor the resources needed to cushion their economies and adjust easily to negative shocks.

As regards the social trends, LDCs as a group have registered encouraging progress towards achieving some of the Millennium Development Goals (MDGs), especially in primary school enrolment, gender parity in primary school enrolment, HIV/AIDS prevalence rates and the share of women in non-agricultural wage employment (Sachs, 2012). However, there have been limited successes in poverty reduction where only 4 out of 33 LDCs for which data was available are on track to halve the incidence of extreme poverty between 1990 and 2015 (UNCTAD, 2011). In line with this, the Istanbul Programme of Action, adopted at the 4th UN Conference on the Least Developed Countries (LDC-IV) highlighted the importance of building the productive base of LDCs' economies and promoting the process of structural transformation involving an increase in the share of high productivity manufacturing and an increase in agricultural productivity (UNCTAD, 2012b).

The LDCs' continued reliance on climate-sensitive activities such as agriculture means that adapting to climate change remains a central development focus for LDCs. Moreover, integrating mitigation and adaptation actions in the context of sustainable development is now widely acknowledged as a meaningful way to address the climate and development challenge (Ayers and Huq, 2009; Martens et al., 2009). For LDCs, avoiding future emissions in pursuit of their development goals is critical. Structural transformation in LDCs must necessarily involve massive capital injection in infrastructure, which presents the opportunity for avoiding future costs of GHG mitigation and pollution abatement interventions by developing clean and efficient manner (Bowen and Fankhauser, 2011). Other emissions avoidance options are also available for LDCs in areas of innovative urban development, improvements in material productivity (Dittrich et al., 2012) and the application of enhanced land use efficiency through intensified agricultural practices and sustainable livestock management (Burney et al., 2010).

Meeting the additional costs associated with decoupling policies to meet the growing infrastructure gap in LDCs could be significant. This raises critical questions on prioritizing the allocation of scarce resources, especially since material extraction and material consumption are extremely low in LDCs (Krausmann et al., 2009). Moreover, the additional costs could deter private investors in low carbon interventions, leaving the public sector with additional burdens, at least in the short-term (UN DESA, 2009; Collier and Venables, 2012). For most LDC governments, creating the conditions for accelerated economic growth and broad-based improvements in human well-being will remain the main driver national development policies. Hence, low carbon development will need to be framed in the context of the development benefits it is likely to be accompanied with (Moomaw and Papa, 2012).

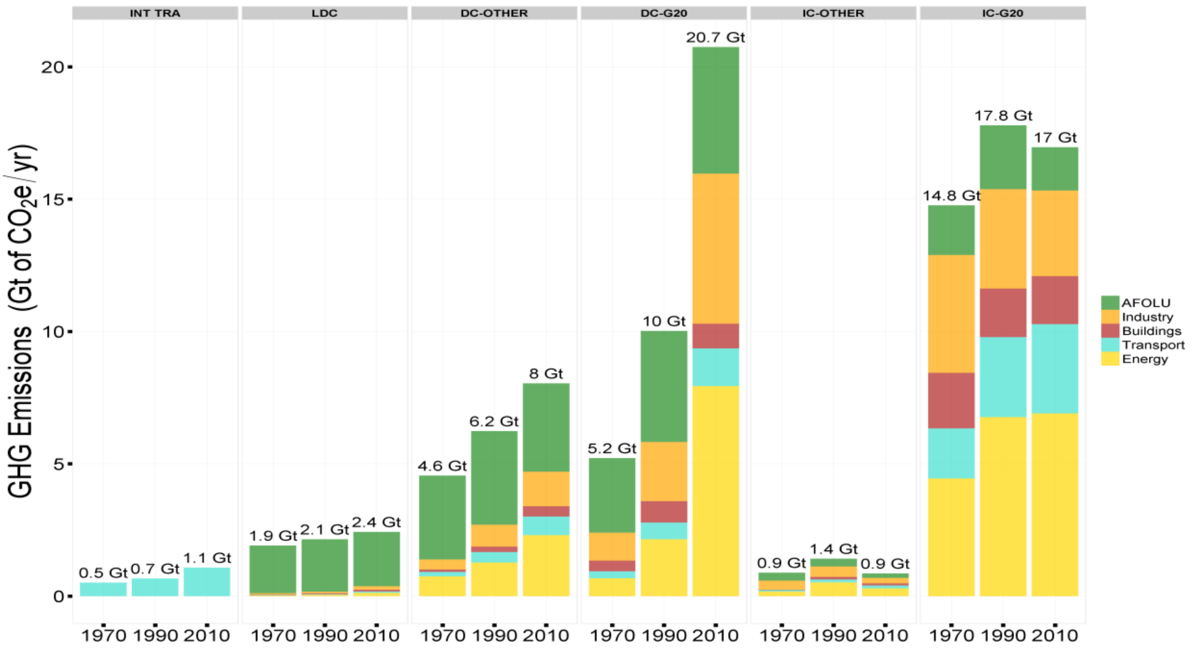


Figure 1.5. Greenhouse gas emissions since 1970 in the five economic sectors covered in chapters 7-11, organized by country grouping (see caption to figure 1.1).

When including indirect GHG emissions from electricity consumption to electricity end-use sectors, the main sectors affected are the industrial and residential sectors, which shares in global GHG emissions then increase by 10%- and 14%-points to 32% and 20%, respectively (see chart B on Figure 1.3). The addition of these so-called "scope 2" emissions is sometimes done to show or analyse the more comprehensive impact of total energy consumption of these end-use sectors to total energy-related emissions.

Figure 1.5 looks at these patterns from the global perspective over time. The AR4 report worked with the most recent data available at the time (2004). Since then, the world has seen sustained accelerated annual growth of emissions—driven by CO_2 emissions from fossil fuel combustion. There was a temporary levelling off in 2008 linked to high fuel prices and the economic crisis that started in North America, but the sustained economic growth in the emerging economies has fuelled continued growth in world emissions since then. This is particularly evident in the economic data (Figure 1.1) showing that the developing countries that are members of the G20—such as China and India—continue to grow despite the world economic crisis and emissions from that group of countries (Figure 1.4 and Figure 1.5) are rising as well.

It is possible to decompose the trends in emissions into the various factors that "drive" these outcomes—an exercise shown in Figure 1.6. Total emissions are the product of population, GDP per capita, energy intensity (total primary energy supply per GDP) and the carbon intensity of the energy system (carbon emitted per unit energy). This approach is also known as the “Kaya Identity” (Kaya, 1990) and resonates with similar earlier work (Holdren and Ehrlich, 1974). A variety of studies have done these decompositions (e.g., (Raupach et al., 2007; Cline, 2011; Steckel et al., 2011).

The analysis reveals enhanced growth in the 2000s of global income, which drove higher primary energy consumption and CO_2 emissions. (That pattern levelled around 2009 when the global recession began to have its largest effects on the world economy.) Also notable in Figure 1.6 is carbon intensity: the ratio of CO2 emissions to primary energy. On average, since 1970 the world’s energy system has decarbonized. However, in the most recent decade there has been a slight re-carbonization due to the rising importance of coal, especially in the rapidly growing developing countries. By contrast, across the highly industrialized world this ratio has been declining due to the shift away from high carbon fuels (notably coal) to natural gas and also to renewables. Technological change might allow for radically lower emissions in the future, but the pattern over this four-decade history suggests that the most important driver of emissions is economic growth.

In the large emerging economies (the developing country members of the G20), today’s levels of carbon intensity and energy intensity are comparable with those of North America in the early 1980s (IEA, 2012b). It may be expected that they will follow similar trends as these countries in the future. Chapter 5 of this report offers a more in-depth region-by-region analysis of Kaya identities (see chapter 5.2 and 5.3).

