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NOVEMBER 2015

PRACTICAL GUIDE TO THE ECONOMICS OF CLIMATE CHANGE

THE PARIS CONFERENCE AND ITS AFTERMATH

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ISBN 978-2-922687-63-7

Legal deposit: 4th quarter 2015
Bibliothèque et Archives nationales du Québec
Library and Archives Canada
Printed in Canada

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Practical Guide to the Economics of Climate Change
The Paris Conference and Its Aftermath

Montreal Economic Institute
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November 2015

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HIGHLIGHTS

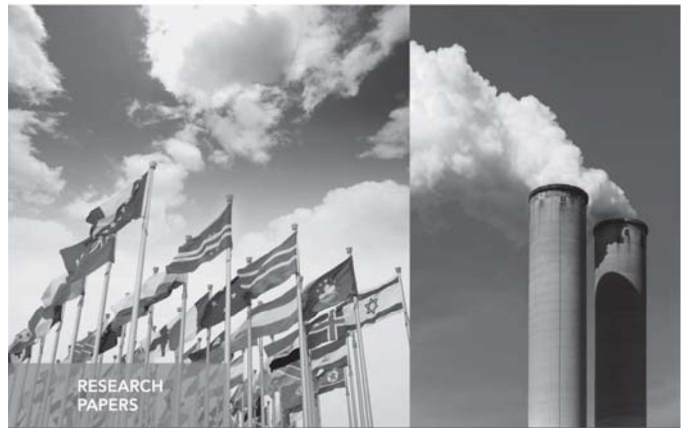
The Paris Conference that opens on November 30, 2015, is drawing plenty of attention to the fight against climate change, an issue that blends political rhetoric, economic logic and climate science. The aim of this *Research Paper* is to make key climate change concepts easier to understand as well as to put the mechanisms discussed here in a Canadian context and to base public policy choices on the most relevant facts. Here, in a nutshell, are the main observations developed in each of the four chapters:

Chapter 1: Climate Change in 20 Questions and Answers

- China is the biggest emitter of greenhouse gas, followed by the United States, the European Union and India.
- Since the first United Nations climate meeting, held in Geneva in 1979, emissions from fossil fuels have risen by 84%.
- Member countries of the Kyoto Protocol have cut emissions by 22.6% compared to 1990, but this has not prevented a 53% rise in global emissions from fossil fuels during the same period.
- Canadian greenhouse gas emissions rose 26% between 1990 and 2012, but their growth has stagnated since 2003.
- Canada generates only 1.59% of global greenhouse gas emissions but has higher per capita emissions than any other country except Australia.
- Various obstacles must be overcome to reach an agreement in Paris, such as the reluctance of some governments to accept binding targets or compensation for developing countries.

Chapter 2: Governmental Measures and Their Effectiveness

- Carbon trading and carbon taxes are two government tools that put a price on carbon.
- These tools enable decision-making to be decentralized, helping meet reduction targets at the lowest possible cost.



- A number of obstacles complicate the proper functioning of these tools, including the difficulty of measuring emissions accurately, the exclusion of some sectors or industries, the impact on business competitiveness, and carbon leakage.
- Fuel taxes are already very high in Canada, generating nearly $22 billion in tax revenue.
- The taxes set on fuels in Canadian provinces amount to a carbon tax, varying from $83 per tonne of greenhouse gases in Alberta to $128 per tonne in Quebec.
- Subsidies for renewable energy and for electric vehicles, or adding ethanol to gasoline, are ineffective in meeting targets for reducing greenhouse gas emissions.
- The constraints imposed by governments all have adverse economic impacts in the short term.
- Climate change has both negative and positive effects. Global warming of less than 2°C, as expected between now and the end of the century, will have positive net effects due in particular to higher crop yields.
- The three interrelated principles that can guide sound public policy in fighting climate change are effectiveness, tax neutrality and minimization of economic impacts.

Chapter 3: The Innovations That Are Revolutionizing Our Energy Consumption

- Energy intensity, or the amount of energy use per measured unit of production, fell at an annual pace of 1.25% between 1990 and 2013. China's progress has been spectacular, with energy intensity dropping by half in 20 years.
- New technologies in the last 40 years have provided energy efficiency gains equivalent to 1.337 billion tonnes of oil in 11 countries.
- Saving energy through greater efficiency produces a rebound effect, with the energy saved being put to other uses. Thus, automobile efficiency gains have been offset by higher auto sales and larger vehicles.
- Compared to the United States, the energy efficiency of automobiles is 26% greater in Europe, where gasoline prices are 137% higher on average.
- Energy consumption in industrialized countries has been relatively stable over the past 15 years. According to the International Energy Agency, these countries will not be consuming any more oil in 2020 than they do today.
- Carbon intensity, or the ratio of carbon dioxide emissions per unit of energy used, reaches higher levels in emerging countries than in industrialized countries.
- In the United States, the shale gas revolution resulting from hydraulic fracturing and horizontal drilling has helped lower the use of more-polluting coal.
- Renewable energy capacity skyrocketed between 2004 and 2014. Global installed capacity rose by 671% for solar energy and by 1,147% for wind energy.
- At the end of 2014, 13 large-scale carbon capture and storage facilities were in operation around the world, with a capacity of 26 megatonnes of CO_2 per year.

Chapter 4: Adapting to Climate Change

- Climate change hits poor countries harder, both in terms of mortality rates and of economic losses as a proportion of GDP.
- Between 1970 and 2008, for example, more than 95% of the deaths caused by natural disasters occurred in developing countries.
- The global rate of mortality due to extreme weather events has fallen by 98% since the 1920s, showing that human vulnerability to climate is due mostly to economic conditions.
- Malnutrition, diarrhea and malaria, made more frequent by climate change, are risks associated mainly with poverty.
- The fight against climate change should not lead us to forget other health problems, such as the fact that three billion people are exposed to smoke from solid fuels used for heating and cooking, according to the WHO.
- Access to cheap electricity is therefore a significant means of improving current health conditions, even if this electricity comes from fossil energy.
- Between now and 2085, only 13% of deaths due to famine, malaria and extreme weather events will result from climate change.
- Environmental awareness is linked to wealth, as shown by a United Nations survey showing that, among 16 priorities, climate change ranks dead last, especially in poor countries.

INTRODUCTION

Understanding the Economic Aspects of the Fight against Climate Change

From November 30 to December 11, Paris will be playing host to the 21st United Nations Climate Conference at which a future agreement is to be negotiated, intended to apply to every country as a way of limiting global warming. Following conferences that were widely regarded as failures, and in the absence of a binding successor agreement to the Kyoto Protocol, the Paris meeting is seen as a turning point. Will there, or will there not, be an agreement? What about North-South negotiations? Will the BRIC countries sign on to the agreement? Will binding targets be set?

All international negotiations pose challenges. This case is no exception, especially with the fight against climate change blending political rhetoric, economic logic and climate science. We are economists, not climatologists, and as such we will not enter into the current scientific debate on climate change. Our premise is that of the great majority of scientists, who hold the view that global warming since the pre-industrial era is caused mostly by human activity. We will content ourselves with presenting an overview of the basic ideas used by climatologists in areas more closely related to the economics of climate change.

Our most relevant contribution focuses on the analysis of public policy, market dynamics, and the choices that lie ahead in dealing with the reality of climate change. The aim of this *Research Paper* is threefold. It seeks to:

- use accessible language to present readers with the key notions surrounding political debate and negotiations on the issue of climate change;
- provide an explanation of the mechanisms under discussion as well as current public policies and the trends at work, especially those affecting the Canadian reality more specifically;
- avoid emotional or moralizing approaches so as to understand public policy choices and to base them on the most pertinent facts.

We have aimed to stay away from declarations and good intentions, focusing instead on results. Around the world, various politicians have spoken loudly, but their words are not always matched by deeds. Opinion leaders talk passionately about our moral responsibility, but neglect certain issues of vital importance. Activists exalt the benefits of certain solutions, but are silent about the costs. An economic approach to climate change pays more heed to tangible results and to the various facets of the issue, taking account of benefits as well as costs.

Four chapters provide an understanding of the climate change issue based on a wide variety of documentary sources, with 43 charts and tables. A bibliography will enable readers to continue seeking answers on their own.

Given our ambition of making the issue understandable to the broadest possible public, it seemed essential to us to start with the facts. An unvarnished diagnosis is necessary, especially as regards the global level of greenhouse gas emissions, which keeps rising despite all the international gatherings since 1979. This is the aim of the first chapter, organized in the form of 20 questions and answers concerning the international negotiations leading up to the Paris Conference.

> **"All international negotiations pose challenges. This case is no exception, especially with the fight against climate change blending political rhetoric, economic logic and climate science."**

Even if the conference were to end in failure, with the world's countries failing to settle on or comply with a binding universal agreement that could serve to limit the likelihood of more than 2°C of warming, this would not prevent various governments from adopting policies to fight climate change. The second chapter shows that, although it is not easy to convert some of the less certain results of climate science into public policy, there are many tools available to governments, and some of them are already being put to use. This applies in particular to Quebec's carbon market and British Columbia's carbon tax. Fuel taxes, as we shall see, are already widely used.

In addition to governments, communities and businesses are also involved in worthwhile developments, many of them highly promising. The third chapter outlines the global trends that offer reason to believe an energy transition is already in progress, even if its effects are still marginal. Global emissions continue to rise, but the intensity of emissions is falling, and some promising technologies could become more widespread.

Finally, the issue of adaptation is addressed in the fourth chapter, since adaptation has always been the way humans respond to variations in climate. Even with warming limited to 2°C, there will be transformations that have both negative and positive effects on various population groups. Factors such as economic development and the availability of technologies will be decisive if adaptation is to be successful.

CHAPTER 1

Climate Change in 20 Questions and Answers

A lot of ink has been spilled over the past several years already regarding the Paris Climate Change Conference that will take place from November 30 to December 11, 2015. The results of the negotiations at this conference will have a considerable impact on the world energy picture in the coming decades. This chapter is organized as a series of questions and answers intended as a guide to help understand the different aspects of the process and the major issues that will be front and centre during the conference.

1. What is the United Nations Framework Convention on Climate Change?

The United Nations Framework Convention on Climate Change (UNFCCC) is a treaty that "establishes a global framework for intergovernmental efforts to face the challenge posed by climate change."[1] According to the Framework Convention, governments must collect and make available information on greenhouse gases (GHGs) and on the best policies to adopt in order to cooperate in facilitating adaptation to climate change.

> **"All countries have a role to play in reducing GHGs, but efforts must take into account the economic and technological capabilities of each country."**

The Framework Convention was adopted in 1992 at the Earth Summit in Rio de Janeiro and came into effect in 1994. Progress in implementing it is measured at a Conference of the Parties (COP) where all the member states have met annually since 1995. Today, 195 states plus the European Union are parties to the Framework Convention.

The Paris Conference is the 21st COP of the UNFCCC and the 11th Conference of the parties participating in the Kyoto Protocol (CMP[2]), whence the abbreviation COP21/CMP11.[3]

2. What is the Kyoto Protocol?

The Kyoto Protocol is the first major international climate change agreement. It was adopted in 1997 at COP3 in Kyoto and came into effect in 2005.

The Kyoto Protocol implemented the United Nations Framework Convention's goal of fighting climate change by legally binding 37 industrialized countries and countries in transition to collectively reduce their average GHG emissions over the 2008-2012 period by 5.2% compared to their 1990 levels.[4]

The protocol respects the principle of "common but differentiated responsibility." This principle recognizes that all countries have a role to play in reducing GHGs, but that efforts must take into account the economic and technological capabilities of each country. Reduction targets were set only for industrialized and transition countries, whereas poorer countries just had to report their emissions.[5]

The collective target was 5.2%, but it varied from country to country. For example, members of the European Union had a GHG reduction target of 8% compared to 1990 levels, whereas Iceland could increase its GHG emissions by 10% compared to the same reference year.[6]

Since then, international negotiations have failed to produce another binding agreement, and much hope rests on the conclusion of such an agreement at the Paris Conference.

1. United Nations Framework Convention on Climate Change, La Convention, 2015.

2. The acronym CMP refers to the Conference of the parties serving as the meeting of the parties to the Kyoto Protocol.
3. Paris 2015, What Is COP21/CMP11? 2015.
4. *Ibid.*, Kyoto Protocol, 2015.
5. United Nations, *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, article 10, 1998.
6. *Ibid.*, Annex B.

3. What is meant by "climate change"?

According to the Intergovernmental Panel on Climate Change (IPCC), an organization that was set up in 1988 to analyze questions related to climate change, this term refers to "any change in climate over time, whether due to natural variability or as a result of human activity."[7]

The UNFCCC's definition is stricter and only includes changes linked directly or indirectly to human activity, therefore excluding natural changes to the climate.[8]

Whether or not the natural variability of the climate is included, climate change is measured by the long-term variation in the Earth's average temperature and by variations in precipitation and wind patterns.

Although the media use the terms "climate change" and "global warming" interchangeably, there is a difference, since global warming refers solely to long-term increases in the average temperature of the Earth's surface. The Industrial Revolution is used as a reference period for the measurement of anthropogenic warming (which is to say, warming caused by human beings).

"NASA estimates that the average temperature at the Earth's surface has risen by 0.8°C since 1889, and that the impact of humans on the climate has surpassed natural changes to the climate."

As for the term "climate change," it includes the long-term variability of the Earth's temperature, as well as that of precipitation and winds. The concept is therefore broader, and is the one generally preferred by the scientific community.[9]

4. Which factors are responsible for climate change?

Climate change is in part a natural phenomenon, influenced by solar energy, volcanic eruptions, changes in the Earth's orbit, and oceanographic changes, among other things.

Humans are also responsible for climate change through activities like the combustion of fossil fuels, agriculture, and forestry, which emit GHGs. A greater concentration of GHGs in the atmosphere, by allowing sunlight to penetrate but absorbing a certain portion of the infrared radiation that bounces back from the Earth, contributes to an increase in the temperature at the Earth's surface. The accumulation of GHGs and the corresponding temperature increase are then associated with climate changes like heavier precipitation in certain places.

According to the IPCC, human influence on the climate since 1750 is clear and has contributed to its warming.[10] NASA estimates that the average temperature at the Earth's surface has risen by 0.8°C since 1889, and that the impact of humans on the climate has surpassed natural changes to the climate. These last have made the temperature vary by an interval of -0.2°C to 0.2°C, according to NASA. Human activity, for its part, has contributed to an increase of 0.8°C.[11]

5. Which GHG emissions are caused by human activity, and which sectors emit them?

Figure 1-1 shows the proportions of anthropogenic GHG emissions in Canada in 2013 by type of gas. The global proportions are similar. Note that 78% of the total consists of carbon dioxide (CO_2) emissions. These last come mostly from the combustion of fossil fuels. Methane, the second most significant anthropogenic GHG (15%), essentially comes from oil and natural gas systems, as well as domestic livestock and landfills.[12] Global proportions are similar.[13]

In 2013, 726 million tonnes of carbon dioxide equivalent (TCO_2e) were emitted in Canada. Figure 1-2 shows the proportions of GHG emissions attributed to each economic sector according to the IPCC's classification.

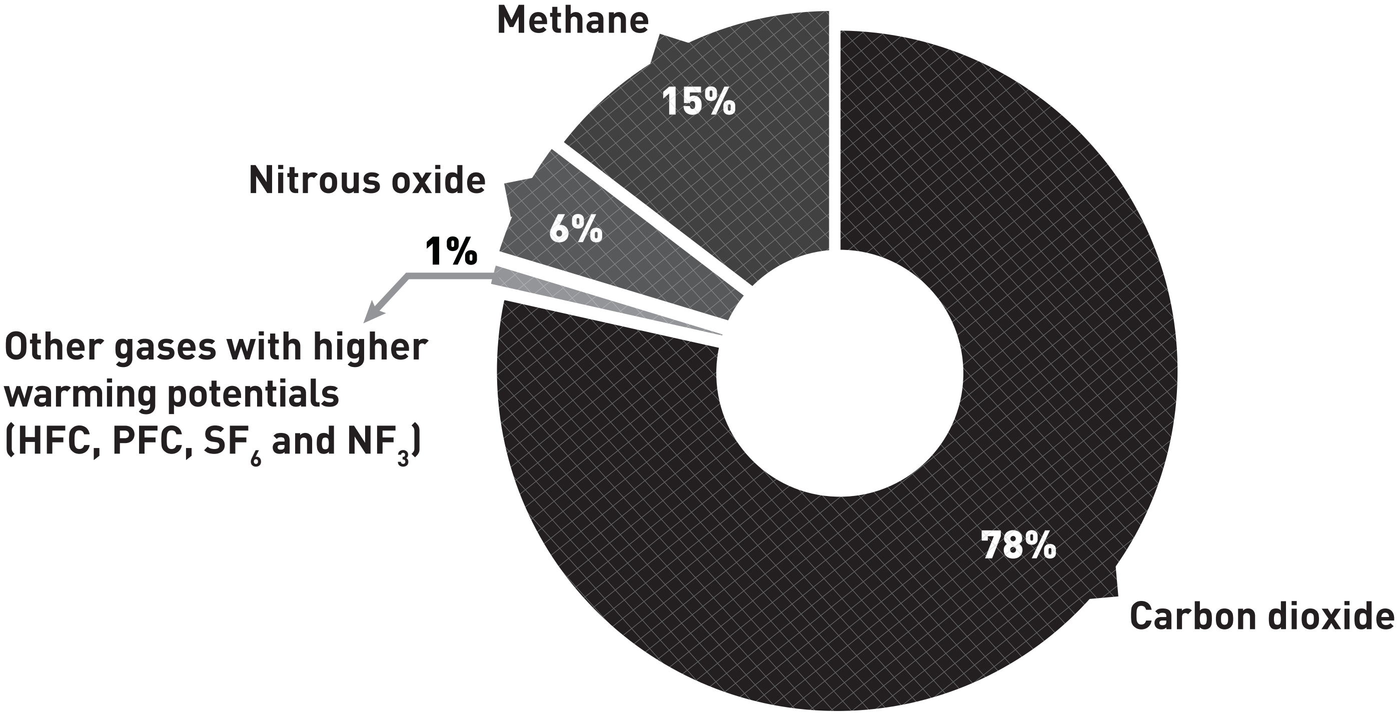
6. What is a carbon footprint?

A carbon footprint is a measure estimating the total contribution of some unit (an activity, a company, a country) to global warming. A carbon footprint not only

7. Intergovernmental Panel on Climate Change (IPCC), *Contribution of Working Group II to the Fourth Assessment Report: Summary for Policymakers*, p. 21.
8. United Nations, *United Nations Framework Convention on Climate Change*, Article 1, 1992.
9. Anthony Leiserowitz *et al.*, *What's in a Name? Global Warming Versus Climate Change*, Yale Project on Climate Change Communication and George Mason University Center for Climate Change Communication, May 2014, p. 6; NASA, What Are Climate and Climate Change? October 26, 2011.
10. Richard B. Alley *et al.*, "Summary for Policymakers," in S. Solomon *et al.* (eds.), *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2007, p. 3.
11. NASA Earth observatory, Is Current Warming Natural?
12. Environment Canada, *National Inventory Report 1990-2013: Greenhouse Gas Sources and Sinks in Canada – Executive Summary*, The Canadian Government's Submission to the UN Framework Convention on Climate Change, 2015, p. 2.
13. United States Environmental Protection Agency, Climate Change Indicators in the United States, Global Greenhouse Gas Emissions, May 2014.

Figure 1-1

GHG emissions in Canada by type of gas, 2013



Source: Environment Canada, *National Inventory Report 1990-2013: Greenhouse Gas Sources and Sinks in Canada – Executive Summary*, The Canadian Government's Submission to the UN Framework Convention on Climate Change, 2015, p. 2.

includes the impact of carbon on the climate, but also the impact of all other GHGs. It is called a carbon footprint because the effect of each GHG is converted into the equivalent in terms of carbon dioxide, the main GHG emitted.

> « Although Canada is not a major emitter compared to China and the United States, it is among the countries with the highest emissions per capita. »

The different greenhouse gases each have a different Global Warming Potential (GWP) calculated in relation to the warming impact of CO_2 over a certain period of time, usually 100 years. Two factors influence the Global Warming Potential of a GHG, namely its energy absorption capacity and the length of time that it remains in the atmosphere. For example, methane (CH_4) has a GWP of 25. This means that each tonne of CH_4 is equivalent to 25 tonnes of CO_2 (see Table 1-1).

7. How are a country's GHGs calculated?

According to the IPCC, "National inventories include greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction."[14] For practical reasons, the IPCC includes only emissions from production.[15]

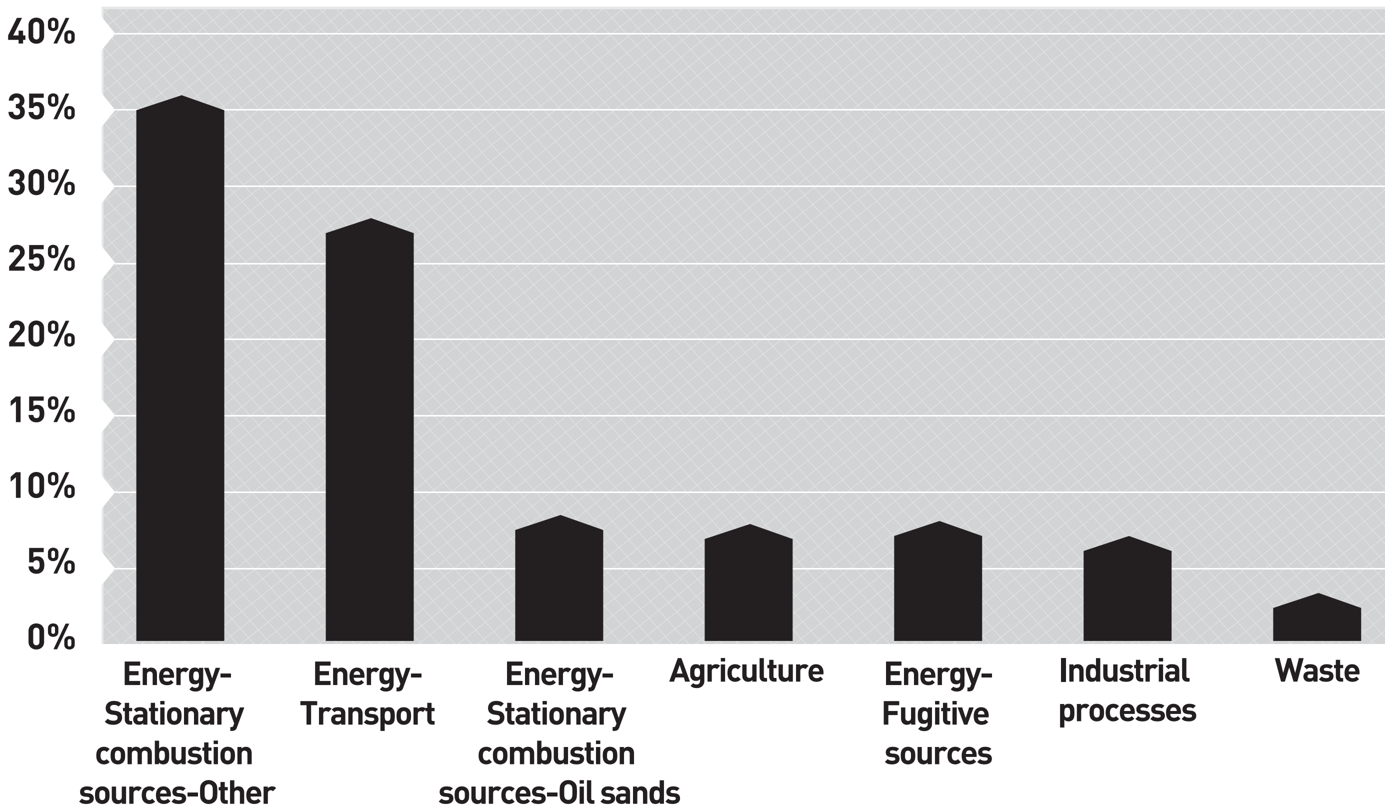
This is the method that was used for the Kyoto Protocol. There is also an approach based on consumption, which includes emissions from the consumption of imported goods.

The method used has considerable repercussions on the emissions calculated. For example, the use of the production-based method allows industrialized countries to improve their emissions records by relocating produc-

14. For road transport, emissions are included where the fuel is sold. IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories – Volume 1: General Guidance and Reporting*, 2006, p. 1.4.
15. Baptiste Boitier, "CO2 emissions production-based accounting vs consumption: Insights from the WIOD databases," Final WIOD Conference: Causes and Consequences of Globalization Groningen, April 2012, p. 2.

Figure 1-2

Proportions of GHG emissions by economic sector in Canada, 2013



Sources: Environnement Canada, "Oil Sands: A Strategic Resource for Canada, North America and the Global Market – GHG Emissions," 2015, p. 1; Environment Canada, *National Inventory Report 1990-2013: Greenhouse Gas Sources and Sinks in Canada – Executive Summary*, The Canadian Government's Submission to the UN Framework Convention on Climate Change, 2015, p. 5.

Table 1-1

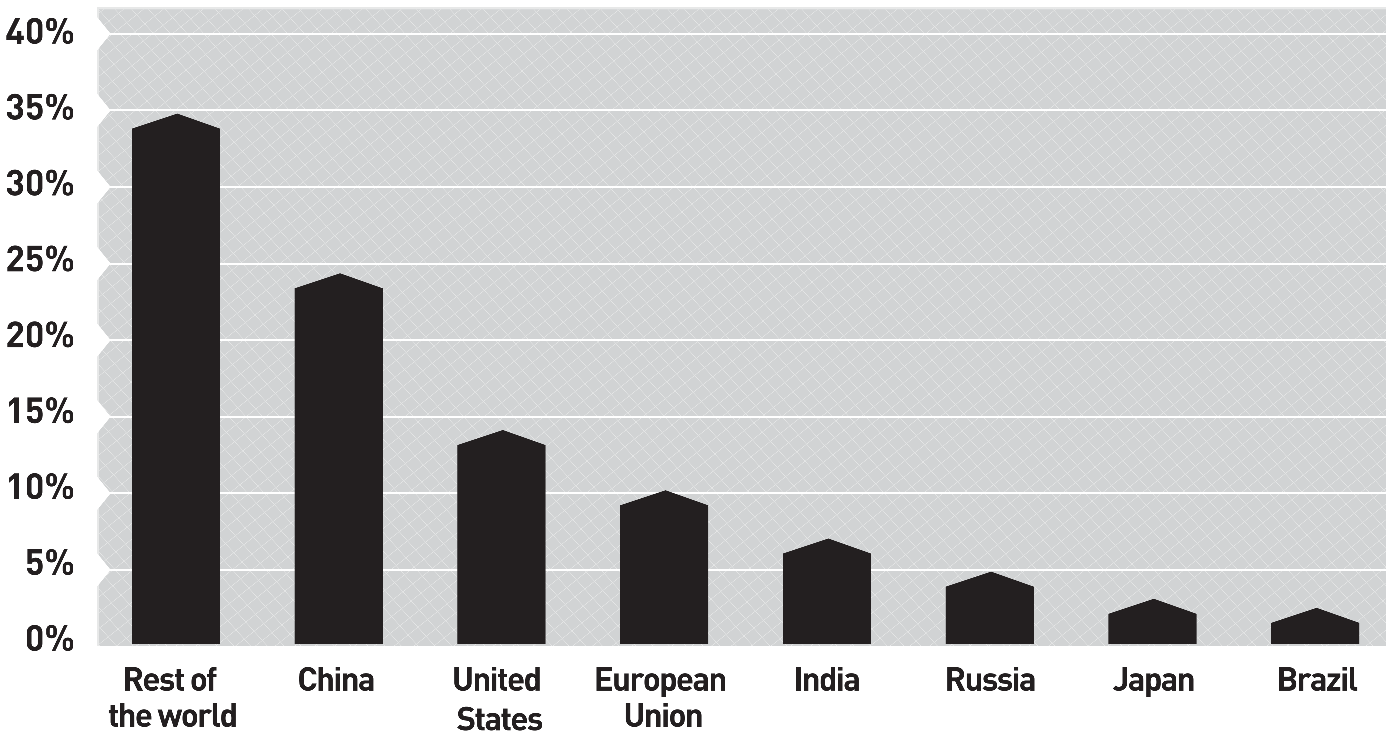
Global Warming Potential for the main GHGs emitted by human activity

GAS	GWP
Carbon dioxide (CO_2)	**1**
Methane (CH_4)	**25**
Nitrous oxide (N_2O)	**298**
Sulfur hexaflouride (SF_6)	**22,800**
Nitrogen trifluoride (NF_3)	**17,200**
Hydrofluorocarbons (HFC)	**from 12 to 14,800**
Perfluorocarbons (PFC)	**from 7,390 to 17,340**

Source: Environnement Canada, Global Warming Potentials, April 17, 2015.

Figure 1-3

Percentage of global GHG emissions, 2012



Source: World Resources Institute, CAIT – Historical Emissions Data (Countries, U.S. States, UNFCCC), Total GHG Emissions Excluding Land-Use Change and Forestry, June 22, 2015.

tion in emerging countries, without reducing their consumption. This "carbon leakage" decreases the effectiveness of local GHG reduction policies.[16]

8. How are global GHG emissions distributed?

The United States, the European Union, Japan, and the BRIC countries (Brazil, Russia, India, and China) are the main emitters of GHGs. Figure 1-3 shows the distribution of GHG emissions by country or region contributing more than 2% of global emissions. Canada, with just 1.59% of global emissions, is included in the "Rest of the world" category.

> **"Quebec is the province that emits the lowest amounts of GHGs per capita, thanks to its extensive production of hydroelectricity."**

9. How does Canada compare with other countries in terms of GHG emissions?

Canadian GHG emissions grew by 26% from 1990 to 2012. However, as shown in Figure 1-4, this growth has stagnated since 2003.

Figures 1-5 and 1-6 demonstrate that although Canada is not a major emitter compared to China and the United States, it is among the countries with the highest emissions per capita, ahead of the United States and the European Union, among others.

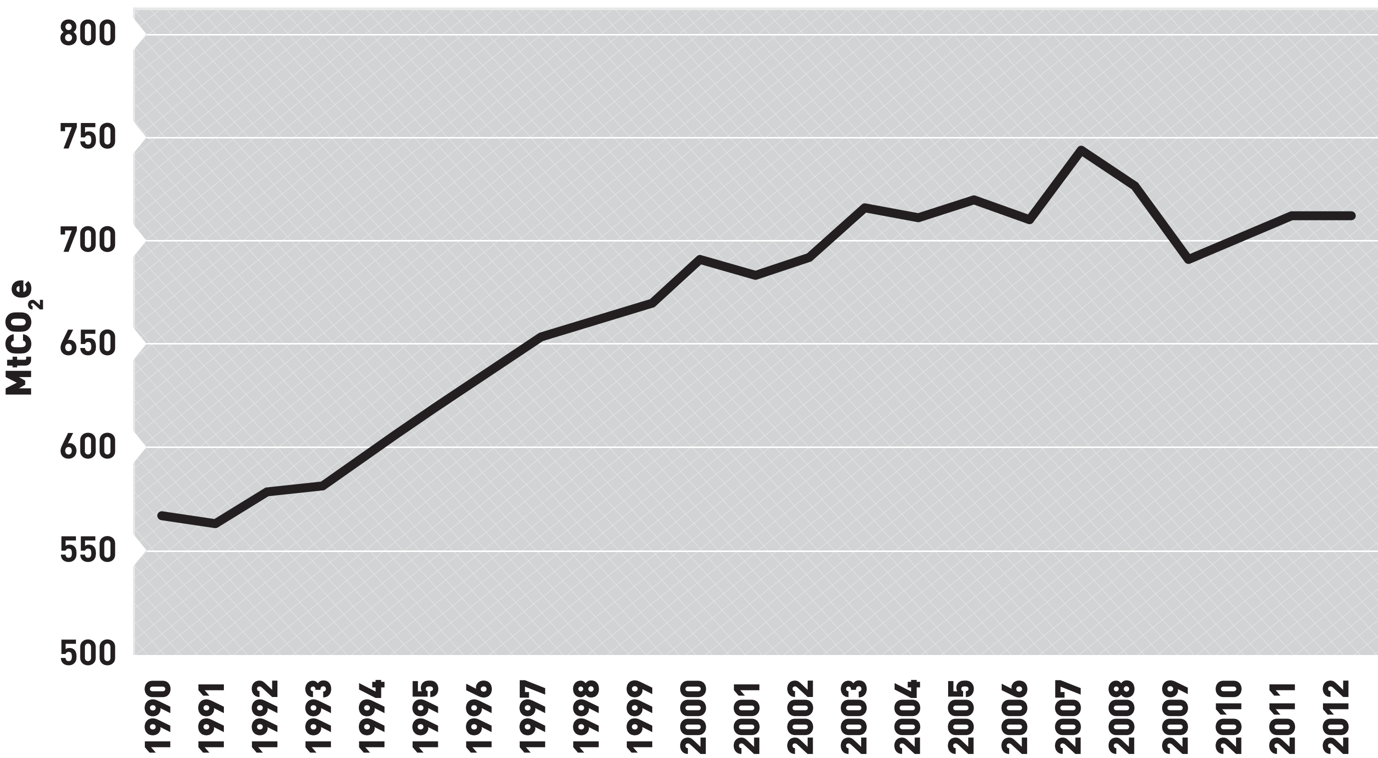
10. How do Canadian provinces fare in terms of GHG emissions per capita?

In 2013, the provinces that emitted the most GHGs per capita were Saskatchewan and Alberta, with 68 and 67 tonnes of CO_2 equivalent respectively. These elevated

16. Glen P. Peters *et al.*, "Growth in emission transfers via international trade from 1990 to 2008," *Proceedings of the National Academy of Sciences*, Vol. 108, No. 21, May 24, 2011, pp. 8903–8908.

Figure 1-4

GHG emissions in Canada in millions of tonnes of CO_2 equivalent, 1990-2012



Source: World Resources Institute, CAIT – Historical Emissions Data (Countries, U.S. States, UNFCCC), Total GHG Emissions Excluding Land-Use Change and Forestry, June 22, 2015.

figures are essentially due to the substantial amount of oil production in these two provinces. Indeed, 76% of oil produced in Canada is produced in Alberta, whereas Saskatchewan, which represents around 3% of the Canadian population, produces 15% of Canadian crude oil.[17] Quebec is the province that emits the lowest amounts of GHGs per capita, at 10 tonnes of CO_2 equivalent, thanks to its extensive production of hydro-electricity (see Figure 1-7).

11. Why do we need to fight against climate change?

In the long term, higher temperatures entail risks of negative consequences for the environment, and so for human beings as well. Global warming could among other things cause extreme climatic events, more severe droughts, floods, and rising sea levels. Such changes could in turn generate negative consequences in terms of food production, water supplies, and human health.

The negative impacts of climate change will be felt most acutely in developing countries, since their ability to adapt is much more limited, on account of their more limited wealth. Moreover, a larger proportion of their economic activity is concentrated in sectors like agriculture that are more sensitive to climate.

