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Chapter 1: Introduction

Contents

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 active efforts around the world to design and adopt climate mitigation policies. Those policies have been local, national and international in scope. They have included market-based approaches such as emission trading systems along with regulation; they encompass many diverse "green growth" strategies that nations have adopted with the goal of promoting human economic welfare and jobs while also cutting an array of environmental impacts including emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs). International diplomacy—leading to agreements such as the United Nations Framework Conventional on Climate Change (UNFCCC) and the Kyoto Protocol—has also 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) 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 national economic and social policies and how those national capabilities, in turn, may influence how governments coordinate their actions internationally (see chapters 13, 14 and 16). There is also growing practical experience and scholarly research concerning a wide array of policy instruments (see chapter 15).

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 makes six arguments. First, efforts at mitigation must begin with assessments of the factors that affect the level of emissions of greenhouse gases (GHGs). Those include population, the structure of the economy, behaviour, and the state of energy technology. 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. In addition, for some countries it is likely that there is a large role for regulatory and market 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 sustainable development, green growth, and energy security. 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." 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 programs—for example through capacity-building—need to engage these broader national priorities.

Third, it is likely that the current trajectory of global emissions of GHGs is inconsistent with the widely discussed goal of limiting global warming at 2 degrees Celsius above the pre-industrial level. [1.2.1.6 and 1.3.3; medium agreement, robust evidence] It is extremely unlikely that meeting even more aggressive goals, such as 1.5 degrees Celsius, will be 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. It is very likely that here are many different development trajectories, but it is virtually certain that the ability to meet those trajectories will be constrained if particular technologies are removed from consideration or are given excessive emphasis. It is likely that the most appropriate policies will vary by sector and country, suggesting the need for flexibility rather than a singular set of policy tools. It is very likely that in most countries the actors that are relevant to controlling emissions aren't just national governments. Many diverse actors participate in climate change policy from the local to the global levels—including a wide array of nongovernmental organizations representing different environmental, business and other interests. [1.4; medium agreement, robust evidence]

Fifth, policies to address mitigation and adaptation arise in the context of many different forms of uncertainty, of which development of the global economy is just one. While there has been much public attention to uncertainties in the underlying science of climate change, it is virtually certain that profound uncertainties arise in many other areas as well: emission patterns, technologies, the effects of policies, and cost. The pervasive 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 emergency geoengineering [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 likely 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 sources of climate change, notably the emission of pollutants that can affect the planet's energy balance. This is the fifth such IPCC comprehensive assessment.

Assessments such as this one have a special role in the international efforts to manage collective challenges like global climate change. By design, such assessments are intended to be comprehensive both with respect to topics covered and participation of different communities – including disparate views, methods, and diverging results for which there is significant scientific or technical support. Such assessments utilize consistent frameworks for identifying costs, risks and benefits of alternative transition pathways, with close attention to how underlying assumptions related to value judgments, interests, beliefs and worldviews affect results. Throughout, this study will use neutral language and good scientific practice and also endeavor to communicate qualitative and quantitative uncertainties. This assessment report is intended to be policy-relevant without being policy-prescriptive.

This chapter covers these topics and introduces the rest of the Working Group III volume. First we focus on the main messages since the publication of AR4 (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 since AR4

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 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.

1.2.1.1 Sustainable development and green growth

Addressing climate change has become the important component of sustainable development. Since the concept of sustainable development was advanced through international processes such as the Brundtland report the concept gradually has been accepted and popularized as one of basic principles to harmonize economic development and environment protection (World Commission on Environment and Development, 1987). This approach, which emphasizes the integration of many different policy goals, is particularly important for climate change as it intersects with many economic and environmental goals—including challenges of establishing fairness between countries and generations of peoples. In many respects, climate change is becoming the key environmental challenge of sustainable development (see chapter 4).

Governments have many different goals, including economic development, poverty alleviation and living standard improvement. This awareness of varied goals is important since there are so many different factors that influence how countries evaluate their national interests. Of paramount importance are the goals and interests framed in developing countries, especially the emerging economies, whose economies are expanding rapidly. Along with the necessary industrialization and urbanization in a traditional growth pattern, combined with industrial reallocation of globalization, energy consumption and consequent carbon emissions in these countries are increasing as well. Like all countries, to different degrees, these countries are devising policies to manage common challenges like high and volatile energy and food prices as well as an array of environmental effects, such as extreme weather events, that presently and in the future may arise from climate change. Mindful of these impacts, these countries have acknowledged that climate change should be tackled as the important component of sustainable development—such as through "green growth" strategies that emphasize the ability to limit growth in emissions while also achieving sustained economic and social development (poverty elimination, job creation, healthcare improvement, enhanced energy security, etc) and enhancing the capacity to adapt to climate impacts (Chinese Academy of Engineering, 2011; OECD, 2011).

Through this approach, developing countries 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. 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, Brazil is one of the leading countries of bio-ethanol production. India is developing a leading program in solar and wind power. The Government of India launched the Jawaharlal Nehru National Solar Mission (JNNSM) to develop solar energy technologies to make solar power competitive with conventional grid power by 2022. By the 2020s the effort aims at expanding grid solar power (up to 20 GW), off-grid solar applications (2 GW) and solar hot water heating (20 million square metre solar thermal collector area).

As a group, the BRICS—the rapidly growing countries of Brazil, Russia, India, China and South Africa—have worked to advance policy initiatives in this area, such as through their March 2012 meeting "Partnership for Global Stability, Security and Prosperity." That event concluded with support for a wide array of sustainable development efforts and urged that climate change action should focus on "sustainable and inclusive growth" rather than "capping development"(BRICS, 2012). The final Declaration from the meeting also affirms that the "still to be defined concept" of green economy has to be seen as a means for achieving sustainable development and poverty eradication, rather than an end in itself. (BRICS, 2012)

Developing 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). Whether this trend indicates a long-term direction for Brazil's emissions from changes in land use is difficult to assess and depends on many factors. Many partnerships with forest-rich nations, such as with Brazil and Indonesia, are aimed at finding new ways to reduce and manage land clearing.

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 developing countries is still far lower than that of developed countries, suggesting that as economies converge that emissions will rise. Low carbon technologies available today are not sufficient to offset the emission increase driven by the economy growth. Moreover, accounting procedures for emissions don't adequately reflect the ultimate drivers of emissions. For example, lots of developing countries act as commodity producers and incur the emissions for products that are sold elsewhere; scholars are now looking at various ways to account for these "embodied" emissions. (IMF, 2009, 2011; Peters et al., 2011) Without much improved technology, accounting systems and other arrangements the international economy system doesn't yet support and encourage the realization of low carbon development.

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 rooted, in part, in poorly regulated financial speculation concentrated in the OECD countries (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 to the core. The International Monetary Fund (IMF, 2009) estimated global credit write-downs in excess of US$4 trillion for 2009 and 2010 of which approximately two-thirds taken by the banking system. Naude (2009) assessed that by October 2008 the crisis had wiped out some US$25 trillion of value from the stock markets. At this writing the crisis was still reverberating through the world economy as the original financial crisis has become subsumed in other economic and political crises, such as in the public budgets of many members of the Euro zone.