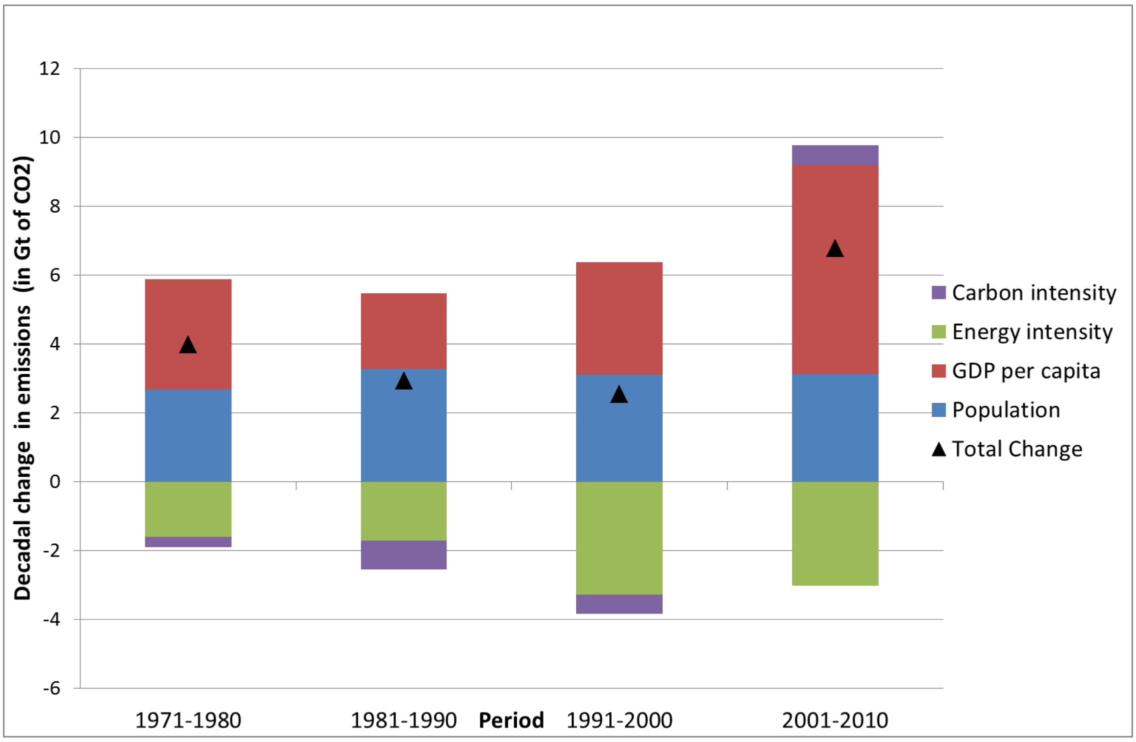


Figure 1.6 The “Kaya Identity” components and their effect on total emissions levels. Decomposition of decadal absolute changes in global energy-related CO2 emissions by the factors in the “Kaya identity”; population (blue), GDP per capita (red), energy intensity (green) and carbon intensity (purple).The bar segments show the changes that would occur due to each factor alone, holding the respective other factors constant. Total decadal changes are indicated by a black triangle. Changes are measures in gigatonnes (Gt) of CO2 emissions. Source: updated from Steckel et al. (2011) using data from IEA (2012b; c).

1.3.2 Perspectives on Mitigation

Looking to the future, it is important to be mindful that the energy system is slow to change, even in the face of concerted policy efforts (Davis et al., 2010; WEF, 2012). For example, many countries have tried to alter trends in CO_2 emissions reflecting the impact of policies aiming to improve energy efficiency and to increase the use of nuclear or renewable energy sources over that of fossil fuels (Chapter 7). So far, while energy efficiency and demand side management measure continue to offer significant lowest cost mitigation benefits and substantial co-benefits, the rate of market uptake has been below its economic potential (GEA, 2012). Chapter 6 in this volume addresses the wide range of risks and opportunities associated with supply and demand side technologies in more detail. Renewable energy's share of the global primary energy supply is just over 8% of total primary energy supply in 2010 when excluding traditional woodfuels and over 16% when including fuelwood and charcoal . The share of nuclear power, the other major non-fossil energy source, remained constant at about 6%, for many years, with nuclear capacity increasing in line with increasing global energy consumption. Since 2005 the growth in nuclear capacity has slowed and as a consequence the nuclear share has declined by half a percentage point. The share of fossil fuels in the world's commercial energy system (excluding traditional woodfuels, many of which are gathered privately and not traded in markets) is barely changed from 1990 to 2010 (88% and 86% respectively) (IEA, 2012d). Similarly, fundamental changes in land use patterns are likely to unfold only slowly, suggesting that emissions from AOFLU sources are also likely to change only slowly over time.

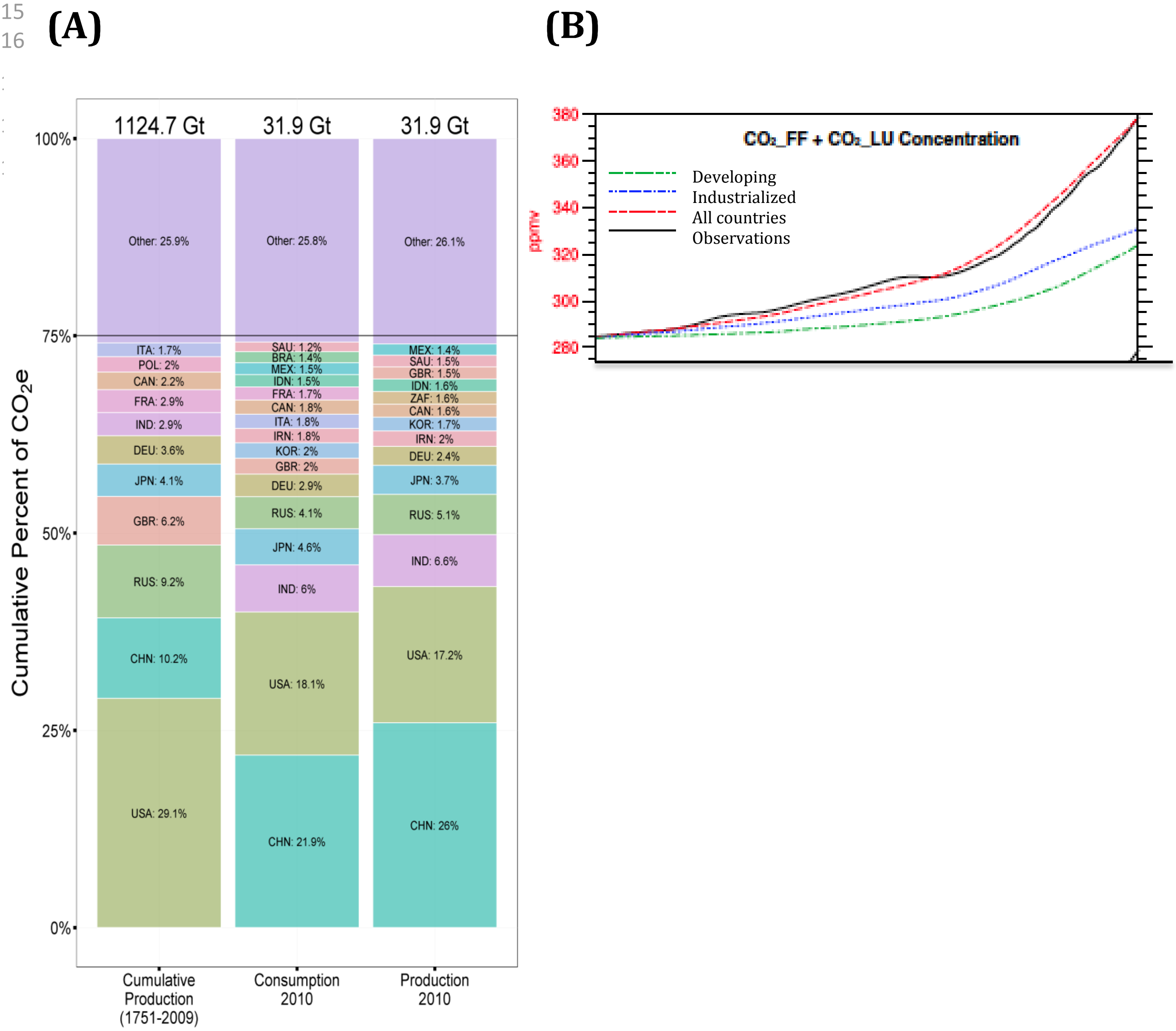
There are many different perspectives on which countries and peoples are accountable for the climate change problem, which should make the largest efforts, and which policy instruments are most practical. Many of these decisions are political, but scientific analysis can help frame some of the options. Here we look at six different perspectives on the sources and possible mitigation obligations for world emissions—illustrated on Figure 1.7 and elsewhere in the text.