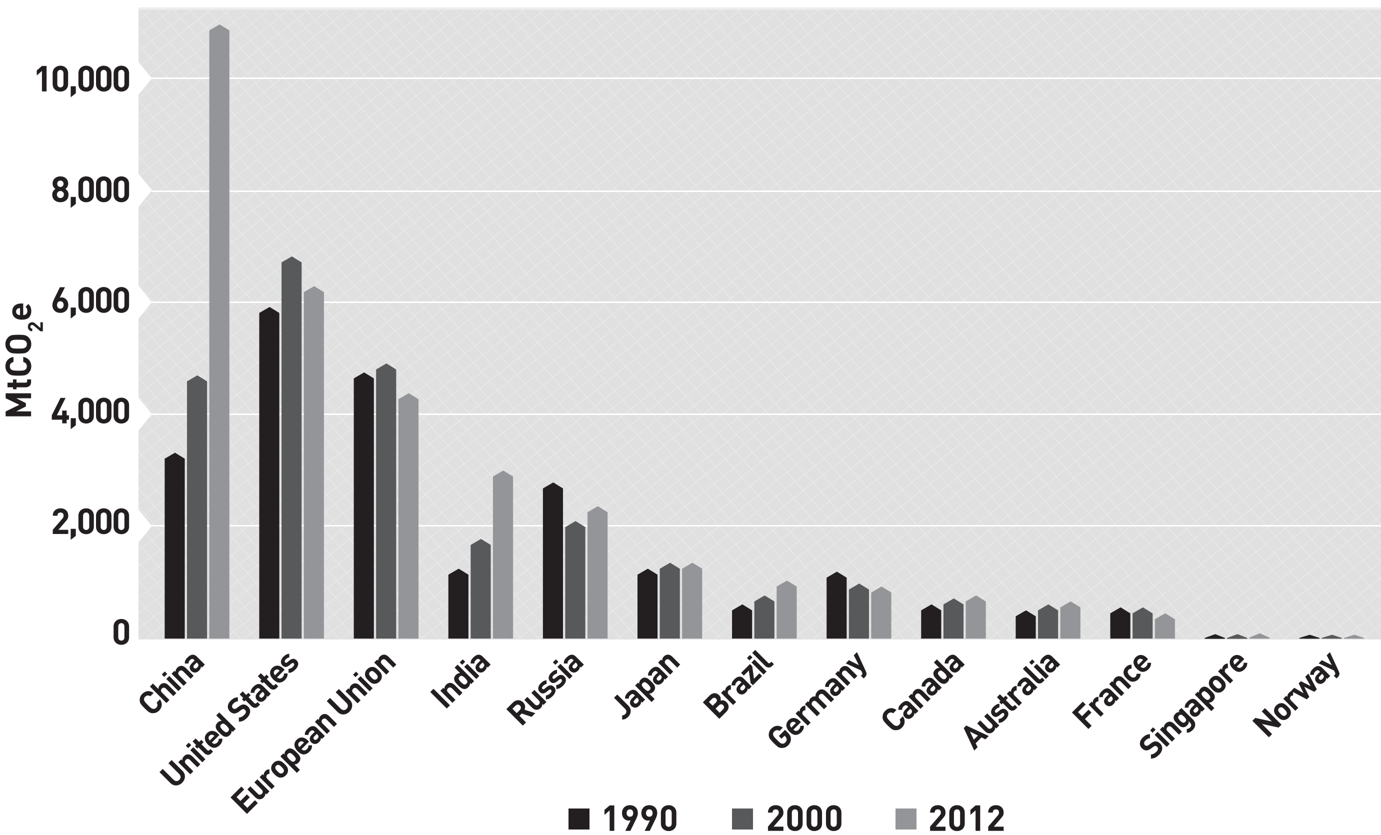
The effects of climate change are not exclusively negative. A higher concentration of CO_2 in the atmosphere reduces the water requirements of plants, thereby allowing for faster growth and increased crop yields. Another benefit is reduced heating costs and cold-related health problems, which entail 17 times more deaths than heat-related health problems.[18]

17. Statistics Canada, CANSIM Table 051-0001: Estimates of population, by age group and sex for July 1, Canada, provinces and territories, 2012; Statistics Canada, CANSIM Table 126-0001: Supply and disposition of crude oil and equivalent, annual (cubic metres), 2012.

18. Antonio Gasparrini *et al.*, "Mortality Risk Attributable to High and Low Ambient Temperature: A Multicountry Observational Study," *The Lancet*, Vol. 386, No. 9991, 2015, pp. 369-375.

Figure 1-5

GHG emissions by country, millions of tonnes of CO_2 equivalent



Source: World Resources Institute, CAIT – Historical Emissions Data (Countries, U.S. States, UNFCCC), Total GHG Emissions Excluding Land-Use Change and Forestry, June 22, 2015.

Certain cost-benefit analyses estimate that global warming on the order of 1°C to 2°C would be beneficial to humanity. In the long term, the negative effects of warming greater than this interval, however, would exceed the benefits.[19]

> **"The negative impacts of climate change will be felt most acutely in developing countries, since their ability to adapt is much more limited, on account of their more limited wealth."**

In order to avoid the potential negative long-term effects of climate change, the UNFCCC member states determined that global warming would have to be limited to 2°C.[20]

12. What is the objective of the Paris Conference?

The goal of the Paris Conference is "to achieve a new international agreement on the climate, applicable to all countries, with the aim of keeping global warming below 2°C."[21]

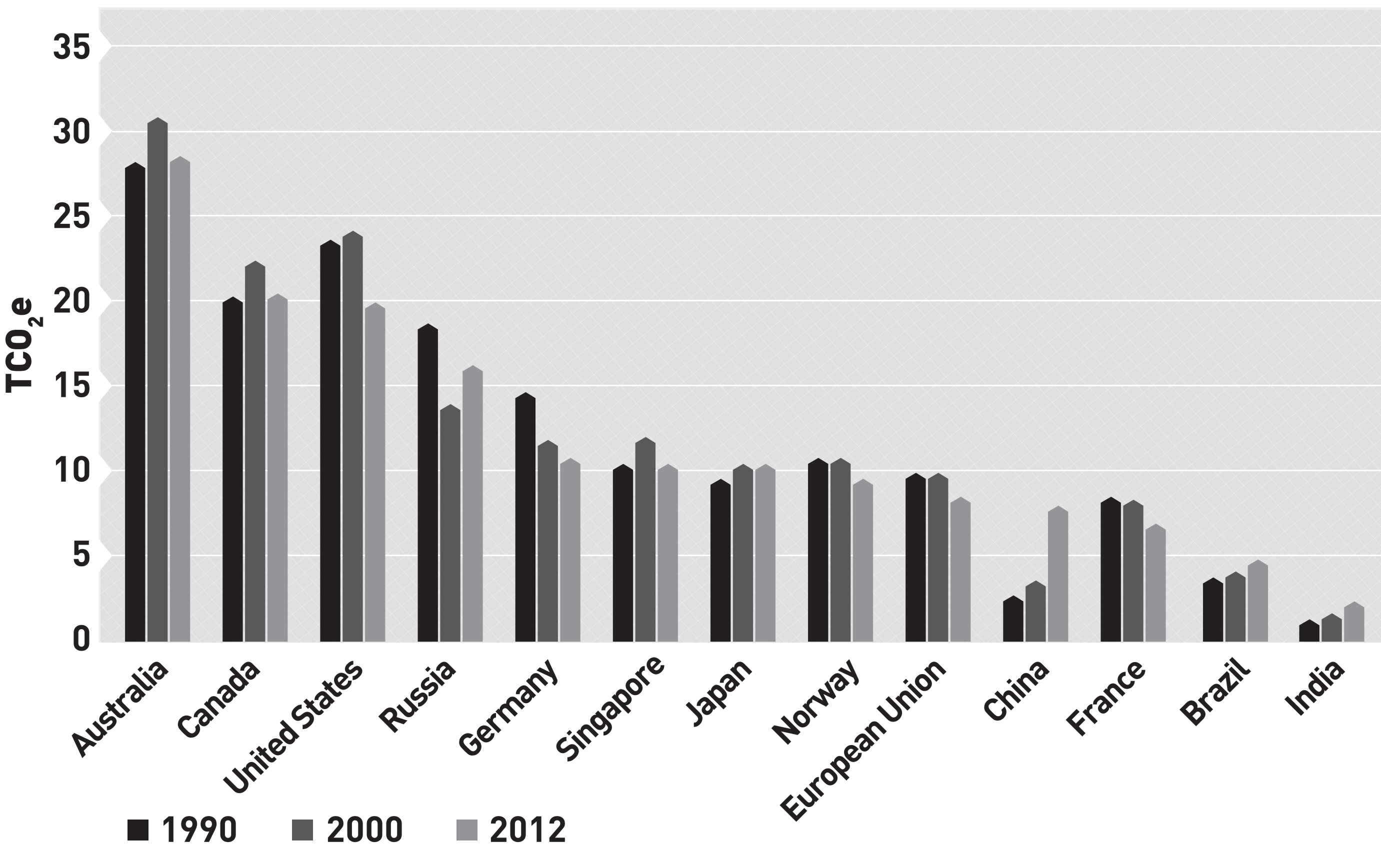
According to existing climate models, the attainment of this objective depends on substantially modifying the composition of the energy used around the world. The International Energy Agency estimates that in 2012, oil,

19. Richard S. J. Tol, "The Economic Effects of Climate Change," *Journal of Economic Perspectives*, Vol. 23, No. 2, 2009, p. 35; Richard S. J. Tol, *Economic Impacts of Climate Change*, Economics Department, University of Sussex, Working Paper Series, No. 75-2015, 2015.

20. Paris 2015, *op. cit.*, footnote 3.
21. *Idem.*

Figure 1-6

GHG emissions per capita, tonnes of CO_2 equivalent



Sources: World Resources Institute, CAIT – Historical Emissions Data (Countries, U.S. States, UNFCCC), Total GHG Emissions Excluding Land-Use Change and Forestry, June 22, 2015; World Bank, Data, Total Population, September 24, 2015.

coal, and natural gas represented nearly 82% of primary energy produced.[22] The global economy will need to have a negative carbon balance by the year 2100 if we want to achieve the 2°C goal, which means that more CO_2 will need to be absorbed by carbon sinks (like the oceans), and removed from the atmosphere using various technologies, than the amount of CO_2 that is emitted.

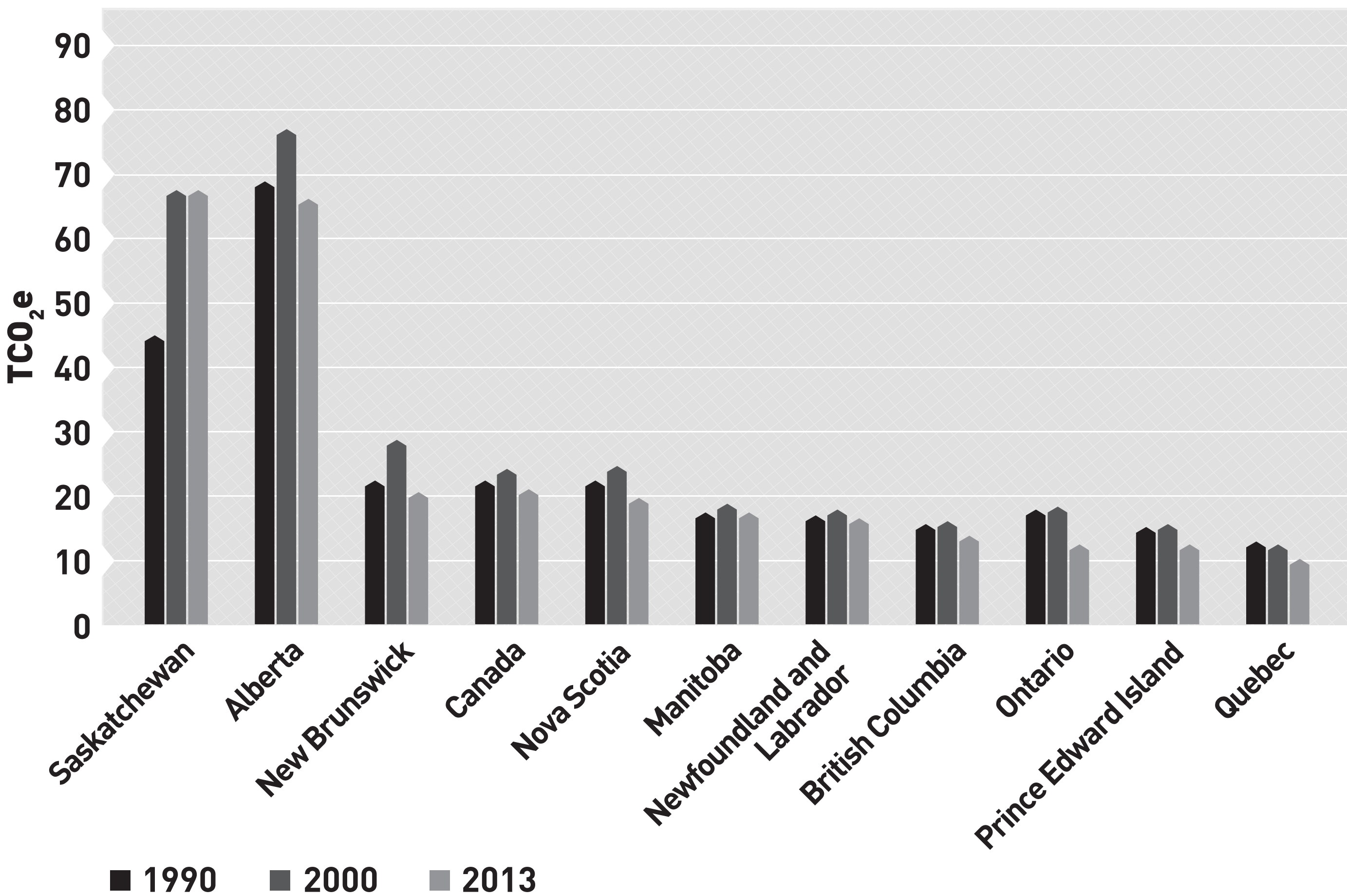
According to the IPCC, the concentration of GHGs in the atmosphere will need to stabilize between 430 and 480 parts per million of CO_2 equivalent by the year 2100.[23] Excluding the other GHGs, this means around 400 parts per million of CO_2.[24] In August 2015, the atmospheric concentration of CO_2 was already close to this limit, at 396.86 parts per million.[25] Figure 1-8 shows the progression of the world's atmospheric CO_2 since 1980, as compiled by the Earth System Research Laboratory.

> **"Certain cost-benefit analyses estimate that global warming on the order of 1°C to 2°C would be beneficial to humanity."**

22. International Energy Agency, *Key World Statistics 2014*, 2014, p. 6.
23. Ottmar Edenhofer *et al.*, "Summary for Policymakers," in Ottmar Edenhofer *et al.* (eds.), *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2014, p. 13.
24. Oceans at MIT, News, 400 ppm CO2? Add Other GHGs, and it's Equivalent to 478 ppm, June 6, 2013.
25. Earth System Research Laboratory, Trends in Atmospheric Carbon Dioxide, Recent Global CO_2, October 9, 2015.

Figure 1-7

GHG emissions per capita, Canadian provinces, tonnes of CO_2 equivalent



Sources: Government of Canada, National and Provincial/Territorial Greenhouse Gas Emission Tables, 1990-2013, August 24, 2015; Statistics Canada, CANSIM Table 051-0001: Estimates of population, by age group and sex for July 1, Canada, provinces and territories, 1990-2013.

13. What reduction in emissions would we need to achieve in order to respect the 2°C target?

On account of the long atmospheric lifetime of CO_2, the level of accumulated CO_2 emissions already in the atmosphere plays an important role in determining the average temperature at the Earth's surface for decades to come.

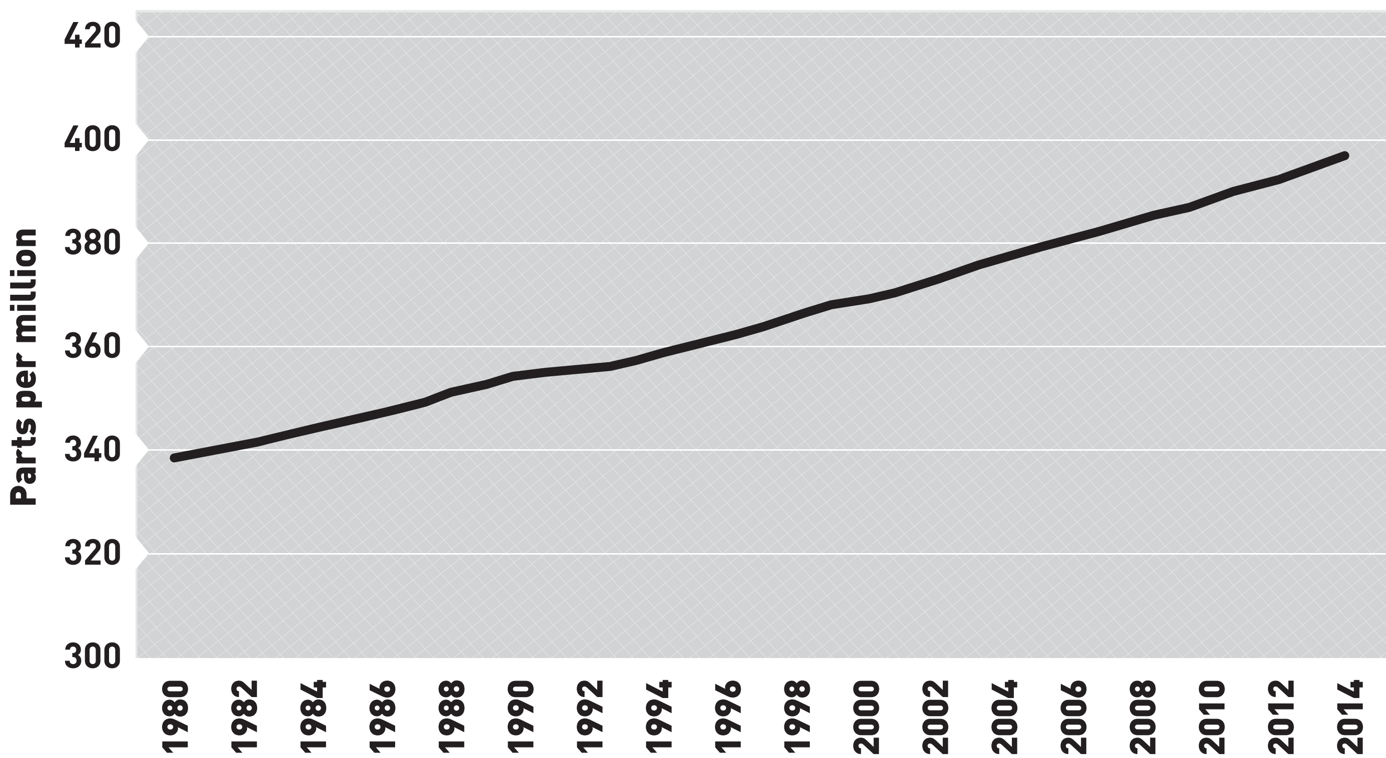
The "carbon budget," or "emissions budget," represents the threshold of CO_2 emissions accumulated since the pre-industrialized period that must not be exceeded between now and 2100 in order to respect a given target temperature. Of the different models used by the IPCC, most estimate that the carbon budget allowing us to respect the 2°C limit is 2,900 billion tonnes of CO_2. In 2011, emissions had already used up around two thirds of the carbon budget.[26]

These models estimate that the cumulative CO_2 emissions remaining if the budget is to be respected for the period from 2012 to 2100 must be limited to between 630 billion and 1,180 billion tonnes of CO_2.[27] Given the current rate of reductions of GHG emissions based on existing policies, the carbon budget could be exhausted by around 2034.[28]

26. United Nations Environment Programme, *The Emissions Gap Report 2014: A UNEP Synthesis Report*, November 2014, p. 2.
27. *Idem.*
28. Price Waterhouse Cooper, IPCC carbon budget to 2100 will be used by 2034 according to PwC analysis, Press release, November 14, 2013.

Figure 1-8

Global atmospheric concentration of CO_2, 1980-2014



Source: Earth System Research Laboratory, Trends in Atmospheric Carbon Dioxide, Globally averaged marine surface annual mean data, October 5, 2015.

It is, however, possible to respect the 2°C limit even while temporarily exceeding the carbon budget in the short run. However, this excess must subsequently be compensated for (sometime around 2065) with a negative global carbon balance. Such a scenario is achievable if anthropogenic GHG emissions are at a certain point more than compensated for by the absorption of carbon associated with reforestation and by the capture and storage of CO_2.

Table 1-2 illustrates the evolution of net emissions through to the end of the 21st century that is required by the carbon budget in order to have a greater than 66% probability of respecting the 2°C limit.

Another method used by the IPCC to illustrate the same goal emphasizes achieving an atmospheric concentration target of 430 to 480 parts per million of CO_2 equivalent by 2100. The different scenarios in which there are no extra efforts on the part of governments to reduce GHG emissions arrive at an atmospheric concentration of 450 parts per million of CO_2 equivalent by 2030, and at concentrations varying from 750 to 1,300 parts per million of CO_2 equivalent by 2100.[29]

Stabilizing the amount of warming at 2°C implies a substantial reduction in anthropogenic GHG emissions between now and 2050. At that time, in addition to significant energy efficiency gains, we will have to get from three to four times more of our energy from renewable sources, from nuclear power, and from biofuels, or from fossil fuels paired with carbon capture and storage.

"Even though the first global climate conference was held over 35 years ago, CO_2 emissions from the consumption of fossil fuels have not stopped increasing since then."

29. Ottmar Edenhofer *et al.*, *op. cit.*, footnote 22, p. 8.

Table 1-2

Net emissions required to respect the 2°C limit with a greater than 66% probability, gigatonnes of CO_2

PERIOD	2015-2025	2025-2050	2050-2075	2075-2100
Net emissions for each period	**370**	**506**	**48**	**-299**

Source: This is a median based on 19 different scenarios. United Nations Environment Programme, *The Emissions Gap Report 2014: A UNEP Synthesis Report*, November 2014, p. 15.

Table 1-3

Maximum annual global emissions and changes compared to emissions in 1990 and 2010 in order to respect the 2°C limit with a greater than 66% probability, gigatonnes of CO_2 equivalent

YEAR	1990	2010	2020	2025	2030	2050	2100
Level ($GtCO_2e$)	**37**	**49**	**52**	**47**	**42**	**22**	**-3**
Change compared to 1990			**+41%**	**+27%**	**+14%**	**-40%**	**-108%**
Change compared to 2010			**+6%**	**-4%**	**-14%**	**-55%**	**-106%**

Source: This is a median based on 18 different scenarios. Authors' calculations. United Nations Environment Programme, *The Emissions Gap Report 2014: A UNEP Synthesis Report*, November 2014, pp. xvi and 16.

Between 2040 and 2070, the energy sector's emissions will have to be reduced by 90% compared to the 2010 level.[30]

Table 1-3 illustrates the GHG reductions required in the 21st century in order to respect the 2°C goal.

14. How have GHG emissions evolved since the first global warming conferences were held?

Even though the first global climate conference was held over 35 years ago, CO_2 emissions from the consumption of fossil fuels have not stopped increasing since then. They rose by 84% from 1980 to 2014. For the 2000-2010 period, they rose twice as fast as they had in any other decade since 1970.[31]

Table 1-4 and Figure 1-9 illustrate the progression of CO_2 emissions from the consumption of fossil fuels.

> **"Non-OECD members were responsible for just 46% of emissions in 1990, compared to a projected share of nearly 70% in 2040."**

15. Have the Kyoto Protocol targets been respected?

According to preliminary figures, global greenhouse gas emissions for countries participating in the Kyoto Protocol were reduced by 22.6% compared to the reference year, 1990.[32] The overall target was substantially

30. *Ibid.*, pp. 12 and 18.
31. BP, Data workbook – Statistical Review 2015, Carbon Dioxide Emissions (from 1965), June 2015.
32. United Nations Framework Convention on Climate Change, "The Kyoto Protocol - A Critical Step Forward: Emissions of Countries with Targets Fell Faster than Expected," February 13, 2015, p. 1.

Table 1-4

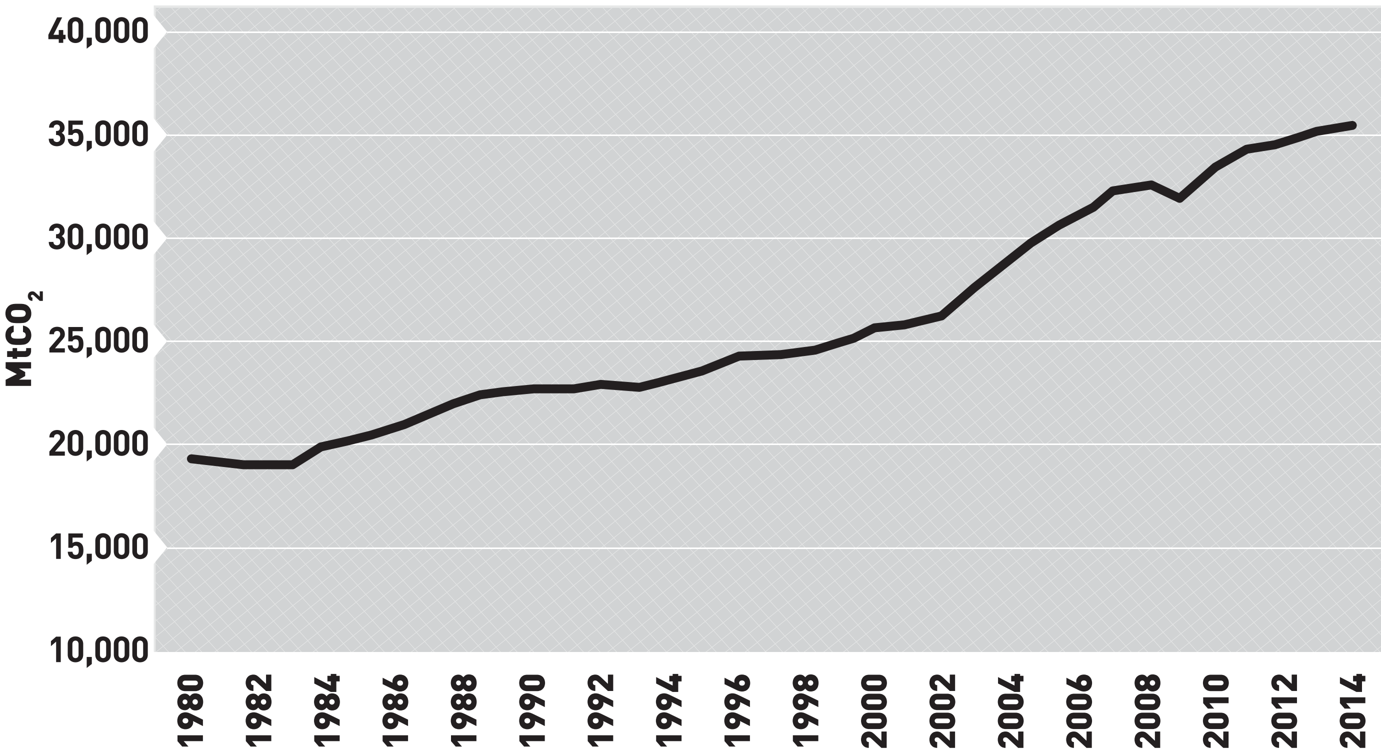
CO_2 emissions from the consumption of fossil fuels

YEAR	UNFCCC	OTHER CONFERENCES AND IMPORTANT EVENTS	CO_2 EMISSIONS FROM THE CONSUMPTION OF FOSSIL FUELS ($MtCO_2$)
1979		**1st global climate conference in Geneva**	**19,517**
1988		**Creation of the IPCC**	**22,154**
1989		**2nd global climate conference in The Hague**	**22,564**
1990		**1st IPCC report**	**22,699**
1992		**Earth Summit in Rio de Janeiro**	**22,863**
1995	**Berlin**	**2nd IPCC report**	**23,564**
1996	**Geneva**		**24,185**
1997	**Kyoto**	**2nd Earth Summit in New York: Earth Summit +5**	**24,423**
1998	**Buenos Aires**		**24,510**
1999	**Bonn**		**24,853**
2000	**The Hague**		**25,501**
2001	**Bonn and Marrakech**	**3rd IPCC report**	**25,825**
2002	**New Delhi**		**26,436**
2003	**Milan**		**27,718**
2004	**Buenos Aires**		**29,144**
2005	**Montreal**	**Kyoto Protocol comes into effect**	**30,279**
2006	**Nairobi**	**1st meeting of the Asia-Pacific Partnership on Clean Development and Climate in Sydney**	**31,187**
2007	**Bali**	**4th IPCC report**	**32,307**
2008	**Poznan**	**Adoption of the "climate and energy package" by the European Council**	**32,597**
2009	**Copenhagen**		**32,004**
2010	**Cancun**		**33,471**
2011	**Durban**		**34,413**
2012	**Doha**	**Rio Conference on Sustainable Development or Rio+20**	**34,819**
2013	**Warsaw**		**35,312**
2014	**Lima (COP20)**	**New York: Climate Summit 2014 – Catalyzing Action 5th IPCC report**	**35,499**

Sources: BP, Data workbook – Statistical Review 2015, Carbon Dioxide Emissions (from 1965), June 2015; United Nations Framework Convention on Climate Change, Meetings; United Nations, Climate Summit 2014: Catalyzing Action, FAQs; Intergovernmental Panel on Climate Change, Fifth Assessment Report.

Figure 1-9

Global CO_2 emissions from the consumption of fossil fuels, 1980-2014, millions of tonnes of CO_2



Source: BP, Data workbook – Statistical Review 2015, Carbon Dioxide Emissions (from 1965), June 2015.

surpassed, but this is not the case for each of the participating countries. Figure 1-10 shows the GHG emissions gap in percentages compared to the initial target.

In Canada, none of the provinces has respected the Canadian GHG reduction target, which was 6% below the 1990 level for the 2008-2012 period. Quebec only exceeded the target by 1%, however, whereas Saskatchewan exceeded it by 66% (see Figure 1-11).

16. Was the Kyoto Protocol a success or a failure?

The fact that an agreement involving a large number of parties with diverging interests was concluded at all is itself a success—even more so given that the overall reduction target was respected.[33]

However, the impact on total emissions and temperature, which was the ultimate goal, was marginal. Global CO_2 emissions from the consumption of fossil fuels were 53% higher in 2012 than they were in 1990.[34] In the hypothetical situation in which all countries had adopted the Kyoto Protocol, it is estimated that the increase in atmospheric temperature would have been just 0.004°C lower by the end of the 21st century.[35]

The Kyoto Protocol required efforts from industrialized countries only, even though emerging and developing countries are responsible for a growing share of emissions. Non-OECD members were responsible for just 46% of emissions in 1990, compared to a projected share of nearly 70% in 2040 (see Figure 1-12).

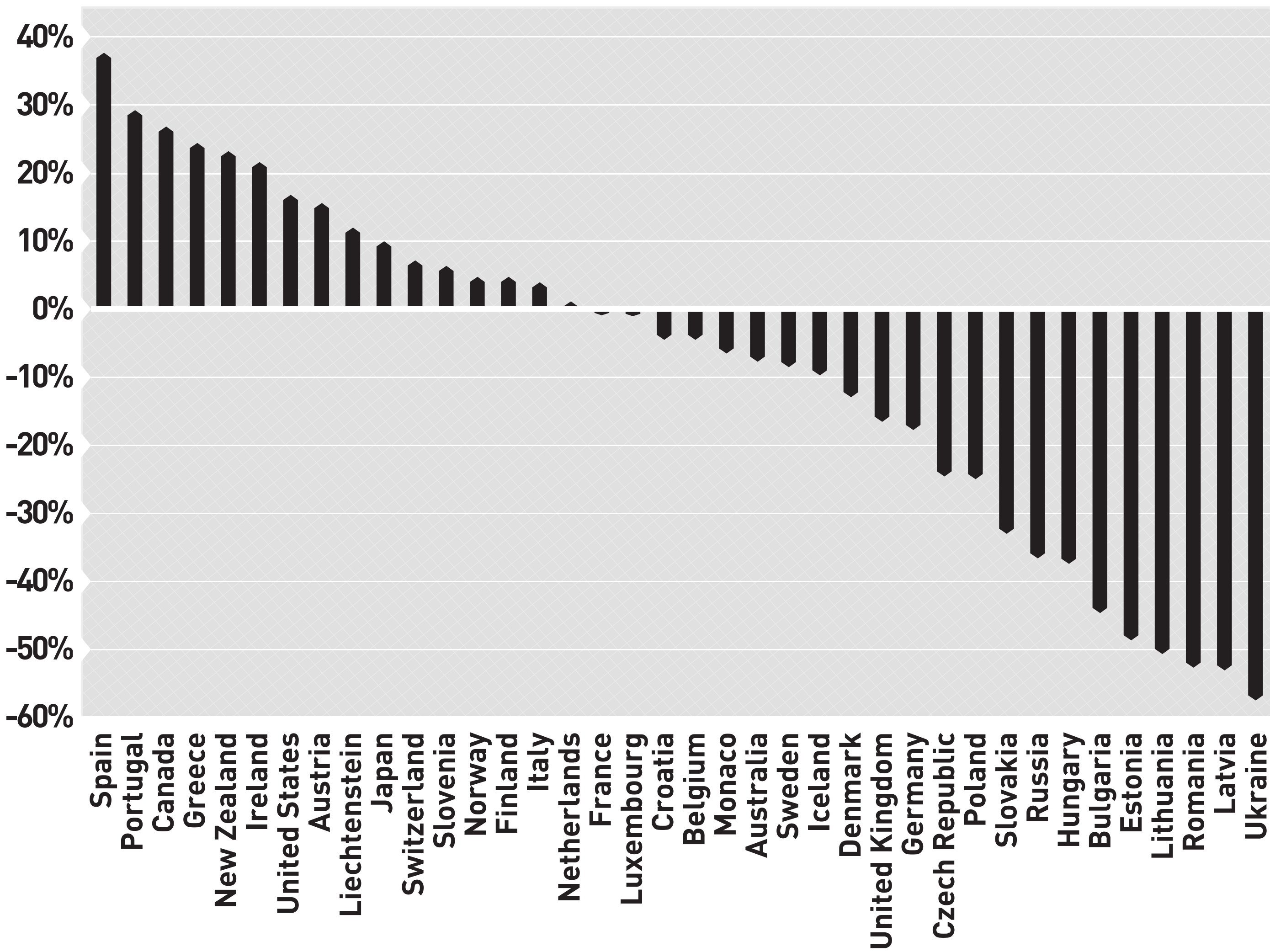
33. In order to evaluate the effectiveness of the Kyoto Protocol in real terms, it would be necessary to determine if it led to the meeting of the targets, or if these would have been met anyway without an agreement. Among other things, one would have to take into account the impact of the 2008-09 economic crisis and the collapse of the Eastern Bloc.

34. BP, Data workbook – Statistical Review 2015, Carbon Dioxide Emissions (from 1965), June 2015.

35. Bjørn Lomborg, "Examining the Threats Posed by Climate Change: The Effects of Unchecked Climate Change on Communities and the Economy," The Senate EPW Committee, Subcommittee on Clean Air and Nuclear Safety, July 29, 2014, p. 15.

Figure 1-10

Gap between actual emissions and Kyoto Protocol GHG reduction objectives



Note: The United States are not part of the Kyoto Protocol, while Canada withdrew from it in 2012. We have included them for purposes of comparison.
Sources: Authors' calculations. United Nations, *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, article 3, 1998; United Nations Framework Convention on Climate Change, *Kyoto Protocol Reference Manual on Accounting of Emissions and Assigned Amount*, 2008, p. 55; United Nations Framework Convention on Climate Change, Time series - Annex I, Data for greenhouse gas (GHG) total.

Furthermore, the United States, the biggest emitter through to the middle of the 2000s, did not ratify the Protocol. For its part, Canada officially withdrew from the Protocol in 2012.[36]

Given that the Kyoto Protocol's objective was reducing overall emissions, these factors substantially qualify its merits.