The financial crisis ended a seven-year period of substantial expansion of the global economy and with it a period of steadily rising and volatile with material and resource prices. Although developing countries were generally not directly affected by the melt-down of financial institutions in the industrialized world—in part due lessons learned from the late 1990s financial crisis in Asia which led many of the largest emerging countries to limit exposure of their financial sectors and adopt more sound financial governance—the contagion of recessions centred on the OECD has spread, especially to countries with small, open and export-oriented economies. The financial crisis has also affected foreign direct investment (FDI) and official development assistance (ODA) (IMF, 2009, 2011).

While uneven, growth around the world was strongly positive from 2000 through 2007 (see 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.

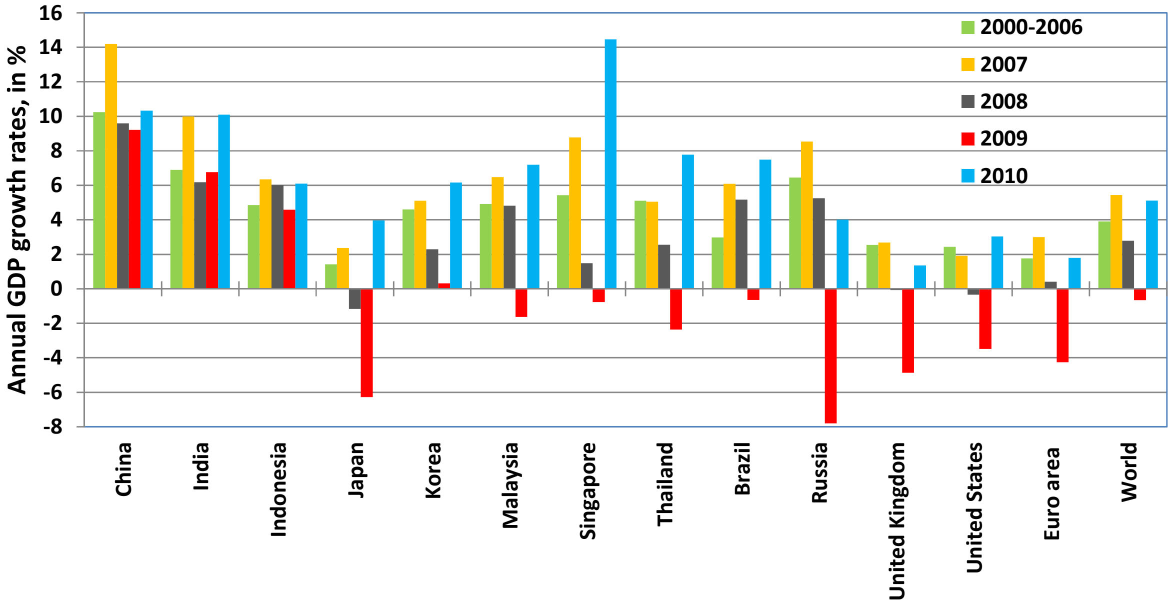

Figure 1.1: Annual growth rates of real GDP for selected countries or regions (Note: for 2000-2006 annual averages are shown). Source: (IMF, 2011).

These uneven growth patterns, exacerbated by the global recession, reveal on-going trend of decoupling of growth rates between developing and developed countries (te Velde 2008; Lin 2008; (ADB 2009; ADB 2010) which enabled the group of large emerging economies—notably the BRICS – to rebound quickly in 2010 after one year of slow performance while OECD growth remains sluggish. (Since then, many of the BRICS have seen slowing economic growth as well.) This rebound in growth in the emerging economies helps explain the rebound of commodity prices in 2009 (see Figure 1.2). That commodity rebound has further helped the economies that are large commodity exporters to grow economically and improve their balance-of- payments. High and volatile commodity prices raise 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 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).

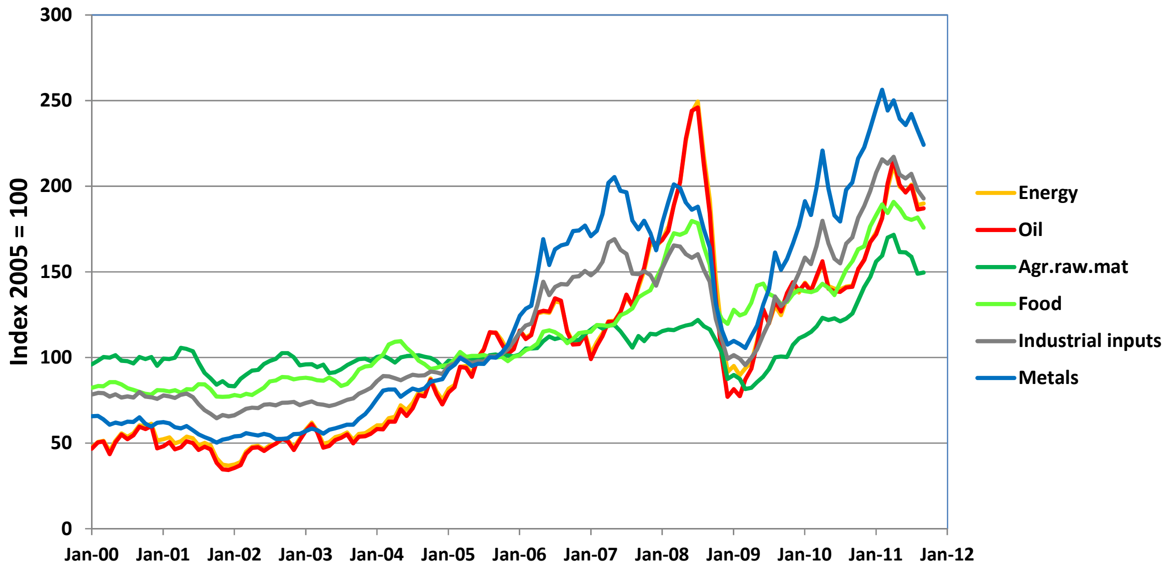

Figure 1.2: Price indices of selected commodities. Source: (Index Mundi, 2011).

Governments responded to the crisis in many different ways, often with fiscal stimulus packages as well as support to ailing banks. For some countries, notably in the OECD, these programs arose in a context of already high government debt, and at this writing a wave of anxiety driven by public debt threatens the world economy. Several highly indebted OECD countries in Europe launched far reaching austerity programmes to avoid national financial insolvency, but austerity has also weakened domestic investment and consumption (Lapavitsas et al., 2010).

The net effect of these crises has further shifted production, investment and technology to emerging economies—a phenomenon that is consistent with the expectation that in a globalized world economy capital resources will shift to emerging economies that can make most productive use of investment (Lamy, 2011). Rising global trade generated large trade surpluses and liquidity in emerging economies but growing current account deficits in many OECD countries. Cheap imports from emerging markets kept OECD inflation in check. The liquidity of Asian and Middle Eastern countries was used to purchase bonds sold by western governments to finance their national budget deficits at low interest rates; inexpensive debt encouraged investors to borrow cheaply while seeking investments in higher yielding assets ranging from stock markets to real estate. Lax regulation allowed a wide array of actors, including banks, to incur and socialize these risks without adequate preparation for the inevitable bust (Overholt, 2010). These financial crises, along with many other shocks such as the 2011 earthquake and tsunami in Japan, have created uncertainty for investors and consumers (WTO, 2011).

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 BRICS, and with that shift has been a consequent shift in the growth of greenhouse gas emissions. However, these economies also face their own challenges. They include inflation in China, the need for new and more robust systems for financial regulation, and diversification of trade.

- Second, much of this shift has arisen in the context of globalization and thus while national emission patterns are also shifting there is also a sharp rise in emissions that are 'embedded" in traded goods and services.