One perspective, shown in panel A of Figure 1.7, concerns total emissions and the countries that account for that total. About ten countries account for 70% of world emissions, if the 27 members of the EU are treated as a single country. This suggests that while all countries have important roles to play, the overall impact of mitigation efforts are highly concentrated in a few.

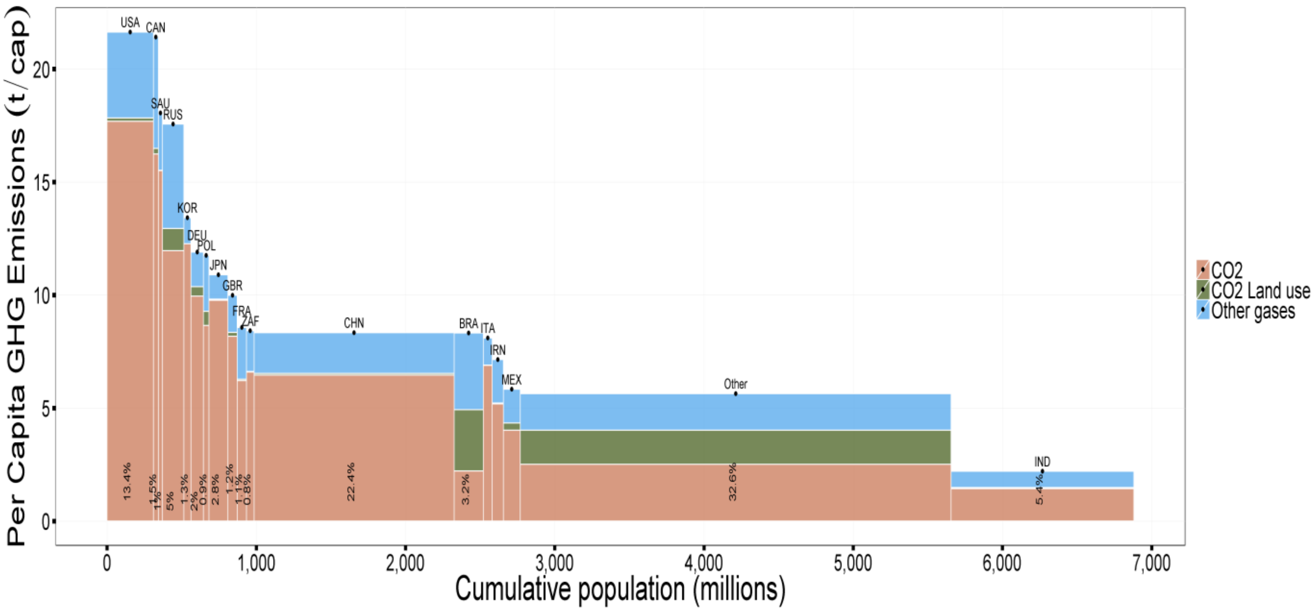
A second perspective concerns the accumulation of emissions since the climate problem is fundamentally due to the "stock" of emissions that builds up in the atmosphere. How countries and regions contribute to global GHG emissions depends on whether accounting systems focus on the total emissions that have accumulated in the atmosphere (left bar of panel A) or current emissions (middle and right bars). Panel B takes this cumulative perspective—looking just at CO2 emissions from burning fossil fuels and changes in land use—and shows that developed countries have for many years accounted for the largest share of the emissions that have accumulated in the atmosphere since the industrial revolution, but in recent years the share for developing countries is nearly equal. Because of the long atmospheric lifetime of CO_2, a fraction of the CO_2 emitted to the atmosphere from James Watt's steam engine that in the late 18th century helped trigger the industrial revolution still remains in the atmosphere. Several studies have accounted in detail for the sources of emissions from different countries over time, taking into account the geophysical processes that remove (at different speeds for different gases, see Table 1.1) these gases (Botzen et al., 2008; Höhne et al., 2011; Wei et al., 2012).

A third perspective concerns the effects of international trade. So far, nearly all of the statistics presented in this chapter have been organized mainly according to the nation where the emissions are released into the atmosphere. In reality, of course, some emissions are "embodied" in products that are exported and discussed in more detail in section 1.2.1.2. A ton of steel produced in China but exported to the United States results in emissions in China when the fundamental demand for the steel originated in the U.S. Comparing the middle and right bars of panel A shows that the total current accounting for world emissions varies considerably—with the largest effects on China and the United States—although the overall ranking does not change much when these trade effects are included.

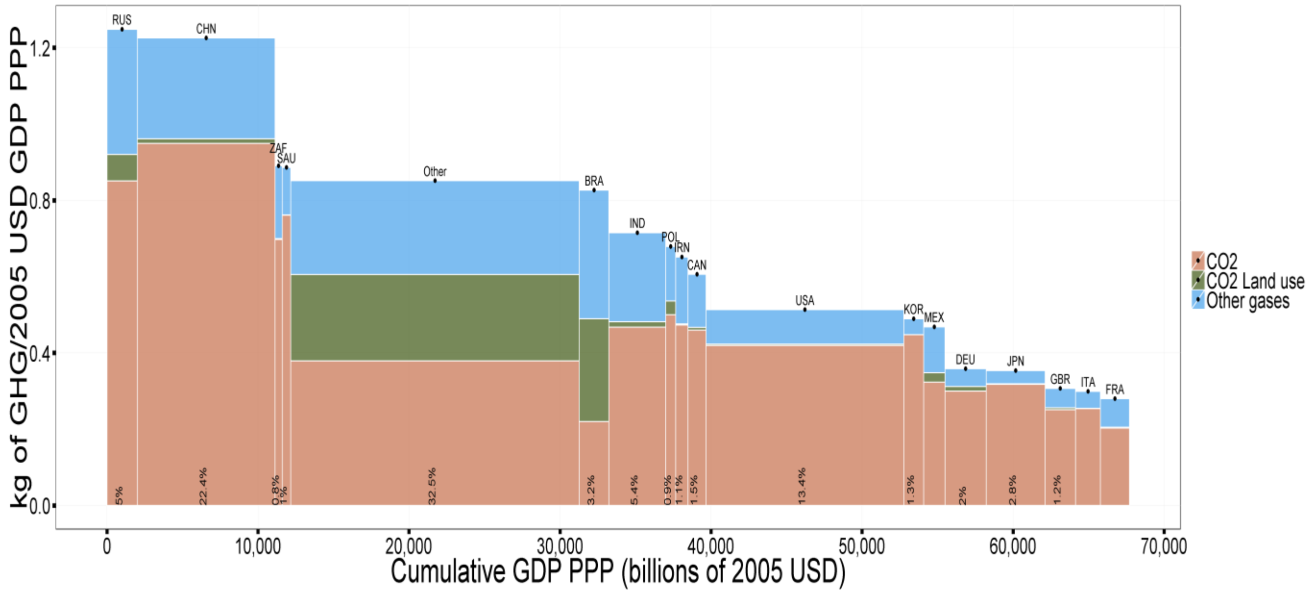
A fourth perspective looks at per-capita emissions, shown in panel C of Figure 1.7. This perspective draws attention to fundamental differences in the patterns of development of countries and the sizes of populations. It suggests that emission control obligations—and perhaps even emission rights in a global emission trading scheme---be allocated along lines of population. While the main driving force for most emissions is the state of the economy, for some countries land use changes (e.g., deforestation) play a large role, which helps account for the particularly high per-capita emissions in Indonesia, for example, when compared with other countries at the same level of per-capita income. Other studies have examined per-capita emissions in a more fundamental shift that would assign responsibility for emissions to individuals rather than nations (Chakravarty et al., 2009). Looking within the categories of countries shown in panel C, some developing countries already have higher per-capita emissions than some industrialized nations.