36. United Nations, "C.N.796.2011.TREATIES-1 (Depositary Notification), Canada: Withdrawal," December 16, 2011.

17. What progress has been made since the Kyoto Protocol?

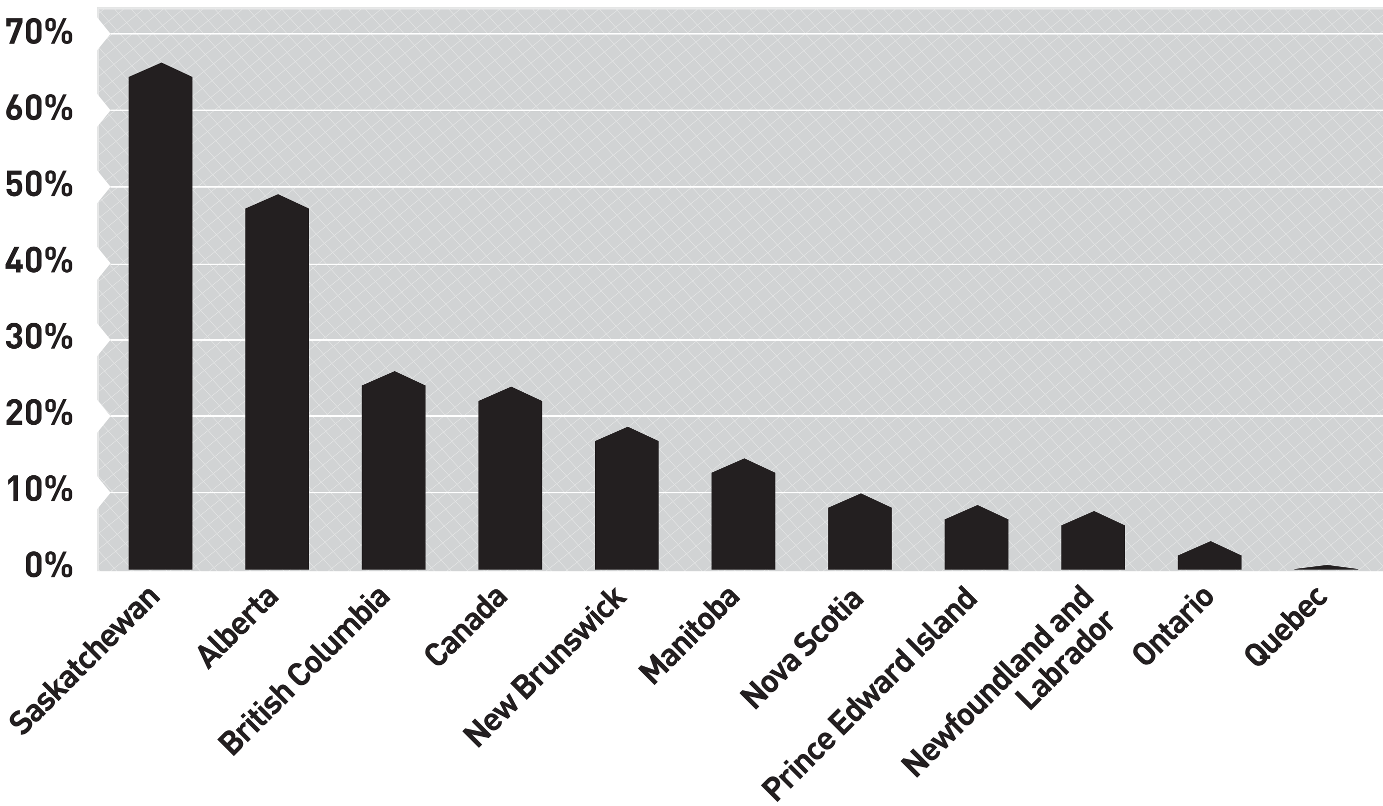
Since the ratification of the Kyoto Protocol, some small progress has been made in international negotiations. The main ones are:

- **The Copenhagen Accord (2009)**

Just as the 2015 Paris Conference seems crucial for reaching an international accord aiming to reduce emissions after 2020, the 2009 Copenhagen Conference

Figure 1-11

Gap between actual emissions and Canada's Kyoto Protocol GHG reduction objectives



Sources: Government of Canada, National and Provincial/Territorial Greenhouse Gas Emission Tables, 1990-2013, August 24, 2015; United Nations, *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, Annex B, 1998.

represented a cut-off date for reaching an international accord to extend the Kyoto Protocol after its expiration in 2012.

Negotiations did not achieve the hoped-for outcome, since the Copenhagen Accord, approved by 141 parties, is not binding.[37] The participants made voluntary commitments to reduce or limit emissions until 2020.

"Without more ambitious GHG emission reductions, the temperature will have climbed 2.6°C by 2100, and 3.5°C over the longer term."

The conference nonetheless gave rise to two ideas that remain crucial in the context of the negotiations leading up to 2015's COP21. The first is the precise definition of the objective to be reached, namely limiting long-term global warming to 2°C. The second is the importance of including developing countries in reduction efforts and the financial commitment of industrialized countries to facilitate this transition through the Green Climate Fund.[38]

- **The Durban Conference (2011)**

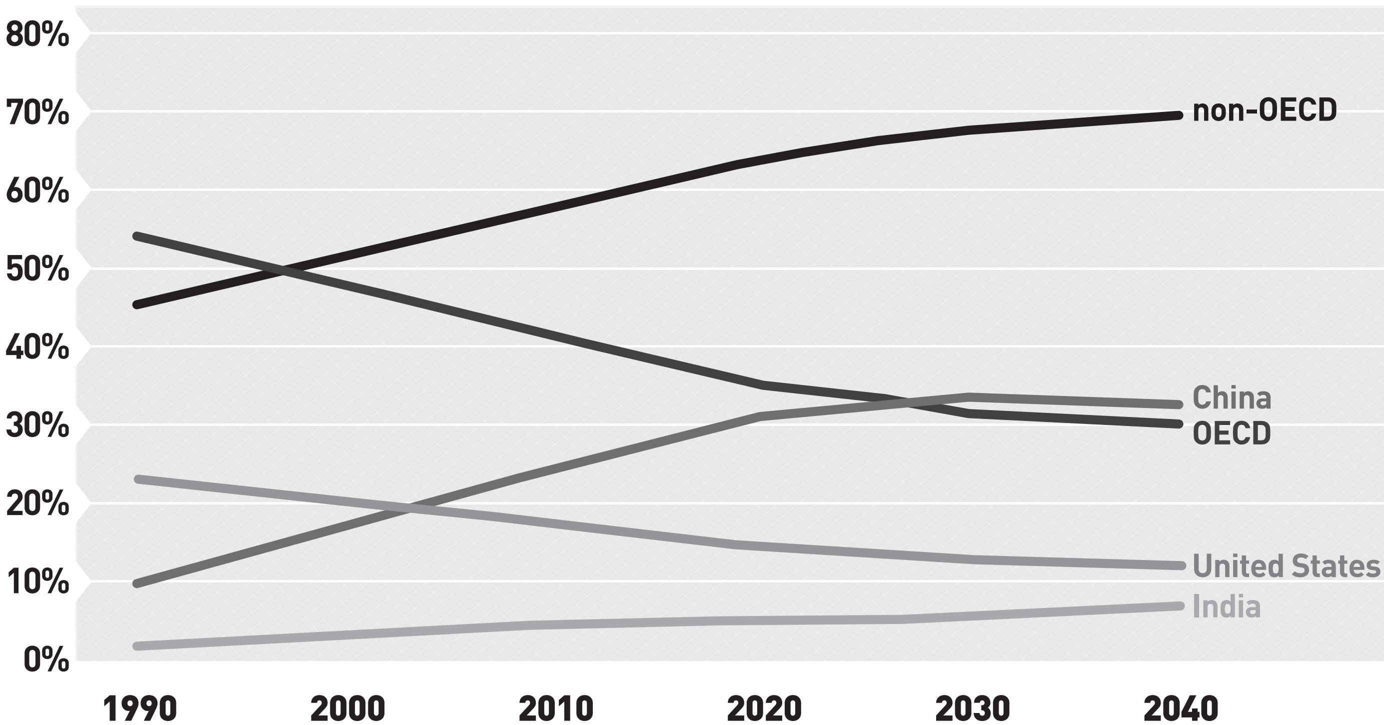
The importance that is accorded to the Paris Conference stems from a decision made during the 2011 Durban Conference to hold international negotiations in order to arrive at a binding agreement by 2015.[39]

37. United Nations Framework Convention on Climate Change, Copenhagen Accord; United Nations, UN and Climate Change, Towards a climate agreement.

38. United Nations Framework Convention on Climate Change, "Draft decision -/CP.15," Conference of the Parties: Fifteenth Session, December 18, 2009.
39. United Nations Framework Convention on Climate Change, Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP).

Figure 1-12

Proportion of emissions for OECD countries, non-OECD countries, the United States, China, and India, 1990-2040



Note: In the absence of compatible data for the year 2000, we extrapolated a linear trend to complete the series.
Source: U.S. Energy Information Administration, *International Energy Outlook 2013: With Projections to 2040*, July 2013, p. 162.

- **The Doha Conference (2012)**

The Doha Conference negotiations led to a commitment by 38 parties to a second round of the Kyoto Protocol, for the 2013-2020 period,[40] while waiting for a new binding agreement, which would be signed in Paris in 2015, to come into effect. The emissions of the signatories represent just 14% of global emissions.[41]

- **The Lima Conference (2014)**

The countries each agreed to submit an Intended Nationally Determined Contribution (INDC) in 2015, before the Paris Conference. INDCs are proposed action plans for each country detailing emission reduction efforts for the post-2020 period.[42]

18. What are the main national commitments and international accords that will serve as the basis for negotiations at the Paris Conference?

At the end of 2014, China and the United States, the two biggest emitters of carbon on the planet accounting for 40% of total emissions, concluded a climate agreement. The United States committed itself to reduce GHG emissions by 26% to 28% compared to its 2005 level by 2025. China, for its part, committed to having its GHG emissions peak in 2030, and to having the share of its energy not coming from fossil fuels climb to 20%.[43]

At a G7 meeting in June 2015, the United States, Germany, Japan, France, Canada, Italy, and the United Kingdom committed to transforming their energy sec-

40. United Nations Framework Convention on Climate Change, Kyoto Protocol.
41. European Commission, Doha Climate Change Conference (COP18/CMP8), December 2012.
42. United Nations Framework Convention on Climate Change, "Lima Call for Climate Action Puts World on Track to Paris 2015," Press release, December 14, 2015.
43. The White House Office of the Press Secretary, "FACT SHEET: U.S.-China Joint Announcement on Climate Change and Clean Energy Cooperation," Press release, November 11, 2014.

tors by 2050 in order to help reduce global GHG emissions by 40% to 70% compared to 2010 and to achieve carbon neutrality by 2100.[44]

On August 3, 2015, the President of the United States unveiled the "Clean Power Plan," which is a detailed action plan to allow the country to achieve its GHG reduction goals. The plan essentially rests on the imposition of pollution standards on power plants. New objectives were also announced: By 2030, GHG emissions must have been reduced to 32% below 2005 levels.[45]

In 2014, the European Union had concluded an accord to reduce emissions to 40% below their 1990 level by 2030.[46] In September 2015, the European Union's 28 Environment Ministers confirmed their commitment by targeting the year 2020 as a peak for their emissions, and 2050 for a 50% reduction below their 1990 level.[47]

> **"Governments have an incentive to behave like free riders, to benefit from the GHG reductions of others without themselves contributing to reduction efforts that would impose costs on their citizens."**

While these agreements seem encouraging, they only represent the contributions already proposed, which are insufficient for respecting the 2°C limit, as we shall see at Question 19. Moreover, it is quite possible that the agreements represent trends that the leaders of the various countries think they will be able to achieve with little effort. For instance, a study from the China Academy of Social Sciences estimates that the slowing down of the rate of urbanization in China means that emissions should naturally reach a peak around 2025 or 2030.[48]

44. "Why the G7 is talking about decarbonisation," *The Economist*, June 10, 2015.
45. The White House, Climate Change and President Obama's Action Plan.
46. These are the targets they submitted to the UNFCCC as INDCs. See Latvian Presidency of the Council of the European Union, "Submission by Latvia and the European Commission on Behalf of the European Union and its Member States," March 6, 2015, p. 1; Arthur Neslen, "EU leaders agree to cut greenhouse gas emissions by 40% by 2030," *The Guardian*, October 24, 2014.
47. Barbara Lewis, "EU ministers unite on climate mandate ahead of Paris summit," Reuters, September 18, 2015.
48. David Stanway, "UPDATE 3-China, US agree limits on emissions, but experts see little new," Reuters, November 12, 2014.

19. Will the proposed Intended Nationally Determined Contributions (INDCs) be sufficient?

Climate Action Tracker, a team made up of several independent scientific organizations, analyzed the INDCs submitted as of October 1st, 2015. The countries covered by the analysis represented 71% of global emissions. According to the group, expected GHG emissions in 2030 would need to be reduced by 30% in order to have a 66% probability of respecting the 2°C limit, without which the global temperature will have increased 2.7°C by 2100.[49]

The International Energy Agency came to a similar conclusion, looking at the INDCs that had been submitted as of May 14, 2015 in order to evaluate the impact of the proposed efforts on the climate. Without more ambitious GHG emission reductions, the temperature will have climbed 2.6°C by 2100, and 3.5°C over the longer term. To reach the 2°C target, the Agency estimates that CO_2 emissions would already have to start falling in 2020, whereas it projects that they will still be growing in 2030 according to the proposed INDCs.[50]

The United Nations also deems that the INDCs proposed as of October 1st will be insufficient to respect the two degree target with a probability of 66%. They estimate that global emissions would be 19% higher in 2020 and 35% too high in 2030 if the INDCs were respected to the letter.[51]

20. Why is a global agreement so difficult to achieve?

The negative externalities from activities that emit GHGs are not borne solely by the citizens of the countries where they are emitted, since they are exported to neighbouring countries, and to the rest of the planet as well. Similarly, the benefits of reducing GHGs are not enjoyed solely in the country that implements mitigation policies, but by people in all countries. Governments therefore have an incentive to behave like free riders,

49. Johannes Gütschow *et al.*, "INDCs lower projected warming to 2.7°C: significant progress but still above 2°C," Climate Action Tracker, October 1, pp. 1 and 5.
50. International Energy Agency, *World Energy Outlook Special Report 2015: Energy and Climate Change*, 2015, pp. 12 and 13.
51. United Nations, *Synthesis Report on the Aggregate Effect of the Intended Nationally Determined Contributions*, United Nations Framework Convention on Climate Change, Report of the Ad Hoc Working Group on the Durban Platform for Enhanced Action, October 30, 2015.

which is to say, to benefit from the GHG reductions of others without themselves contributing to reduction efforts that would impose costs on their citizens.

In order to eliminate this incentive and ensure that all countries live up to their commitments, it is logical to try to establish a binding international agreement that would impose penalties for missing targets. The need for an agreement to be binding, however, reduces the chances of signing one, since countries prefer voluntary, non-binding reduction targets.

The differing economic contexts of different countries also make the signing of a binding agreement very difficult. The principle of "common but differentiated responsibility," which recognizes that all countries have a role to play but which takes into account the particularities of each, is a good illustration of the divergent interests of industrialized and developing countries.

Industrialized countries, which are responsible for the majority of GHG emissions to date, will have less impact in the future since the proportion of emissions from less developed countries is growing. Moreover, the impact of the climate change so far caused by the emissions of industrialized countries will be disproportionately felt in developing countries. Their lower adaptive capacity, which is proportional to wealth levels, makes them more vulnerable.

> **"Poorer countries demand targets that are adapted to their situation, as well as financial support for their energy transition."**

Industrialized countries will not sign a binding agreement without a non-negligible contribution from those who will have high growth rates in the coming years. For their part, poorer countries demand targets that are adapted to their situation, as well as financial support for their energy transition, since their current wealth levels do not allow them to forgo the affordable energy supplied by fossil fuels.

"Climate finance" is the solution envisioned. It allows for the transfer of financial resources from industrialized to developing countries for the mitigation of, and adaptation to, climate change.

Certain mechanisms, like the Adaptation Fund and the Clean Development Mechanism, created for the parties to the Kyoto Protocol, as well as the Global Environment Facility, already allow for the financing of climate change projects in countries that are in transition.

In the context of the 2015 Paris Conference negotiations, the Green Climate Fund, set up to help meet the UNFCCC's objectives, will have a determining influence on the signing of a binding agreement that includes developing countries. Industrialized countries promised, in 2009 and 2010, during the Copenhagen and Cancun negotiations, to raise $30 billion for the 2010-2012 period, and $100 billion a year starting in 2020, for the energy transition of developing countries.[52] However, as of October 5, 2015, only $10.2 billion had been promised for the initial capitalization of the fund.[53]

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CHAPTER 2

Governmental Measures and Their Effectiveness

The countries of the world, with or without a global protocol, are already taking action to measure, limit, and reduce their greenhouse gas emissions. Admittedly, a global agreement represents an ideal tool for guaranteeing that GHG concentrations remain within the prescribed limits in order to reduce the probability of catastrophic events. By acting in concert, all countries are assured that their efforts will be matched by similar efforts in other countries and that they will not be alone in suffering the economic consequences of the imposed restrictions.

Barring a global treaty, many governments of industrialized countries will nonetheless wish to convince their populations that they are acting to limit or reduce GHG emissions, because there exists a political demand for such measures. In Canada, the adoption of measures to fight climate change is an important factor for nearly one in two voters.[54] Although it is secondary to concerns regarding the economy, health care, employment, and safety, this issue remains among the most important ones.

However, political gestures must be distinguished from real actions. Many politicians talk about climate change and make announcements committing themselves to limiting or reducing national emissions in the more or less distant future, knowing that another government will have replaced them when the time comes to act.

Beyond all the talk, measures adopted must be judged according to their results. Some measures are more effective than others when it comes to reducing emissions. Their economic and social impacts also vary.

A. The Carbon Market

Most experts and scientists agree that the levying of a tax on carbon or the creation of a carbon market are two of the most effective mechanisms for limiting GHG emissions and for reducing the probability of climate catastrophes. These two mechanisms, similar in several ways, aim to establish a price for carbon, thereby allowing emitters to internalize the social cost of this substance.[55]

How Does a Carbon Market Work?

A carbon market, also known by the more technical name of a cap-and-trade system for greenhouse gas emission allowances, is simple in principle. It consists of limiting the total emissions of a group of political jurisdictions by setting an emission ceiling and creating emission allowances corresponding to this ceiling. These emission allowances then become an indispensable requirement for legally emitting one tonne of carbon into the atmosphere. Governments are charged with setting the ceiling and managing the initial sale of emission allowances, either by distributing them free of charge or through an auction. This is the "cap" part of the equation.

> **"Many politicians talk about climate change and make announcements knowing that another government will have replaced them when the time comes to act."**

Businesses, institutions, and industries must therefore procure these allowances by obtaining them free of charge from the government or by purchasing them on the carbon market (or carbon exchange). They can also, if they possess unused emission allowances, sell them on this same carbon market. This is the "trade" part of the equation.

The relative effectiveness of a mechanism like a carbon market lies in the decentralization of decisions regarding emission reductions. The government determines the ceiling of emissions allowed, but it does not decide who will emit what. It is the companies and institutions sub-

54. IPSOS, "Canadian Voters Say Managing Economy in Tough Times (76%), Fixing Healthcare (73%) and Creating Jobs (73%) Are Absolutely Crucial Policy Planks for Parties to Address to Win Their Vote," Press release, August 13, 2015.

55. See for example Catherine Potvin *et al.*, *Acting on Climate Change: Solutions from Canadian Scholars*, UNESCO-McGill Chair for Dialogues on Sustainability, March 2015. This initiative brings together 60 experts recommending either a carbon tax or a carbon market. See also OECD, *Effective Carbon Prices*, November 2013, p. 12. "The highest costs by far per tonne of CO_2 abated are associated with various capital subsidies and feed-in tariff systems […]. The lowest costs per tonne abated were for trading systems, in line with classical economic theory—a fact which confirms 'textbook suggestions' that trading systems (and broad-based carbon taxes) are the most economically efficient policy tools to mitigate climate change."

ject to the carbon market that decide if it is more advantageous to reduce their emissions or to procure more emission allowances.

This decentralized decision-making normally allows for the most optimal reductions to take place. In theory, companies are in the best position to evaluate the cost of reducing emissions and deciding to go forward or to purchase compensatory allowances. The carbon market mechanism allows the results of millions of individual evaluations to be communicated through the market price of emission allowances. Therefore, only the most effective reductions, and the ones that are less expensive than the price of emission allowances, will be carried out. The price of emission allowances will adjust itself as a consequence of the opportunities and constraints of each participant in the market.

> **"The relative effectiveness of a mechanism like a carbon market lies in the decentralization of decisions regarding emission reductions."**

The economic impact of a carbon market is identical to the impact of a carbon tax, with one exception. As we shall see, the rate of the carbon tax is known. The price of an emission allowance is not, since it is set by the market. Nonetheless, in both cases, the immediate result is to increase the relative cost of carbon-intensive products like fuel, which favours reduced consumption as well as substitution toward other, less carbon-intensive products.

In order to control emissions and regulate the carbon market, governments deal directly with the sources of emissions that are companies and institutions. Although the price of emissions is integrated upstream of consumers, they are the ones who bear the true economic cost.[56]

56. The demand for gasoline actually has very low price elasticity. The U.S. Energy Information Administration uses a short-term price elasticity of 0.02 in its models. See U.S. Energy Information Administration, Gasoline prices tend to have little effect on demand for car travel, December 15, 2014; Martijn R.E. Brons *et al.*, "A Meta-Analysis of the Price Elasticity of Gasoline Demand. A System of Equations Approach," Leibniz Information Centre for Economics, Tinbergen Institute Discussion Paper, No. 06-106/3, 2006; Molly Espey, "Gasoline Demand Revisited: An International Meta-Analysis of Elasticities," *Energy Economics*, Vol. 20, 1998, p. 277; Phil Goodwin *et al.*, "Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review," *Transport Reviews*, Vol. 24, No. 3, May 2004, p. 278.

The Challenges of Setting Up a Carbon Market

In practice, setting up a carbon market requires that numerous elements be determined. The emissions of economic entities, necessarily defined arbitrarily (an industry, a specific company, or each factory?), must be measured, and reliable data be gathered on the emissions effectively released. In addition, it becomes necessary to control the availability of allowances equivalent to these emissions and to impose penalties on delinquent institutions and companies.

The ceiling must be established and gradually lowered. This task is more complex than it sounds. Companies can find themselves becoming less competitive and will then ask the government for help in one form or another. For example, governments can grant emission allowances free of charge to certain companies to keep their competitors, who are not subject to the same environmental rules, from enjoying an unfair advantage. Other industries will want to be entirely exempt from the carbon market. Any favouritism toward some will only increase the cost to be borne by the other industries and companies. A ceiling that is too ambitious runs the risk, in carbon-intensive sectors, of displacing economic activity toward other regions, a phenomenon known as "carbon leakage."

Another source of difficulty comes from the revenues from allowances. These can be used for various ends, or on behalf of various political clienteles, since governments have an incentive to use the resources at their disposal so as to favour their re-election. For example:

1. The government can use these funds to favour environmental projects in order to further reduce GHG emissions in addition to the carbon market. To this end, they will subsidize renewable energy or research and development into certain so-called green technologies.

2. The government can also choose to compensate certain industries or certain companies by giving them funds in the form of transition assistance. The funds will be paid out on condition that they adopt GHG reduction plans, the latest clean technologies, or other programs of this sort. In the case of compensations to businesses, as in the case of subsidies for environmental projects, the use of funds is often not very well controlled. The sums are allocated without clear objectives, without selection or call for tenders, and without management by results.

Information regarding the projects that are funded is not always available, which raises doubts about the relevance or the fulfillment of these projects.[57]

3. Finally, the government can decide to compensate taxpayers by redistributing the sums collected through the mechanism of a tax reduction. What is collected as revenue for the emission allocations is therefore returned to consumers through lower taxes. We speak of "tax neutrality" when the amounts collected are exactly offset by reductions.[58]

Although carbon markets are simple in principle, in practice they raise tricky questions of equity and control. The transition from economic theory to practical application is very complex.

An Existing Carbon Market: Quebec, California… and Ontario

The Western Climate Initiative (WCI) is a carbon market linking Quebec and California. Although 11 states and provinces participated in its creation,[59] only these two jurisdictions have implemented it. Recently, the government of Ontario announced its intention to set up a carbon market and join the WCI.[60]

The Western Climate Initiative aims to reduce the total emissions of the participating regions while mitigating the economic impact on consumers, revenues, and employment.[61] This initiative leaves a lot of latitude to participants to determine how to implement the market. A central organization was set up, however, to supervise emission allocation auctions and to oversee exchanges.[62]

The agreement reached between the participants excludes the agricultural, forestry, and waste management sectors in order to protect them.[63] Like all other organizations not subject to the carbon market, companies in these sectors can nevertheless put in place projects to reduce their emissions and obtain compensatory credits that can then be sold.[64]

Agriculture represents 8.3% of Quebec's emissions and 8% of California's (see Figure 2-1). For purposes of comparison, this is nearly as much as the combined emissions of the residential, commercial, and institutional sectors, which amount to 9.7% of total emissions in Quebec, and it's more than the emissions of the residential sector in California (7%). Since the agricultural sector generates less than 1.6% of Quebec's GDP,[65] it is a very GHG-intensive sector.

> **"A ceiling that is too ambitious runs the risk of displacing economic activity toward other regions, a phenomenon known as 'carbon leakage'."**

Waste management is also a sector that is overrepresented in terms of emissions, since this single activity is responsible for 5.5% of total emissions in Quebec. The high intensity of GHGs, both in the agricultural sector and in the waste management sector, is due among other things to the fact that these two sectors produce GHG emissions that are more powerful than CO_2, like methane (CH_4).[66] However, emissions in the waste management sector have fallen by 41% in Quebec between 1990 and 2012, whereas those of the agricultural sector have increased by 3.9% over the same period.[67]

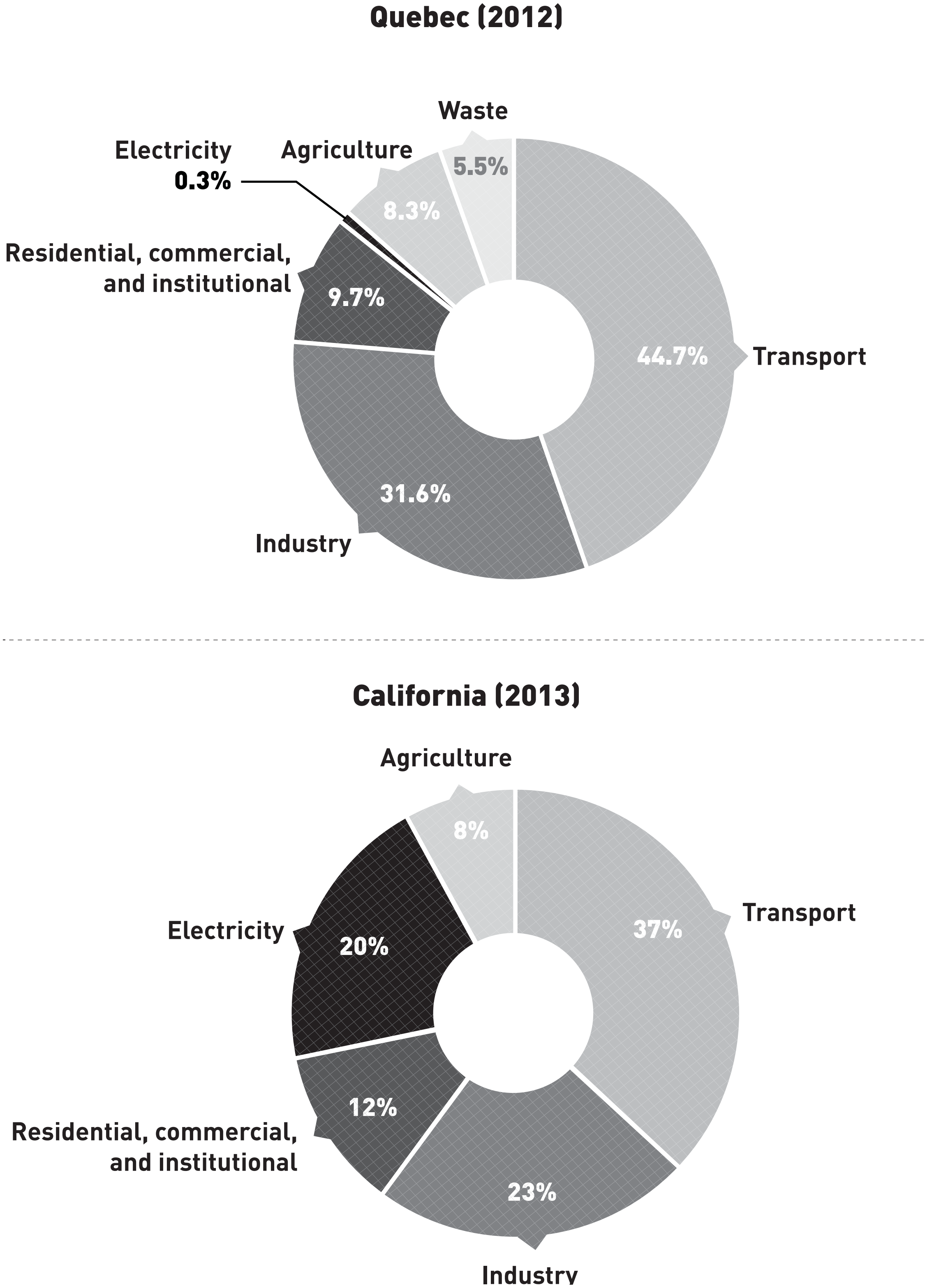
The exclusion of the agricultural, forestry, and waste management sectors from the areas covered by the carbon market therefore sets aside some significant sources of emissions.

The participating governments have a substantial amount of discretion in allocating free emission allowances to certain industries. They can also use the funds from auctions for various purposes, either to encourage

57. Auditor General of Quebec, *Fonds vert : gestion et aide financière*, Chapter 4 of *Rapport du vérificateur général du Québec 2014-2015*, Spring 2014, p. 3.
58. Tax neutrality is a principle that can be applied to a wide variety of public policies that involve revenue for the government. It can be applied to a carbon market, but also to a carbon tax, as is the case with the carbon tax that is in effect in British Columbia.
59. Western Climate Initiative, "Modèle recommandé pour le programme régional de plafonds-échanges de la Western Climate Initiative," September 23, 2008. These were Arizona, British Columbia, California, Manitoba, Montana, New Mexico, Ontario, Oregon, Quebec, Utah, and Washington State.
60. Government of Ontario, "Cap and Trade System to Limit Greenhouse Gas Pollution in Ontario," Press release, April 13, 2015.
61. Western Climate Initiative, *op. cit.*, footnote 59, p. 6.
62. Western Climate Initiative, Home.
63. Western Climate Initiative, *op. cit.*, footnote 59, p. 17.
64. Quebec Department of Sustainable Development, Environment and the Fight against Climate Change, Marché du carbone, Crédits Compensatoires.
65. The agricultural, forestry, and fishing and hunting sectors (NAICS code 11) represented a combined 1.6% of Quebec's GDP in 2014. Institut de la statistique du Québec, *Produit intérieur brut par industrie au Québec*, May 2015, pp. 12 and 14.
66. Nature Québec, "La part du secteur agricole dans les émissions de gaz à effet de serre," May 2011, p. 1; Environment Canada, Municipal Solid Waste and Greenhouse Gases, July 25, 2014.
67. Department of Sustainable Development, Environment and the Fight against Climate Change, "Inventaire québécois des émissions de gaz à effet de serre en 2012 et leur évolution depuis 1990," 2015, p. 11.

Figure 2-1

GHG emissions in Quebec and California by sector of economic activity



Source: Quebec Department of Sustainable Development, Environment and the Fight against Climate Change, "Inventaire québécois des émissions de gaz à effet de serre en 2012 et leur évolution depuis 1990," 2015, p. 8; California Environmental Protection Agency, Air Resources Board, "California Greenhouse Gas Emission Inventory – 2015 Edition," June 30, 2015.

energy efficiency, provide "green jobs," encourage renewable energy, or reduce the impact on consumers and industries.[68]

Since January 2015, companies that sell fuel are subject to the carbon market. They must procure allowances corresponding to the emissions of the products they sell, which means that they must compensate for the GHGs of their customers. Of course, this cost is included in the price of the fuels consumed, as if it were a carbon tax.[69] Although the data is still incomplete, it is estimated that the cost of the carbon market raises the cost of each litre of gasoline by around 4¢ in Quebec.[70] Over the longer term, the cost for consumers will depend on the cost of the emission allowances traded on the carbon market and the adaptation of consumers and companies.

"It is estimated that the cost of the carbon market raises the cost of each litre of gasoline by around 4¢ in Quebec."

How Is the Price of One Tonne of Emissions Set in the Western Climate Initiative?

The price is set by the market, which is to say by the buying and selling of emission allowances, notably during auctions held by the participating governments. The governments always set a reserve price for each auction, below which they do not sell the emission allowances. This reserve price increases each year by 5% plus the rate of inflation. Figure 2-2 shows the price of emission allowances at the auctions held since December 2013.

What the carbon market's regulatory authorities determine, for their part, is the quantity of emission allowances given out free of charge or made available at auction. The quantity of total allowances is determined jointly by the WCI Inc. organization,[71] according to the assessments of the two participating jurisdictions and their reduction objectives for the year 2020.

The Quebec government decided to reduce the province's emissions 20% below its 1990 level by the year 2020.[72] California, for its part, adopted the far less ambitious target of returning to its 1990 level by 2020.[73] Figure 2-3 shows the evolution of GHG emissions in recent years and the forecast trends to be followed to hit the targets set for 2020.

Since the emission allowances are fully recognized in both regions, the GHG reductions forecast for California and Quebec could take place in either one. It is therefore possible, for example, for Quebec's emissions to fall less than expected, but for California's to fall more than expected in compensation, or the reverse. Given that Quebec's objectives are more ambitious, it might be more likely that emitters in this province will purchase more allowances in order to avoid draconian reductions.

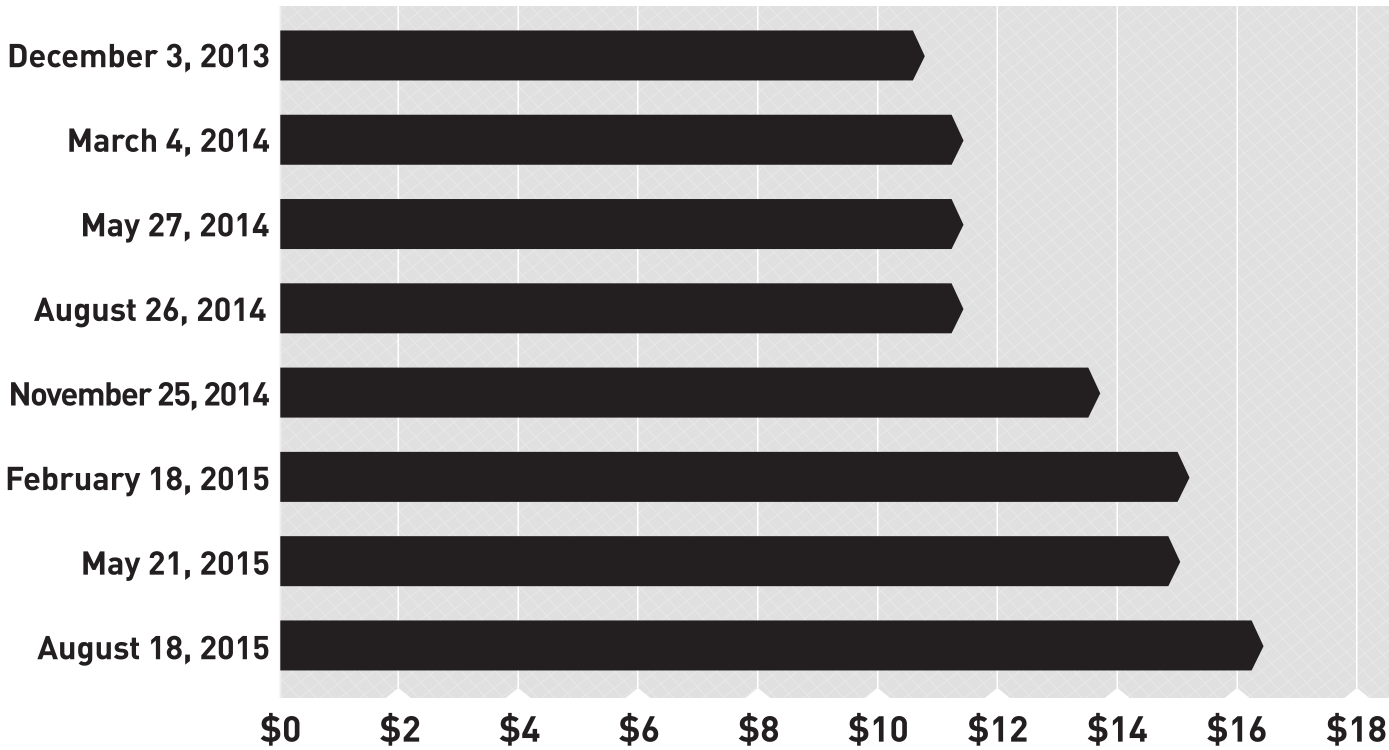
B. The Carbon Tax

The second mechanism for incentivizing the reduction of GHG emissions is the levying of a carbon tax. This mechanism is favoured over a carbon market by a growing number of economists and other specialists on the matter, mainly because of its simplicity and its predictability.[74]

68. Western Climate Initiative, *op. cit.*, footnote 59, p. 13.
69. The fact that consumers bear the majority of the costs associated with a carbon market or a carbon tax reflects their lower price elasticity than that of producers faced with a common constraint to their industry as a whole, or even the entire economy. The reduction of aggregate demand following a price increase entails, for its part, a loss for producers. Among many others, we can consult the work of Robert N. Stavins, of Harvard University, who has attempted to measure the various impacts that a carbon market would have in the United States. Robert N. Stavins, "Addressing Climate Change with a Comprehensive US Cap-and-Trade System," *Oxford Review of Economic Policy*, Vol. 24, No. 2, 2008, pp. 298-321.
70. Given that a litre of gasoline emits around 2299 g of CO_2e according to Environment Canada, we can estimate that a price of $10 per tonne of GHG is equivalent to a 2.3¢ tax per litre of gasoline. The average price of $17.98 obtained in the August 2015 auction corresponds to 4.13¢ per litre. Department of Sustainable Development, Environment and the Fight against Climate Change, "Ventes aux enchères no 4 d'août 2015 : Rapport sommaire des résultats," August 25, 2015; Environment Canada, Fuel Combustion, Mobile Combustion, June 21, 2013.
71. Western Climate Initiative, *op cit.* footnote 62.
72. Department of Sustainable Development, Environment and the Fight against Climate Change, *Le Québec en action vert 2020 : Plan d'action 2013-2020 sur les changements climatiques—Phase 1*, 2012, p. 5.
73. California Environmental Protection Agency, Air Resources Board, California 1990 Greenhouse Gas Emissions Level and 2020 Limit, May 6, 2015. The 2020 emissions limit is therefore set at 431 million tonnes of CO_2e.
74. Reuven S. Avi-Yonah and David M. Uhlmann, "Combating Global Climate Change: Why a Carbon Tax Is a Better Response to Global Warming Than Cap and Trade," *Stanford Environmental Law Journal*, Vol. 28, No. 3, 2009; Lawrence H. Goulder and Andrew R. Schein, "Carbon Taxes Versus Cap and Trade: A Critical Review," *Climate Change Economics*, Vol. 4, No. 3, 2013 : "[Exogenous pricing helps] prevent price volatility, [reduces] expected policy errors in the face of uncertainties, helps avoid problematic interactions with other climate policies and helps avoid large wealth transfers to oil exporting countries."; William D. Nordhaus, "Life After Kyoto: Alternative Approaches to Global Warming Policies," NBER Working Paper No. 11889, 2005; N. Gregory Mankiw, "One Answer to Global Warming: A New Tax," *The New York Times*, September 16, 2007.