- Third, this shift in wealth formation and emissions has an impact on the political aspects of climate change—among them has been a shift in priorities within the countries where economic growth remains sluggish to adopt climate policies on their own. Coupled to that is a lower turnover in the capital stock in this historically industrialized countries, which means that policies once adopted are generally slow to have practical impact.

- Fourth, technological innovation that is an essential part of cutting emissions has shifted (and is shifting) to these emerging economies. 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. Those high costs have implications for how jurisdiction set policy priorities as well as the cost of energy systems, to which we now turn.

1.2.1.3 The availability, cost and performance of energy systems

The purpose of energy systems is to provide affordable energy services to fuel economic and social development. Hence it comprises all stages from resource extraction, conversion, refining and distribution to the production of energy services for final consumption. The costs of energy services, therefore, are the combination of the costs (investments, operating, maintenance and fuels cost) of the technologies and infrastructures and their performance (efficiency and process intensity) associated with each stage. Of special importance is the performance of end-use infrastructures (buildings and habitat arrangements, transportation systems, industrial production, etc.). The costs also depend whether or not externalities are included.

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). There is a substantial scientific literature focused on the internal political effects of countries that rely on exports of commodities such as oil for their national income (e.g., (Ross, 2012) as well as increasing scientific study of the kinds of firms that are the central players in this industry (Victor, Hults, and Thurber 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 - inadequate 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). At this writing, high prices along with a series of technological innovations 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 an array of associated environmental consequences such as extra emissions of warming gases and other air and water pollutants as well as potentially large local environmental burdens from extracting and processing unconventional oil. There is a large number of contrasting view points about the future of these resources (e.g. 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. (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, 52% of electric power came from coal in 2006, and by 2012 that share had declined to 37% and was expected to decline further. Worldwide, however, most projections still envision robust growth in the utilization of coal, which already is one of the 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.

Since AR4 there have been many technological developments surrounding new energy supplies along with practical experiences that many of the difficulties in developing, testing and deploying new energy systems. For example, a potential route for utilizing coal while cutting emissions is carbon capture and storage (CCS) processes. CCS figures prominently in many studies that look at how atmospheric concentrations can be capped at levels such as 450 ppm, which roughly corresponds with stopping warming at 2 degrees (IEA 2010a; IEA 2011a; IIASA 2012); however, CCS still has not attracted much tangible investment. By mid-2011 there are eight large-scale projects in operation globally and a further six under construction. The total CO_2 emissions avoided by all 14 projects in operation or under construction are about 33 million tonnes a year (Global CCS Institute, 2011). The implementation of large-scale CCS systems generally requires extensive funding that, in the present economic situation and absent of comprehensive legal and regulatory frameworks, cannot be justified commercially (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. 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, including next generation fuels that have lesser impacts on food security and the environment. 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 are intermittent, which can make them difficult to integrate into electric grids at scale (IPCC, 2011). Some technologies, especially solar, are hard to promote without various kinds of subsidies such as feed-in tariff or investment tax credit (ex. Spain, UK, Germany, Japan and USA). Some biofuels are contested due to fears for food security and high lifecycle greenhouse gas emissions of some fuel types (Delucchi, 2010).

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 technologies (ICTs) that enable greater energy efficiency and flexibility in energy use and the integration of intermittent renewable energy sources are increasingly tested in many municipalities. This interconnection offers the promise of energy systems—especially in electricity—that integrate demand response with supplies, allowing for smooth and reliable operation of grids even with fluctuating renewable supplies.

Interest in the use of nuclear power has increased significantly since AR4. Traditional 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, some 60 countries currently without nuclear power expressed interest in introducing 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 and will probably leave many reactors shut in that country, the future patterns in nuclear power investment are more difficult to parse. Some countries have scaled back nuclear investment plans; some, notably Germany, have accelerated plans to close existing reactors. In other countries, including all the countries that have been most active in building new reactors (e.g., China, India, Russia, Finland, and Korea), there aren't many noticeable results from Fukushima and the investment in this energy source seems to be accelerating—these countries' massive investments in nuclear were much less evident, especially in China, India and Korea, at the time of AR4.

Among the many challenges in scaling up these promising systems that rely on new technology—from renewable energy supplies to nuclear power, coal with CCS and energy efficiency—is finding business models and technologies that do not depend on government subsidy or other costly policy supports that are difficult to sustain as some nations face public budget deficits. One fundamental change is the economics of energy systems observed since the AR4 (and expected to continue), be it energy supply or end-use, is their higher upfront capital intensity but lower operating costs (except fossil fuels with CCS) in providing energy services.

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 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 treaty concerned numerical emission targets for industrialized countries during the years 2008 to 2012, which meant that a successor treaty would be needed to cover the period after 2012. When AR4 concluded in 2007 the world was readying for the beginning of the Kyoto regulatory periods and negotiations on a successor treaty were just under way. 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. Subsequent rounds of talks have tried to narrow these gaps and devise new strategies for crafting international agreements.

The growing complexity of international diplomacy on climate mitigation 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. A wide array of other institutions has become engaged with the climate change issue. The G8, for example, has repeatedly underscored the importance of limiting warming to 2 degrees and implored its members to take further actions; through the "G8+5" process it has engaged the large emerging countries as well. The G20 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) 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).

In addition, 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). The WTO and other trade institutions can influence the spread of mitigation technology; a role for the WTO also arises because the fraction of emissions embodied in internationally traded goods and services is rising with the globalization and shifting engines of economic growth reviewed above.

The WTO might also play a role in managing trade sanctions that could be used to help enforce compliance with mitigation commitments (Bacchus et al., 2010). An open, liberal trading regime—for which the WTO is the keystone—also allows potentially large amounts of greenhouse gas mitigations embodied in traded goods, such as aluminium, steel, cement and other products whose production processes can be intensive in emissions (Houser et al., 2008). Relationships between international trade agreements and climate change have been a matter of long standing interest in climate diplomacy. 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." The Joint Working Party on Trade and Environment of the Organization of Economic Cooperation and Development (OECD) has been focussing on this field for more than 20 years and devoted, in recent years, more attention to the intersection of trade and climate change.

Since the IPCC AR4 in 2007 the scholarly community has analysed these issues extensively. Scientists have explored at least three aspects of the complexity and dispersion of international diplomacy on climate change. First, a body of research has emerged to explain why negotiations on complex topics such as climate are prone to gridlock (e.g., see (Victor, 2011). Second, there is 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 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).(Abbott et al., 2000; Koremenos et al., 2001) Much of that research program has sought to explain when and how international institutions, such as treaties, actually help solve common problems (for a review see Hafner-Burton, Victor, and Lupu (2012). 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, Rocke, and Barsoom (1996); (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 at many different levels of government has been mixed (Rezessy and Bertoldi, 2011). Third, scholars have sought to explain why some areas of cooperation are marked by decentralized "complexes" of institutions while others lead to institutions that are highly integrated (Raustiala and Victor, 2004; Alter and Meunier, 2009; Zelli et al., 2010). For example, international institutions on the ozone layer are focused exclusively on the Montreal Protocol. By contrast, for some topics (including climate change) the institutions are much more fragmented (Keohane and Victor, 2011). Similar concepts have emerged in other areas of research on collective action (e.g., (McGinnis, 1999). Further discussion of these issues is found in chapter 13.