(C)


Per Capita GHG Emissions (t/cap)
0
5
10
15
20
USA
CAN
SAU
RUS
KOR
DEU
POL
JPN
GBR
FRA
ZAF
CHN
BRA
ITA
IRN
MEX
Other
IND
13.4%
1.5%
1%
5%
1.3%
2%
0.9%
2.8%
1.2%
1.1%
0.8%
22.4%
3.2%
32.6%
5.4%
CO2
CO2 Land use
Other gases
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Cumulative population (millions)

(D)


kg of GHG/2005 USD GDP PPP
0.0
0.4
0.8
1.2
RUS
CHN
ZAF
SAU
Other
BRA
IND
POL
IRN
CAN
USA
KOR
MEX
DEU
JPN
GBR
ITA
FRA
5%
22.4%
0.8%
1%
32.5%
3.2%
5.4%
0.9%
1.1%
1.5%
13.4%
1.3%
2%
2.8%
1.2%
CO2
CO2 Land use
Other gases
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
Cumulative GDP PPP (billions of 2005 USD)

(E)

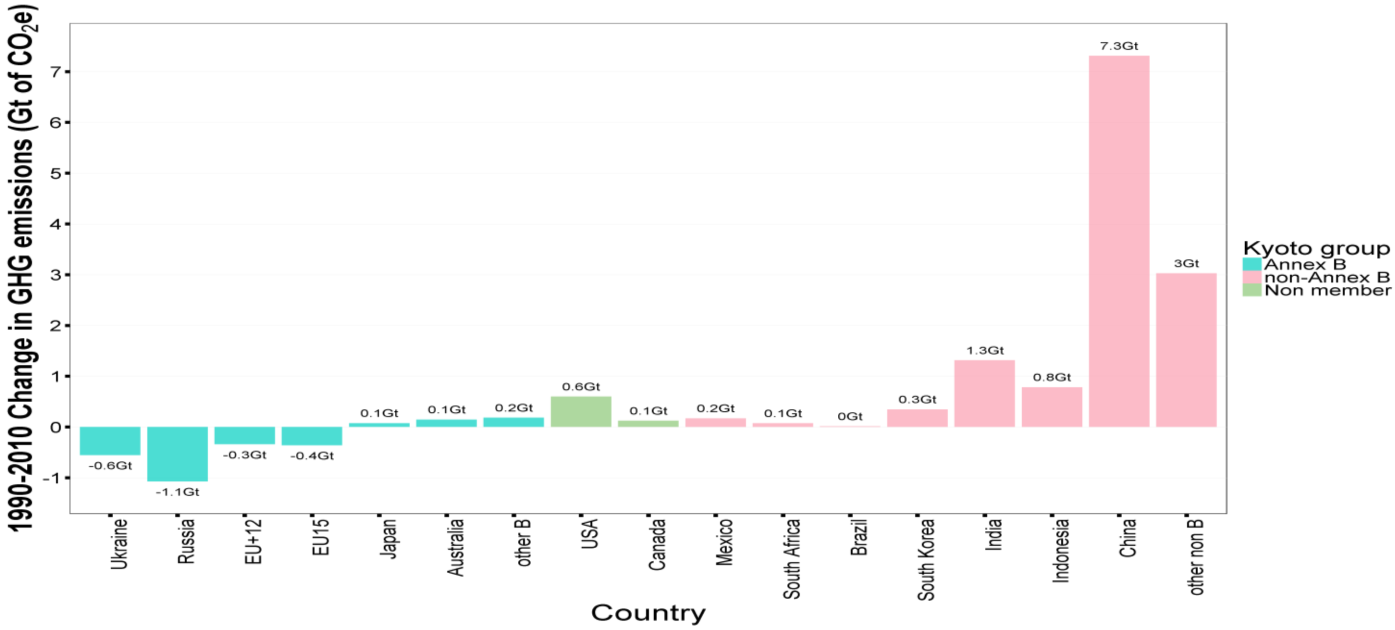

1990-2010 Change in GHG emissions (Gt of CO2e)
-1
0
1
2
3
4
5
6
7
-0.6Gt
-1.1Gt
-0.3Gt
-0.4Gt
0.1Gt
0.1Gt
0.2Gt
0.6Gt
0.1Gt
0.2Gt
0.1Gt
0Gt
0.3Gt
1.3Gt
0.8Gt
7.3Gt
3Gt
Ukraine
Russia
EU+12
EU15
Japan
Australia
other B
USA
Canada
Mexico
South Africa
Brazil
South Korea
India
Indonesia
China
other non B
Country
Kyoto group
Annex B
non-Annex B
Non member

Figure 1.7 (previous pages): Multiple Perspectives on Climate Mitigation. Panel A: Cumulative emissions since 1750 (left) and current emissions using the consumption (middle) and production (right) methods of accounting. **Panel B:** Allocation of rising CO2 concentrations due to combustion of fossil fuels and changes in land use in developing countries (i.e., countries not listed in Annex I of the UNFCCC) and developed countries. **Panel C:** per-capita emissions for major emitting countries (same countries as on panel A), shown as a cumulative function of population. Orange shading is CO2 from fossil fuels; green is from changes in land use and blue is other Kyoto gases. **Panel D:** Same as panel C except countries ranked by carbon intensity of their economies (emissions per unit GDP, weighted with purchasing power parity). **Panel E:** Emissions changes from 1990 to 2012 divided into Annex B of the Kyoto Protocol (countries with quantified emission targets, dark green), countries that were eligible for Annex B but are not members (Canada and the U.S., light green) and non-Annex B countries (red). Sources: Panels A, C and D adapted from data reported in (Olivier et al., 2011); Panel B reprinted from S.2 in (Wei et al., 2012).

A fifth perspective is the efficiency of the national economy, examined in Figure 1.6 and on panel D of Figure 1.7. This perspective draws attention to the emission intensity of economies, commonly measured as the ratio of emission to unit economic output (CO_2/GDP). Typically, economies at an earlier stage of development rely heavily on extractive industries and primary processing using energy intensive methods often reinforced with subsidies that encourage excessive consumption of energy. As the economy matures it becomes more efficient and shifts to higher value-added industries, such as services, that yield low emissions but high economic output. From this perspective, emission obligations should reflect the pattern of economic development and should reward economies that make a rapid transition to low intensity.