Figure 2-2

Price of the emission allowances traded on the WCI carbon market



Source: Joint auction summary results reports published by Quebec's Department of Sustainable Development, Environment and the Fight against Climate Change and the California Air Resources Board (starting in November 2014, the two agencies publish the reports jointly).

How Does a Carbon Tax Work?

The levying of a carbon tax represents a mechanism similar to a carbon market in that it allows for limiting GHG emissions without imposing arbitrary limits on each emitter. It consists of taxing the economic inputs that produce greenhouse gas emissions, like fossil fuels: coal, natural gas, and products derived from oil. In principle, this additional cost allows emitters to internalize the social cost of carbon.

As in the case of a carbon market, a carbon tax is a mechanism that allows for the decentralization of emission reduction decisions. The government determines the tax rate, and it lets companies and individuals make their own decisions. Faced with higher costs for carbon-intensive goods, there will be a tendency to consume less and to substitute other goods that emit less GHGs.

The government therefore does not decide who will emit what. Contrary to the carbon market, it does not even set the overall emissions allowed. The only lever upon which it can act is the rate of the tax, which can be raised or lowered in order to achieve an emissions objective.

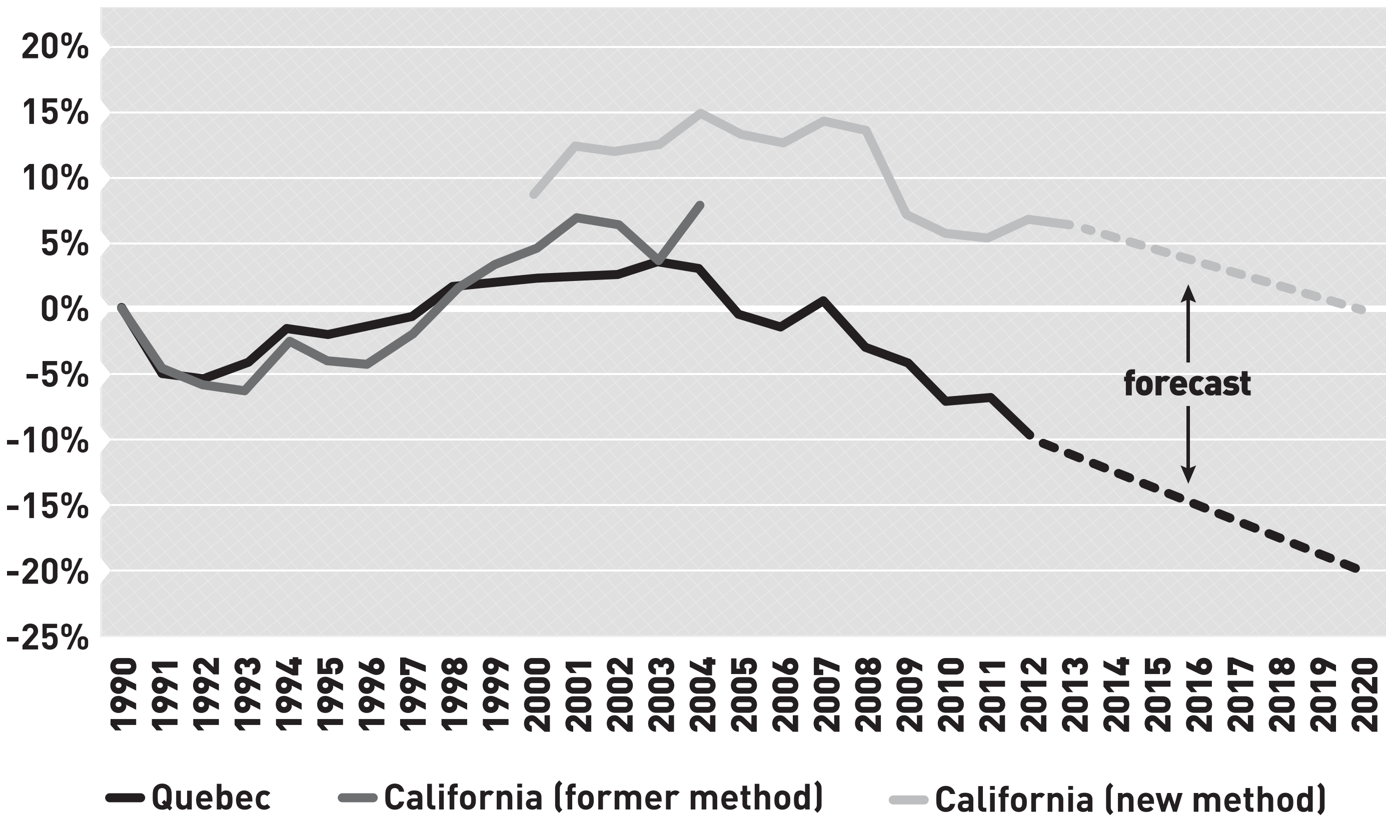
> **"Given that Quebec's objectives are more ambitious, it might be more likely that emitters in this province will purchase more allowances in order to avoid draconian reductions."**

The Challenges of Setting Up a Carbon Tax

The main challenge to the implementation of a carbon tax is political, for the simple reason that it is a mechanism that has the label "tax" attached to it, contrary to a carbon market. Even though the two concepts are similar in terms of economic impact, the carbon tax is perceived more as a fiscal lever. The 2008 federal election, in which the Liberal Party of Canada proposed a carbon

Figure 2-3

Evolution of GHG emissions for WCI participants and their targets for 2020



Source : California Environmental Protection Agency, Air Resources Board, "California Greenhouse Gas Inventory for 2000-2013 – by Sector and Activity," April 24, 2015, p. 2; California Environmental Protection Agency, Air Resources Board, "2020 Statewide Greenhouse Gas Emissions and the 2020 Target," May 27, 2014, p. 1; California Environmental Protection Agency, Air Resources Board, "California Greenhouse Gas Inventory (millions of metric tonnes of CO2 equivalent) – By IPCC Category," November 19, 2007, pp. 22-23; Department of Sustainable Development, Environment and the Fight against Climate Change, *Inventaire québécois des émissions de gaz à effet de serre*, various editions.
Note: The data before 1990-2004 in California are not comparable to those from 2000-2013. The most recent data are for the year 2012 for Quebec and 2013 for California.

tax offset by income tax reductions, provided a convincing illustration of the unpopularity of such a proposition.[75]

The major obstacle when it comes to the effectiveness of a carbon tax is the risk of carbon "leakage." If a government adopts such a tax, but its neighbours do not, a portion of emissions will in all likelihood simply be displaced from this region to the others, which will reduce its emissions record without actually reducing overall emissions—among others the emissions associated with imported goods. The phenomenon is illustrated by drivers living near the border who will be tempted to gas up on the other side.[76]

Since it is overall GHG emissions that influence the climate, the displacement of certain emissions neutralizes in part the effectiveness of a carbon tax. In an ideal scenario, all countries of the world would levy the same tax at the same time, at a relatively low rate. The improbability of this scenario leads rapidly to imbalances between countries, to higher rates in countries that adopt the tax and lower effectiveness in reducing emissions. William Nordhaus of Yale University calculated that given the participation of only 50% of countries, the economic costs associated with a tax would be 250% higher than an optimal tax.[77]

75. Bernard Simon, "Canada's Dion to step down as Liberal leader," *Financial Times*, October 21, 2008.
76. Philip Cross, "The carbon tax illogic," *Financial Post*, January 13, 2015.

77. William D. Nordhaus, *A Question of Balance—Weighing the Options on Global Warming Policies*, Yale University Press, 2008, p. 19.

Finally, other technical challenges of implementation can arise, similar to those of a carbon market, if the government tries to exempt certain economic sectors or particular companies.

An Example of a Carbon Tax: British Columbia

The province of British Columbia introduced a carbon tax in 2008.[78] From $10 per tonne of GHG emissions at the time, this tax grew to $30 in 2012 following four annual increases of $5 each. At the current rate, it corresponds to 6.67¢ per litre of gasoline and 7.67¢ per litre of diesel.[79] The tax generates total revenues of $1.2 billion for the government.[80]

What is particular about this carbon tax is that it is revenue neutral. In other words, British Columbia's Ministry of Finance has a mandate to reduce other taxes by an amount equal to the revenues brought in by the carbon tax. This objective is fulfilled primarily through personal and corporate income tax rate reductions. A tax credit for low-income families was also introduced to compensate these households. The effect on the province's economy also seems to have been quite small, and even positive overall, thanks to the income tax reductions that have offset the levying of the carbon tax.[81]

Between 2007, which was before the carbon tax came into effect, and 2012, fuel consumption in British Columbia fell by 17.4%. During this same period, fuel consumption went up by 1.5% in the rest of Canada. GHG emissions per capita were reduced by 10% in British Columbia versus a reduction of 1.1% in the rest of Canada.[82] But are these results really a consequence of the carbon tax?

Economists generally recognize that the price elasticity of demand for fuel, which measures the reaction of consumers to a price variation, is very low.[83] A tax of 6.67¢ per litre, which represents an increase of less than 6%, would entail a reduction of far less than 6%. A government that wanted to appreciably reduce transportation-related GHG emissions would have to increase the price of gas considerably in order to entail a substantial modification of behaviours.[84]

Other considerations must therefore also be taken into account in order to understand the reduced fuel consumption in British Columbia. There was for instance the considerable decline of the forestry industry, a major economic sector, after the 2008 housing crisis. The explanation of a temporary reduction in fuel consumption due to other factors appears all the more justified given that since 2012, the data show a rapid increase in fuel consumption. Indeed, the recent data indicate that British Columbia now consumes more than it did before the carbon tax, both overall and per capita, as demonstrated by Philip Cross, the former chief economic analyst at Statistics Canada.[85]

"The major obstacle when it comes to the effectiveness of a carbon tax is the risk of carbon 'leakage'."

Other criticisms have been heard underlining the possibility of carbon leakages, among other things due to truckers and other drivers filling up beyond the province's borders.[86] This phenomenon seems to have doubled since the introduction of the carbon tax, which has not been the case in Ontario or Quebec. The carbon tax will continue to be a topic of debate, but its effect now appears marginal in the explanation of long term trends.

How Is the Carbon Tax Rate Determined?

The rate of the carbon tax is set by the government. For example, the British Columbian government set the rate of its tax at $30 per tonne of GHG emissions. What is uncertain is the level of emissions and the likelihood of carbon leakage. The government that adopts such a tax must therefore determine a rate that will lead to an ef-

78. Government of British Columbia, *Carbon Tax Act*, Chapter 40, October 21, 2015.
79. British Columbia Ministry of Finance, How the Carbon Tax Works.
80. British Columbia Ministry of Finance, *Budget and Fiscal Plan 2015/16 to 2017/18*, February 17, 2015, p. 60.
81. Stewart Elgie and Jessica McClay, "BC's Carbon Tax Shift after Five Years: Results—An Environmental (and Economic) Success Story," *Sustainable Prosperity*, 2013, p. 7.
82. *Ibid.*, pp. 2 and 4.
83. *Op. cit.*, footnote 56.
84. This relation is true, unless a carbon tax has an effect that is different from a regular price increase. Some claim, however, that the "salience" of a carbon tax, namely its impact on behaviour, is greater than that of a regular gasoline tax. This concept of "salience," difficult to measure, and criticized, is the explanation offered by two University of Ottawa researchers. Nicholas Rivers and Brandon Schaufele, *Carbon Tax Salience and Gasoline Demand*, Working Paper No. 1211E, Department of Economics at the University of Ottawa, August 2012.
85. Philip Cross, *op. cit.*, footnote 76; Terence Corcoran, "No B.C. carbon tax miracle on 120th St.," *Financial Post*, January 13, 2015.
86. Jock Finlayson, "B.C.'s carbon tax hurting businesses," *The Vancouver Sun*, August 1st, 2013; Robert P. Murphy, "British Columbia's Carbon Tax and 'Leakage' Into the U.S.," Institute for Energy Research, July 6, 2015.

fective reduction of emissions corresponding to its targets without entailing too large a displacement of economic activities with heavy emissions.

C. Fuel Taxes in Canada

The carbon tax in British Columbia and the additional charges related to the carbon market in Quebec do not appear explicitly as taxes on sales slips. However, they increase producers' costs, and consequently retail prices as well. It is therefore consumers who bear the economic cost by paying more for a litre of gas, just like a regular tax. Yet gasoline is already heavily taxed in Canada.

> **"British Columbia's Ministry of Finance has a mandate to reduce other taxes by an amount equal to the revenues brought in by the carbon tax."**

The base price of gasoline is determined by the market, which is to say by the price of crude oil and the profit margins of intermediaries (refining, transportation, retail). To this base price are added the taxes levied by the various levels of government.[87] The 10¢ excise tax levied by the federal government since 1995 is fixed. All provinces also levy fixed taxes on fuels.[88] To this are added municipal taxes levied by Vancouver (11¢ per litre), Victoria (3.5¢), and Montreal (3¢) (see Figure 2-4). Federal and provincial sales taxes are added to this total, and are therefore also applied to the excise taxes of the three levels of government.[89]

Since certain taxes are fixed and others are proportional to price, the amount of taxes paid on each litre of gasoline and the proportions of these taxes vary constantly, as do the revenues governments collect from them. In 2014-2015, the federal government registered revenues of $5.528 billion from energy taxes,[90] primarily the excise tax on gasoline and diesel.

As can be seen in Table 2-1, federal, provincial, and municipal gasoline taxes represented revenues of $11 billion for governments in 2014. If we add in sales taxes, these revenues totalled $16.3 billion. Diesel taxes, for their part, brought in $3.2 billion to governments in 2014. Including sales taxes on this fuel, total revenues amounted to $5.3 billion. In all, governments therefore collect nearly $22 billion in various fuel taxes.

The taxes act like any mechanism aiming to internalize the cost of GHG emissions for fuel consumers, even though this was not the intention that led to their adoption. They were imposed in order to generate revenue for governments or to finance the maintenance of the road network, certainly, but they also entail a reduction in fuel consumption. Based on the emissions of one litre of gasoline, we can therefore deduce that the federal excise tax and the provincial fixed taxes on fuels correspond to a carbon tax of between $83 and $128 per tonne of GHGs,[91] as illustrated in Figure 2-5. In the cities of Montreal and Vancouver, it reaches levels equivalent to a carbon tax of $141 and $155 respectively.

The imposition of a mechanism whose goal is to put a price on GHG emissions, like a carbon tax or a carbon market, therefore cannot be done without taking into account the taxes already in effect.

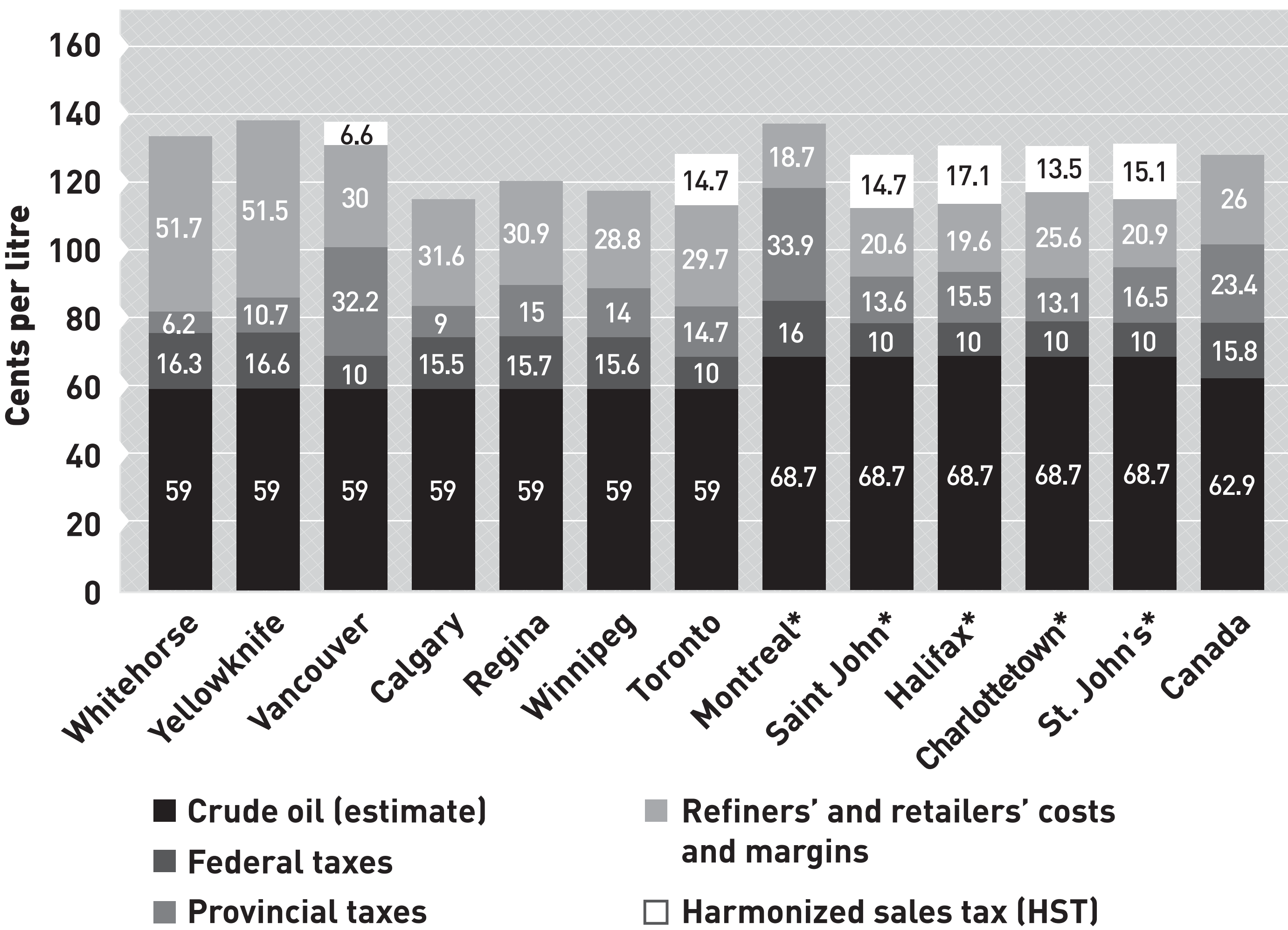
D. Subsidies and R&D in the Field of Green Energy

Governments also act by subsidizing various initiatives related to the fight against climate change, like research and development activities, the production or use of renewable energy, the purchase of electric cars, or energy efficiency measures. In Canada, numerous examples exist. The federal government lists 224 subsidy and financial incentive programs regarding energy efficiency administered by Natural Resources Canada.[92] Moreover, the provincial governments are also active in several areas.

87. The price of gasoline has been the subject of numerous analyses. Natural Resources Canada published a bi-weekly Fuel Focus bulletin on gasoline containing a wealth of relevant information. Available at http://www.rncan.gc.ca/energie/prix-carburant/4594.
88. Provincial excise taxes are set in relation to the price of gasoline and are calculated in cents per litre. However, their application varies, with certain regions seeing their taxes go up or down. In Quebec, for example, a reduced rate applies to border regions like the Gaspé Peninsula and Magdalen Islands and the Outaouais. To complicate the collecting of the provincial excise tax even more, regions contiguous to an American state or located close to a peripheral region sees the tax vary for service stations according to distance. Revenue Quebec, "Table of Fuel Tax Rates in Québec, by Region in force as of April 1, 2015," April 2015.
89. Natural Resources Canada, Government taxes on gasoline, September 15, 2014; CAA Quebec, How is the price of a litre of gasoline determined?; Marc-André Pigeon, Federal Taxes on Gasoline and Heating Fuels, Library of Parliament of Canada, September 16, 2005.
90. Department of Finance Canada, *Annual Financial Report of the Government of Canada Fiscal Year 2014–2015*, 2015, p. 17.
91. The conversion from cents per litre to dollars per tonne of GHGs is based on the emission of one litre of gasoline for light-duty gasoline vehicles as indicated by Environment Canada. Environment Canada, *op. cit.*, footnote 70. The U.S. Energy Information Administration also provides equivalencies. U.S. Energy Information Administration, Frequently Asked Questions, How much carbon dioxide is produced by burning gasoline and diesel fuel? July 7, 2015.
92. Natural Resources Canada, Grants and Financial Incentives, April 1st, 2014.

Figure 2-4

Composition of the retail price of gasoline in several Canadian cities, 2014



* Regulated markets; calculations are based on the average price for the year 2014.
Source: Natural Resources Canada, *Fuel Focus: Understanding Gasoline Markets in Canada and Economic Drivers Influencing Prices—2014 Annual Review*, January 23, 2015, p. 2.

R&D

Research and development of solutions to reduce GHG emissions is sometimes carried out by private companies, sometimes by public companies like Hydro-Québec or Ontario Power Generation, and sometimes by university research centres.

Various research centres and companies supported by governments concentrate on questions of clean energy,[93] like the NSERC/Hydro-Québec Industrial Research Chair in Energy Efficiency in Electrical Machines for Small Scale Renewable Energy Production Systems at Concordia University.[94] Collegiate initiatives also receive support, like the Industrial Research Chair for NSERC Colleges in Sustainable Energy Technology and Energy Efficiency.[95]

The federal government had also launched the Clean Energy Fund Program, which received $205 million for various research projects, including CO_2 capture and storage projects. The sums granted had been completely used up by March 31, 2012.[96]

93. Prime Minister of Canada, PM announces energy innovation projects across Canada, May 3, 2013.

94. Natural Sciences and Engineering Research Council of Canada, Chairholder Profile, Pragasen Pillay.
95. Natural Sciences and Engineering Research Council of Canada, Chairholder Profile, Martin Bourbonnais.
96. Natural Resources Canada, Clean Energy Fund Program, June 11, 2014.

Table 2-1

Government revenues from excise and sales taxes on fuel, 2014

REVENUE (MILLIONS OF DOLLARS)	TAXES ON GASOLINE	TAXES ON DIESEL
Federal government	**4,263.8**	**646.8**
Newfoundland and Labrador	**161.3**	**85.1**
Prince Edward Island	**26.2**	**16.0**
Nova Scotia	**152.5**	**75.3**
New Brunswick	**110.6**	**109.8**
Quebec	**1,646.9**	**833.9**
Ontario	**2,325.0**	**596.7**
Manitoba	**229.4**	**54.9**
Saskatchewan	**316.5**	**108.6**
Alberta	**605.8**	**298.8**
British Columbia	**1,009.1**	**366.8**
Territories	**2.6**	**14.0**
Municipalities	**281.8**	**18.6**
Total fuel taxes	**11,131.7**	**3,225.3**
Total sales taxes	**5,189.8**	**2,045.8**
Total government revenue	**16,321.6**	**5,271.1**
Total revenue		**21,592.6**

Source: Kent Marketing Services and Canadian Fuels Association, data provided to authors on demand.

Other subsidy programs exist, for example:

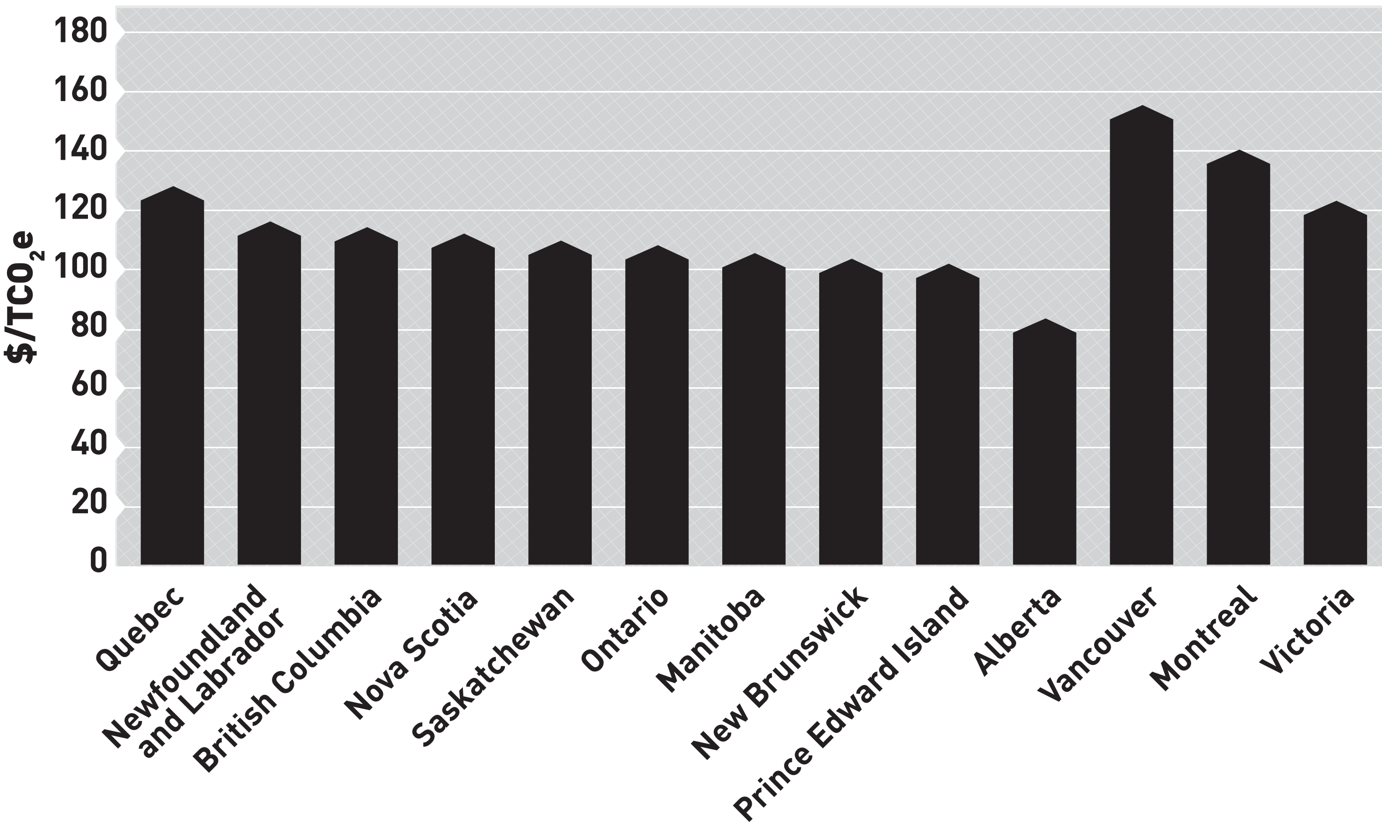
- The Program of Energy Research and Development (PERD) whose mandate is specifically to provide financial assistance to research and development "designed to ensure a sustainable energy future for Canada."[97]
- The ecoENERGY Innovation Initiative, whose goal "is to support energy technology innovation to produce and use energy in a cleaner and more efficient way." This initiative, according to the federal government, "is a key component of the Government of Canada's actions to achieve real emissions reductions."[98]

97. Natural Resources Canada, Program of Energy Research and Development, July 5, 2013.

98. Natural Resources Canada, The ecoENERGY Innovation Initiative, October 17, 2014.

Figure 2-5

Carbon taxes implicit in excise taxes



Source: Environment Canada, Fuel Combustion, Mobile Combustion, June 21, 2013 and authors' calculations.

The results of supported R&D projects are difficult to evaluate. Nonetheless, they are part of a process of constant innovation which leads to improvements in the energy intensity and carbon intensity of the economy, concepts which will be examined in some detail in the following chapter. Moreover, the Copenhagen Consensus Center asked several renowned economists to evaluate which social objectives should be prioritized on a planetary level, and the conclusion arrived at was that in the case of climate change, R&D represented the most efficient allocation of funds.[99]

The Production and Use of Renewable Energy

The GHG emissions associated with the production of electricity vary depending on the primary energy source that is transformed into electricity. Hydroelectric and nuclear power plants have negligible carbon footprints, whereas coal-fired power plants generate substantial amounts of emissions.

> **"Economists generally recognize that the price elasticity of demand for fuel, which measures the reaction of consumers to a price variation, is very low."**

99. Isabel Galiana, "Benefits and Costs of the Climate Change Targets for the Post-2015 Development Agenda," Copenhagen Consensus Center, 2014.

Other sources of less traditional energy, like solar and wind energy, arouse the interest of certain governments because they could lead to emission reductions.[100] This is why the production of electricity from so-called renewable energy sources is widely subsidized.

This is the case of the federal government's ecoENERGY for Renewable Power program, launched in 2007. This program grants subsidies of one cent per kilowatt-hour (kWh) to the production of electricity. The projects, which are subsidized for ten years, can use "wind, low-impact hydro, biomass, photovoltaic and geothermal energy." In all, the 104 qualified projects will receive $1.4 billion by 2021, and they represent 4,500 megawatts of installed power.[101]

"In all, governments collect nearly $22 billion in various fuel taxes."

It is provincial programs, though, that involve the largest sums. The Feed-In Tariff Program offered by the Ontario government for the production of renewable energy entailed a loss of $4.9 billion in 2014.[102] This program will contribute to there being an installed power of renewable energy of 10,700 megawatts by 2018. This enormous expense is borne, however, by Ontario consumers who are seeing their electricity bills grow. This cost is very real, whereas the results in terms of GHG reductions have not been clearly evaluated.[103]

Quebec, for its part, encourages renewable energy through contracts awarded by Hydro-Québec. The cost of these opaque programs is not rigorously evaluated, but it amounts to approximately $695 million a year, according to our calculations.[104] Once again, it is residential consumers and businesses footing the bill. Of course, given that the production of hydroelectricity accounts for 97% of total Quebec production,[105] the other renewable energy sectors have practically no impact on the province's GHG emissions.

These subsidies are among the most expensive, and therefore the least efficient, ways of reducing GHG emissions.[106] In particular, they have significant economic and social consequences. By raising the costs of electricity for the consumers who finance them, these subsidies generate energy poverty among the most vulnerable households. They also hurt the competitiveness of companies that see their rates go up. The European experience is telling. Several countries have had to shrink the subsidies they give out to producers of renewable energy.[107]

Finally, in terms of using renewable energy, subsidies exist for replacing oil heating systems with electrical heating systems[108] and for encouraging companies to turn away from fossil fuels.[109] Energy efficiency programs have also been set up by various government bodies and public corporations. For example, the Rénoclimat program targets the residential sector, offering financial support for renovations.[110]

Electric Car Subsidies

The electrification of transportation seems like a promising avenue for reducing the personal transportation sector's large and growing emissions. Here too, however, the assessment of existing programs is controversial. For example, in the case of the electrification of public transit, we're talking about emission reductions for methods of transportation that are already responsible for less emissions per passenger, with little room for improvement.

In the case of subsidies for the purchase of electric passenger vehicles, the effective reductions are very small. Over its lifecycle, an electric vehicle emits no GHGs dur-

100. Electricity generated by solar and wind energy also emits GHGs, when the entire lifecycles of technologies are taken into account. Daniel Nugent and Benjamin K. Sovacool, "Assessing the Lifecycle Greenhouse Gas Emissions from Solar PV and Wind Energy: A Critical Meta-Survey," *Energy Policy*, Vol. 65, 2014, pp. 229-244.
101. Natural Resources Canada, ecoENERGY for Renewable Power, June 29, 2015.
102. Independent Electricity System Operator, Global Adjustment - Archive, Global Adjustment Values – 2005-2014. This figure is approximate because the real cost of the program is not provided by the Ontario government, for which it was in fact reproached by the Auditor General in its 2013 report. See Auditor General of Ontario, *2013 Annual Report of the Office of the Auditor General of Ontario*, 2013, p. 309.
103. Auditor General of Ontario, *2011 Annual Report of the Office of the Auditor General of Ontario*, 2011, pp. 89, 94 and 119.
104. Youri Chassin and Guillaume Tremblay, "The Growing Cost of Electricity Production in Quebec," Economic Note, Montreal Economic Institute, June 2013.
105. Montreal Economic Institute, *Canada's Energy Profile in 40 Questions*, Question 27, 2014.
106. OECD, *op. cit.*, footnote 55.
107. Brady Yauch, "Governments rip up renewable contracts," *Financial Post*, March 18, 2014. The German Auditor General looked into the Energiewende (Energy Revolution) policy and concluded that it is poorly planned: See Stefan Maas, "Energiewende - schlecht geplant?" *Deutschlandfunk*, August 20, 2014.
108. Quebec Department of Energy and Natural Resources, Heating with Green Power.
109. Quebec Department of Energy and Natural Resources, Programme d'aide financière pour des projets d'efficacité énergétique et de conversion.
110. Quebec Department of Energy and Natural Resources, Rénoclimat.

Table 2-2

Cost of reducing one tonne of GHG emissions using different approaches

	NORWAY	QUEBEC
Electrification of transportation (Cost per tonne avoided)	**$6,925.00**	**$1,560.00**
Carbon market (Cost per tonne avoided)	**$10.39 (European carbon market*)**	**$17.98 (Western Climate Initiative)**
Number of tonnes avoided for the same amount	**666.4**	**86.8**

* The average exchange price for an emission allowance for one tonne of CO2 for 2015 at the time of writing was 7.40 euros per tonne, and the Bank of Canada's average exchange rate from January to September 2015 was 1.4043 Canadian dollars per euro.
Sources: Youri Chassin and Guillaume Tremblay, "Do We Need to Subsidize the Purchase of Electric Cars?" Economic Note, Montreal Economic Institute, November 2014; Quebec Department of Sustainable Development, Environment and the Fight against Climate Change and the California Environmental Protection Agency, "Système de plafonnement et d'échange de droits d'émission de gaz à effet de serre du Québec et programme de plafonnement et d'échange de la Californie—Vente aux enchères no 4 d'août 2015 : Rapport sommaire des résultats," August 25, 2015; Bank of Canada, Monthly Average Exchange Rates: 10-Year Lookup; EEX, Results EUA Primary Auction Spot—Download, Emission Spot Primary Market Auction Report 2015.

ing its use, but its manufacture leads to emissions that are twice as high as the manufacture of a traditional automobile.[111]

Norway is perceived as the country at the forefront of the electrification of transportation, with around 75,000 electric vehicles on the road in September 2015.[112] The numerous programs providing financial support to owners of electric vehicles include financial purchase assistance, a sales tax exemption, toll exemptions, and free parking areas. Each tonne of GHGs avoided, however, cost $6,925 in various subsidies, not including the GHGs emitted during the manufacture of the battery.[113] If Quebec imitated Norway, as it seems to want to do,[114] the government would pay out the equivalent of $1,560 in subsidies for each tonne of GHGs avoided.[115] By including the GHGs emitted during the manufacture of the battery, the results climb to over $100,000 per tonne of GHGs avoided in Norway[116] versus $1,910 for Quebec.