1.2.1.5 Understanding the roles of emissions beyond fossil fuel CO_2

Most policy analysis has focused on CO_2 from burning fossil fuels. However, the UNFCCC and the Kyoto Treaty cover a wider array of warming pollutants—including methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). This large list was included, in part, to create opportunities for firms and governments to optimize their mitigation efforts across different pollutants. Indeed, depending on the region, mitigation of these different pollutants varies enormously in cost. [Note from Authors: cross-chapter reference to be added]

In addition to the UNFCCC/Kyoto gases, other short-lived substances have come under scrutiny. Those include tropospheric ozone (originating from air pollutant emissions of nitrogen oxides and various forms of reduced carbon) and aerosols (primary such as black carbon and organic carbon and secondary such as sulphates) contribute to climate forcing (see Chapter 8, Section 8.2.2). Although the impact of these short-lived aerosols is more region-specific, studies such as in Figure 1.3 have estimated global average effects of these different sources (Unger et al., 2010). In the case of aerosols, their contribution to climate change is currently negative, i.e. they cool the atmosphere. Since emission reduction technologies may simultaneously affect emission rates of direct greenhouse gases and other substances, for optimal radiative forcing reduction policies the integrated total effect should be estimated. 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. 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 feasible to reach near-term temperature goals (Ramanathan and Xu, 2010).

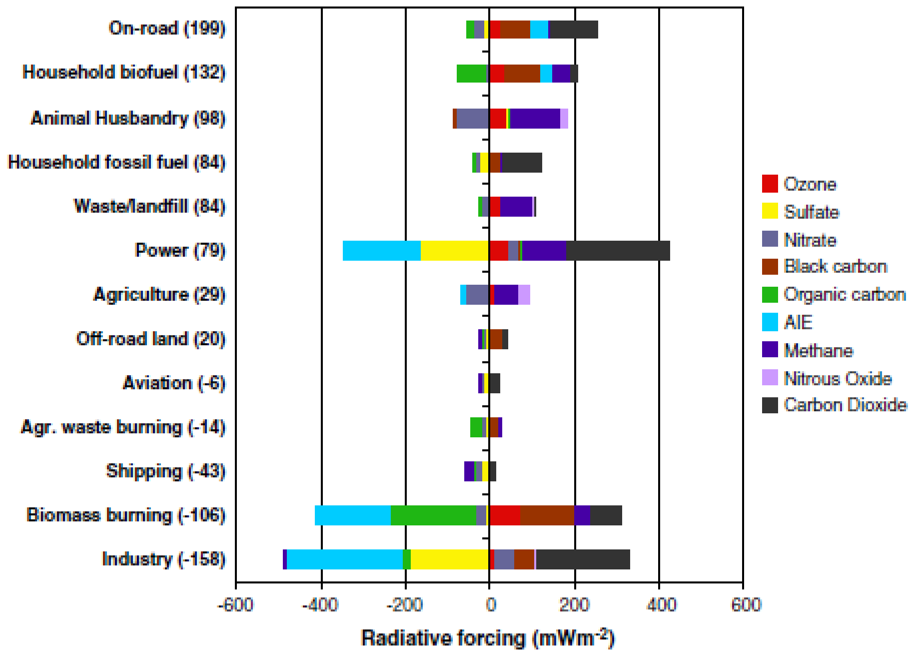

Figure 1.3: Radiative forcing due to perpetual constant year 2000 emissions grouped by sector at 2020 showing the contribution from each substance. The net sum of total radiative forcing (RF) is indicated by the title of each bar. A positive RF means that removal will result in climate cooling and vice versa. Source: (Unger et al., 2010).

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."

Other sections of the UNFCCC also elaborate on the treaty's goals, such as Article 3 (clause 3): "Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost".

These goals build on earlier diplomacy such as the Noordwijk Declaration adopted in November, 1989 (Noordwijk Declaration on Atmospheric Pollution and Climate Change (1989). Interpreting the UNFCCC goals is purposely 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—a point made in chapter 1 of AR4 and which remains robust today. The second part of Article 2 is laden with conditions whose interpretation is even less amenable to scientific analysis. Chapter 1 of AR4/WG3 described that the choice of stabilization level is balancing the risks of climate change against the risk of response measure. However, since the publication of AR4 a series of high-level political events have sought to create clarity about what Article 2 means in practice. In the G8 Summit held in Heiligendamm in June 2007, heads of government or state agreed to explore halving global emissions by 2050, though the base year was unclear. The Bali Action Plan, adopted at COP 13 held in Bali, Indonesia, in December 2007, cited particular tables and assessments from Working Group 3 of AR4 (Table SPM5: and Box 13.7) in guiding international negotiations that were supposed to conclude by COP15 (Copenhagen). At the L'Aquila G8 Summit in 2009, five months before COP15, leaders recognized the scientific view that temperature increase should be limited to 2 degrees, and they also agreed to cut their emissions at least 80% by 2050. At COP 15 in Copenhagen, delegates "took note" of the Copenhagen Accord which "[recognized] the scientific view that the increase in global temperature should be below 2 degree Celsius." In more recent COP meetings, additional goals such as limiting warming to 1^{o} or 1.5^{o} have also been discussed. However, the scientific foundation for establishing these targets—in light of the broad goals articulated for the UNFCC—has remained elusive (Victor, 2011).

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. Weitzman (2009) raised the concern on how to deal with low probability but high impact catastrophe. Facing with the increasing possibilities of abrupt or catastrophic damages, small but growing number of literatures on geo-engineering (direct artificial interference with the climate system) are emerging from various footings as well as from various aspects (Barrett, 2008; Schneider, 2008; The Royal Society, 2009).

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 policies makes it harder to identify the right framework for evaluating the costs and effectiveness of policies that governments pursue for a variety of reasons, rather than singularly for the purpose of controlling emissions of climate altering gases. The plethora of international institutions working on matters related to climate requires looking 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. Rising awareness of the importance of pollutants beyond fossil fuel CO_2—including short-lived pollutants such as soot—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 stop warming at 2 degrees Celsius means that analysts have had to devise a larger number of alternative goals.

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 focus, especially, on setting 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 in the energy system, such as through greater use of renewable technologies (e.g., biofuels and wind) and improvements in energy efficiency. While mitigation of CO_2 emissions from fossil fuels has been limited, in many countries around the world there have been substantial efforts to limit other warming pollutants such as soot and methane—in part because these other pollutants are also linked to many local environmental ills and are also easier for nations to justify on their own (UNEP, 2011; Shindell et al., 2012).

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.[1] 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.)

These gases vary in their radiative effects and in their atmospheric lifetimes, and thus the IPCC has long used global warming potentials (GWPs) to convert these gases with different properties into common units.[2] As shown in Figure 1.4, since 1970 these emissions have risen sharply, and in the period since AR4 (after 2004) that pattern is little changed except for the sustained accelerated annual growth rate of CO_2 emissions from fossil fuel combustion that started in 2002 and a temporarily levelling off in 2008 linked to high fuel prices and the economic crisis that started in North America (see section 1.3.2 for more recent trends). Emissions related to fossil-fuels dominate the global trend in total greenhouse-gas emissions. Between 1970 and 2008, global anthropogenic CO_2 emissions increased by about 80%, CH_4 and N_2O by about 45% and 40% respectively and the collection of industrial fluorinated gases (SF_6, PFCs, HFCs, CFCs, and HCFCs) by about 650%. Total emissions of all greenhouse gases - weighted by their global warming potential (GWP) with 100 year time horizon - increased by about 75% since 1970 (Figure 1.4).