A sixth perspective (panel E of Figure 1.7 looks at the relationship between emissions and mitigation obligations under the Kyoto Protocol. That panel divides the world into two groups—the Annex I countries that agreed to targets under the Kyoto Protocol (and which most of those nations formally ratified, making them binding law) and the non-Annex I countries that joined the Kyoto Protocol but had no formal quantitative emission control targets under the treaty. The Annex I countries excluding Canada and the USA, have a target of reducing their greenhouse gas emissions by 4.2 % on average for the period 2008-2012 relative to the base year, which in most cases is 1990. (We treat Canada and the U.S. differently from other Annex I countries because the former withdrew from the treaty and the latter never ratified.) For 2008-2012, the countries that ratified the Kyoto Protocol and adopted national emission targets are certain to comply with their collective target quite comfortably even without obtaining emission credits through the Kyoto Protocol’s Clean Development Mechanism (CDM). However, there are large national differences and some individual countries will not meet their national target without emissions trading and need to purchase emission credits from other countries (Den Elzen et al., 2009, 2011). The trends on this panel reflect many distinct underlying forces. The big decline in Ukraine, Russia, the 12 new members of the EU (EU+12) and one of the original EU members (Germany, which now includes East Germany) reflect restructuring of those economies in the midst of a large shift away from central planning. The relatively flat emissions patterns across most of the industrialized world reflect the normal growth patterns of mature economies. The sharp rise in emerging markets, notably China and India, reflect their rapid industrialization—a combination of their stage of development and pro-growth economic reforms.

There are many ways to interpret the message from this sixth perspective, which is that all countries are likely to comply with the Kyoto Protocol. One interpretation is that treaties such as the Kyoto Protocol have had some impacts on emissions, which is why nearly all the countries that ratified the Kyoto obligations are likely to comply. Another interpretation is that the Kyoto Protocol is a fitting illustration of the concept of “common but differentiated responsibility,” which holds that countries should undertake different efforts and that those most responsible for the underlying problem should do the most. Still another interpretation is that choice of Kyoto obligations largely reveals “selection effects” through which countries, in effect, select which international commitments to honour. Countries that could readily comply adopted and ratified binding limits; the others avoided such obligations—a phenomenon that, according to this perspective, is evident not just in climate change agreements but other areas of international cooperation as well (see generally Downs, Rocke, and Barsoom (1996); Victor (2011)).

Still other interpretations are possible as well, with varied implications for policy strategies and the allocation of burdens and benefits among peoples and nations.

1.3.3 Scale of the Future Mitigation Challenge

Future emission volumes and their trajectories are hard to estimate, and there have been several intensive efforts to make these projections. Most such studies start with one or more "business as usual (BAU)" projections that show futures without any policy interventions, along with scenarios that explore the effects of policies and sensitivities to key variables. Chapter 5 looks in more detail at the long term patterns in such emissions, and Chapter 6 examines the varied models that are widely used to make emission projections. Using a database of those models described in Chapter 6, Figure 1.6 also shows the emission trajectories that are consistent with a variety of widely-discussed goals, such as stabilizing warming at 1.5 or 2 degrees. There is no precise relationship between such temperature goals and emissions largely because the sensitivity of the climate system to changes in atmospheric concentrations is not known with precision. There is also uncertainty in the speed at which future emissions will be net removed from the atmosphere since that removal process determines the fraction of emissions that remains and accumulates, as examined in more detail in panel C of Figure 1.7. If removal processes are relatively rapid and climate sensitivity is low, then a relatively large quantity of emissions might lead to small changes in global climate. If those parameters prove to have less lucky values then even modest increases in emissions could have big impacts on climate. The range of those values is reflected in the range of the colored bars in Figure 1.8. While these uncertainties in how the natural system will respond are important, recent research suggests that a wide uncertainties in social systems—such as the design of policies and other institutional factors—are likely to be a much larger factor in determining ultimate impacts on warming from human emissions (Rogelj et al., 2012).

Figure 1.8 underscores the scale of effort that would be needed to move from likely future emissions to meet widely discussed goals. A variety of studies has probed whether emission reduction pledges, such as made in the aftermath of the Copenhagen conference, would be sufficient to put the planet on track to meet the 2 degree target (Den Elzen et al., 2011; Rogelj et al., 2011). For example, Den Elzen et al. (2011) found the gap between allowable emissions to maintain a "medium" chance (50-66%) of meeting the 2 degree target and the total reduction estimated based on the pledges made at and after COP 15, are as big as 2.6-7.7 GtCO_2e in 2020 when considering least-cost scenarios. Cline finds that in order to achieve 2 degree target by converging global per capita emissions equal by 2050, emissions must be reduced by 89% for industrial countries (91% for the United States) and 69% for developing countries (88% for China) by 2050 respectively from baseline emissions (Cline, 2011). And according to Yamaguchi (2012), in order to reduce global CO_2 emissions by 50%, even if Annex I countries are successful to reduce their per capita CO_2 emissions by 80% from 11t (in 2000) to 2.2t CO_2 by 2050, the room left for Non- Annex I countries' per capita emissions in that year would be 1.1 tCO_2. Such a goal seems extraordinary challenging in view of the fact that Non-Annex I countries' per capita emissions have already (by 2009) increased to 2.7tCO_2. By logical extension, limiting warming to 1.5 degrees (or even 1 degree, as some governments and analysts suggest should be the goal) is even more challenging. In a major inter-comparison of energy models, only 8 among 14 scenarios found that emissions controls broadly consistent with limiting warming to 2 degrees would be achievable even under optimal conditions in which all countries participated promptly in global regulation of emissions and a temporary overshooting of the 2 degree goal is allowed (Clarke et al., 2009). If some portions of the developing world are allowed to delay their participation, which is a politically likely, then only 2 of 14 models found the 2° goal achievable. Most of those scenarios were based on emission controls that envisioned approximately a 60% reduction in CO_2 emissions below 2000 levels by 2050—a major and probably costly task.

It is impossible to say with precision whether any particular goal is achievable because the models that are used to analyze emissions must contend with many uncertainties about how the real world will evolve. While the list of those uncertainties is long, the model outcomes are particularly sensitive to five that are discussed in much more detail in chapter 6:

- Participation. Studies typically analyze scenarios in which all nations participate with the same timing and level of effort, which also probably leads to the least costly total level of effort. However, a variety of "delayed participation" scenarios are also analyzed, and with delays it becomes more difficult (and costly) to meet mitigation goals.
- International institutions. Outcomes such as global participation will require effective institutions, such as international agreements and schemes like international trading of emission offsets and financial transfers. If those institutions prove difficult to create or less than optimally effective then mitigation goals are harder to reach.
- Technology. The least cost outcomes (and greatest ease in meeting mitigation goals) requires that all emission control technologies be available as quickly as possible. In many models, meeting aggressive goals also requires the availability of negative emission technologies—for example, power plants fired with biomass and including carbon sequestration. No such plant actually exists in the world today and with pessimistic assumptions about the availability of such technologies it becomes much harder or impossible to reach aggressive mitigation goals.
- Economic growth. If growth is high then so are emissions (and in some models, so is the rate of technological innovation). More pessimistic assumptions about growth can make emission goals easier to reach (because there is a smaller gap between likely and desired emissions) or harder to reach (because technologies will not be invented as quickly).
- Peak timing. Because long-term climate change is driven by the accumulation of long-lived gases in the atmosphere (notably CO2), these models are sensitive to the exact year at which emissions peak before emission reductions slow and then stop accumulation of carbon in the atmosphere. Models that allow for early peaks create more flexibility for future years, but that early peak also requires the early appearance of mitigation technologies. Later peak years allow for delayed appearance of new technologies but also require more aggressive efforts after the peak.