111. Troy R. Hawkins *et al.*, "Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles," *Journal of Industrial Ecology*, Vol. 17, No. 1, 2013, pp. 53-64.
112. Gronnbil, EVs in Norge, September 2015.
113. Because of the battery, the manufacture of an electric vehicle produces twice the emissions as the manufacture of a gasoline-powered vehicle. Troy R. Hawkins *et al.*, *op. cit.*, footnote 111.
114. Government of Quebec, Propelling Quebec Forward with Electricity, A Responsible Action Plan Providing Structure and Direction.
115. Youri Chassin and Guillaume Tremblay, "Do We Need to Subsidize the Purchase of Electric Cars?" Economic Note, Montreal Economic Institute, November 2014.
116. This is due to the small number of kilometres driven by the owners of electric vehicles in Norway.

We can see just how inefficient electrification of transportation policies are in fighting climate change by comparing the costs per tonne of GHGs avoided with the price of an emission allowance on the carbon market. Table 2-2 summarizes these comparisons and shows that the sums involved in the electrification of transportation can be used to reduce emissions much more efficiently.

"These subsidies are among the most expensive, and therefore the least efficient, ways of reducing GHG emissions."

E. Regulations

Governments also adopt laws and regulations concerning GHG emissions and fuels. For example, the government of Canada adopted a law on fuel consumption standards for motor vehicles.[117] The regulation imposes on automobile manufacturers an average fuel consumption for the vehicles they make.[118] Fuel savings are also a concern for drivers, especially when the price of gas is high. Automobile manufacturers therefore have a strong incentive to produce vehicles that are more and more fuel efficient, as we shall see in Chapter 3.

117. Government of Canada, *Motor Vehicle Fuel Consumption Standards Act*, 1985.
118. Martin Croteau, "Ottawa impose de nouvelles normes sur la consommation de carburant," *La Presse*, November 27, 2012.

The composition of gasoline is also regulated, for instance regarding the addition of at least 5% of ethanol in ordinary gasoline due to a federal regulation.[119] This renewable fuel is made primarily from corn and wheat in Canada, but it can be also made from other agricultural materials or from forestry waste.[120] This is a renewable fuel that emits less GHGs.

> **"We can see just how inefficient electrification of transportation policies are in fighting climate change by comparing the costs per tonne of GHGs avoided with the price of an emission allowance on the carbon market."**

However, we now know that the production of biofuels like ethanol from grains is very harmful both economically and environmentally. When its production, its lower energy density, and the performance it allows are all taken into account, ethanol does not provide any notable benefits in terms of reducing GHG emissions.[121] Furthermore, because a significant amount of it is made from cultivated grains, the use of ethanol leads to price increases for basic foodstuffs on global markets and entails negative financial and human consequences for the poorest populations, and also increases the use of land for agriculture.[122] Indeed, the Canadian government recognizes that the benefits of this regulation are outweighed by its costs.[123] The appreciable increase in its production in recent decades is therefore accompanied by numerous negative effects.

An original regulation adopted in Alberta in 2007 seeks to reduce the intensity of GHG emissions. The Specified Gas Emitters Regulation (SGER) applies to facilities emitting 100,000 tonnes or more of GHGs and requires them to reduce their emissions by 12% per unit of production compared to their average level for the period from 2003 to 2005. This target will be 15% next year and 20% in 2017. If these objectives are not met, a facility must offset its emissions with credits or by contributing to the Climate Change and Emissions Management Fund at a cost of $15 per tonne of GHGs. The current price will be gradually increased to $30 by 2017.[124]

This kind of regulation is not identical to a carbon market in its effects. Because it does not limit the level of emissions, but only their intensity, it cannot guarantee an absolute reduction. However, like other kinds of regulations, the SGER encourages private companies to measure their emissions and adopt industrial processes that are less carbon-intensive.

F. The Economic Impact of Governmental Measures

Governmental measures to fight climate change necessarily generate negative economic effects. Indeed, economic theory shows that since GHG emissions into the atmosphere constitute an externality, economic activity does not take them into account without regulation to this effect. Imposing limits on emissions or putting a price on them necessarily imposes an economic constraint that would not otherwise exist. Under this constraint, companies and individuals will have to make different choices than the ones they consider optimal and would have made barring such regulation.

The Montreal Economic Institute already published a *Research Paper* dealing specifically with the cost of an accelerated energy transition, as advocated by the environmentalist groups Équiterre and Vivre en ville[125]. The annual cost of $6.4 billion for the Quebec economy represented $1,875 per household. In a poll carried out be-

119. Environment Canada, Renewable Fuels Regulations, July 14, 2015; Petro-Canada, Looking for a Fuel That Fits Your Needs?
120. Natural Resources Canada, What is ethanol? November 19, 2014.
121. Erica Gies, "As Ethanol Booms, Critics Warn of Environmental Effect," *New York Times*, June 24, 2010; Xiaoyu Yan *et al.*, "Effects of Ethanol on Vehicle Energy Efficiency and Implications on Ethanol Life-Cycle Greenhouse Gas Analysis," *Environment Science Technology*, Vol. 47, No. 11, 2013, pp. 5535-5544; OECD, *op. cit.*, footnote 55: "The estimated carbon prices in the *road transport* sector also show considerable variation. The costs per tonne of CO_2eq abated are *very* high in certain cases; exceeding EUR 1000 per tonne for some policies related to the promotion of biofuels."
122. Rafael E. De Hoyos and Denis Medvedev, "Poverty Effects of Higher Food Prices: A Global Perspective," World Bank, Policy Research Working Paper 4887, 2009, p. 23; Indur M. Goklany, "Could Biofuel Policies Increase Death and Disease in Developing Countries?" *Journal of American Physicians and Surgeons*, Vol. 16, No. 1, 2011, pp. 9-13.
123. The federal government's cost-benefit analysis indicates that the present value of the estimated benefits amount to $1.1 billion based on the reduction of GHG emissions. As for the present value of the costs, these are estimated at $4.8 billion. Environment Canada, Federal Renewable Fuels Regulations: Overview, April 21, 2015.
124. Alberta Environment and Parks, Industrial Emissions Management, October 13, 2015.
125. Youri Chassin and Germain Belzile, *Can We Get Rid of Oil? The Costs of an Accelerated Energy Transition*, Research Paper, Montreal Economic Institute, December 2014.

fore the appearance of this publication, only 12% of Canadians were ready to pay over $1,500 a year in order to reduce oil consumption in Canada.[126]

Several activist groups have found it difficult to convince populations to consent to significant economic sacrifices in order to fight climate change. This explains why they now prefer to state that the fight against climate change will not harm the economy, and would even have a positive effect on economic growth.[127] Unfortunately, their reasoning is incomplete and illogical.[128] This kind of analysis generally stresses the creation of subsidized jobs, without however taking into account the jobs destroyed by the taxes that serve to finance these subsidies. Sometimes, reductions of oil imports are stressed, but without mentioning that these imports serve a purpose in transportation, nor that the alternative has a necessarily higher economic cost.

Recognized institutions, though, make the opposite argument in order to convince governments to intervene more. In short, they state that there is a large cost associated with future mitigation efforts in the absence of immediate actions. This argument speaks to the economic costs inevitably associated with the binding reduction of GHG emissions. A report produced as part of the World Bank's initiative on climate change mentions, for example, that:

> The International Energy Agency (IEA) has warned, and numerous energy system modelling exercises have confirmed, that unless urgent action is taken very soon, it will become extremely costly to reduce emissions fast enough to hold warming below 2°C.[129]

It is therefore dishonest to declare that the economic constraints imposed to fight against climate change would not immediately harm the economy. The new economic activities that are developed in response to subsidies, regulations, or fiscal levers will certainly add to economic growth. They will not, however, fully offset the economic activities lost elsewhere in the economy due to these same measures. In other words, if it is possible to achieve greater economic vigour under some new constraint, it is necessarily possible to achieve it without this constraint, and economic agents will do so anyhow.

Certain actions with beneficial economic effects, even in the short term, also have the effect of reducing GHG emissions. When one saves expensive energy through energy efficiency, the investment can be cost-effective.[130] Reducing GHG emissions from a source can also reduce other polluting emissions and thereby improve air quality.[131] In such cases, the potential benefits themselves justify the costs of the required investments, without the need to impose any constraints. The reduction of GHG emissions associated with these measures thus constitutes an additional benefit of economic or environmental decisions that are profitable in themselves—a side effect of sorts.

> **"The production of biofuels like ethanol from grains is very harmful both economically and environmentally."**

While there is no doubt about the short-term cost of government constraints, it can nonetheless be economically beneficial to impose some in order to reduce GHG emissions in the long term.[132] Governmental measures can therefore be deemed useful or necessary if the benefit of reducing emissions in terms of general well-being and future economic prosperity is superior to the negative economic impact of such measures.

This is a classic cost-benefit analysis, but one that includes an appreciable degree of uncertainty. Current scientific knowledge is based on several hypotheses and models to establish estimates that are the best guidelines for the adoption of public policies. Technical—but crucial—variables included in the models are constantly being studied to specify the estimates made by scientists and economists: demographic and economic

126. Léger, "A Study of Canadian Support for Measures to Reduce Oil Consumption," Opinion poll carried out on behalf of the Montreal Economic Institute, November 2014.
127. Philippe Bourke, "Remettre les changements climatiques à l'ordre du jour," *La Presse+*, September 11, 2015; Greenpeace, *Green Is Gold: How Renewable Energy Can Save Us Money and Generate Jobs*, 2013; Pembina Institute and David Suzuki Foundation, *Climate Leadership, Economic Prosperity: Final Report on an Economic Study of Greenhouse Gas Targets and Policies for Canada*, 2009.
128. The rhetoric of green growth and low mitigation costs is criticized within the scientific community. See for example Kevin Anderson, "Duality in Climate Science," *Nature Geoscience*, October 12, 2015.
129. World Bank, *Turn Down the Heat: Confronting the New Climate Normal*, 2014, p. xviii. The IPCC also explicitly recognizes this reality. See R. K. Pachauri *et al., Climate Change 2014: Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2014, p. v.
130. World Bank and ClimateWorks Foundation, *Climate-Smart Development: Adding Up the Benefits of Actions That Help Build Prosperity, End Poverty and Combat Climate Change*, 2014, pp. 1 and 8.
131. Johannes Bollen *et al., Co-Benefits of Climate Change Mitigation Policies: Literature Review and New Results*, OECD, Economics Department Working Papers No. 693, April 2009, p. 6.
132. This may be the case due to the temporal myopia of actors, or because GHG emissions are a negative externality. See William D. Nordhaus, *The Climate Casino: Risk, Uncertainty, and Economics for a Warming World,* Yale University Press, 2015.

trends, carbon intensity, the absorption of the oceans, anthropogenic radiative forcing, equilibrium climate sensitivity, etc. The Annex to this *Research Paper* provides, for the interested reader, an overview of the uncertainty associated with the IPCC's approach and the work of economists, as well as the impact of this uncertainty on cost-benefit analyses.

Uncertainty is not a justification for inaction, though, since the estimated probability of major catastrophes in case of a large amount of warming is not zero. The prudent approach, in such a case, is to take on insurance, just as we insure ourselves against disasters that, while certainly improbable, have consequences that are terrible.[133]

Unfortunately, very few studies quantify the socio-economic harm associated with increases of more than 3°C in order to determine the costs of global warming, as shown by the IPCC's reviews.[134] And the estimates we do have are sometimes controversial. The British economist Nicholas Stern attempted to determine the costs of climate change and concluded that it would be more expensive not to act. His eponymous report,[135] however, was heavily criticized.[136] Among his critics is William D. Nordhaus of Yale University. He demonstrates that the conclusions of the Stern Report are highly dependent on certain unrealistic hypotheses like the discount rate and a specific utility function.[137] Beyond this economic jargon, Nordhaus's conclusion is that the Stern Report is too alarmist.

Nordhaus's argument is based on Richard Tol's review attempting to measure the costs and benefits of climate change in the long term. His conclusion, which is in agreement with the recent studies addressing this question, is that warming on the order of 1°C to 2°C would probably generate positive effects overall.[138] He takes into account the numerous studies attempting to show that modest global warming, of the kind we will experience from now until the end of the century, will entail among other things an increase in agricultural productivity.[139] However, he also states that the overall impact of climate change will be negative in the longer term, when the 2°C threshold is surpassed.[140] This estimate contradicts the omnipresent rhetoric, according to which every negative event is perceived as a symptom of climate change, and shows the importance of a more qualified assessment.

Given the uncertainty surrounding this question, it is likely that the debates surrounding the evaluation of the consequences of climate change will remain lively.

> **"This kind of analysis generally stresses the creation of subsidized jobs, without however taking into account the jobs destroyed by the taxes that serve to finance these subsidies."**

G. Three Principles for Sound Public Policies

Circumstances in each country influence the political debate and the solutions that are adopted. Even without proposing one-size-fits-all solutions, certain lessons can be drawn from existing experiments that could inspire the world's governments. At least three interrelated principles stem from this exercise: effectiveness, tax neutrality, and a minimal economic burden.

The Effectiveness of GHG Reduction Policies

Among the broad range of so-called "green" policies for sustainable development or the fight against climate change, there are a number of initiatives that sometimes have only a tenuous link with the goal of reducing GHG emissions. Yet sound public policy should always be effective, and in the context of climate change, effectiveness means reducing GHG emissions.

133. Martin Weitzman, "Some Basic Economics of Climate Change," in Jean-Philippe Touffut, *Changing Climate, Changing Economy*, Edward Elgar, 2009; Robert S. Pindyck, "Climate Change Policy: What Do The Models Tell Us?" *Journal of Economic Literature*, Vol. 51, No. 3, 2013, pp. 860-872.
134. Douglas J. Arent *et al.*, "Key Economic Sectors and Services," in Christopher B. Field *et al.* (eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects, Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2014, p. 690.
135. Nicholas Stern, *The Economics of Climate Change: The Stern Review*, Cambridge University Press, 2007.
136. Martin Weitzman, "A Review of *The Stern Review on the Economics of Climate Change*," *Journal of Economic Literature,* Vol. 45, No. 3, 2007, pp. 730-724.
137. "An examination of the Review's radical revision of the economics of climate change finds, however, that it depends decisively on the assumption of a near-zero time discount rate combined with a specific utility function. The Review's unambiguous conclusions about the need for extreme immediate action will not survive the substitution of assumptions that are consistent with today's marketplace real interest rates and savings rates." William D. Nordhaus, "A Review of the 'Stern Review on the Economics of Climate Change'," *Journal of Economic Literature*, Vol. 45, No. 3, 2007, pp. 686-702.
138. Richard S. J. Tol, "The Economics Effects of Climate Change," *Journal of Economic Perspectives*, Vol. 23, No. 2, 2009; Richard S. J. Tol, *Economic Impacts of Climate Change*, Economics Department, University of Sussex, Working Paper Series, No. 75-2015, 2015.
139. *Idem*; William D. Nordhaus, *op. cit.*, footnote 132, p. 83.
140. *Op. cit.*, note 138; William D. Nordhaus*, op. cit.*, footnote 132, p. 141.

The corollary of the principle of effectiveness is that reductions should be obtained at the lowest possible cost. If better results can be achieved at the same cost, the policy that was implemented is necessarily not as efficient as it could have been.

To ensure that policies are effective, it is crucial to assess the programs and actions arising from them. Without this type of assessment, it is not possible to tell the good policies from the bad. Yet continuous policy improvement should be vital in an uncertain context in which the results of each action need to be maximized.

For politicians, though, such assessments can be a harsh test. There is sometimes a wide gap between government talk and government actions. Announcing ambitious goals costs little, but fulfilling them can sometimes be much harder if it requires going back on other promises or displeasing certain social actors. The environment and the fight against climate change are two themes about which there has been plenty of political posturing. Serious evaluations would reveal that results may fail to measure up.

The Tax Neutrality of Measures with a Financial Impact

Governments that introduce carbon taxes or carbon markets to limit GHG emissions should avoid treating the revenue thereby generated as additional funds that are available to finance new programs. Even if the new spending is connected to fighting climate change, the revenue from carbon pricing results in poorer households and harms the competitiveness of business.

Like British Columbia's carbon tax, any financial instrument should be revenue neutral. Reductions in personal or corporate income taxes, lower social security contributions, or even an increase in refundable tax credits for low-income households are ways of keeping consumers' purchasing power from falling. In this way, tax neutrality is a way of mitigating the adverse economic impacts of these taxes, especially for the less fortunate, since energy taxes are often regressive.[141]

When governments seek to keep this revenue, we run the risk that these extra funds will be used to finance ineffective projects or to compensate companies or industrial sectors that have the ear of government, or that they will be diverted from their intended purpose. When new funds replace other spending in projects that would have existed anyway, these funds are being indirectly diverted from their goals.

Keeping the Economic Impact to a Minimum

Reducing economic growth would be counterproductive in the fight against climate change. On the contrary, adequate resources are needed to sustain the innovations required for reducing emissions. A level of economic activity suppressed by too many rules and taxes would not generate the tax revenue that governments expect nor the corporate sales income from which R&D is financed. As we shall see in Chapter 4, economic prosperity is also a vital factor in the absolutely necessary adaptation to climate change.

> **"To ensure that policies are effective, it is crucial to assess the programs and actions arising from them."**

In addition to tax neutrality, other aspects of policy should be adjusted with the aim of limiting the adverse economic impact from binding emission reductions. The simplicity of regulations, for example, provides a more straightforward way of complying and gives companies clearer rules. Complicated rules are often contested in court or are applied arbitrarily, creating uncertainty that is inimical to economic prosperity.

In the economic jargon, tax levers create "economic distortions," meaning that they alter people's decisions. In the context of carbon pricing, the aim is precisely to create a distortion, but only in the single area of GHG emissions. The potential for unwanted distortions must therefore be reduced. For example, the various sectors of the economy should be treated as equally as possible. However, this central principle bumps up against the reality of certain industries being more exposed to international competition, in particular from companies that are not subject to similar regulations, and governments do not want to see these industries disappear.

Other constraints must necessarily be considered, to abide both by the effectiveness principle and by the principle of limited economic impact. First of all, gasoline prices already consist largely of taxes, as we have seen. We also need to look at current policies elsewhere. Otherwise, an overly demanding policy will lead to carbon leakage through the relocation of high-emis-

141. Congressional Budget Office, "Trade-Offs in Allocating Allowances for CO_2 Emissions," Economic and budget issue brief, 2007; John Hills, *Getting the Measure of Fuel Poverty: Final Report of the Fuel Poverty Review*, CASE report 72, 2012, p. 8.

sion industrial activity. This leakage may artificially improve the emissions record of a given jurisdiction without, however, reducing emissions worldwide.

Given the need to limit distortions, and due to the constraints that exist, governments cannot very well impose a very high price on carbon. Generally speaking, a key strength of a carbon tax or carbon market is precisely that it can limit distortions other than those being sought. The simplest and least expensive emission cuts are selected by market interactions. Reduction targets do not have to be fleshed out through action plans detailing the means to be adopted in every institution and every business.

"Tax neutrality is a way of mitigating the adverse economic impacts of these taxes, especially for the less fortunate, since energy taxes are often regressive."

This is what makes these market mechanisms so powerful: Their effectiveness is maximized and their economic impact is minimized (although it may be high in absolute terms if the carbon price is high). When the amount of the tax is known for the years to come, for example by announcing planned annual increases in advance, it gives the various economic sectors an incentive to innovate, to invest in R&D, and to find solutions. This does not mean that companies are not doing this already. Governments are not alone in acting to meet political demands from their electors. Companies also attempt to meet the demands of their consumers, as we shall see in the next chapter.

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CHAPTER 3

The Innovations That Are Revolutionizing Our Energy Consumption

At international negotiations on climate change such as those at the Paris Conference, the centralized, top-down approach is favoured. Similarly, when governments impose regulations or hand out subsidies, decisions are also centralized. As we saw in the previous chapter, however, policies using market mechanisms are more efficient precisely because they allow for decision-making to be decentralized.

One encouraging but largely overlooked trend is taking shape in businesses and institutions: that of constantly innovating to meet the public desire for limits on GHG emissions. This chapter deals with the new realities that could very well change the picture of GHG emissions over the coming years and decades.[142] Though their impact may sometimes be hard to measure since they are not determined by governments, emerging decentralized solutions can be particularly effective.

This trend can be seen more clearly when we focus less on the overall emissions level and more on the factors that determine this level, such as energy intensity and carbon intensity. Per capita GHG emissions in various countries around the world can be seen as the result of a combination of three factors: standard of living, energy intensity, and carbon intensity. This is presented in the Kaya identity, an equation used by the IPCC for GHG emissions scenarios, which can be represented schematically as follows:

GHGs/capita = Standard of living (GDP/Population) X Energy intensity (Energy/GDP) X Carbon intensity (Emissions/Energy)

This equation shows that the growth of GHG emissions depends on the variation of each of these factors. Adopted and proposed government policies on the mitigation of GHG emissions aimed at limiting climate change impose a price directly on carbon through a tax or an emission allowance trading market, for example. Government-imposed environmental regulations and standards influence one factor in greenhouse gas emissions, namely carbon intensity. The same can be said for renewable energy subsidies.

Market mechanisms, in contrast, affect greenhouse gas emissions by fostering wealth creation—in other words, by raising living standards—but also by influencing energy intensity and carbon intensity.

Reducing Energy Intensity Around the World

Various markets, through the incentives provided by price mechanisms, allow for resources—among them, energy—to be allocated optimally based on the needs of the members of society. In meeting the demands of their customers, businesses naturally seek to minimize their costs, and therefore to the least possible resources and energy per unit produced. Our ability to do more with less energy, or the capacity to perform the same amount of work with less energy, is what the International Energy Agency (IEA) calls "energy efficiency."[143]

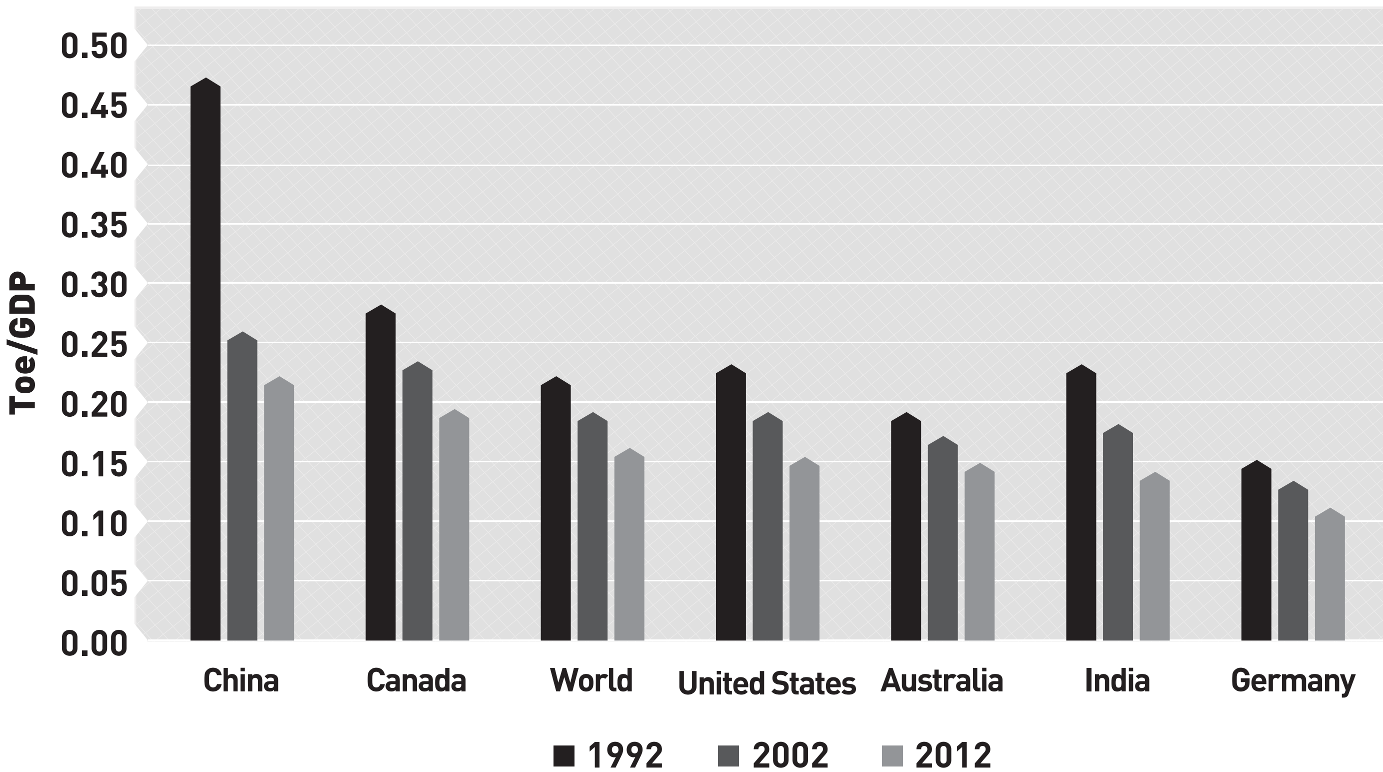
Energy intensity, which measures the quantity of primary energy used per unit of GDP, provides a good estimate of energy efficiency. The more efficient an economy is, the less energy it uses per dollar of GDP. Figure 3-1 shows that energy intensity falls with economic development, among both rich and emerging countries. China's progress in this regard has been spectacular, with energy intensity having been reduced by half in 20 years. At the global level, energy intensity fell at an annual pace of 1.25% between 1990 and 2013.[144]

142. Agence France-Presse, "Dix poids lourds du pétrole et du gaz s'unissent pour le climat," *La Presse*, October 16, 2015.

143. International Energy Agency, Energy efficiency.
144. Ren21, *Renewables 2015 Global Status Report*, 2015, p.114.

Figure 3-1

Energy intensity in tonnes of oil equivalent per thousand U.S. dollars, 1992-2012



Note: These are 2005 US dollars, adjusted for purchasing power parity.
Sources: International Energy Agency, Statistics, Report; International Energy Agency, *Energy Efficiency Market Report 2014: Market Trends and Medium-Term Prospects*, 2014, p. 210.

Energy intensity is not a perfect measure of energy efficiency since it does not take account of the structure and size of the economy nor of a region's climate. For example, a service-based economy in a mild climate will have lower energy intensity than a manufacturing-based economy in a cold climate, even though it is possible that it uses its energy less efficiently.[145]

The IEA has been attempting for the past few years to calculate energy efficiency more precisely. It estimates how high energy consumption would have been if wealth and population had grown at the same pace but without technological advances to improve energy consumption in buildings, machines, vehicles and even electric light bulbs.[146]

The amount of energy saved through efficiency gains using new approaches is substantial. The IEA estimates that in 2011, for an 11-country sample, total energy consumption avoided through technological improvements since 1973 amounted to 1,337 million tonnes of oil equivalent. As indicated in Figure 3-2, this saving is greater than the final consumption of any single form of energy.

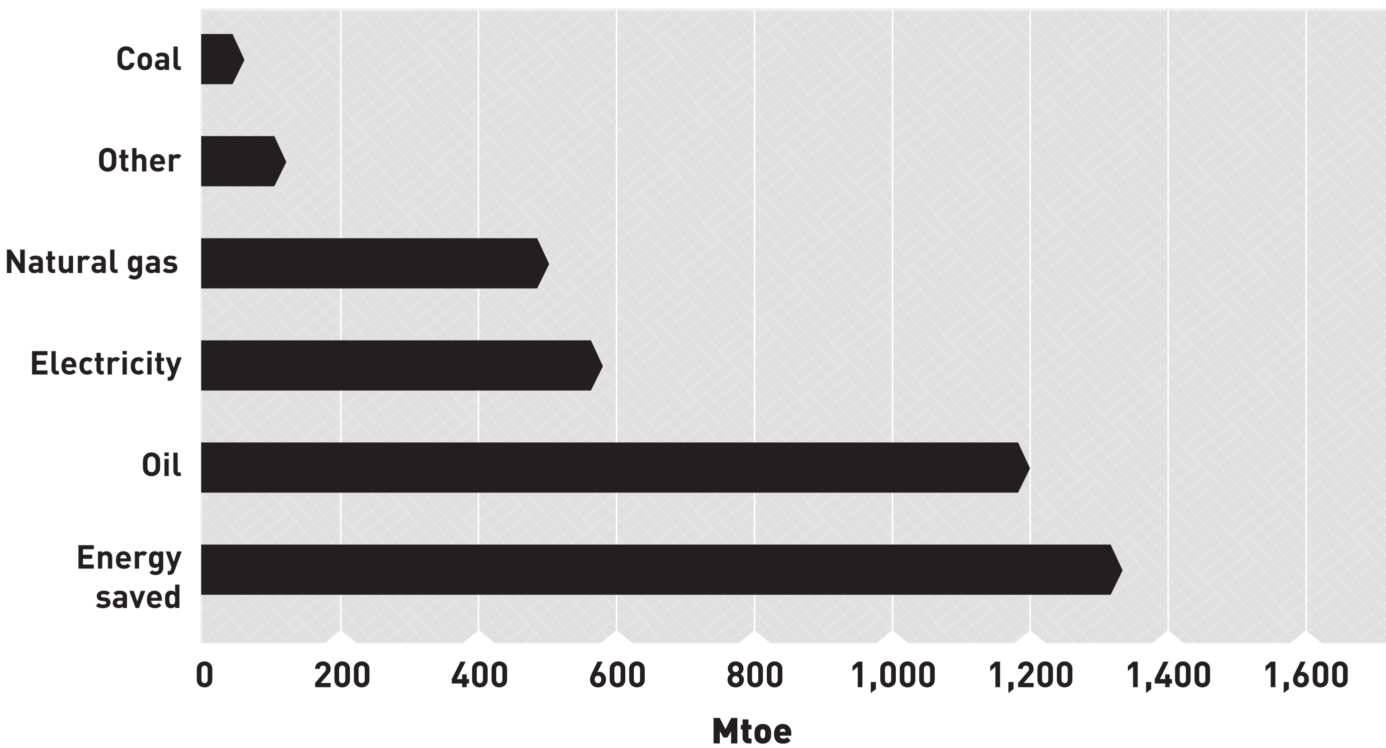
"One encouraging but largely overlooked trend is taking shape in businesses and institutions: that of constantly innovating to meet the public desire for limits on GHG emissions."

These efficiency gains have two contradictory effects on greenhouse gas emissions. First, a smaller quantity of energy per unit of production obviously results in lower emissions, all else being equal.

145. International Energy Agency, *Energy Efficiency Indicators: Fundamentals on Statistics*, 2014, p. 19.
146. International Energy Agency, *Energy Efficiency Market Report 2014: Market Trends and Medium-Term Prospects*, 2014, p. 26.

Figure 3-2

Energy saved due to efficiency gains compared to consumption of various forms of energy, in millions of tonnes of oil equivalent, 2011



Note: The 11 countries evaluated are Australia, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Sweden, the United Kingdom and the United States.
Source: International Energy Agency, *Energy Efficiency Market Report 2014: Market Trends and Medium-Term Prospects*, 2014, pp. 26-27.

However, using less energy per unit of production does not necessarily mean that less energy will be used. The energy that is freed up also allows for more to be produced with the same quantity of resources. This increased production can therefore offset the effect of the efficiency gains, in whole or in part. Energy saved and used for other purposes is a phenomenon that economists call the "rebound effect." Various IEA reports estimate that this rebound effect would be on the order of between 9% and 30%,[147] but it could be higher.[148]

"Efficiency gains in the automobile market represent a trend that can be seen all around the world."

It is also possible that more energy is used because efficiency gains make it more abundant and reduce its marginal cost of use. The total effect on GHG emissions into the atmosphere is therefore uncertain.

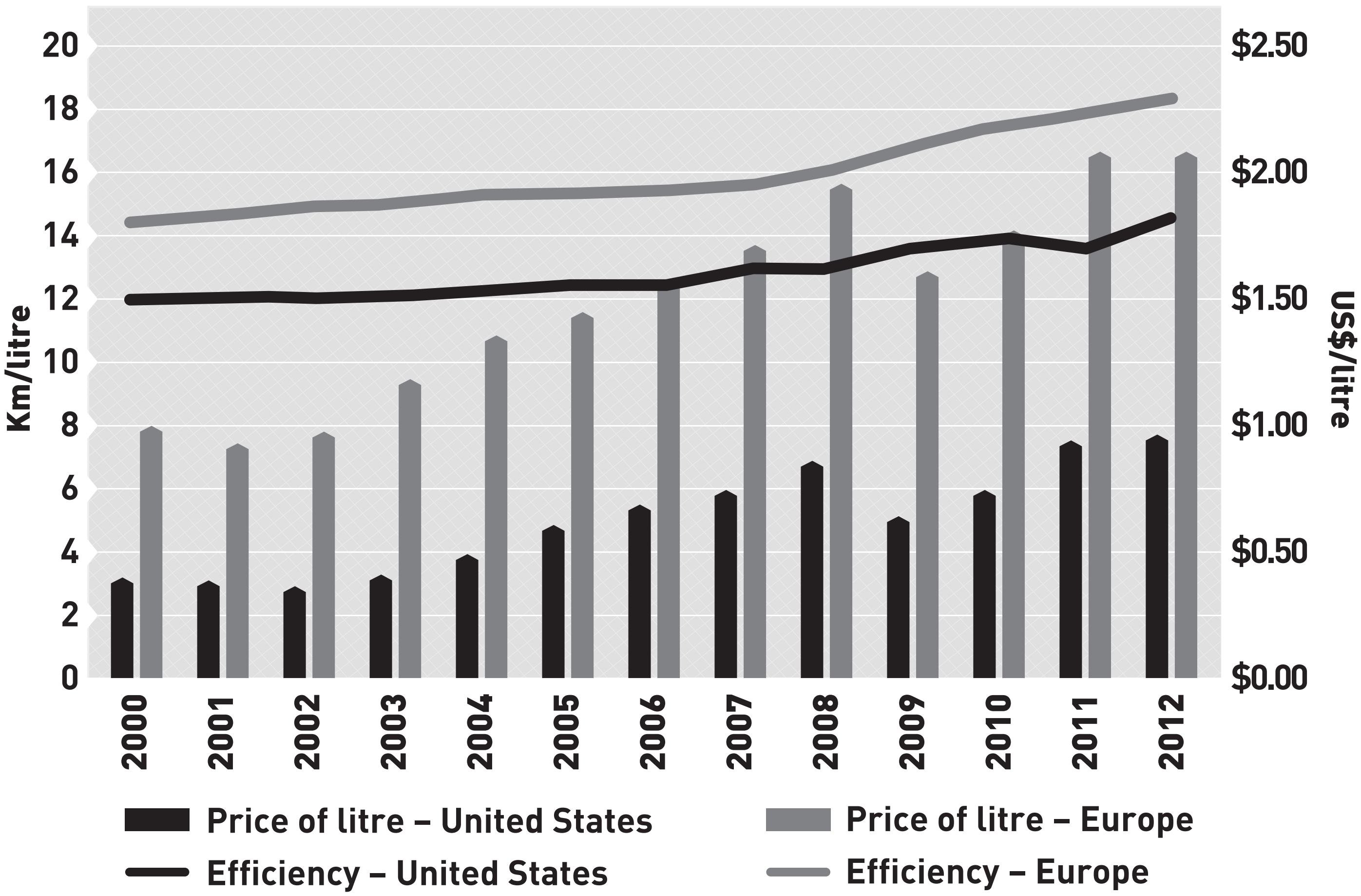
The energy intensity of automobiles provides a tangible illustration of a high rebound effect, which may even exceed 100%. Technological advances in recent decades, including in the choice of materials, have greatly reduced the amount of energy needed to travel a given distance. However, in the United States, the energy savings resulting from this improved efficiency were more than offset by the purchase of heavier, more powerful vehicles and by greater annual distances travelled. American vehicles therefore consumed 35% more energy in 2000 than in 1980 despite greater efficiency.[149]

147. *Ibid.*, p. 27.
148. Harry D. Saunders, "Recent Evidence for Large Rebound: Elucidating the Drivers and Their Implications for Climate Change Models," *The Energy Journal*, Vol. 36, No. 1, 2015, pp. 23-48.