Looking at the total source of warming gases (Figure 1.4, right panel), 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 were CO_2 from biomass burning (11%, mostly forest and peat fires and post-burn decay in non-Annex I countries), and CO_2 from cement production (3%, of which half originated in China).

[1] The EDGAR 4.2 FT2008 database (Olivier and Janssens-Maenhout, 2011) contains global GHG emission trends categorized by countries and by detailed source sectors for the period 1970–2008. For global CO2 emissions, Boden et al. (2011) report emissions from fossil fuel use and cement production by country and by main fuel type for 1751-2008 and IEA (2011c)(2011c) reports emissions from fossil fuel use by country and by sector for the period 1960/1971-2009. All three databases show similar temporal trends of CO2 emissions

[2] [later add cite to ipcc wg1]

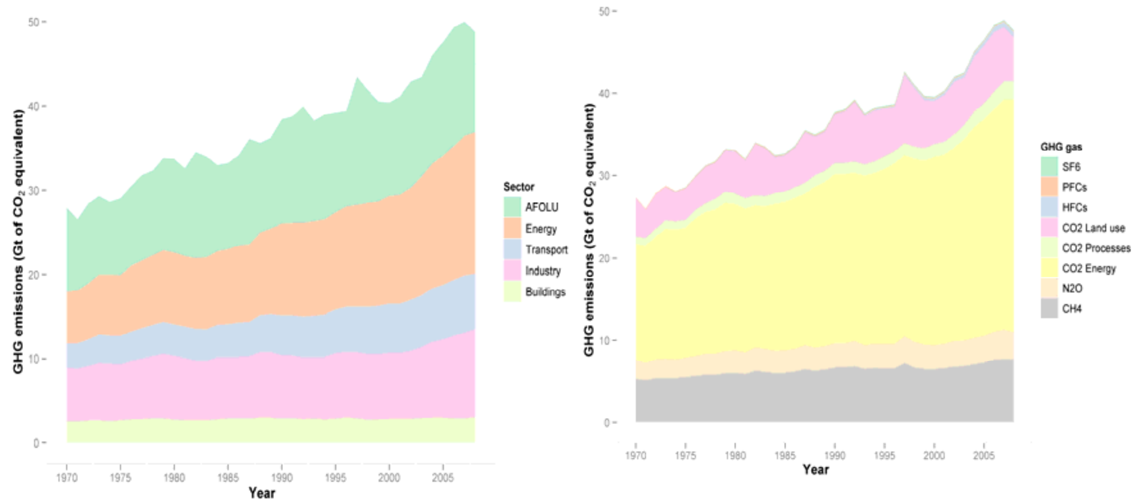

Figure 1.4: Long-term trend in global greenhouse gas emissions 1970-2009 by economic sector (left) and gas (right). Source: (European Commission, Joint Research Centre (JRC) and Netherlands Environmental Assessment Agency (PBL), 2011).

Notes: AFOLU: Agriculture, Forestry and Other Land Use; SF_6: Sulfur hexafluoride; PFCs: Perfluorocarbons; HFCs: Hydrofluorocarbons; N_2O: Nitrous Oxide; CH_4: Methane

The sources of these increases are varied. Since 1970, total CH_4 emissions have risen by about 45% from 1970 (15% from 1990)—mainly to higher emissions from livestock (40% since 1970 and 10% since 1990), oil and gas production and transmission (120% since 1970 and 35% since 1990), and landfills and wastewater (together an increase of 90%, with 20% since 1990). Offsetting these rises has been a 20% decrease in CH_4 from rice cultivation (5% since 1990). Emissions of N_2O have risen by about 40% since 1970 (8% since 1990), mainly due to large increases in agricultural—N_2O from synthetic fertilisers has risen 190% and there has been a 50% increase in emissions from grazing livestock. By contrast, there has been a 60% decrease resulting from N_2O abatement in specific industrial processes. In 2008, total emissions from HFCs, PFCs and SF_6, although currently only contributing a few percent to total global climate emissions, were threefold the fluorinated gas emissions in 1990, mainly due to replacement of ODS gases by HFCs and growing use of fluorinated gases for new industrial activities such as semiconductor manufacture.

Most of the total rise in emissions over the last four decades has come from fossil fuel CO_2, where emissions have risen 40% since 1990. About 2% of that rise has been in the highly industrialized “Annex I” countries and 87% in developing “non-Annex I” countries. This broad pattern is analysed in more detail in Figure 1.5, which shows the same data presented in Figure 1.4 but allocated among major world regions. Total GHG emissions from the newly industrialised countries are a factor of four higher and from the other developing countries a factor of two higher in than four decades ago. Since 1990, total emissions of these regions increased by about 100% and 30%, respectively. Emissions from OECD North America are about one third higher, whereas total GHG emissions from OECD Europe and OECD Pacific have not changed much. Emissions from the Economies-In-transition (EIT) declined in the 1990s and have since levelled. Emissions from international transport doubled compared to 1970.

Following the breakdown in sectors discussed in this report (Chapters 6 to 12), Figure 1.6 looks at global emissions by sector. Emissions from the energy system (mainly electricity) and from transportation dominate the global trends. The energy system has nearly tripled since 1970, and transport has doubled. Since 1990 CO_2 emissions from electricity and heat production increased by 27% for highly industrialized (so-called “Annex II” countries); in other countries the rise has been 64%. Over the same period, CO_2 emissions from road transport increased by 29% in Annex II countries and 61% in the other countries. In 2008 these two sectors together accounted for about 60% of global total CO_2 emissions from fuel combustion.

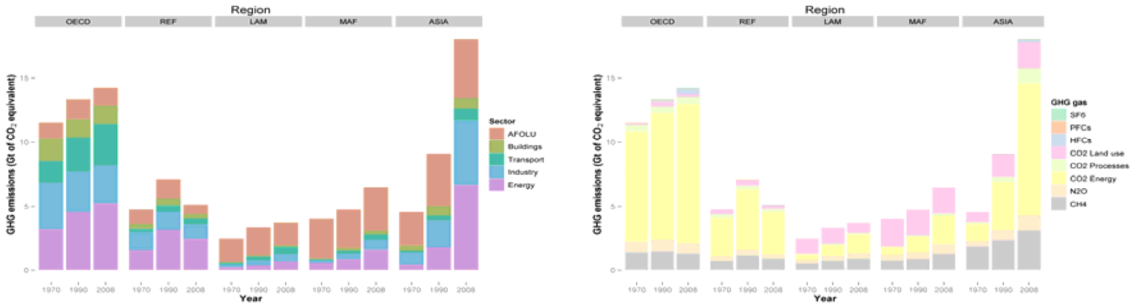

Figure 1.5: Long-term trend in regional greenhouse gas emissions 1970-2008 by economic sector (left) and gas (right). Source: (European Commission, Joint Research Centre (JRC) and Netherlands Environmental Assessment Agency (PBL), 2011)

A factor analysis can reveal the forces that drive these changes in emissions. Here we focus on CO_2 because it plays the largest role in total emissions. Figure 1.6 shows the underlying driving forces at the global level: population (P), GDP (G), total primary energy supply (TPES), and the carbon intensity of the energy system (C). Total emissions are the sum of these individual forces—also known as the "Kaya Identity" (Kaya, 1990). Dotted lines on Figure 1.6 show important ratios of those underlying forces, such as TPES/G, C/E and G/P. This approach was used by Raupach et al. (2007) to study global and regional trends for the period 1980-2004, and Figure 1.6 updates that analysis. It reveals an enhanced global annual growth after 2004 of global income (global total GDP), primary energy consumption and CO_2 emissions, which level off in 2009 when the global recession due to the credit crunch started that affected most countries. Within these broad global patterns, groups of countries and individual countries vary. Within broad groupings of countries—industrialized and emerging—patterns are broadly similar. One exception, however, is the ratio of CO_2 emissions to primary energy (CO_2/TPES)—a measure of the "carbonization" of the energy system—which has been increasing slowly in emerging economies, on average, due to the rising importance of coal. 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 renewables. Although over the future new technologies might allow for radically lower emissions, over this four decade history the most important driver of emissions is economic growth. In highly industrialized countries the economy has grown steadily with some interruptions in the early 1990s and from 2008-2010; in the last few years while in emerging economies have grown much more rapidly.