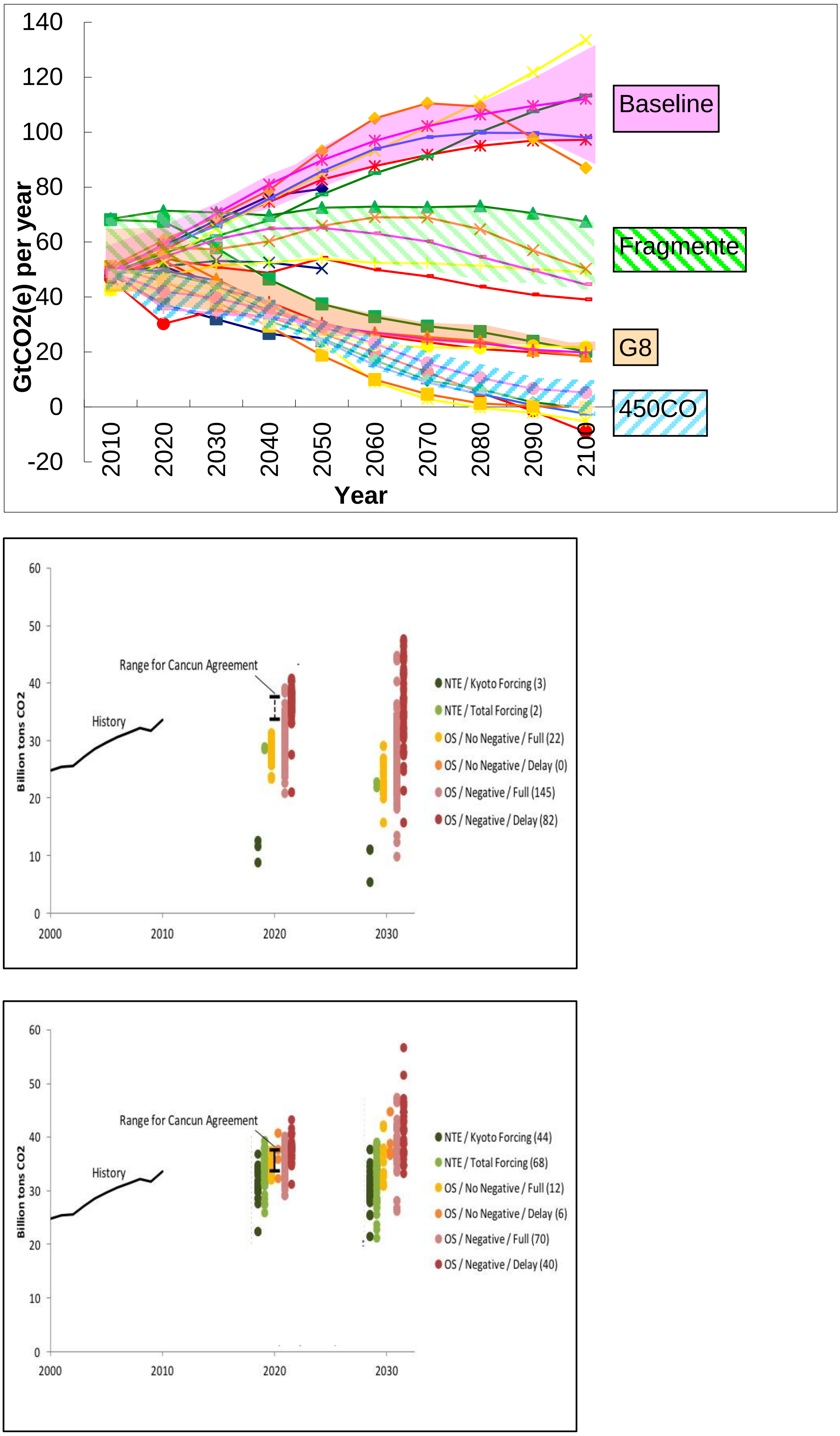


Figure 1.8. The Scale of the Mitigation Effort Needed. Top Panels shows 26 Long term runs from 7 models that explore four different visions of the world: baseline emissions, policy that is fragmented, policy that is consistent with the public proclamations of the G8 (ie, industrialized countries cutting emissions 80% by 2050, full implementation of the Copenhagen pledges, and substantial reductions by developing countries), and optimal policies needed to stabilize emissions at 450ppm CO2(e),

which is broadly consistent with warming of about 2 degrees. Middle Panel looks at near term emissions consistent with that 450ppm goal. As the 450ppm goal looks increasingly difficult, also shown are results for a 550 ppm CO2(e) goal, which probably corresponds with about 3 degrees of warming. [Author note to reviewers: previous sentence to be updated per input from WG1 and also review by the IAM teams in chapter 5.] For middle and bottom panels, individual model results (254 in middle panel; 240 in bottom panel) are indicated with colors referring to scenario classification as not-to-exceed (NTE) vs. overshoot (OS); CO2 equivalence in terms of Kyoto gas contributions or total contributions to forcing; availability of a negative emissions technology; and timing of international participation (full vs. delay). Also shown are the range of pledges made in the aftermath of the Copenhagen meeting and reaffirms and clarified in Cancun in 2010, suggesting that those pledges are likely consistent with a 550ppm goal but probably not 450. Sources: EMF27 databases summarized in [Author note: cite to EMF27 overview paper will be added once it clears review]; additional discussion in chapter 6.

In general, only when the most optimistic assumptions are made—such as permission for some temporary overshooting of goals and allowing models the maximum flexibility in the technologies that are utilized and the countries that make efforts—is the result is a least cost, "optimal" outcome. Since AR4 the modeling community has devoted much more attention to varying those assumptions to allow for less flexible assumptions that are typically better tuned to real world difficulties. These more realistic assumptions are often called "second best." At present, with the most optimistic assumptions many models suggest that the goal of reaching 2 degrees is feasible. With a variety of second best assumptions that goal is much more difficult to reach, and some models find the goal infeasible. These practical difficulties suggest that while optimal analyses are interesting, the real world is likely to follow pathways that are probably more costly and less environmentally effective than optimal outcomes. They are also a reminder that such models are a portrayal of the world that is necessarily simplified and highly dependent on assumptions. There can be many unforeseen changes that make such goals easier or more difficult to reach. For example, unexpectedly high economic growth and expansion of coal-fired electricity has raised emissions and made goals harder to reach; unexpected innovations in renewables, energy efficiency and natural gas are possibly making goals easier to reach.

1.4 Mitigation Challenges and Strategies

While this report addresses a wide array of subjects related to climate change, our central purpose is to discuss mitigation of emissions. The chapters that follow will examine the challenges for mitigation in more detail, but five are particularly notable. These challenges, in many respects, are themes that will weave through this report and appear in various chapters.

1.4.1 Reconciling priorities and achieving sustainable development

Climate change is definitely one of the most serious challenges human beings face. However, it is not the only challenge. For example, a survey of the Millennium Development Goals (MDGs) offer examples of the wider array of urgent priorities that governments face. These goals, worked out in the context of the United Nations Millennium Declaration in September 2000, cover eight broad goals that span eradication of extreme poverty and hunger, reduction of child mortality, combating HIV/AIDS, malaria and other diseases, and eighteen targets have been set. For example, halving, between 1990 and 2015, the proportion of people whose income is less than $1 a day, and halving, between 1990 and 2015, the proportion of people who suffer from hunger, are among targets under the goal of eradicate extreme poverty and hunger. (Since then, the official poverty level has been revise upwards to $1.25/day by the World Bank.) MDGs are unquestionably the urgent issues human beings should cope with immediately and globally. Achieving such goals along with an even broader array of human aspirations is what many governments mean by "sustainable development" as echoed in many multilateral statements such as the declaration from the Rio +20 conference in 2012 (United Nations, 2012).