149. Vaclav Smil, *Energy at the Crossroads: Global Perspectives and Uncertainties*, The MIT Press, February 2005, p. 333.

Figure 3-3

Gasoline prices and average vehicle efficiency in Europe and the United States



Sources: The International Council on Clean Transportation, Global Transportation Roadmap Model, Data Tables, August 2015; European Environment Agency, Nominal and real fuel prices, July 2015; U.S. Energy Information Administration, Petroleum and Other Liquids, Data, U.S. All Grades All Formulations Retail Gasoline Prices, 2015; CanadianForex, Yearly Average Exchange Rates for Currencies.

Efficiency gains in the automobile market represent a trend that can be seen all around the world.[150] It is hard to tell for sure, however, whether government-imposed standards play a greater role than consumer demand for more efficient vehicles, which is influenced by generally increasing gasoline prices.

Figure 3-3 illustrates the evolution of gasoline prices in Europe and the United States as well as the average energy efficiency of vehicles, measured in kilometres travelled per litre of gasoline. It is no surprise that cars purchased in Europe go 26% further per litre than cars purchased in the United States, given that the price of gasoline was on average 137% higher there from 2000 to 2012.

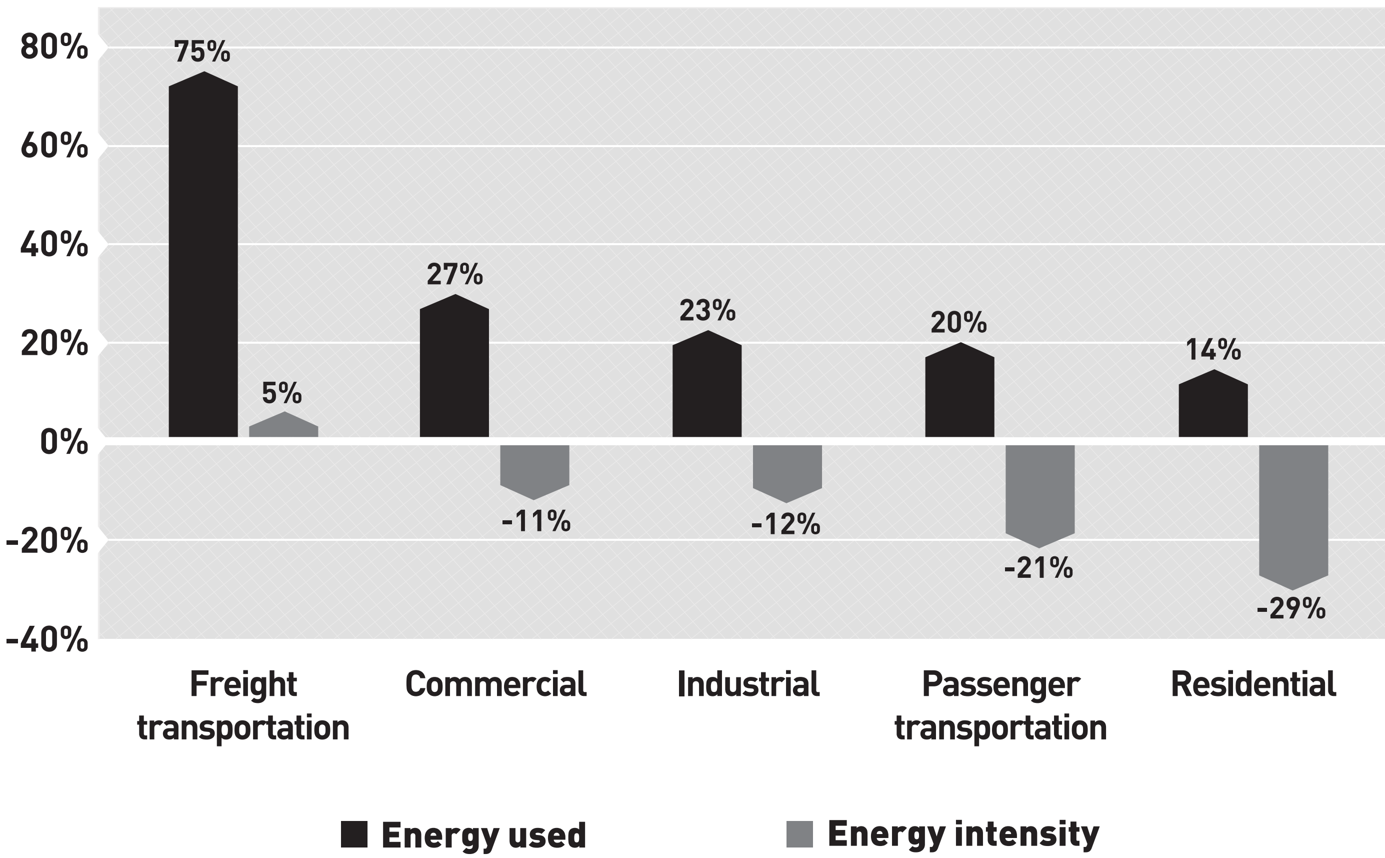
The trend toward greater energy efficiency applies to many sectors in Canada. Figure 3-4 shows the relationship between energy used and energy intensity in Canada in industry (forestry, mining, manufacturing, construction) and in the residential and commercial sectors, as well as in personal and commercial transportation. We can see that the bigger the drop in energy intensity (due to efficiency gains), the smaller the rise in total energy used. This trend demonstrates the importance of being more energy-efficient, regardless of how big the rebound effect may be.

Nevertheless, wealth and population increases, and to a lesser extent the rebound effect, help explain why global energy consumption has increased substantially over the past 40 years despite efficiency gains.

150. International Energy Agency, *op. cit.*, footnote 146, p. 72.

Figure 3-4

Variation in energy used and energy intensity by sector in Canada, 1990-2011



Source: Natural Resources Canada, *Energy Markets: Fact Book — 2014-2015*, p. 88.

Comparing changes in primary energy consumption between industrialized and emerging countries allows us to understand why an international climate agreement will necessarily have to include the latter. China and India have seen their primary energy consumption rise 957% and 736% respectively since 1974, while the increase has been far more modest in industrialized countries. In Germany, there was even a 6% decline in consumption over the same period (see Figure 3-5).

In Western countries, primary energy consumption has been fairly stable over the past 15 years (see Figure 3-6). Moreover, this trend should continue according to the IEA, which forecasts for example that "industrialized countries will consume no more oil in 2020 than they do today."[151]

Likewise, per capita primary energy consumption in industrialized countries has been stagnating or even declining since the early 1970s (see Figure 3-7). As the IEA remarks with unusual optimism, "the technological and economic context has changed, and that changes everything."[152] Tough environmental standards, the effect of the Internet on retail trade, and the aging of the population—older people use cars less—are three factors identified as significant and positive trends.[153]

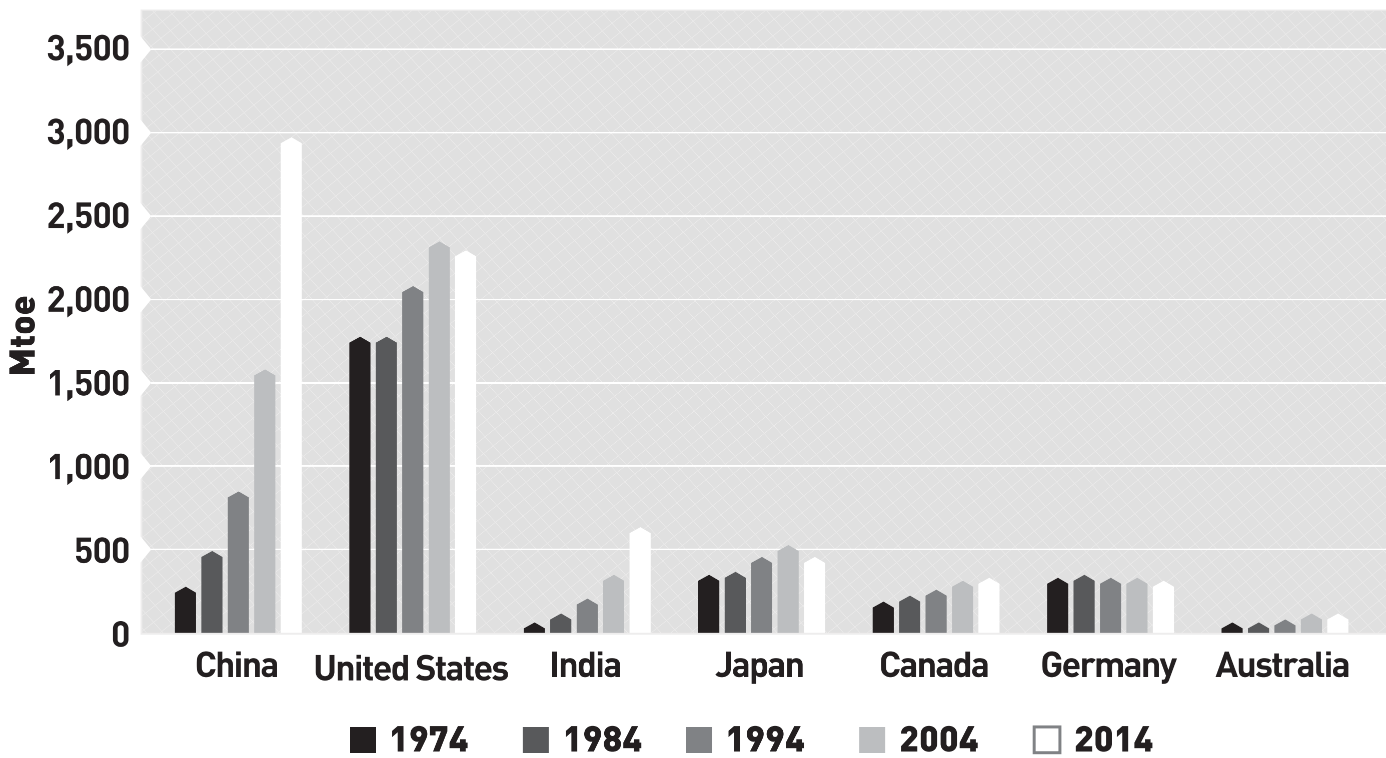
> **"It is encouraging to note that more efficient ways of using energy result in a tendency for per capita energy use to stabilize with prosperity."**

151. André Pratte, "Le monde change… lentement," *La Presse*, February 10, 2015.

152. *Idem.*
153. *Idem.*

Figure 3-5

Change in primary energy consumption in millions of tonnes of oil equivalent, 1974-2014



Source: BP, Data Workbook – Statistical Review 2015, Primary Energy: Consumption – Mtoe (from 1965), June 2015.

It is thus encouraging to note that more efficient ways of using energy result in a tendency for per capita energy use to stabilize with prosperity. Moreover, starting at a certain level of wealth, average household size declines, which has the effect of putting a break on population growth,[154] and therefore on emissions.

The reduction of energy intensity and its positive impact on emissions do not tell the whole story, however. It is also necessary to measure the emissions produced compared to the energy used.

Carbon Intensity Depends on Which Forms of Energy Are Used

Carbon intensity is defined as the ratio of carbon dioxide emissions per unit of energy used. Technological change and the price of energy resources play a predominant role in choosing which form of energy to use, and therefore in carbon intensity. All other things being equal, we will use the resources that provide us with a given amount of energy at a lower cost. The natural resources that are the most advantageous to use therefore determine the level of GHG emissions related to energy consumption.

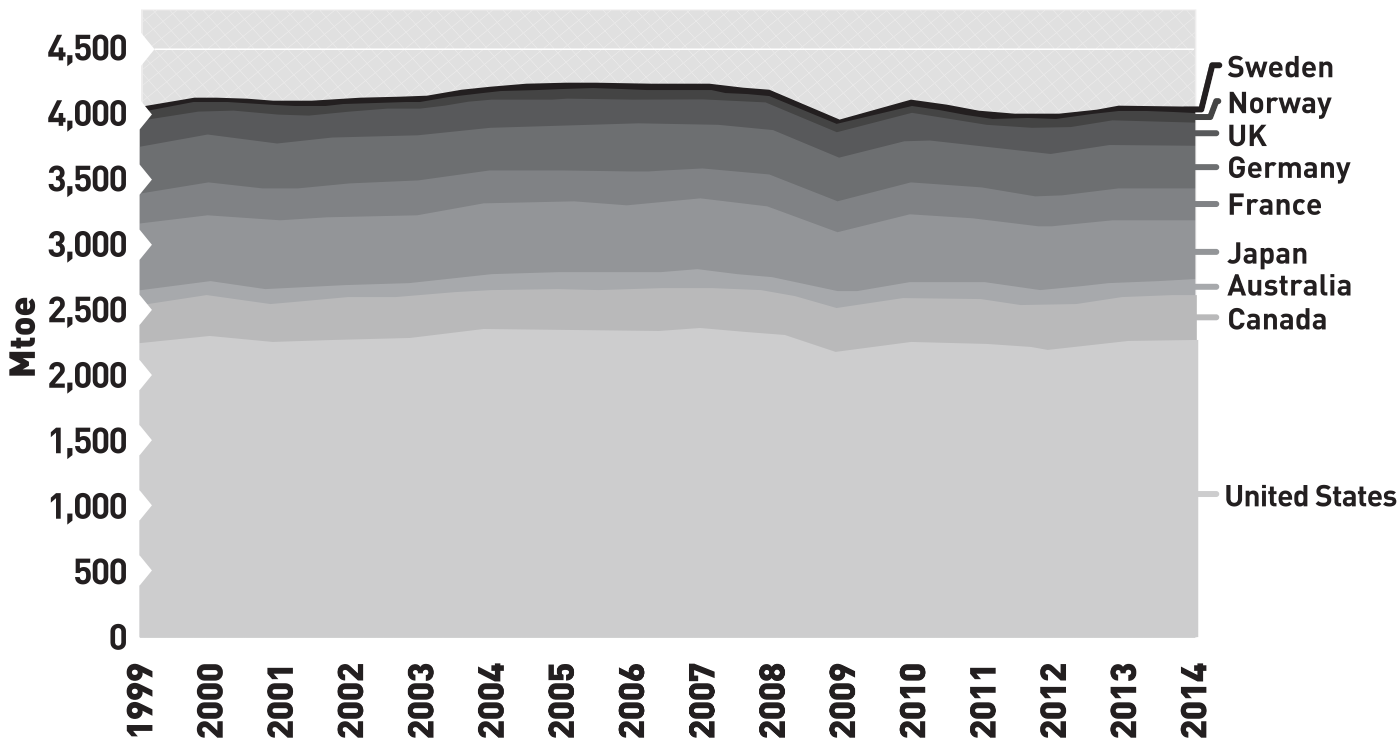
> **"A true energy revolution is underway, and it could pick up steam with the increased use of carbon-neutral energy sources and technologies."**

Large-scale coal use began around the middle of the 19th century, marking the start of the current era in which fossil fuels have almost completely replaced renewable energy. Indeed, prior to the massive use of fossil fuels, most societies depended on the burning of biomass (wood twigs, crop residues, and manure), wind energy (sailboats and windmills) and hydraulic power (watermills) to complement human and animal muscle

154. Indur M. Goklany, *The Improving State of the World: Why We're Living Longer, Healthier, More Comfortable Lives on a Cleaner Planet*, Cato Institute, 2007.

Figure 3-6

Change in primary energy consumption in industrialized countries in millions of tonnes of oil equivalent, 1999-2014



Source: BP, Data Workbook – Statistical Review 2015, Primary Energy: Consumption – Mtoe (from 1965), June 2015.

power.[155] The economic growth brought on by the coal revolution was accompanied by a proportionate increase in GHG emissions.[156]

The fact that coal remains the cheapest source of electricity is not unrelated to the staggering growth in coal consumption in recent decades. Coal was partly replaced by oil and natural gas in the early 20th century, but for several decades, consumption of coal has increased more quickly than that of other fossil fuels.[157] Since 2004, CO_2 emissions from the burning of coal have exceeded those from oil (see Figure 3-8).

It is therefore no surprise that the economies of emerging countries, whose growth continues to depend on coal, show rising carbon intensity. As Figure 3-9 shows, China[158] and India emit more CO_2 per unit of energy used than in the early 1970s, in contrast with industrialized countries, which are emitting less.

The five countries with the fastest growth in CO_2 emissions per kg of oil equivalent in the period from 1971 to 2011 are Cameroon, Angola, Benin, Vietnam and Nepal, all of which are developing countries (see Figure 3-10). These five countries have seen their energy intensity increase by an average of 188%, while the euro zone, Canada and the United States have reduced their energy intensity by 15%, 6% and 3% respectively during the same period.

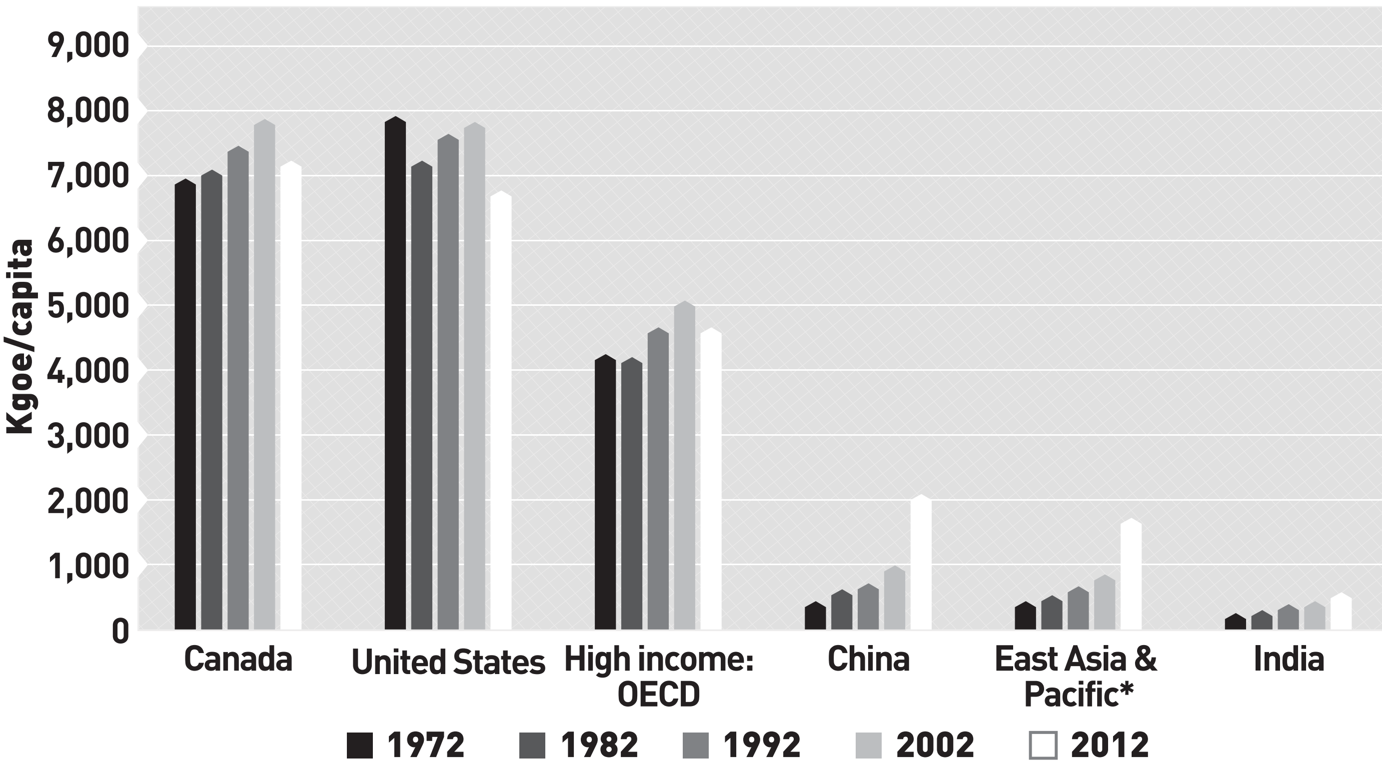
Technological change and new approaches can also have a positive impact on GHG emissions. In the United States over the past 10 years, hydraulic fracturing and horizontal drilling have allowed for the exploitation of

155. Pierre Desrochers and Hiroko Shimizu, *Innovation and the Greening of Alberta's Oil Sands*, Research Paper, Montreal Economic Institute, October 2012, p. 9.
156. Indur M. Goklany, "Humanity Unbound: How Fossil Fuels Saved Humanity from Nature and Nature from Humanity," Policy Analysis No. 715, Cato Institute, December 2012, p. 3.
157. BP, Statistical Review—Data Workbook, June 2015.

158. However, coal consumption and production in China fell by 2.9% and 2.5% respectively in 2014. See Timothy Puko and Chuin-Wei Yap, "Falling Chinese Coal Consumption and Output Undermine Global Market," *The Wall Street Journal*, February 26, 2015.

Figure 3-7

Change in primary energy consumption in kilograms of oil equivalent per capita, 1972-2012



* Includes only developing countries.
Source: World Bank, Data, Energy use (kg of oil equivalent per capita), October 2015.

shale gas deposits that were not previously economically viable. These technological advances have had a remarkable impact on natural gas prices in North America. Indeed, the gap between the price of natural gas in the United States and the prevailing prices in Europe and Japan has widened considerably since 2008 (see Figure 3-11).

The use of natural gas emits less CO_2 than coal for a given amount of energy.[159] As was the case in the early 20th century when less polluting fossil fuels were substituted for coal, the abundance of natural gas means that less coal need be used, and therefore leads to lower GHG emissions and lower carbon intensity (see Figure 3-12).[160] The shale gas revolution, although it involves a fossil fuel, has therefore led to a reduction in GHG emissions in the production of electricity. Moreover, this reduction in emissions was a side effect of the economic growth associated with affordable energy: It is estimated that hydraulic fracturing raises American GDP by $283 billion per year.[161]

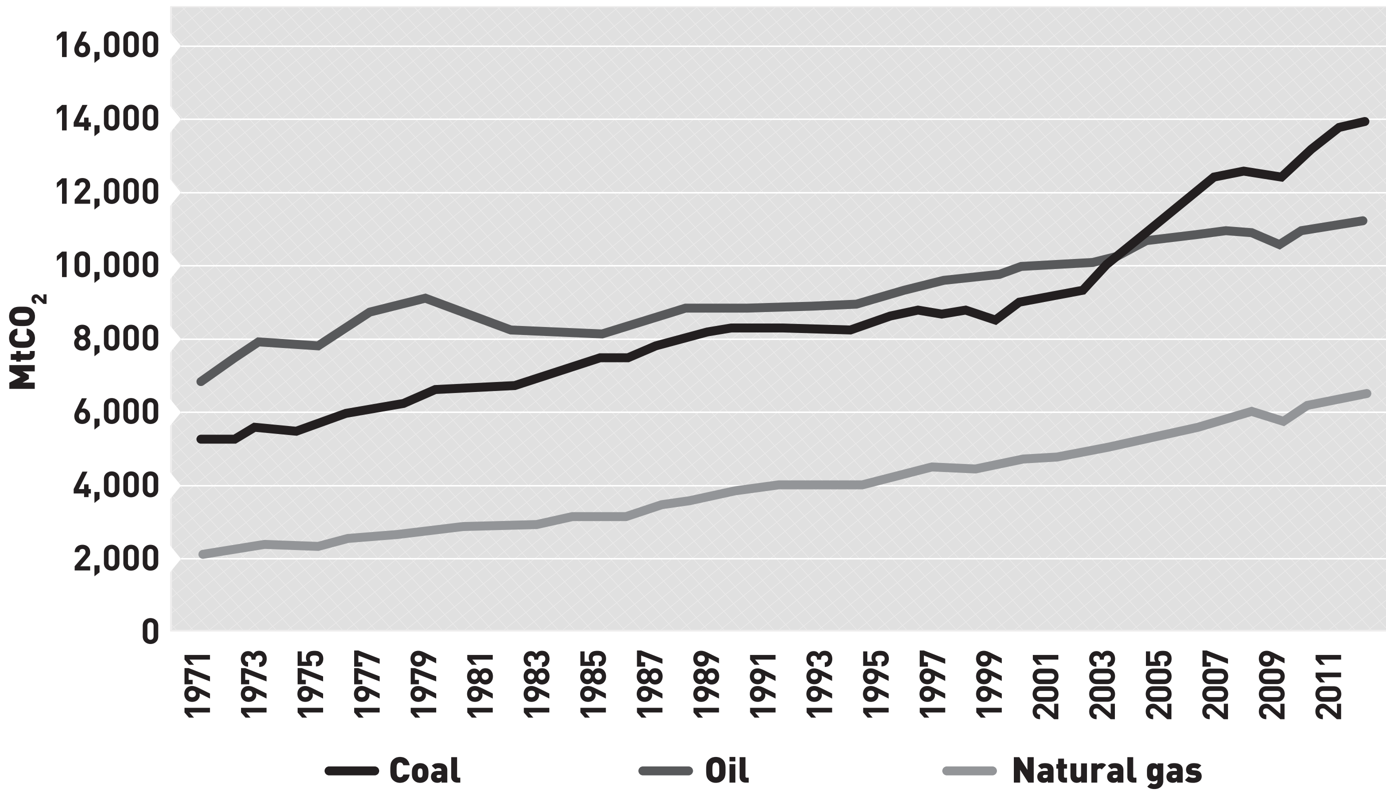
It is a safe bet that the shale gas revolution will continue, thanks to "re-fracking," or fracking a well for a second time with more efficient extraction technologies. This innovation is now being considered by gas companies for horizontal wells. A second round of fracking, which is about one quarter as expensive as building a new well, would allow for production levels to approach initial levels, which can fall by 70% one year after the initial fracking.[162] Increased natural gas production at

159. Kristin Suleng, "Using fossil fuels buys us time to develop alternative energies that will shape our future," *Open Mind*, October 14, 2014.
160. David G. Victor *et al.*, "Introductory Chapter," in Ottmar Edenhofer *et al.* (eds.), *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2014, p. 119.

161. Bjørn Lomborg, "Examining the Threats Posed by Climate Change: The Effects of Unchecked Climate Change on Communities and the Economy," The Senate EPW Committee, Subcommittee on Clean Air and Nuclear Safety, July 29, 2014, p. 21.
162. Trefis Team, "Oilfield Services Companies Are Betting On Re-Fracking. Will It Catch On?" *Forbes*, June 23, 2015; Dan Murtaugh, Lynn Doan and Bradley Olson, "Refracking Is the New Fracking," *Bloomberg Business*, July 7, 2015.

Figure 3-8

Change in global emissions in millions of tonnes of CO_2, 1971-2011



Source: International Energy Agency, CO_2 Emissions From Fuel Combustion Highlights 2014, Excel tables.

lower cost will help keep the price of this fuel relatively low compared to other energy resources and is likely to favour electricity production at natural gas power plants.

Innovation also allows coal power plants to have a lower carbon intensity. Their ability to convert thermal energy into mechanical energy (thermal efficiency) is inversely proportional to their GHG emissions. In other words, in addition to allowing for the generation of more electricity per gram of coal burned, technological innovations also have the benefit of leading to lower CO_2 emissions per kilowatt-hour produced. Table 3-1 illustrates this phenomenon by using the thermal efficiency of several technologies used by coal power plants.

All of these trends in emission intensity augur well. In the United States, the world's second largest emitter, natural gas is partly replacing coal. Although global coal use is growing, it can be exploited more efficiently all while reducing its environmental impact. This also applies to the exploitation of synthetic oil, as can be seen in the Alberta oil sands, where energy intensity fell 29% between 1990 and 2009.[163] A true energy revolution is therefore underway, and it could pick up steam with the increased use of carbon-neutral energy sources and technologies.

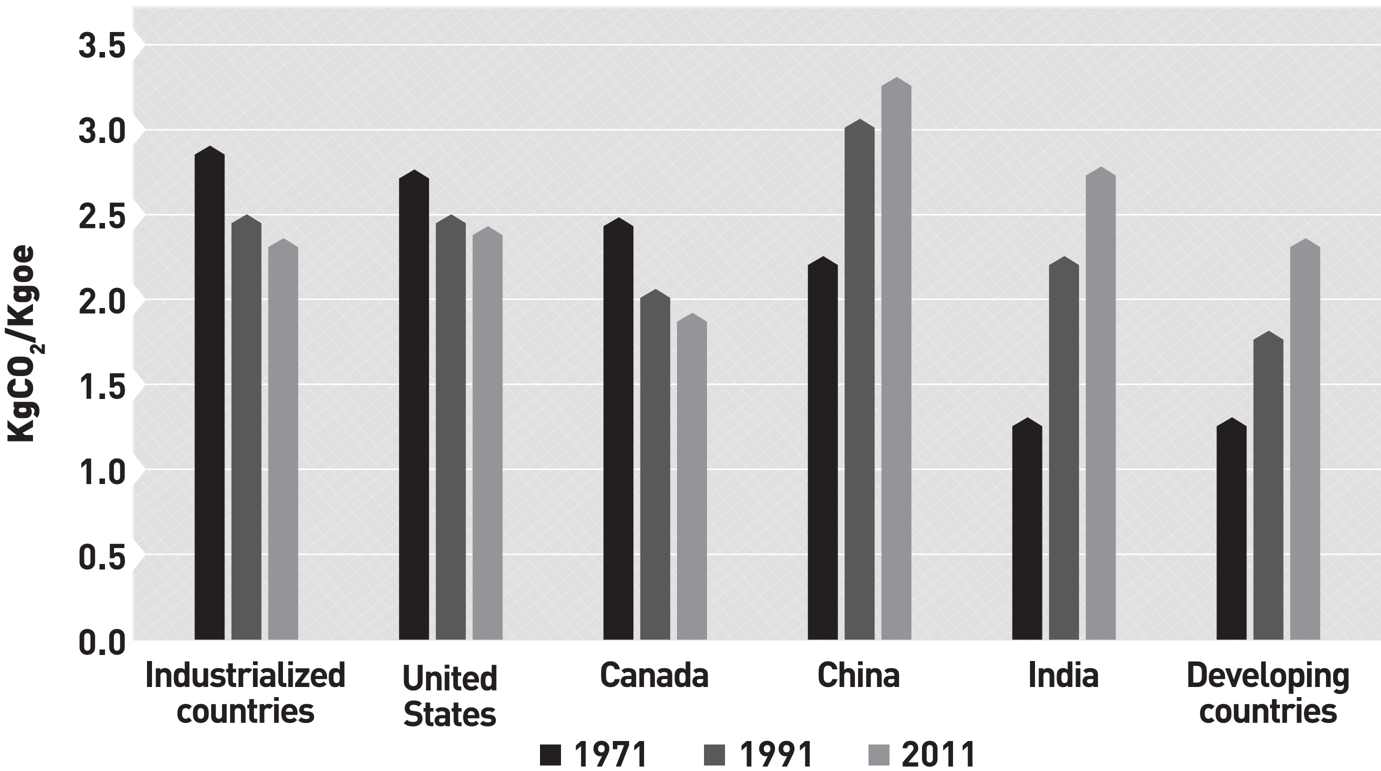
Toward a Carbon-Neutral Economy Thanks to Innovation

Breaking the Kaya identity down into its component parts is highly relevant, because it shows that energy consumption is not a problem in itself. It is possible for energy consumption to rise at a sustained pace without a substantial environmental impact, as measured in terms of CO_2 emissions. Indeed, the environmental impact could be almost nil if any of the following three factors gains in importance: renewable energy, large-scale carbon capture and storage technologies, or commercial applications for carbon.

163. Pierre Desrochers and Hiroko Shimizu, *op. cit.*, footote 155, p. 28.

Figure 3-9

Carbon intensity, 1971-2011



Note: This shows CO_2 in kilograms emitted for each kilogram of oil equivalent consumed.
Source: World Bank, Data, CO_2 intensity (kg per kg of oil equivalent energy use), October 2015.

1. Renewable Energy

The economic viability of using renewable energy has the potential to speed up the transition to a carbon-neutral or carbon-negative economy.

Growing investment in renewable energy can be a good indicator of future viability.[164] These investments have advanced at a dizzying pace over the past 10 years. Between 2004 and 2014, investment in the solar and wind industries jumped by 1,147% and 456% respectively.[165]

During the same period, global solar and wind capacity grew by 4,684% and 671% respectively. Global wind energy capacity had reached 370 gigawatts in 2014, compared to 177 gigawatts for solar energy (see Figure 3-13).

Massive investments have also helped lower the price of crystalline-module photovoltaic solar panels, down by an average of 66% over the past five years in Germany, China and Japan, the three countries with the largest installed solar capacity (see Table 3-2).[166]

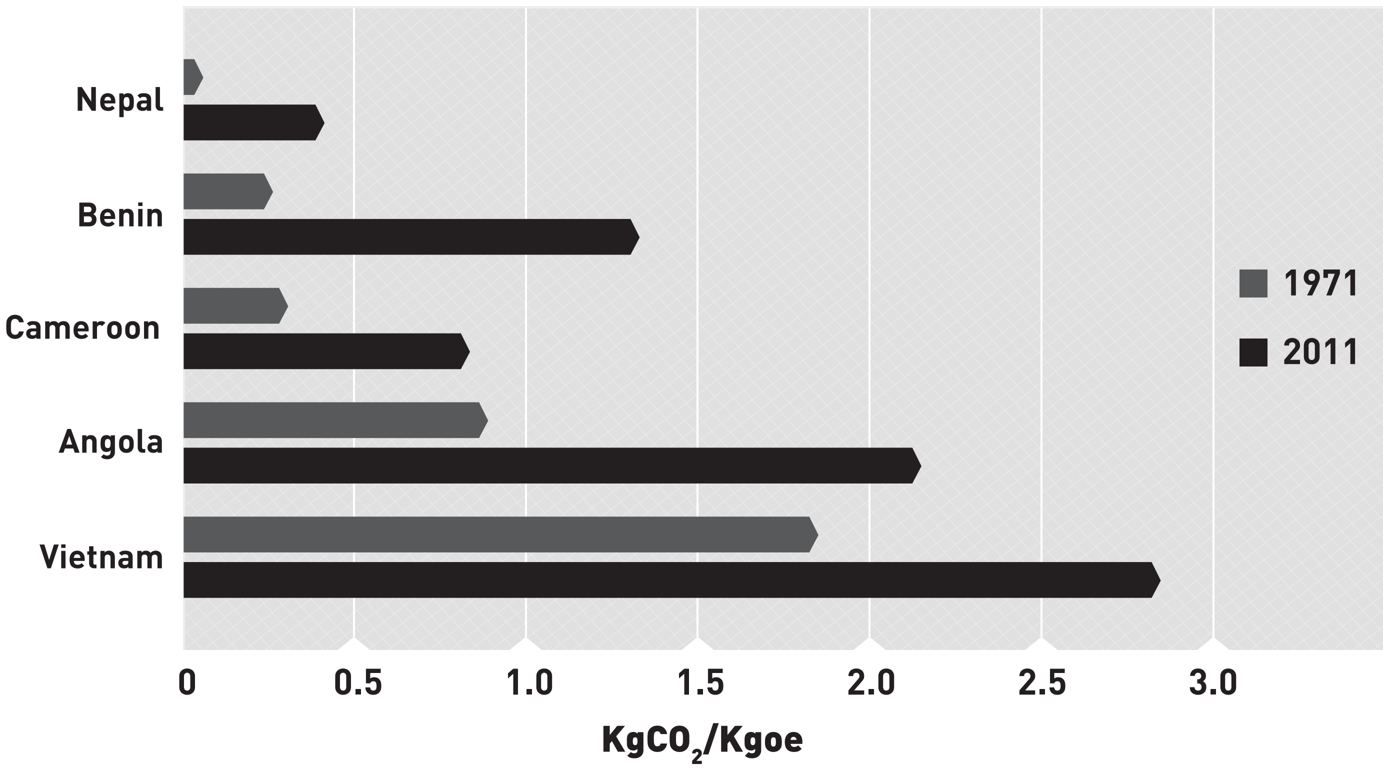
"Although global emission levels continue to rise due to increased production, the picture is improved by a combination of energy efficiency and reduced carbon intensity."