Since 2005 the annual change in global intensities of TPES/GDP and CO_2/GDP decreased to about 2%, about twice as much as in the 5 years before. Regionally, annual TPES/GDP change since 2005 was -2.1% for Annex I countries (down from -1.5%), -2.7% for the emerging economies (down from -1.5%) and -1.4% for other developing countries (down from -0.4%). However, national or regional differences in these three groups can be large, such as for economies that underwent transition from Soviet-style central planning (the so-called economies in transition, or "EIT" countries) and specific emerging economies. Slowly the CO_2/TPES ratio of these regions is converging—ultimately to the same level.

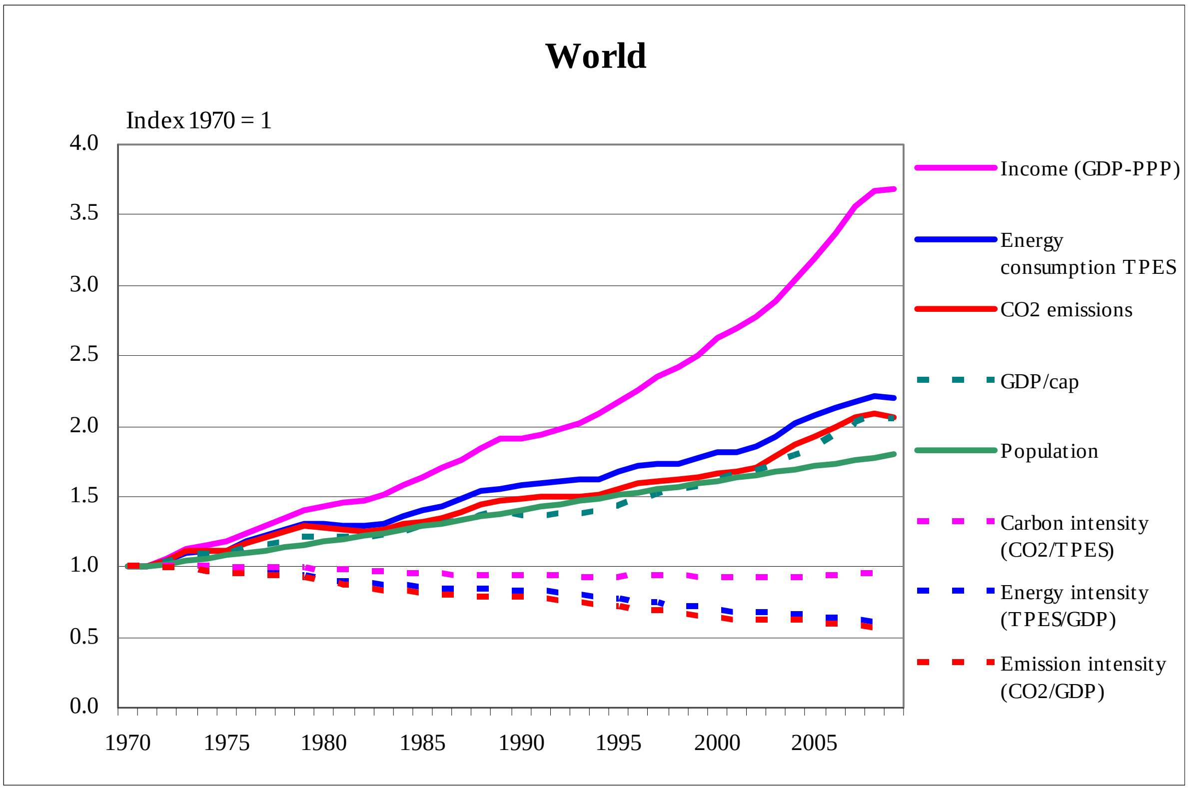

Figure 1.6: Intensities of energy use and CO_2 emissions, 1970-2009: world. Source: (2011c)(2011c)(IEA, 2011c).

1.3.2 Perspectives on mitigation

Looking to the future, it is important to be mindful that the energy system—the main source of CO_2 emissions—is slow to change, even in the face of concerted policy efforts. 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). But future CO_2 emission reduction in the power generation and transport sectors will require considerable structural changes to achieve a shift in the source energy mix that cannot be realised overnight. Renewable energy's share of the global energy supply has increased from 7% by 2004 to over 8% by 2009 and 2010 (excluding traditional biofuels such as fuelwood and charcoal). The share of nuclear power, the other non-fossil energy source, remained constant at about 6%, for many years, with nuclear capacity increasing in line with increasing global energy consumption. However, since 2005 the growth in nuclear capacity has slowed and as a consequence the nuclear share has declined by a half per cent. Taken together nuclear and renewable energy sources—the two largest sources of zero emission electricity—have led to a decline in overall share of fossil fuels from 88% in 1990 to about 86%, the lowest in decades.

Because energy systems are slow to change and transformation of these systems could be costly (and highly beneficial), 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 four different perspectives on the sources and possible mitigation obligations for world emissions—illustrated on four panels in Figure 1.7.