All countries, in different ways, seek sustainable development, and each puts its priorities in different places. Those priorities also vary over time—something evident as immediate goals such as job creation and economic growth have risen in salience in the wake of the global financial crisis of the late 2000s. Moreover, sustainable development requires tradeoffs and choices because resources are finite. There have been many efforts to frame priorities and determine which of the many topics on global agendas are most worthy. Making such choices, which is a highly political process, requires looking not only at the present but also posterity (Summers, 2007). Applying standard techniques for making tradeoffs—for example, cost-benefit analysis (CBA)—is extremely difficult in such settings, though importance of CBA itself is well recognized (Sachs, 2004). Important goals, such as equity, are difficult to evaluate alongside other goals that can more readily be monetized. Moreover, with climate change there are additional difficulties such as accounting for low probability but high impact catastrophic damages and estimating the monetary value of non-market damages (Nussbaum, 2000; Weitzman, 2009).

1.4.2 Uncertainty and Risk Management

The policy challenge in global climate change is one of risk management under uncertainty. The control of emissions will impose costs on national economies, but the exact amount is uncertain. Those costs could prove much higher if, for example, policy instruments are not designed to allow for flexibility. Or they could be much lower if technological innovation leads to much improved energy systems. Mindful of these uncertainties, there is a substantial literature on how policy design can help contain compliance costs, allowing policy makers to adopt emission controls with greater confidence in their cost (e.g., (Metcalf, 2009).

Perhaps even more uncertain than the costs of mitigation are the potential consequences of climate change. As reviewed elsewhere in the IPCC assessment there is growing evidence that feedbacks along with high degrees of climate change could lead to impacts much greater than most analysts originally expected—for example, higher sea levels and greater impacts on natural ecosystems (later add citation to relevant parts of IPCC WG2; see also IPCC WG1, chapters 11-14 and Annex I). Investments in adaptation, which vary in their feasibility, can help reduce exposure to climate impacts and may also lessen uncertainty in the assessment of possible and probable impacts (World Bank, 2010).

Since risks arise on both fronts—on the damages of climate change and on the costs of mitigation responses—scholars often call this a “risk-risk” problem. In the case of climate change, management in this context of risk and uncertainty must contend with another large challenge. Mitigation actions and effects of climate change involve a multitude of actors working at many different levels, from individual firms and NGOs to national policy to international coordination. The interest of those different actors in undertaking climate mitigation also varies. Moreover, this multitude faces a large array of decisions and can deploy many different instruments that interact in complex ways. Chapter 2 explores the issues involved with this multitude of actors and instruments. And Chapter 3 introduces a framework for analysing the varied policy instruments that are deployed and assessing their economic, ecological, ethical and other outcomes.

Scientific research on risk management has several implications for managing the climate change problem. One is the need to invest in research and assessment that can help reduce uncertainties. In relation to climate change these uncertainties are pervasive and they involve investments across many intellectual disciplines and activities, such as engineering (related to controlling emissions) and the many fields of climate science (related to understanding the risks of climate change). In turn, these knowledge generating and assessment processes must be linked to policy action in an iterative way so that policy makers can act, learn, and adjust while implementing policy measures that are “robust” across a variety of scenarios (McJeon et al., 2011). Another major implication is the need to examine the possibilities of extreme climate impacts. These so called “tail” risks in climate impacts could include relatively rapid changes in sea level, feedbacks from melting permafrost that amplify the concentrations of greenhouse gases in the atmosphere, or possibly a range of so far barely analysed outcomes (see generally Weitzman (2011). One element of such a risk management approach may be "geoengineering" that could crudely offset the impacts of some climate change (Cicerone, 2006). Since AR4 a growing number of studies have looked at geoengineering options—the technology, possible impacts and risks of testing and deploying geoengineering, and strategies that might be needed to govern geoengineering (Barrett, 2008; Victor, 2008; The Royal Society, 2009).

1.4.3 Encouraging international collective action

Unlike many matters of national policy, a defining characteristic of the climate change issue is that its sources are truly global. Nearly all climate-altering gases have atmospheric lifetimes sufficiently long that it does not matter where on the planet they are emitted. They spread worldwide and affect the climate everywhere. Thus national governments develop their own individual policies with an eye to what other nations are likely to do and how they might react. Even the biggest emitters are mostly affected by emissions from other countries rather than principally their own pollution. International collective action is unavoidable.

Collective action is needed on many fronts. Those include not only coordination on policies to control emissions but also collective efforts to promote adaptation to climate change. International coordination is also needed to share information about best practices in many areas. For example, many of the promising options for reducing emissions involve changes in behaviour; governments are learning which policies are most effective in promoting those changes and sharing that information more widely can yield practical leverage on emissions. Coordination is also essential on matters of finance since many international goals seek action by countries that are unwilling or unable to pay the cost fully themselves.

1.4.4 Promoting Investment and Technological Change

Successful mitigation will require moving towards a low carbon development pathway, and the level of effort needed is probably very large in light of the huge gap between likely future emissions and the levels needed to reach widely discussed goals. Delinking GHG emissions from GDP growth will probably require massive changes in technology. In turn, that will require closer attention to technology innovation and deployment strategies. Technologies vary in many ways--they have different maturity stages and potential for improvement through "learning"; they have different carbon mitigation potentials and require different policy responses in developing and developed countries. Other studies have looked in detail at how this diversity of approaches might influence climate policy discussions in the future (WBCSD, 2009). But all low GHG technology options share one commonality - a shift in the cost structure of supplying energy services, i.e., from operating/fuel costs to upfront capital costs. Mobilizing investments is therefore key for climate protection (as well as coping with the impacts of climate change).

To stimulate investment in appropriate technologies at the right time and place, it will help if countries and other key actors such as firms would consider the full life cycle of technology and enable a portfolio of technologies to be developed in parallel, not sequentially. In addition, it is important to consider the life-cycle and turnover of existing capital infrastructure as new low-carbon technologies are phased in and new long-term energy infrastructure is built.

International cooperation, finance and technology transfer have an important role to play as a catalyst to accelerate technology progress at each stage (see chapter 13 on international cooperation). Businesses have been historically active in international cooperation in the deployment of technologies. For example, wind turbine manufacturers and developers frequently cooperate with local partners on the deployment of wind energy in different markets, including training sub-suppliers, transferring technological know-how in the form of, inter alia, personnel training, and implementing high-level quality standards. Such outcomes probably require more active efforts to ensure the exchange of research outcomes that are in the public domain and creation of mechanisms to ensure that private knowledge also diffuses more widely where economically appropriate.

A point of common ground is on the pivotal role of energy efficiency. The business case for energy efficiency is clear and includes: reducing levelized costs of energy services, alleviating energy dependency, decreasing vulnerability to energy price volatility, reducing emissions and improving the efficient use of natural resources. Energy efficiency can generate positive returns on investment and has the potential to promote high value adding activities and job creation. The deployment of energy efficient technologies can alleviate energy supply shortages and contribute to reducing energy supply investment requirements at lower total system costs. Numerous studies indicate that it will be unlikely to avoid dangerous anthropogenic interference with the climate system without drastic efficiency improvements (but also life style changes) (Huntington and Smith, 2011a; UNECE, 2010; OECD, 2011; IEA, 2012e; Riahi et al., 2012).