164. Subsidies can, however, alter economic calculations and make a project attractive even if it would not be viable without financial incentives, as shown by the experience of certain countries where renewable energy industries are in trouble following the abandonment of subsidies. See Brady Yauch, "Governments rip up renewable contracts," *Financial Post*, March 18, 2014.
165. During this period, more than 82% of renewable energy investments were in the wind and solar sectors. Ren21, *op. cit.*, footnote 144, p. 136.

166. Ren21, *op. cit.*, Note 144, p. 20; pvXchange, Price index.

Figure 3-10

The five countries with the fastest growth in carbon intensity, 1971-2011



Note: This shows CO_2 in kilograms emitted for each kilogram of oil equivalent consumed.
Source: World Bank, Data, CO_2 intensity (kg per kg of oil equivalent energy use), October 2015.

This price decline is reflected in the "levelized cost of electricity" (LCOE), a widely used measurement for assessing the competitiveness of the various energy sources in electricity generation. This measurement calculates the cost per megawatt-hour of an electric power plant over its lifespan, including investments as well as operating and maintenance costs.[167]

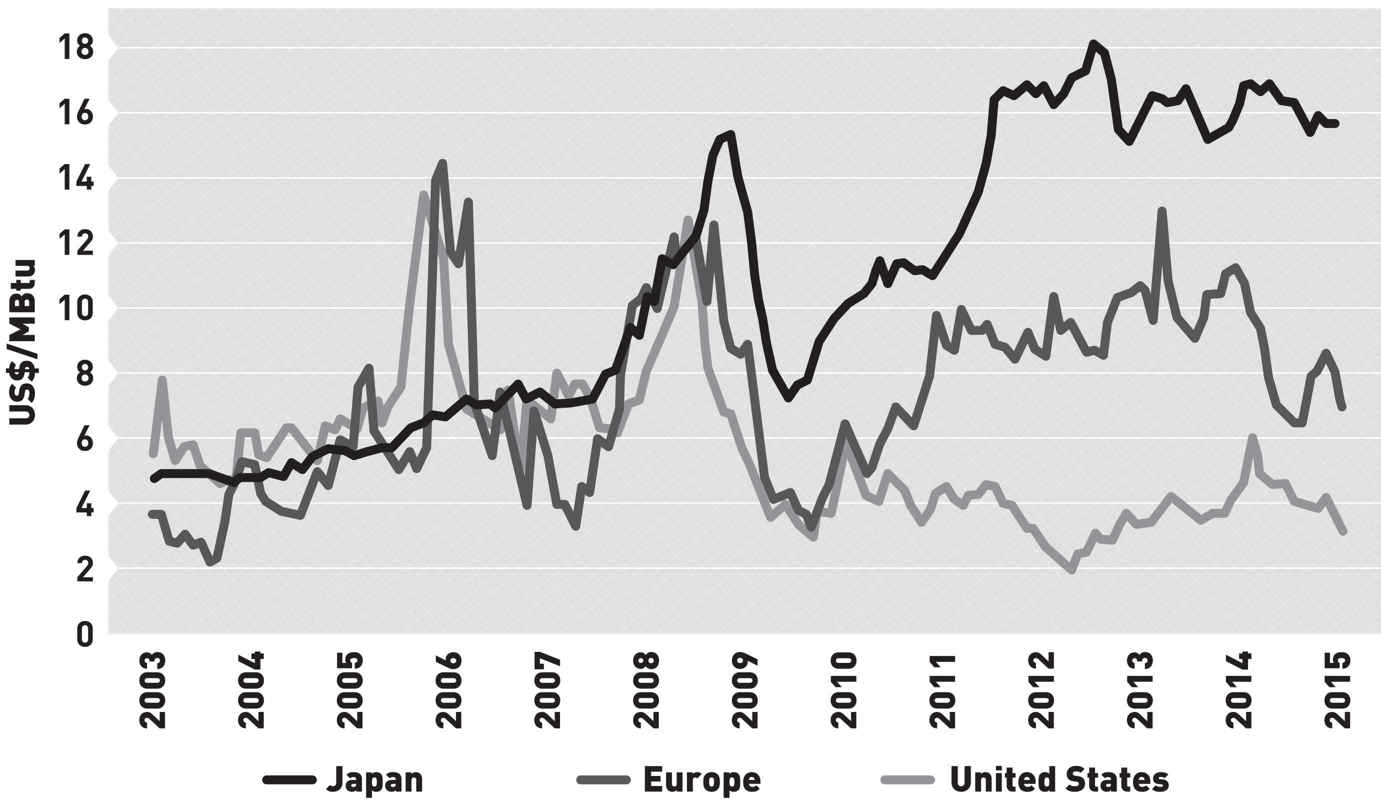
According to Bloomberg New Energy Finance, the global average LCOE of wind energy has remained fairly stable over the last five years, while that of crystalline silicon photovoltaic panels has fallen by 48%.[168] The IEA has made a similar observation, finding that the LCOE in some twenty countries has remained relatively stable for wind energy while falling considerably for solar projects.[169] In some countries, bids to supply solar energy have even been made at prices competitive with those of fossil fuels.[170]

The LCOE of electricity produced from solar or wind energy is not comparable, however, with the LCOE of energy produced by gas, coal or nuclear power.[171] Indeed, since the wind and the sun are not available on demand and their energy is intermittent, the economic value of electricity produced by these sources is not the same as electricity from a source available at all times. In other words, even if the costs of electricity produced from solar and wind are getting closer to the costs of energy from traditional sources, these renewable energy forms cannot fully replace fossil fuels and uranium. Until there is an economically feasible way of storing electricity on a large scale, our basic energy needs will be met

167. U.S. Energy Information Administration, "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2015," June 2015.
168. Frankfurt School, Global Trends in Renewable Energy Investment 2015 (Datapack), March 2015.
169. International Energy Agency, *Projected Cost of Generating Electricity—2010 Edition*, 2010, p. 62; International Energy Agency, "Executive Summary: Projected Cost of Generating Electricity—2015 Edition," 2015, p. 6.
170. Ren21, *op. cit.*, footnote 144, p. 62.
171. U.S. Energy Information Administration, *op. cit*, footnote 167, p. 3.

Figure 3-11

Natural gas prices in Europe, Japan and the United States, in U.S. dollars per million BTUs, 2003-2015



Source: International Energy Agency, Tracking Clean Energy Progress 2015, Power Generation.

by fossil fuels and nuclear power. To ensure the reliability of the network, solar and wind will complement traditional sources at peak periods.

Renewable energy subsidies therefore have only limited potential. In 2012, renewable energy generated just 5% of electricity worldwide, or 21% if hydro is included (see Figure 3-14).

2. Large-Scale Carbon Capture and Storage Technologies

Carbon capture and storage (CCS) is a technology that will be necessary, according to the IPCC, if we want to have a high probability of respecting the 2°C limit.[172] To respect this limit, the IEA estimates for its part that CCS will have to increase considerably from current levels and that it will have to account for 14% of emission reductions in 2050.[173]

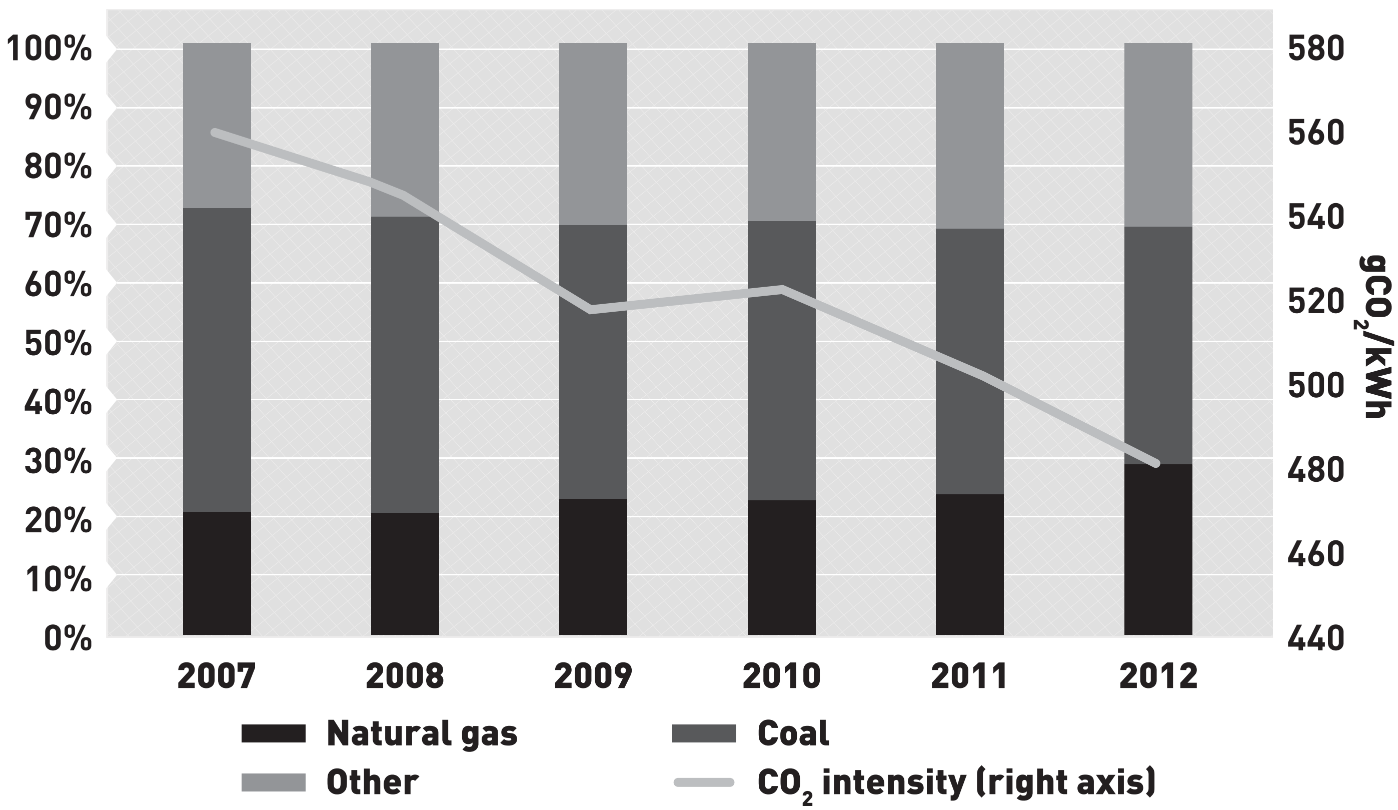
CCS involves selectively removing CO_2 from the effluent gases of a power plant or other industrial source and permanently storing the emissions deep underground.[174] Storage happens in depleted oil and gas deposits or in deep saline formations. At the end of 2014, only 13 large-scale CCS projects were in operation, with a total annual capture capacity of 26 megatonnes of CO_2.[175] This small number of projects is due to the fact that CCS is very expensive to set up. For example, the cost of a cement plan with CCS would be double that of

172. Ottmar Edenhofer *et al.*, "Summary for Policymakers," in Ottmar Edenhofer *et al.* (dir.), *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2014, p. 12.

173. International Energy Agency, About carbon capture and storage; International Energy Agency, *Tracking Clean Energy Progress 2015*, 2015, p. 33.
174. CO_2 Solutions, Carbon Capture and Sequestration (CCS).
175. International Energy Agency, *Tracking Clean Energy Progress 2015*, 2015, p. 32.

Figure 3-12

Proportion of natural gas used in the production of electricity and carbon intensity in the United States, in grams of CO_2 per kilowatt-hour, 2007-2012



Source: International Energy Agency, Tracking Clean Energy Progress 2015, Power Generation.

a conventional cement plant.[176] The cost of this technology will therefore remain prohibitive, unless the global price of carbon is much higher or commercial applications for carbon are developed.

3. Commercial Applications for Carbon

One thing that has the potential to improve the current energy system's environmental impact quite considerably is the use of carbon for commercial purposes. If it were economically viable to use carbon as an input for various industrial processes, its value would lead to its being captured instead of discharged into the atmosphere. Research in this field abounds, and to date, several companies have already developed promising technologies.

Carbon Recycling International is an Icelandic company that takes carbon discharged by a geothermal electric power plant and turns it into methanol. Methanol can be used as a transportation fuel and as a raw material for various substances.[177] In Denmark, one gas station is already offering drivers of electric cars with methanol fuel cells the chance to fill up their tanks. The methanol is converted to electricity while driving, saving drivers from having to wait several hours for a battery recharge.[178]

Carbon nanofibres are used in various industries because of their conductivity, flexibility and resistance. Producing carbon nanofibres is very expensive, however, requiring 30 to 100 times more energy than the production of aluminum.[179] Researchers at George Washington

176. The Energy and Climate Change Committee, *Carbon Capture and Storage Ninth Report of Session 2013–14*, Information document prepared at the request of the House of Commons of the United Kingdom, May 21, 2014, p. 25.

177. Carbon Recycling International, Methanol.
178. Carbon Recycling International, First renewable methanol fuel station in the world for electric cars, August 31, 2015.
179. Jiawen Ren *et al.*, "One-Pot Synthesis of Carbon Nanofibers from CO_2," *Nano Letters*, No. 15, 2015, pp. 6142.

Table 3-1

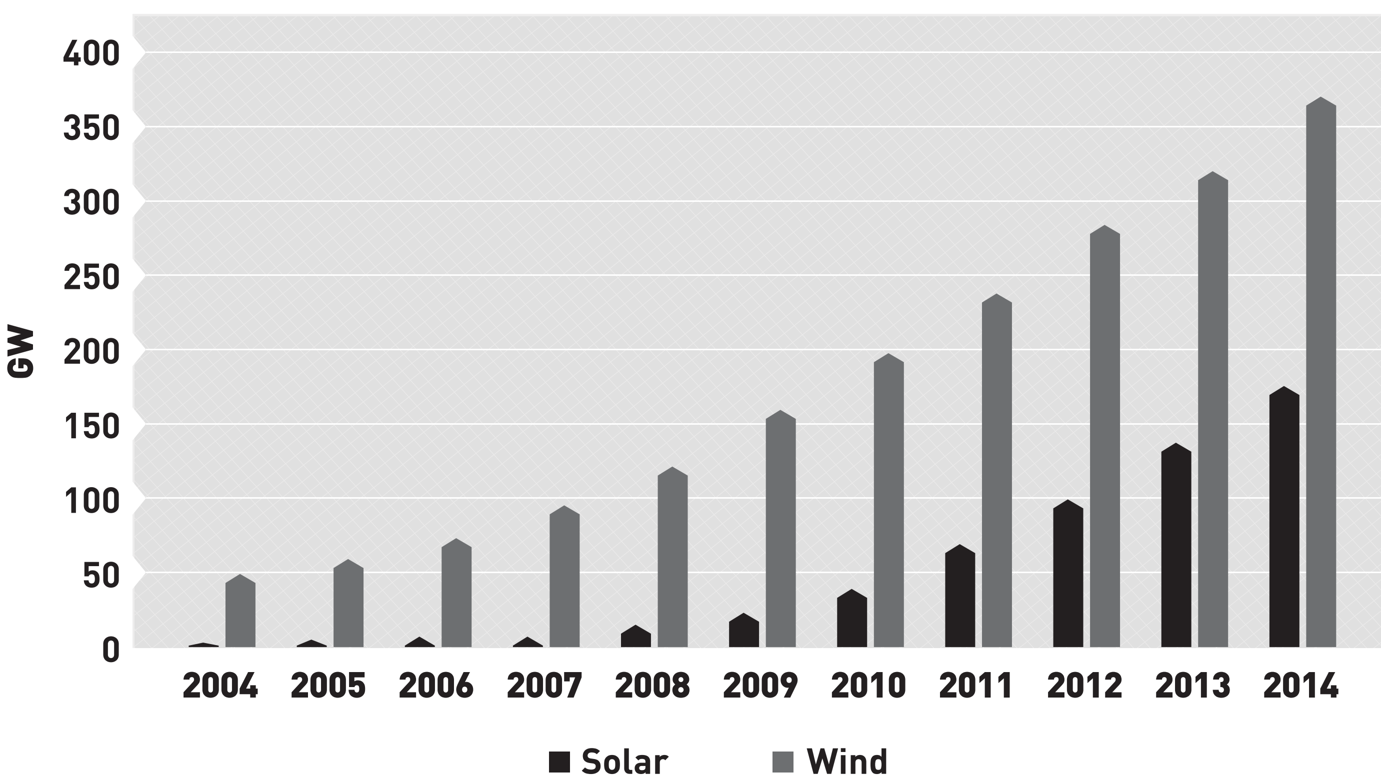
Thermal efficiency and carbon intensity of different technologies for coal power plants

TECHNOLOGY	MAXIMUM THERMAL EFFICIENCY	COAL CONSUMED PER KWH (GRAMS)	CO_2 EMISSIONS PER KWH (GRAMS)
Subcritical	**38%**	**379**	**881**
Supercritical	**42%**	**343**	**798**
Ultra-supercritical	**45%**	**320**	**743**
Advanced ultra-supercritical	**50%**	**288**	**669**

Source: Shoichi Itoh, "A New Era of Coal: The 'Black Diamond' Revisited," 2014 Pacific Energy Forum Working Papers, April 2014, p. 6.

Figure 3-13

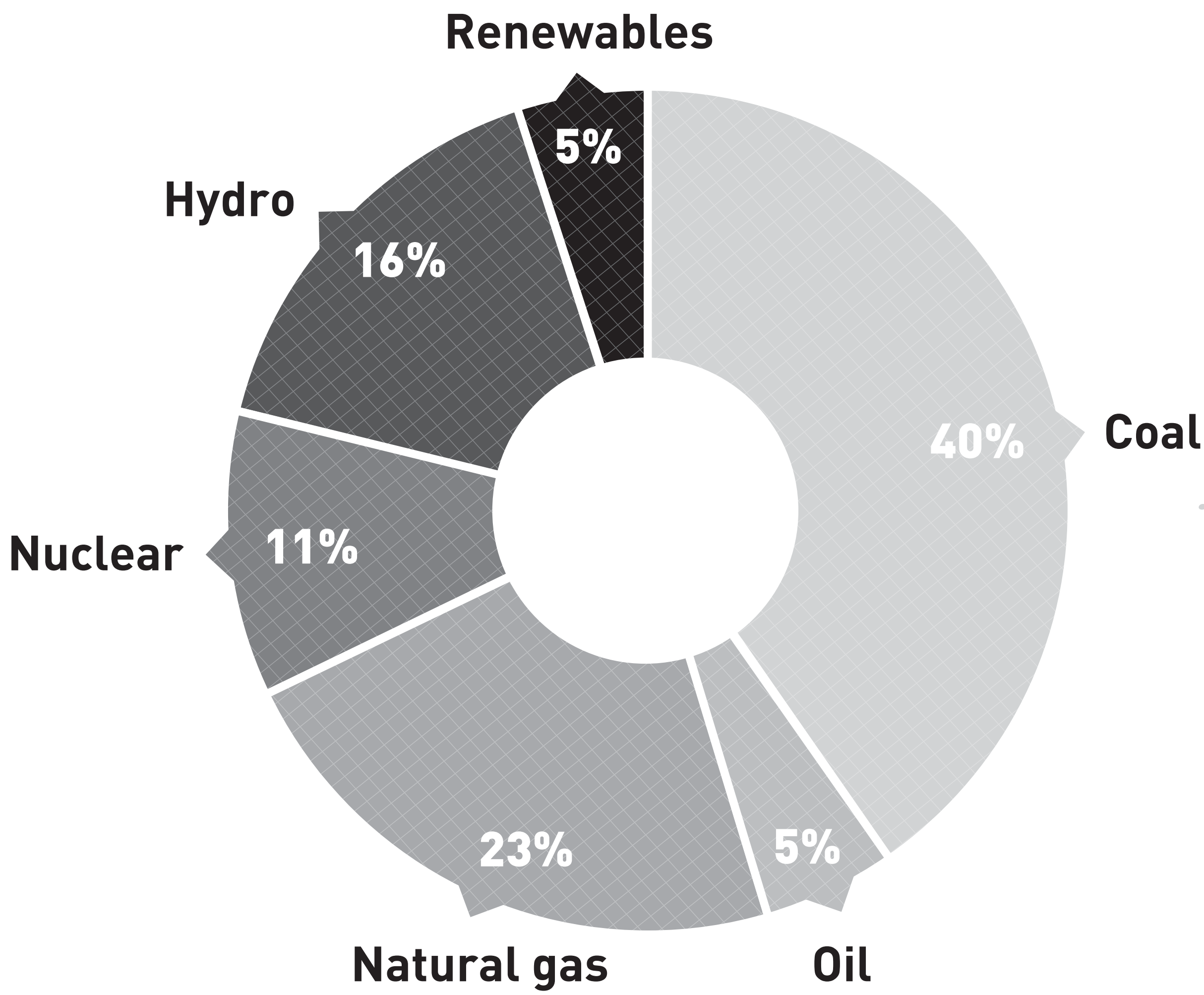
Global installed capacity in solar and wind energy in gigawatts, 2004-2014



Source: Ren21, *Renewables 2015 Global Status Report*, 2015, pp. 59 and 71.

Figure 3-14

Electricity generation by fuel, 2012



Source: International Energy Agency, *Key World Energy Statistics 2014*, 2014, p. 24.

Table 3-2

Change in the price of crystalline module photovoltaic solar panels (euros per peak watt*)

	AUGUST 2010	AUGUST 2015	VARIATION
Germany	**1.87**	**0.57**	**-70%**
China	**1.61**	**0.57**	**-65%**
Japan	**1.82**	**0.65**	**-64%**

Source: pvXchange, Price index.
* Peak watts are a unit of measurement representing the maximum power of a device.

University have developed a method for converting carbon dioxide into oxygen and carbon nanofibres using an electrochemical process that is apparently less expensive than other existing methods. With favourable economic conditions, these researchers estimate that their method could remove enough carbon from the atmosphere to return to the atmospheric CO_2 concentrations of the pre-industrial era. This could be done in 10 years, using an area equal to 10% of the Sahara Desert.[180]

"Each dollar of economic growth generated tends to be cleaner and cleaner."

Carbon capture technologies can also be used to capture methane, a GHG with a global warming potential 25 times greater than that of CO_2. New Light Technologies is a company that can decompose the carbon (C) and hydrogen (H) in previously captured methane (CH_4). The carbon and hydrogen are then combined with oxygen to form a long-chain polymer called AirCarbon.[181] This type of plastic is used to make carbon-negative items. The Dell computer company uses it as a material for laptop computer bags, while the KI furniture company uses it in the production of chairs. Large-scale production of this plastic has the potential to have a substantial environmental impact. In addition to reducing the quantity of methane in the atmosphere, it could replace oil in the manufacture of plastics since this substance is similar to petroleum-based plastics.[182]

Algae-based fuels are also promising for reducing GHGs. Algae feed on CO_2 and sunlight as they are cultivated. The oil accumulated during their growth is then extracted and refined to produce algofuels. CO_2 capture during the process means that CO_2 emissions can be reduced by 50% to 70% compared to petroleum-based fuels.[183]

In addition to absorbing CO_2, algae cultivation provides other environmental benefits since it can be done on infertile land or in wastewater or saline basins of low economic value. It therefore does not require the use of scarce resources.[184] According to a report prepared for the IEA, biofuels derived from algae have the potential to replace a significant portion of the diesel fuel used today while leaving a reduced environmental footprint.[185]

Wealth: A Non-Negligible Factor

The Kaya identity allows us to understand which factors influence the growth of GHG emissions. Although global emission levels continue to rise due to increased production, the picture is improved by a combination of energy efficiency and reduced carbon intensity. These positive trends result in declining GHG emissions per unit of GDP worldwide, with each dollar generated around the world being increasingly green.

This trend is all the more impressive in that it is also occurring in certain emerging countries such as China and India, both of which are making increasing use of coal to generate electricity. China emitted 52% less carbon dioxide per unit of GDP in 2011 than in 1991, while India succeeded in becoming 25% cleaner over the same period (see Figure 3-15).

As the IEA notes, global CO_2 emissions from the energy sector did not grow in 2014 despite world economic growth of 3%. This is the first time in 40 years that stagnating emissions are not connected to an economic downturn. This "decoupling" of emissions and growth is a very encouraging first according to Fatih Birol, the IEA's executive director.[186]

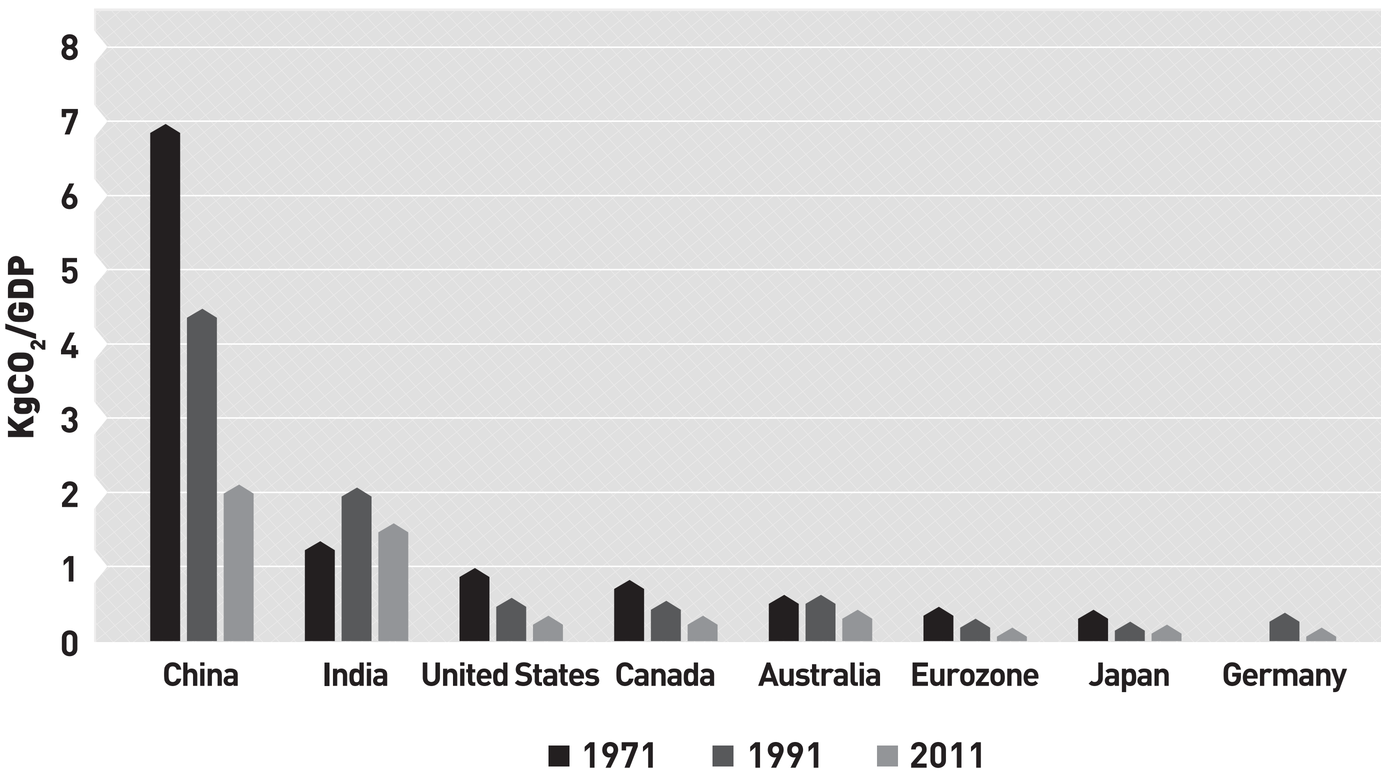
With increased wealth, a reduction can be seen in energy intensity and in per capita energy use.[187] Moreover, each dollar of economic growth generated tends to be cleaner and cleaner. Sustained economic growth also allows for the investments needed for carbon-neutral technologies (CCS, electricity storage) to be deployed on a large scale.

History shows that wealth, energy used, and technological change are interdependent factors in a virtuous circle generating greater wealth and technological innovation.[188] Material wealth not only stimulates the

180. Mike Orcutt, "Researcher Demonstrates How to Suck Carbon from the Air, Make Stuff from It," *MIT Technology Review*, August 19, 2015.
181. New Light Technologies, Our Technology: Greenhouse Gas to Plastic.
182. Nate Berg, "AIRCARBON : Et si le plastique était la solution au réchauffement climatique?" *El Watan*, September 20, 2014.
183. Xiaowei Liu *et al.*, "Pilot-Scale Data Provide Enhanced Estimates of the Life Cycle Energy and Emissions Profile of Algae Biofuels Produced Via Hydrothermal Liquefaction," *Bioresource Technology*, Vol. 148, 2013, pp. 163-171.
184. Al Darzins, Philip Pienkos and Les Edye, *Current Status and Potential for Algal Biofuels Production*, Information document prepared on the request of the IEA Bioenergy Task 39, Report T39-T2, August 6, 2010, p. ii.
185. *Ibid.*, p. vi.
186. International Energy Agency, "Global energy-related emissions of carbon dioxide stalled in 2014," Press release, March 13, 2015.
187. Jason Channell *et al.*, *Energy Darwinism II: Why a Low Carbon Future Doesn't Have to Cost the Earth*, Citi GPS, August 2015, p. 25.
188. Pierre Desrochers and Hiroko Shimizu, *op. cit.,* footnote 155.

Figure 3-15

Kilograms of CO_2 emissions per unit of GDP, 1971-2011



Source: World Bank, Data, CO_2 Emissions (kg per 2005 US$ of GDP), October 2015.

technological innovation needed to enhance environmental conditions, but also helps the most vulnerable groups adjust more effectively to climate change.

> **"The increasingly green direction that the world economy seems to be taking has come about without an international climate treaty and without a global carbon price."**

The increasingly green direction that the world economy seems to be taking has come about without an international climate treaty and without a global carbon price.[189] This is hardly surprising since, historically, choosing which form of energy to use has been influenced mostly by local factors, such as economic development, national security, and air quality.[190]

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CHAPTER 4

Adapting to Climate Change

As a result of greenhouse gas emissions since the Industrial Revolution, the climate is bound to change. Regardless of the course that events may take, the planet's average temperature will keep rising from now until the end of the 21st century. The world's nations will need to adapt to these gradual changes, so it is important to understand the conditions that will allow for the best possible adaptation.

Climate Change Hits Poor Countries Harder

Climate change will entail numerous environmental changes, including rising sea levels, more frequent heat waves, and variations in fishing and agricultural conditions.[191] Among the many effects of climate change, the most worrisome are naturally extreme weather events that can cause human casualties. According to the IPCC, the overall warming of the atmosphere will make these events more frequent, and their intensity will increase, as shown in Table 4-1.

It should not be assumed, however, that all weather phenomena result directly from climate change. For example, studies on extreme hurricane winds in the United States and the Caribbean, on tornados in the United States, and on storm winds in Europe have failed to establish a link with anthropogenic climate change.[192] The same can be said of droughts, which have changed little over the past 60 years.[193]

The frequency and intensity of extreme weather events are not the only factors that determine the severity of their impacts. The IPCC's Fifth Assessment Report states that the exposure and vulnerability of physical assets should also be taken into account. Both of these factors are directly related to the level of economic development.[194] This explains why the poorest population groups are disproportionately affected by these disasters, as noted in a report produced for the World Bank.[195]

This does not mean that developed countries are spared. The IPCC states that the absolute value of economic losses related to the weather and to climate events will be higher in industrialized countries, due to the higher value of their built heritage. Fortunately, insurance against such damage is also more common. However, the same report notes the following with respect to developing countries:

> Fatality rates and economic losses expressed as a proportion of GDP are higher in developing countries (high confidence). Deaths from natural disasters occur much more in developing countries. From 1970 to 2008, for example, more than 95% of deaths from natural disasters were in developing countries.[196]

"Economic development is the best way to reduce the adverse effects of climate change in relative terms and to reduce the loss of human life."

In other words, economic development is the best way to reduce the adverse effects of climate change in relative terms and to reduce the loss of human life. A clear example may be seen by comparing two tragic events: Hurricane Katrina, which struck the United States in 2005, and the tropical cyclone that hit the Bay of Bengal in 1970. These two Category 3 storms threatened populations of comparable size, but it is estimated that there were 150 times fewer deaths in the United States, where the level of wealth supports technologies, infrastructure and institutions that reduce people's vulnerability to climate change.[197]

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194. "The impacts of extreme weather events depend on the frequency and intensity of the events, as well as the exposure and vulnerability of society and assets." Wolfgang Cramer *et al.*, *op. cit.*, footnote 192.
195. Postdam Institute for Climate Impact Research and Climate Analytics, *Turn Down the Heat: Why a 4°C Warmer World Must Be Avoided*, Report produced for the World Bank, November 2012, p. 56.
196. Virginia R. Burkett *et al.*, "Point of Departure," in Christopher B. Field *et al.* (eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A : Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2014, p. 187.
197. Keith H. Lockitch, "Climate Vulnerability and the Indispensable Value of Industrial Capitalism," *Energy and Environment,* Vol. 20, No. 5, 2009, p. 737.

Table 4-1

Probability of extreme weather and climate events

PHENOMENON AND EXPECTED CHANGE	LIKELIHOOD THAT CHANGES OCCURRED (SINCE 1950)	HUMAN CONTRIBUTION TO OBSERVED CHANGES	LIKELIHOOD OF FURTHER CHANGES – EARLY 21ST CENTURY	LIKELIHOOD OF FURTHER CHANGES – LATE 21ST CENTURY
Warmer and/or fewer cold days and nights over most land areas	**Very likely**	**Very likely**	**Likely**	**Virtually certain**
Warmer and/or more frequent hot days and nights over most land areas	**Very likely**	**Very likely**	**Probable**	**Virtually certain**
Warm spells/heat waves: Frequency and/or duration increases over most land areas	**Medium confidence**	**Likely**	**Not formally assessed**	**Very likely**
Heavy precipitation events: Increase in the frequency, intensity and/or amount of heavy precipitation	**Likely**	**Medium confidence**	**Likely**	**Very likely**
Increases in intensity and/or duration of drought	**Low confidence**	**Low confidence**	**Low confidence**	**Likely**
Increases in intense tropical cyclone activity	**(Since 1970) Low confidence**	**Low confidence**	**Low confidence**	**More likely than not**
Increased incidence and/or magnitude of extreme high sea level	**(Since 1970) Likely**	**Likely**	**Likely**	**Very likely**

* *Low confidence* at a global level.
** *Low confidence* when it comes to long-term climate change (at the scale of centuries). *Almost certain* in the North Atlantic since 1970.
Source: Lisa V. Alexander *et al.*, "Summary for Policymakers," in T. F. Stocker *et al.* (eds.), *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2013, p. 7.
Note: *The terms used for likelihoods may be interpreted as follows:*

CONFIDENCE TERMINOLOGY	DEGREE OF CONFIDENCE
Medium confidence	**About 5 out of 10 chance**
Low confidence	**About 2 out of 10 chance**
Virtually certain	**Over 99% likelihood**
Very likely	**Over 90% likelihood**
Likely	**Over 66% likelihood**
More likely than not	**Over 50% likelihood**

Source: IPCC, *Climate Change 2007: Working Group I: The Physical Science Basis*, 1.6 The IPCC Assessments of Climate Change and Uncertainties, 2007..