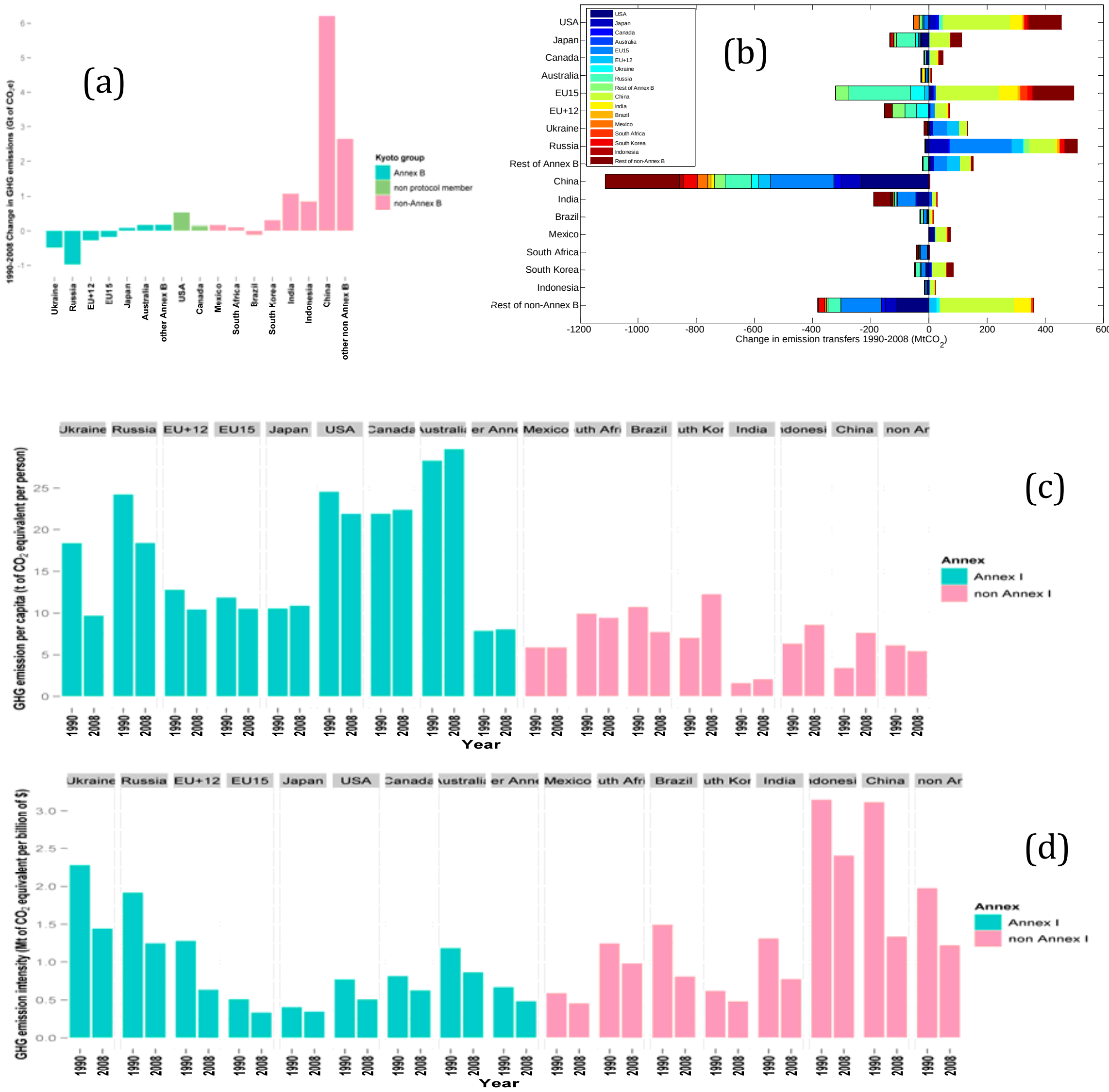

Figure 1.7: Four Perspectives on Climate Mitigation**.** Panel A: trends in greenhouse gas emissions of some Kyoto Protocol countries, divided into Annex B (countries with quantified emission targets, dark green), countries that were eligible for Annex B but are not members (Canada and the U.S., light green) and non-Annex B countries (red). The "EU+12" denotes the full 27 members of the EU while the EU15 is the core group of countries that were EU members at the time Kyoto was crafted. Blue bars show non-Annex I countries. Source: Adapted from (Olivier et al., 2011). Panel B: net transfers of emissions that are embodied in traded goods. Source: (Peters et al., 2011). Panel C: Emissions per-capita in 1990 and 2008 for major countries and regions that are members of Annex I (green) and not members of Annex I (red). Source: (European Commission, Joint Research Centre (JRC) and Netherlands Environmental Assessment Agency (PBL), 2011; United Nations Department of Economic and Social Affairs, Population Division, 2011). Panel D: Emission intensity (emissions per unit economic output) for major countries and regions that are members of Annex I (green) and not members of Annex I (red). Source: (European Commission, Joint Research Centre (JRC) and Netherlands Environmental Assessment Agency (PBL), 2011; World Bank, 2012)

One perspective (upper left panel) 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 an 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.) With an estimated average emission reduction of 16% for 2008-2012, they are certain to exceed their 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). Emissions from Japan probably won't meet the 6% cut that Japan adopted under the Kyoto agreement, but when CDM credits are included in the analysis Japan may be in compliance. The trends on this panel reflect many distinct underlying forces. The big decline in Ukraine and Russia, for example, 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 panel, which is that all countries are likely to comply with the Kyoto treaty. One interpretation is that treaties such as Kyoto have had big 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 treaty 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 strict 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)).

A second perspective concerns trade. So far, all of the statistics presented in this chapter have been organized by nation and region. Emissions are tabulated according to the country (or region) where the emissions occur. In reality, of course, some emissions are "embodied" in products that are exported. 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. The upper right panel of Figure 1.7 shows one method (reported in (Peters et al., 2011) for estimating the volumes of emissions that are embodied in trade. One implication of this perspective is the need for climate mitigation to engage more centrally with the reality that large (and growing) emissions are embodied in trade and, most likely, the need for integration of climate and trade rules.

A third perspective looks not at treaties but at the per-capita emissions, shown in the middle panel of Figure 1.7 over time for several important countries and groupings. This perspective draws attention to fundamental differences in the stages of development of countries and the sizes of populations. It suggests that emission obligations—and perhaps even emission rights in a global emission trading scheme---be allocated along lines of population. Equally interesting on this plot are the large differences within categories of countries—such as within Annex I—and among the least developed countries. 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 its economic peers.

A fourth perspective is the efficiency of the national economy. This perspective draws attention to the emission intensity of economies, commonly measured as the ratio of emission to unit economic output (CO_2-eq/GDP), shown in the bottom panel of Figure 1.7. Typically, economies at an earlier stage of development rely heavily on extractive industries and primary processing using energy intensive methods. 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 stage of economic development and should reward economies that make a rapid transition to low intensity.

Still other interpretations are possible as well, and the exact interpretation of what explains these interpretations has large implications for policy and for expectations about likely future emissions and emission obligations adopted by countries.

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. The EMF 22 international scenarios study (Clarke et al. (2009)) is the most recent study and engaged ten leading integrated assessment models; Figure 1.8 shows the base case emissions from these models out to year 2100, with increases from 2000 levels of 3 to 6 times. According to the study, if nations were to set the strict target as 450 ppmCO_2e (corresponding with the 2°C goal, assuming IPCC's most likely climate sensitivity[3] of 3°C) none of the ten models found the target achievable. Even if all countries were to participate and if modest overshooting of the 450 ppm goal were allowed, only a small majority of the model scenarios found the target achievable. Most of those scenarios were based on emission controls that envisioned a 60% reduction in CO_2 emissions below 2000 levels by 2050—a Herculean task. Figure 1.8 shows BAU CO_2 emissions of EMF comparison study.