After the Fukushima Daiichi accident, life style and behavioural change curbed energy demand by 5% during the winter 2011/12 compared with the previous year (after accounting for degree day differences). Similarly, electricity demand in the Tokyo area was 10-15% lower in the summer 2012 than in 2010.

However, energy efficiency faces barriers when it comes to implementation—for example, the difficulty in obtaining reliably information about the cost and performance of installing more efficient technologies—that policy reforms can help to address. Energy efficiency policies and measures need to be integral part of energy sector reform ensuring that market signals (prices) fully reflect the true cost of producing and consuming energy services and thus stimulate investment in energy efficiency (United Nations - Energy, 2010). While energy efficiency often offers least-cost energy services, consumer decisions are based upon multiple criteria that in addition to least-costs include “quality, reliability, convenience and many other traits that may have little to do with energy efficiency. As a result, these factors reduce the projected gains in energy efficiency relative to those based upon only the technology performances and costs in isolation from these other conditions” (Huntington and Smith, 2011b).

At the same time, the potential of end-use energy efficiency must neither be under- or overestimated. Efficiency improvements that lower service costs may directly or indirectly induce additional demand (rebound effect) for energy services, thus partly offset the efficiency gains (Sorrell et al., 2009; Lee and Wagner, 2012). While many policy efforts focus on end-use efficiency, improvements in efficiency are relevant across the entire value chain from primary energy supplies to final users.

1.4.5 Rising Attention to Adaptation

For a long time, nearly all climate policy has focused on mitigation. Now, with some change in climate inevitable (and a lot more likely) there has been a shift in emphasis to adaptation. While adaptation is beyond the scope of this report, there are important interactions between mitigation and adaptation in the development of a climate mitigation strategy. If it is expected that global mitigation efforts will be limited then adaptation (and perhaps also geoengineering) will play a larger role in overall policy strategy. If it is expected that countries (and natural ecosystems) will find adaptation particularly difficult then societies should become more heavily invested in the efforts to mitigate emissions (and perhaps also prepare geoengineering).

Mitigation and adaptation also have quite different implications for collective action by nations. A strategy that relies heavily on mitigation requires collective action because no nation, acting alone, can have much impact on the global concentration of warming pollutants. Even the biggest nations account for only one-quarter of emissions. By contrast, most activities relevant for adaptation are local—while they may rely, at times, on international funding and know-how they imply local expenditures and local benefits. The need for (and difficulty of) achieving international collective action is perhaps less daunting than for mitigation (Victor, 2011).

Developing the right balance between mitigation and adaptation requires many trade-offs and difficult choices. In general, societies most at risk from climate change—and thus most in need of active adaptation—are those that are least responsible for emissions. That insight arises, in part, from the fact that as economies mature they yield much higher emissions but they also shift to activities that are less sensitive to vagaries of the climate. Other tradeoffs in striking the mitigation/adaptation balance concern the allocation of resources among quite different policy strategies. The world has spent more than 20 years of diplomatic debate on questions of mitigation and has only more recently begun extensive discussions and policy planning on the strategies needed for adaptation.

1.5 Roadmap for WG III report

The rest of this report is organized into four major sections.

First, chapters 2-5 introduce fundamental concepts and framing issues. Chapter 2 focuses on risk and uncertainty. Almost every aspect of climate change—from the projection of emissions to impacts on climate and human responses—is marked by a degree of uncertainty and requires a strategy for managing risks; since AR4 a large number of studies has focused on how risk management might be managed where policies have effects at many different levels and on a diverse array of actors. Scholars have also been able to tap into a rich literature on how humans perceive (and respond to) different types of risks and opportunities. Chapter 3 introduces major social, economic and ethical concepts. Responding to the dangers of unchecked climate change requires tradeoffs and thus demands clear metrics for identifying and weighing different priorities of individuals and societies. Chapter 3 examines the many different cost and benefit metrics that are used for this purpose along with ethical frameworks that are essential to any full assessment.

Chapter 4 continues that analysis by focusing on the concept of “sustainable development,” a concept whose varied definitions and practices reflect the many distinct efforts by societies and the international community to manage tradeoffs and synergies involved with economic growth, protection of the environment, justice and other goals.

Second, chapters 5-6 put the sources of emissions and the scale of the mitigation challenge into perspective.

Chapter 5 evaluates the factors that determine patterns of anthropogenic emissions of gases that affect climate. While there are many such pollutants, the analysis in chapter 5 focuses where the data are most robust—emissions of CO2 from the energy system—and explores the relative (and interdependent) roles of factors such as population, consumption, and the intensity with which energy is used in various economies. It finds that economic growth, which is closely related to the consumption of goods and services, is the single largest driver of emissions. It also shows that international trade is having a growing impact on exactly where on Earth emissions are released. Chapter 6 looks at the suite of computer models that simulate how these underlying driving forces may change over time. Those models make it possible to project future emission levels and assess the certainty of those projections; they also allow evaluation of whether and how changes in technology, economy, behavior and other factors could lower emissions as needed to meet policy goals.

Third, chapters 7-11 look in detail at the five sectors of economic activity that are responsible for nearly all emissions. Those include energy systems (chapter 7), such as the systems that extract primary energy and convert it into useful forms such as electricity and refined petroleum products.

While energy systems are ultimately responsible for the largest share of anthropogenic emissions of climate gases, most of those emissions ultimately come from other sectors such as transportation that make final use of energy products. Chapter 8 looks at transportation, including passenger and freight systems. Chapter 9 examines buildings and chapter 10 is devoted to industry. Chapter 11 focuses on agriculture, forestry and other land use (AFOLU), the only sector examined in this study for which the majority of emissions are not rooted in the energy system.

Looking across chapters 7-11 one major theme that emerges is the concept of co-benefits: the ability to limits emissions of climate-altering pollutants while also yields other important benefits such as reducing erosion caused by deforestation or lowering the harmful health effects of soot when firms switch to less polluting combustion technologies and fuels. These co-benefits often play a large role in evaluating the costs and benefits of mitigation policies.

Often, this approach of looking sector-by-sector (and within each sector at individual technologies and practices) is called “bottom up.” That perspective, which is evident in chapters 7-11 complements the “top down” perspective of chapters 5-6 in which emissions are analyzed by looking at the whole economy of a nation or the planet.

Fourth, chapters 12-16 examine the major issues that arise with mitigation efforts. Chapter 12 looks at spatial planning since many emissions are rooted in how humans live, such as the density of population and the infrastructure of cities.

Chapter 13 concentrates on the special issues that arise with international cooperation. Since no nation accounts for more than about [one-fifth] of world emissions and economies are increasingly linked through trade and competition, a large body of research has examined how national policies could be coordinated through international agreements like the UN Framework Convention on Climate Change and other mechanisms for cooperation. Chapter 14 continues that analysis by focusing on regional cooperation and development patterns.

Chapter 15 looks at what has been learned within countries about the design and implementation of policies. Nearly every chapter in this study looks at an array of mitigation policies, including policies that work through market forces as well as those that rely on other mechanisms such as direct regulation. Chapter 15 looks across that experience at what has been learned.

Chapter 16, finally, looks at issues related to investment and finance. The questions of who pays for mitigation and the mechanisms that can mobilize needed investment capital are rising in prominence in international and national discussions about mitigation. Chapter 16 examines one of the most rapidly growing areas of scholarship and explores the interaction between public institutions such as governments and private firms and individuals that will ultimately make most decisions that affect climate mitigation. Among its themes is the central role that financial risk management plays in determining the level and allocation of investment financing.

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