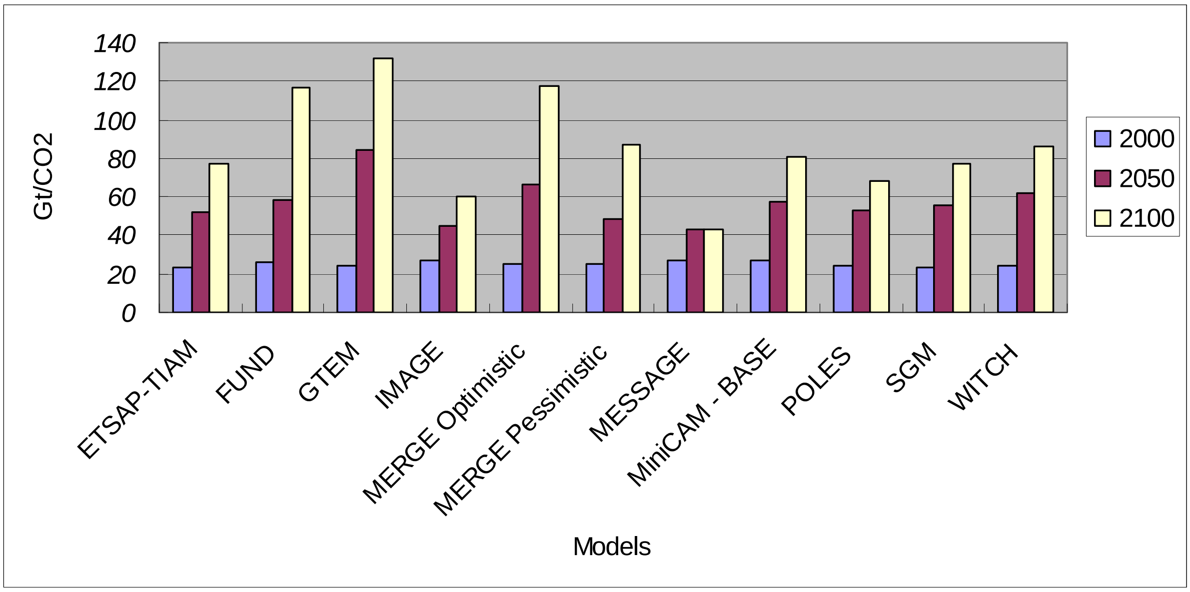

Figure 1.8: Fossil & Industrial CO_2 Emissions by various models (Reference Case) Units $GtCO_2$/yr. Source:http://emf.stanford.edu/events/emf_briefing_on_climate_policy_scenarios_us_domestic_and_international_policy_architectures. [Note from Authors: This chart will be updated or perhaps replaced with chart showing mitigation gaps under different scenarios]

According to AR4, if we are to limit warming to about 2 degrees, governments have to set goals such as cutting global CO_2 emissions at least in half by 2050 relative to 2000. This corresponds to the outcomes of the EMF 22 study mentioned above. However, BAU projections such as in Figure 1.8 are

[3] the global average surface warming following a doubling of carbon dioxide concentrations

wildly at odds with those ambitions and global emissions continue to increase. Mindful of this gap, most governments made pledges at the Copenhagen conference to control their emissions. A variety of studies has probed whether those pledges are sufficient to put the planet on track to meet the 2 degree target. 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. And according to Yamaguchi et al. (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 1.1tCO_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, meeting goals such as limiting warming to 1 degree or 1.5 degrees would require even more challenging.

Another point to consider is uncertainty, such as in climate sensitivity. According to Meinshausen (2006), if we successfully stabilize concentration at 450 ppm CO_2e, probability of exceeding 2 degrees above pre-industrialization is between 26-78% (mean 54%). Put differently, even at the stabilization level of 350 ppm CO_2e, the probability of exceeding 2 degrees still exists (between 0-31%).

Since concentrations of warming gases already exceed 350 ppm and are rising unchecked, such studies add to the growing body of scientific research suggesting that stopping warming at 2 degrees will be exceptionally difficult if not impossible. That reality has created new pressures to address climate adaptation as an integral part of climate policy strategy. It also means, for mitigation, efforts to cut emissions must be redoubled

The newest scenarios, used in conjunction with this AR5 report, point to similar findings. For the AR5 process the climate modelling community has published four sets of Representative Concentration Pathways (RCP). This approach aims to identify a set of benchmark emissions scenarios, known as RCP 8.5, 6.0, 4.5 and 2.6. They are named according to their increase in radiative forcing by 2100. Of particular interest among them is the RCP2.6 scenario that roughly corresponds to the 2 degree target and allows for temporary overshoot. (van Vuuren et al., 2011) explore the conditions that would allow this scenario to be achieved, which include: reduction of annual emissions by 4% (of 2000 emissions) per year, full global participation, peaking of global emissions around 2020, mobilization of all technologies such as increased use of renewable energy and nuclear power, use of CCS and increased use of bioenergy, etc. It is uncertain at this stage whether all those conditions could be met. For example, in view of the Decision at COP 17 that "a protocol, a legal instrument or agreed outcome with legal force" applicable to all parties to take effect from 2020—the very year that global emissions would need to peak.

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, and 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. 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 (United Nations, 2012).

All countries, in different ways, seek sustainable development, and each places 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—such endeavors are both essential and highly controversial (e.g., Lomborg (2004); Sachs (2004). 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 (e.g., (Azar, 1998).

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). Investments in adaptation, which vary in their feasibility, can help reduce exposure to climate impacts and may also lessen uncertainty (World Bank, 2010).

Risk management in climate change requires attention to time horizons. Greenhouse gases vary in their residence times and their climatic impact. While the bulk of the climate change problem is due to long-lived carbon dioxide (CO_2), whose net emissions are mainly due to burning of fossil fuels, other substances also play a role (IPCC WG1 chapter on radiative forcing). Some of these substances are short-lived with relatively large impacts on climate, such as black carbon, methane and some industrial gases that are substitutes for ozone-depleting substances (Montzka et al., 2011). While a long-term solution to climate will require limits on all these substances, especially CO_2, management of near-term and transient risks from climate change might focus more heavily on short-lived substances because limiting these might yield a prompt effect on climate (e.g., (Jacobson, 2010; Ramanathan and Xu, 2010; UNEP, 2011). It should be noted that limiting black carbon aerosols might result in opposite effects (i.e., warming the atmosphere) because of possible changes in cloud condensation nuclei (Chen et al., 2010). Uncertainties on the sources and ultimate fate of essentially all greenhouse gases are high; they are particularly high for short-lived substances since their emissions are not well inventoried and their removal from the atmosphere depends on complex chemical and dynamic processes that are particularly not well understood.

Scientific research on risk management has several implications for managing the climate change problem (see generally chapter 2). One is the need to invest in research and assessment that can help reduce uncertainties. In climate 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 systems 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 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 any 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).

To stimulate investment in appropriate technologies at the right time and place, countries will need to 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 and technology transfer have an important role to play as a catalyst to accelerate technology progress at each stage. 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 creating of mechanisms to ensure that private knowledge also diffuses more widely where economically appropriate. In order to achieve the required emissions reductions there is a need to unleash the potential of existing low-carbon technologies, bring new technologies to the market and deploy available technologies to developing countries. Experts agree an international technology diffusion/transfer plays very important role. They also agree that without radical technology innovation deep reductions are not possible by 2050 (IEA, 2010b).

A point of common ground is on the pivotal role of energy efficiency. The business case for energy efficiency is clear and includes: reducing 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 costs. However, energy efficiency faces barriers when it comes to implementation—barriers that can be addressed with policy reforms. 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). There is a need to educate consumers about the financial and environmental benefits of rational energy use and the rebound effect, which will support effective consumer decisions. There are barriers to the deployment of energy-efficient technologies and practices, however [Note from Authors: cross reference to other chapters will be added].

1.4.5 Interactions between mitigation and adaption

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. More countries are rightly focusing on 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 less daunting (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 to contemplate the policy strategies needed for adaptation.

1.5 Roadmap for WG III report

[Note from Authors: 1 page to be drafted later in the process]

1.6 Frequently Asked Questions

[Note from the TSU: FAQ will be presented in boxes throughout the text in subsequent draft]

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 occurs when any activity that results in 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.

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 fraction also comes from other activities like agriculture, industrial processes and municipal waste.

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