Technology is closely linked to level of economic development. On the one hand, prosperity is what allows us to use the most advanced tools made available by scientific and technological progress. In addition, technological discoveries themselves owe much to economic growth, whose dynamic process rewards innovation.[198] The technology level is also a significant condition facilitating adaptation, and partly determines the resilience of societies and economies faced with the consequences of climate change. For example, knowledge of genetics have a strong influence on how climate change will affect agriculture and harvests.[199]

Climate Change Adaptation and Living Standards

The living conditions of human beings have undergone rapid change over the past century. Life expectancy has risen substantially. Whereas it was just 31 years for humanity as a whole in 1900, and less than 50 years even in the most highly developed countries,[200] it now stands at 68.7 years.[201] Indeed, the overall health of the human population has improved, many previously fatal diseases are now treated more effectively or have been eradicated, and infant mortality has fallen sharply. These notable changes reflect reductions in hunger, malnutrition and poverty, thanks to a widespread improvement in economic living conditions.[202]

Renowned author Indur M. Goklany, who worked at the IPCC and contributed to its First Assessment Report among other things, shows that these tremendous developments are closely linked to the living standards made possible by the use of fossil fuels and by the impressive technological progress of the past century.[203] In other words, as they seek to avert catastrophes related to excessive global warming, the nations of the world should avoid causing the kinds of human catastrophes that result from a decline in living standards.

The economic growth that raises living standards is all the more important because it allows for a better adaptation to climate change. Since the 1920s, the global mortality rate from extreme weather events has fallen by 98%.[204] This statistic suggests that human vulnerability is due less to climate than to economic conditions.[205]

"The technology level is also a significant condition facilitating adaptation, and partly determines the resilience of societies and economies faced with the consequences of climate change."

Despite extensive media attention, the climate change issue remains essentially a future risk. As we saw in Chapter 2, Richard Tol calculated that the overall impact of global warming has been positive up to now. An article appearing in *Nature* magazine attributed over 150,000 deaths to climate change during the year 2000.[206] The study, which did not go uncriticized,[207] categorized these deaths as follows:

- 77,000 of the 250,000 deaths due to protein malnutrition;
- 47,000 of the 2 million deaths due to diarrhea;
- 27,000 of the more than one million deaths due to malaria;
- 2,000 deaths caused by floods.[208]

As we can be, the three health problems accounting for most of the deaths that were attributed up to a certain point to climate change are not a concern in any industrialized country, nor even in many developing countries.

198. Indur M. Goklany, "Humanity Unbound: How Fossil Fuels Saved Humanity from Nature and Nature from Humanity," Policy Analysis No. 715, Cato Institute, December 20, 2012. This relationship can be observed in various sectors, including pharmaceutical research. See Yanick Labrie, "How Pharmaceutical Innovation Has Revolutionized Health Care," Economic Note, Montreal Economic Institute, June 2014.
199. Rebecca Clements *et al.*, *Technologies for Climate Change Adaptation: Agriculture Sector*, UNEP Risø Centre on Energy, Climate and Sustainable Development, August 2011, p. 110-116. The technology factor and its impact on capacities for adaptation are a focus of Goklany's criticism of studies on the impacts of climate change. Many of these studies appear not to take recent developments into account, especially in genetics. "Generally, the adaptation technologies available in these studies are from the early 1990s or earlier vintages. Thus the food and hunger study doesn't include consideration of adaptations that may be possible through genetically modified crops." Parry *et al.*, "Effects of Climate Change," p. 57, quoted in Indur M. Goklany, "What to Do about Climate Change," Policy Analysis No. 609, Cato Institute, February 5, 2008, p. 25.
200. Thomson Prentice, "Health, History and Hard Choices: Funding Dilemmas in a Fast-Changing World," presentation as part of the Health and Philanthropy: Leveraging Change conference, University of Indiana, August 2006, p. 7.
201. Central Intelligence Agency, World Factbook, People and Society, Life expectancy at birth.
202. Indur M. Goklany, *op. cit.*, footnote 198.
203. *Idem.*
204. Indur M. Goklany, "Wealth and Safety: The Amazing Decline in Deaths from Extreme Weather in an Era of Global Warming, 1900-2010," Policy Study No. 393, Reason Foundation, September 2011, p. 6.
205. Keith H. Lockitch, op. cit., footnote 197, p. 733.
206. Jonathan A. Patz *et al.*, "Impact of Regional Climate Change on Human Health," Nature, Vol. 438, No. 7066, November 2005, p. 312.
207. Indur M. Goklany, *op. cit.*, footnote 204, p. 13
208. Jonathan A. Patz *et al.*, *op. cit.*, footnote 206.

The main cause of mortality in these three cases, and perhaps also in the fourth, has more to do with the poverty that puts entire populations at risk.

This was a clumsy move by the World Health Organization. By seeking to show that its mission also involved fighting climate change, possibly to benefit from additional funding, the WHO has ended up diminishing the importance of climate change. Indeed, according to its own analysis, if countries and societies around the world had put extensive efforts into reducing GHG emissions, this would have had the effect of saving these 150,000 victims. In contrast, normal economic development can eliminate the *causes* of these 150,000 deaths, and prevent not merely these, but also the 3.3 million deaths that are really at issue on this list, and among which the victims of climate change account for only 5%.

> **"As they seek to avert catastrophes related to excessive global warming, the nations of the world should avoid causing the kinds of human catastrophes that result from a decline in living standards."**

The IPCC's assessment of the current consequences of climate change is far more nuanced, as we saw in Table 4-1. The effects on human health are relatively minor, and in particular are not well quantified. With medium confidence, experts state that there is a rise in heat-related deaths and a decline in cold-related deaths.[209] Given that there are nearly 17 times more deaths related to cold than to heat,[210] it is quite possible that the overall balance is positive.

Since the adaptive capacity of human societies is directly linked to their prosperity,[211] public policies and international agreements must avoid pitting global warming mitigation against the equally important goal of adapting to unavoidable climate change. With limited economic resources, choices in the fight against climate change have to be made intelligently and rationally.[212]

Weighing the Importance of the Climate Change Fight

The aim of this *Research Paper* is not to determine the public policies that should be adopted. It is rather an assessment of the available information that is useful in the debate over these policy choices. The possibility of adaptation thanks to economic prosperity is crucially important. Another thing that must be mentioned is that fighting climate change remains one of the many political and social goals pursued by the world's countries. The moral imperative is to improve the overall lot of human beings, taking into account every challenge we face, including the effects of climate change, but not to the exclusion of all else.[213]

On the eve of the Paris Climate Conference, the importance and the enormity of the task involved in the fight against climate change must not overshadow more immediate problems that also need to be tackled. Some issues may go hand in hand with a reduction in GHG emissions, but others show the limits of actions centred solely on reducing such emissions. Three challenges may serve to illustrate this: infectious diseases (health), air quality (environment), and access to electricity (energy).

a) Infectious Diseases: The Case of Malaria

One of the adverse effects of climate change may be the wider spread of infectious diseases such as malaria. This potentially fatal disease is transmitted by mosquito bites, mainly in Africa, but it is fairly simple to treat.

The latest World Health Organization data show that there were 214 million cases of malaria in 2015, and 438,000 deaths were attributed to this disease. These figures, although quite striking, represent a remarkable improvement. The mortality rate from malaria has fallen by 60% since 2000, and by 65% among children.[214]

With climate change, conditions favouring the proliferation of mosquitos could spread. Fighting climate change effectively could therefore slow the propagation of this disease. However, money spent on reducing emissions

209. Christopher B. Field *et al.*, "Summary for Policymakers," in Christopher B. Field *et al.* (eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2014, p. 6. Excerpt: "At present the worldwide burden of human ill-health from climate change is relatively small compared with effects of other stressors and is not well quantified. However, there has been increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming (*medium confidence*)."
210. Antonio Gasparrini *et al.*, "Mortality Risk Attributable to High and Low Ambient Temperature: A Multicountry Observational Study," *The Lancet*, Vol. 386, No. 9991, July 2015, p. 372.
211. Gary W. Yohe, "Mitigative Capacity: The Mirror Image of Adaptive Capacity on the Emissions Side," *Climatic Change*, Vol. 49, No. 3, May 2001, pp. 247-262.
212. See Post-2015 Consensus, Expert Panel; Bjørn Lomborg, *The Nobel Laureates Guide to the Smartest Targets for the World 2016-2030*, Copenhagen Consensus Center, 2015.
213. Bjørn Lomborg, "On climate change, Pope Francis isn't listening to the world's poor," *New York Post*, September 23, 2015.
214. World Health Organization, Malaria, Fact sheet No. 94, October 2015.

could also be directed to the search for a vaccine that could completely eradicate the disease and save more lives.

International aid to poor countries is increasingly oriented toward projects related to climate change.[215] Malaria, however, has been functionally eradicated in societies where the GDP per capita is at least $3,100, due to better health conditions and the better housing this standard of living provides.[216] In any event, the malaria problem could be solved in the coming decades, meaning that climate conditions in the late 21st century would have no influence on it. With the growing effectiveness of malaria prevention measures, which are rapidly reducing the infection rate, the effects of climate change are declining accordingly.

b) Air Quality

Many countries are seeking to reduce pollution levels, first and foremost for the direct well-being of their populations. Whether urban or rural, citizens have a strong interest in living in a healthy environment, and exert greater political pressure as they become wealthier. Indeed, it is understandable that people in a very poor rural area will not object to the opening of a polluting factory that provides good jobs. The need to survive and to improve their lot, even if only marginally, takes precedence over environmental quality. Meanwhile, in places where the middle class is getting stronger and families worry about the effects of poor environmental quality on their health and on the value of their homes, a closer watch is being kept on the environmental practices of industries and institutions.

As with the eradication of malaria, there is a well-documented link between living standards and indicators of environmental quality.[217] Here in Canada, it is notable that air quality has improved significantly in the past few decades along with economic and technological progress. Concentrations of various atmospheric pollutants have fallen substantially across the country.[218]

This trend is all the more important in that improving air quality is often used to justify tangible government actions in the fight against climate change. The sources of GHG emissions are often the same ones that belch pollutants into the air. In China, India, and various other developing countries, the battle against smog is encouraging governments to adopt targets for reducing GHG emissions.[219]

> **"The moral imperative is to improve the overall lot of human beings, taking into account every challenge we face, including the effects of climate change, but not to the exclusion of all else."**

From the standpoint of public health, the combination of these two goals is fortunate, because they are not opposed. Otherwise, priority would undoubtedly go to reducing atmospheric pollutants rather than GHG emissions. Among various factors that may affect the length and quality of life, urban air pollution far exceeds the effects of climate change. In rural areas, indoor smoke from solid fuels for heating or cooking is also a bigger problem.[220]

c) Access to Electricity

Rated as the foremost environmental threat,[221] smoke from solid fuels is often related to limited access to electricity. Access to cheap sources of electricity often makes electrical cooking and heating devices more appealing, even for low-income households. Energy poverty is still a widespread phenomenon, however. The World Health Organization estimates that 3 billion people worldwide cook their food or heat their homes using fireplaces or traditional ovens, burning wood, agricultural waste, coal or manure. Indoor air pollution leads to about 4.3 million deaths each year, primarily women and children, by causing pneumonia, strokes, heart and lung disease, and even lung cancer.[222]

Access to cheap electricity is an important method of getting out of dire poverty and improving everyday health conditions.[223] More than 1.2 billion people world-

215. Axel Michaelowa and Katharina Michaelowa, "Climate or Development: Is ODA Diverted from Its Original Purpose?" *Climatic Change*, Vol. 84, No. 1, September 2007, pp. 5-21.
216. Richard S. J. Tol, and Hadi Dowlatabadi, "Vector Borne Diseases, Development & Climate Change," *Integrated Assessment,* Vol. 2, No. 4, October 2001, p. 177.
217. Thomas M. Selden and Daqing Song, "Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions?" *Journal of Environmental Economics and Management*, Vol. 27, No. 2, September 1994, pp. 147-162; Nemat Shafik, "Economic Development and Environmental Quality: An Econometric Analysis," Oxford Economic Papers, New Series, Vol. 46, Special Issue on Environmental Economics, October 1994, pp. 757-773.
218. Environment Canada, National Air Pollution Surveillance Program (NAPS), July 9, 2013.
219. Center for Clean Air Policy, *Greenhouse Gas Mitigation in Brazil, China and India: Scenarios and Opportunities through 2025*, November 2006, p. 1.
220. Indur M. Goklany, *op. cit.*, footnote 204, p. 14.
221. Marianne Lavelle, "Cookstove Smoke Is 'Largest Environmental Threat,' Global Health Study Finds," *National Geographic*, December 13, 2012.
222. World Health Organization, Household air pollution and health, Fact sheet No. 292, March 2014.
223. Marianne Lavelle, "The Solvable Problem of Energy Poverty," *National Geographic*, September 23, 2010.

wide have no such access.[224] The problem affects rural households in particular. Geographically, the majority of people without access to electricity are found in sub-Saharan Africa and Southeast Asia.[225]

This problem requires concrete solutions. Yet cheap electricity still comes mostly from fossil fuels. Renewable energy such as wind and solar power are almost invariably far more expensive. Even though fossil fuels emit greenhouse gases, does this justify depriving the poorest people on the planet of such essential access to living conditions favouring their health and enhanced economic prospects?

In the industrialized world, policies promoting renewable energy have led to a higher proportion of electricity being generated from solar or wind energy in some countries.[226] This transition has not necessarily resulted in an environmental success story, as can be seen in the case of Germany, where it has gone hand in hand with higher production from coal-burning power plants.

"Fighting climate change should not be seen as a reason for maintaining the harsh living conditions afflicting more than a billion people."

Regardless of whether or not it has been an environmental success, the transition has been costly. It is estimated that in 2014, the German energy revolution led to an increase of $323 per household's electricity bill, meaning a subsidy of $34 billion to producers of renewable energy.[227] Same thing in England, where renewable energy increased electricity bills for the English by 15% over the past decade.[228]

In Spain, the energy transition was achieved by granting preferential rates to producers of renewable energy. Since 2000, these implicit subsidies have amounted to more than $40 billion.[229] Lacking the political will to raise consumers' electricity bills, the government added to its debt on financial markets by creating the Electricity Deficit Amortisation Fund (FADE). The billions of euros this has brought in will eventually have to be repaid by Spanish taxpayers.

Renewable energy can prove an attractive solution in some cases, for example, in remote communities that cannot easily be connected to a national grid. As a general rule, however, fighting climate change should not be seen as a reason for maintaining the harsh living conditions afflicting more than a billion people.[230] It is possible, and necessary, to fight climate change while keeping a clear idea of the relative importance of this battle among a broad range of issues.

Fighting Poverty and Climate Change

It is obvious that poverty is a scourge that must not be ignored, especially not under the pretext of fighting climate change. Worse yet, some policies for fighting climate change have adverse effects on the poorest of the poor, such as the production of biofuels from crops.[231] Poorer population groups are likelier to suffer the adverse effects of climate change precisely because of their poverty. Greater prosperity and development through strong and sustained economic growth would significantly help mitigate climate-related risks.

This thinking resonates with the broader public. A United Nations survey reveals that, among 16 priorities, climate change ranks dead last, reflecting a clear sense that future climate change is simply not the priority for poor people.[232] In other words, there is greater concern for the environment among people who are not suffering from hunger, who are not dying of easily curable diseases, who are able to find work and send their children to school.

Between now and 2085, only 13% of deaths due to famine, malaria and extreme weather events will be a result of climate change. Until then, the positive effects of climate change will likely continue to surpass the negative effects.[233] These observations lead author Indur Goklany to draw the following conclusion:

224. Marianne Lavelle, "Five Surprising Facts about Energy Poverty," *National Geographic*, May 30, 2013.
225. Ren21, *Renewables 2015: Global Status Report*, 2015, p. 103.
226. U.S. Energy Information Administration, European Nations Are Increasing Electricity Generation Using No-Carbon Sources, September 22, 2014.
227. "Green Revolution? German Brown Coal Power Output Hits New High," *Spiegel International*, January 7, 2014; Bank of Canada, "Financial Markets Department: Year Average of Exchange Rates," 2014.
228. Stanley Reed, "Britain plans to cut subsidy to renewable energy," *The New York Times*, July 22, 2015.
229. Brady Yauch, "Governments rip up renewable contracts," *Financial Post*, March 18, 2014.
230. Michael Jakob and Jan Christoph Steckel, "How Climate Change Mitigation Could Harm Development in Poor Countries," *Wiley Interdisciplinary Reviews: Climate Change*, Vol. 5, No. 2, March/April 2014, pp. 161-168.
231. Robert Mendick, "Biofuels do more harm than good, UN warns," *The Telegraph*, March 23, 2014.
232. United Nations poll available at the following address: http://data.myworld2015.org/.
233. Indur M. Goklany, "Is Climate Change the Number One Threat to Humanity?" *Wiley Interdisciplinary Reviews: Climate Change*, Vol. 3, No. 6, November/December 2012, pp. 489-508.

> The warmest world, being wealthier, should also have greater capacity to address any problem, including warming. Therefore, other problems and, specifically, lowered economic development are greater threats to humanity than global warming.[234]

"Between now and 2085, only 13% of deaths due to famine, malaria and extreme weather events will be a result of climate change."

This conclusion of Goklany's is also an excellent reason to be optimistic about the future and to fight our world's many problems, of which climate change is one, with determination, intelligence, and rationality.

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234. *Idem.*

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CONCLUSION

For a Balanced and Pragmatic Approach to the Problem of Climate Change

The Paris Conference constitutes a turning point in the fight against climate change. Reaching a binding agreement that applies to all countries and that is effective in meeting the 2°C target is unquestionably the most ambitious goal since the early days of the United Nations Framework Convention on Climate Change. If this goal is attained, the implementation of measures to meet the targets that are set will feed discussion for years to come. Even if the opposite occurs, debate will persist in the Canadian political arena.

Whatever the result on December 11, public conversation will continue, and we can hope it will rest on a clear understanding of the facts and on the available data. The importance of fighting climate change is unquestionable, and denying it to avoid discussion is no longer possible. Similarly, a doom-mongering attitude used to justify draconian solutions regardless of the economic impacts also serves to prevent a productive dialogue. Canadians are prepared to make an effort, but not to give up their quality of life.

This balanced approach is also something to strive for in the public policies to be adopted. Many means can be considered for reducing Canada's carbon footprint. We have analyzed the advantages and drawbacks of a wide variety of tools: carbon markets, carbon taxes, fuel taxes, regulations, subsidies, and so on. The essential contribution from the field of economics to the discussion, simple in principle, consists of using cost-benefit analysis as a basis, paying special attention to the unwanted effects of public policies, and assessing these policies regularly.

The aim of this *Research Paper* was not to propose an action plan or specific solutions, but to review existing approaches. Nevertheless, it is worth recalling here three interrelated principles that can guide us in our collective choices:

1. ENVIRONMENTAL EFFECTIVENESS: The measures adopted should produce real reductions in global greenhouse gas emissions at the best possible price, in other words, the greatest reductions for a given amount. Market mechanisms favouring decentralized decision-making present a significant advantage in this regard.
2. TAX NEUTRALITY FOR CITIZENS: The measures adopted should give consumers and businesses an incentive to make choices that offer lower carbon intensity without impoverishing them. This suggests that measures leading to higher government revenue should be offset by an equivalent reduction in other tax levies, such as personal and corporate income taxes.
3. MINIMAL ECONOMIC IMPACT: The measures adopted should limit unwanted economic distortions, minimize carbon leakage, and take companies' competitiveness into account.

These three principles are directly inspired by the balanced approach discussed here. They call for citizens' ability to pay to be respected while contributing to our planet's health.

The adoption of binding measures to fight climate change inevitably goes together with a short- and medium-term economic cost. To think otherwise is incompatible with a clear understanding of how the economy works. There are three reasons economic prosperity should not be disregarded.

"The adoption of binding measures to fight climate change inevitably goes together with a short- and medium-term economic cost."

First, the most vigorous economies are the ones best able to support substantial research and development to find technological solutions. Whether conducted at government research centres, universities, or businesses, current research is highly promising. In the decades to come, its potential will be more fully appreciated, but we already know it will help mitigate our impact on the environment without completely sacrificing our comfort and standard of living.

Second, prosperity plays a decisive role in the adaptation needed to deal with unavoidable climate change. Poor countries are the ones that are most threatened by the effects of weather and environmental disasters, due primarily to their poverty. Countries that get richer see a very significant decline in key factors such as deaths due to climate change, not to mention that economic prosperity goes together with huge benefits in health, education and other indicators of human development.

Third, it is the more affluent societies that show concern for the environment and, consequently, are willing to fight climate change. This popular awareness is not something to be taken lightly since it is a key motivation for many politicians and businesses.

For all these reasons, a healthier environment and greater prosperity are not contradictory goals, provided that the political choices we make are reasonable. This is why it seems to us both possible, and essential, to fight climate change with determination, but also with intelligence and rationality.

TECHNICAL ANNEX

Uncertainty in the Determination of Public Policies to Fight Climate Change

In order to determine the best climate change policies to adopt, it is necessary to have a proper understanding of the scientific conclusions of experts on the matter. The acquisition of scientific knowledge being a long, rigorous, constantly evolving process, these conclusions are always tinged with margins of error and uncertainty. This does not mean that the conclusions of scientists are false, but rather that they are perfectible and that they will become more precise with each new discovery.

From an economic point of view, it is essential to evaluate the impacts of climate change. Once these impacts have been quantified, it is then possible to compare the economic and social costs of proposed policies with the benefits resulting from the avoided climate change. According to economic theory, the ideal GHG mitigation policy is the one that minimizes the sum of the current value of net mitigation costs and the harm resulting from future climate change.[235]

The Six Steps of Scientific Projections

This calculation is not simple to carry out, however. In order to do so, scientists and economists use integrated assessment modelling, which integrates climate models and socioeconomic models. These models allow us to calculate the total damages caused by climate change, the cost of mitigation policies, and the social cost of carbon. Most models include hypotheses on the six following steps, as illustrated in Table A-1.[236]

Step 1. Projections of GHG Emissions

First of all, it is necessary to develop different GHG emissions scenarios. The development of these scenarios requires hypotheses on the different factors that affect GHG emissions, connected by the Kaya identity, explained in Chapter 3. In addition to those influencing GDP growth, such as demographic trends, it is also necessary to produce hypotheses regarding carbon intensity (the quantity of GHGs emitted per unit of energy produced) and energy intensity (primary energy used per unit of GDP). The evolution of green technologies can also affect these factors. The predictions obtained must stretch over several decades, even up to a few centuries.[237] Knowing that socioeconomic projections are rarely realistic for periods of more than 10 years, such long-term projections always include a wide margin of error.[238]

Step 2. Atmospheric Concentrations of GHGs According to Different Scenarios

Once the emissions scenarios have been established, the resulting atmospheric concentrations must then be determined. These concentrations are difficult to model since "carbon sinks" like oceans, vegetation, and soils absorb a portion of emissions.[239] One reason for this difficulty is that the past absorption rates of the oceans do not allow us to determine the rates for the coming years since the oceans are finite sinks, which means that they will be saturated at some point.[240]

In its most recent report, the IPCC developed four RCP scenarios (Representative Concentration Pathways) that are representative of simulations based on two elements: the evolution of GHG emissions and the atmospheric concentrations of CO_2 that are associated with them throughout the 21st century.

The four RCPs represent GHG emissions scenarios that vary as a function of a modelling of the global level of efforts devoted to the mitigation of GHG emissions. The atmospheric concentrations of CO_2 and CO_2e associated with the different RCPs at the end of the 21st century vary according to the intensity of mitigation policies, as shown in Table A-2.

235. William D. Nordhaus, "An Optimal Transition Path for Controlling Greenhouse Gases," *Science*, Vol. 258, No. 5086, November 1998, pp. 1315-1319.
236. Elements 2 and 3 are estimated based on climate models, while elements 1, 4, 5, and 6 are based on socioeconomic models. See Robert S. Pindyck, "Climate Change Policy: What Do the Models Tell Us," *Journal of Economic Literature*, Vol. 5, No. 3, September 2013, pp. 860-872.

237. For example, the temporal horizon for the *Stern Review of the Economics of Climate Change* is 200 years. See Nicholas Stern, *The Economics of Climate Change: The Stern Review*, Cambridge University Press, 2007, p. 202.
238. Irene Lorenzoni and W. Neil Adger, "Critique of Treatments of Adaptation Costs in PAGE and FUND Models," in Rachel Warren *et al.* (eds.), *Spotlighting Impacts Functions in Integrated Assessment Models: Research Report Prepared for the Stern Review on the Economics of Climate Change*, Tyndall Centre for Climate Change Research, Working Paper 91, 2006, p. 74; Frans Berkhout and Julia Hertin, "Socio-Economic Scenarios for Climate Impact Assessment," *Global Environmental Change*, Vol. 10, No. 3, October 2000, pp. 165-168.
239. Philippe Ciais *et al.*, "Carbon and Other Biogeochemical Cycles," in Thomas F. Stocker *et al.* (eds.), *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2013, p. 468.
240. William D. Nordhaus and Joseph Boyer, *Roll the Dice Again: Economic Models of Global Warming*, MIT Press, 1999.

Table A-1

Steps for determining the costs of proposed policies and the benefits resulting from the avoided climate change

LOGICAL STEPS	HYPOTHESES TO BE MADE	FACTORS OF UNCERTAINTY
1 **Projections of GHG emissions**	**• How much economic growth will there be?** **• How much demographic growth will there be?** **• How will the energy intensity of economic activity evolve?** **• How will carbon intensity evolve?**	**• Projection of the global economy over the very long run** **• Possible changes in demographic trends** **• Multiplicity of factors affecting carbon intensity and energy intensity** **• Hard-to-predict evolution of green energy sources**
2 **Atmospheric concentrations of GHGs according to different scenarios**	**• What is the absorption rate of carbon sinks (vegetation, oceans, soils)?** **• Does the relative saturation of the oceans slow down their absorption of GHGs?** **• What will be the level of global efforts to reduce emissions (in connection with the first step)?**	**• The preceding hypotheses** **• Saturation of finite carbon sinks (oceans)** **• Absorption capacity of other carbon sinks (vegetation, soils)** **• The IPCC's RCP scenarios**
3 **Temperature changes resulting from an increase in the atmospheric concentration of CO_2**	**• What is the equilibrium climate sensitivity, namely its reaction to GHGs, including the doubling of CO_2?** **• What are the feedback effects?** **• Are they positive overall (reinforcing warming)?** **• What is the magnitude of each of these effects?** **• How will global warming affect each region?**	**• The preceding hypotheses** **• Sensitivity between 1.5 and 4.5** **• Growing uncertainty since the 4^{th} assessment report** **• Inconsistencies between the empirical data and climate models** **• The effect of water vapour and clouds, the albedo effect of ice and other surfaces, etc.** **• Regional effects, ocean currents, etc.**
4 **Socioeconomic damage associated with a temperature increase**	**Enumerative method:** **• Which effects should be included?** **• Which estimates for each effect?** **• Does adaptation change the results?** **Statistical method:** **• Are climate effects well reflected by the level of well-being (income and consumption)?** **• Is adaptation well integrated?** **• What value should be placed on biodiversity and other hard-to-quantify effects?** **• Probability of extreme catastrophes?**	**• The preceding hypotheses** **• Sea level elevation** **• Melting of ice sheets** **• Net effects on agriculture (climate variation and fertilizing effect of CO_2)** **• Effects on other industries** **• The adaptive capacities of societies** **• Future technologies** **• Presence of hard-to-quantify effects** **• Non-zero chance of extreme climate catastrophes**
5 **The economic costs resulting from GHG reduction policies**	**• What replacement options will companies and individuals choose?** **• What new technologies will emerge in response to reduction policies?**	**• The preceding hypotheses** **• Reactions of economic agents** **• New technologies (renewable energy)**
6 **The discount rate used to compare the damage avoided with the costs of GHG mitigation policies**	**• What discount rate should be chosen (and what intertemporal preference rate)?**	**• The preceding hypotheses** **• Choice of discount rate (including the intertemporal preference rate)** **• Sensitivity of models to the choice of discount rate**

Note: This table summarizes this Annex. See the corresponding sources at each of the steps.

Table A-2

Characteristics of the different RCPs

RCP NAME	GHG REDUCTION EFFORTS	ATMOSPHERIC CONCENTRATION OF CO_2 IN 2100 (PARTS PER MILLION)	ATMOSPHERIC CONCENTRATION OF CO_{2E} IN 2100 (PARTS PER MILLION)
RCP2.6	**Rigorous**	**421**	**475**
RCP4.5	**Intermediate**	**538**	**630**
RCP6.0	**Intermediate**	**670**	**800**
RCP8.5	**None**	**936**	**1,313**

Source: Lisa V. Alexander *et al.*, "Summary for Policymakers," in Thomas F. Stocker *et al.* (eds.), *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2013, p. 29.

Step 3. Temperature Changes Resulting from an Increase in the Atmospheric Concentration of CO_2

The increasing temperature of the Earth's atmosphere following an increase in the atmospheric concentration of CO_2 is estimated by the equilibrium climate sensitivity. This is "a measure of the climate system response to sustained radiative forcing" and represents "the equilibrium global average surface warming following a doubling of CO_2 concentration."[241] The equilibrium climate sensitivity is therefore a central element when it comes to the development of public policies concerning climate change, since temperature variations determine the future harm to humans and to biodiversity.

The level of sensitivity is a variable whose exact value always remains unknown, and whose level of uncertainty has climbed over the past decade. The uncertainty regarding the sensitivity level to be used is illustrated by the differences between the two most recent IPCC reports, from 2007 and 2013. The fourth IPCC report, released in 2007, estimated that this sensitivity was between 2°C and 4.5°C, with a more likely estimate of 3°C (which is to say that an atmospheric concentration of CO_2 that is twice as high entails a 3°C temperature increase).[242] The fifth IPCC report, released in 2013, proposes a larger interval, from 1.5°C to 4.5°C, but without providing a most likely estimate.[243]

The IPCC is not in a position to provide a most likely estimate because of "a lack of agreement on values across assessed lines of evidence and studies."[244] This lack of agreement is explained by the divergence between the estimates of empirical data and those of climate models. Indeed, these last overestimated the temperature increases of the past twenty years, marked by a pause in global warming. For the 1998-2012 period, the average of a sample of 117 simulations from 37 models overestimated the observed temperature increase by a factor of more than four.[245] According to the IPCC, 111 of the 114 available models overestimated the temperature trend over the same period.[246] This does not mean that the average temperature is not trending upward, but is an indication of an overestimation of the equilibrium climate sensitivity by the models, which still remains to be confirmed.

241. IPCC, *IPCC Fourth Assessment Report: Climate Change* 2007, 2.3: Climate sensitivity and feedbacks.

242. *Ibid.*
243. Mark C. Freeman *et al.*, "Climate Sensitivity Uncertainty: When Is Good News Bad?" National Bureau of Economic Research Working Paper 20900, January 2015.
244. Lisa V. Alexander *et al.*, "Summary for Policymakers," in Thomas F. Stocker et al. (eds.), *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2013, p. 16.
245. John C. Fyfe *et al.*, "Overestimated Global Warming over the Past 20 Years," *Nature Climate Change*, Vol. 3, No. 9, September 2013.
246. IPCC, "Observed Changes and Their Causes," in Rajendra K. Pachauri *et al.* (eds.), *Climate Change 2014: Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 2014, p. 43.

The difficulty of establishing an estimate of sensitivity comes from feedback effects. It is recognized that the doubling of the atmospheric concentration of CO_2 entails a direct temperature increase of around 1.2°C.[247] The sensitivity estimates are located in an interval that is higher than 1.2°C (from 1.5°C to 4.5°C). Scientists therefore estimate that following an increase in the atmospheric concentration of CO_2, certain effects will amplify the direct initial warming. This is what is called a positive feedback effect.

Changes in the quantity of water vapour stemming from higher concentrations of CO_2 represent the most well-known positive feedback effect, whereas the feedback effect of clouds represents the largest source of uncertainty.[248] This uncertainty is well illustrated by a study presented as part of the fourth IPCC report, which arrives at different equilibrium climate sensitivity, ranging from 1.9°C to 5.4°C, solely by altering the radiative properties of clouds.[249]

Step 4. Socioeconomic Damage Associated with a Temperature Increase[250]

Once the equilibrium climate sensitivity has been determined, it is possible to estimate the warming associated with different scenarios of atmospheric concentrations of GHGs. The next step is to estimate the corresponding socioeconomic damage. This last is measured in losses of GDP or of consumption for future generations.

Two methods are generally employed to quantify this damage, namely the enumerative method and the statistical method. The enumerative method is based on the estimates of the research in various fields of the natural sciences measuring the impacts of temperature variations on the environment. An economic value is then attributed to the environmental impact in question. For example, an increase in the sea level will entail the loss of livable and arable land, and will necessitate the construction of additional dikes, which are variables with market values. The value of the resources used for the protection of coasts and of land lost because of rising sea levels will be added to the impacts on the other economic sectors, such as energy, agriculture, forestry, tourism, etc. A value must then be assigned to certain effects that do not have market values, like human health or the disappearance of animal and plant species.

The statistical method quantifies socioeconomic damage, but without referring to the natural sciences literature. This method is based solely on the observed relation between climate variations and well-being, which presupposes that the evolution of the climate is entirely reflected in the evolution of incomes and consumption.

Neither of these two methods is perfect. One variable in the evaluation of the damage caused by climate change, but which is not entirely integrated in the integrated assessment models, is the capacity of populations to adapt to climate variations, which varies positively with economic and technological development. The models based on the enumerative method neglect the fact that different economic agents will react and adapt to the physical changes caused by climate variations, and thereby mitigate the magnitude of the potential harm. On the contrary, those based on the statistical method implicitly take into account adaptive capacity. However, the adaptation taken into account is often conditioned by the technologies existing today, which considerably overestimates the socioeconomic damage caused by climate change.[251]

On the other hand, the models do not take into account certain hard-to-quantify impacts, although these remain relatively small compared to total damage. According to most experts, these omissions underestimate total harm only a little in the models.[252]

Furthermore, most models do not take into account the non-zero chance of a substantial loss of global well-being following extreme climate catastrophes. This once again underestimates the damage due to climate change. The few models that account for such risks probably assign too low a probability to their occurrence.[253]

247. David A. Randall *et al.*, "Climate Models and Their Evaluation," in Susan Solomon *et al.* (eds.), *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2007, p. 631.
248. IPCC, *op. cit.*, footnote 241.
249. Hervé Le Treut *et al.*, "Historical Overview of Climate Change," in Susan Solomon *et al.* (eds.), *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2007, p. 114.
250. The ideas in this section are drawn primarily from Richard S. J. Tol., "The Economic Effects of Climate Change," *Journal of Economic Perspectives*, Vol. 23, No. 2, 2009.
251. Indur M. Goklany, "What to Do about Climate Change," Policy Analysis No. 609, Cato Institute, February 5, 2008, p. 6.
252. Douglas J. Arent *et al.*, "Key Economic Sectors and Services," in Christopher B. Field et al. (eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2014, p. 690.
253. Martin Weitzman, *Some Basic Economics of Climate Change*, in Jean-Philippe Touffut (ed.), *Changing Climate, Changing Economy*, Edward Elgar, 2009.

Step 5. The Economic Costs Resulting from GHG Reduction Policies

GHG reduction policies will inevitably entail economic costs. Companies will have to resort to more expensive alternatives in order to limit their GHG emissions. The reduction in economic activity and higher prices that result will have an impact on GDP and consumption. Technological progress, however, allows us to reduce the cost of transitioning toward less carbon-intensive energy sources, as illustrated by the reductions in the cost of renewable energy sources over the past decade.[254]

Hypotheses regarding technological change have an impact not only on emissions scenarios, and therefore on atmospheric concentrations of GHGs, but also on the economic costs of an accelerated transition toward a carbon-free economy.

As we can see, this step in the calculation involves less uncertainty that the others.

Step 6. The Discount Rate Used to Compare the Damage Avoided with the Costs of GHG Mitigation Policies

In order to be in a position to adopt the most appropriate public policies for limiting the harm caused by climate change, it is essential to compare the costs of mitigation policies with the benefits to be had from the reduction of GHG emissions, in order to ensure that the costs do not exceed the benefits. Ideally, we should adopt mitigation policies up until the point at which the marginal cost of reducing one tonne of GHGs is equal to the marginal benefit of the tonne of GHGs avoided.

The difficulty of this exercise stems from the fact that the benefits associated with the reduction of GHGs will accrue to the citizens of future generations, whereas the costs of mitigation policies will be borne by the citizens of current generations. Taking into account the fact that present consumption is always more highly valued than future consumption, we use a positive discount rate. However, comparing the consumption of current generations to that of generations that have not yet been born raises ethical considerations, which are widely used to justify a lower discount rate than for relatively shorter horizons. Indeed, economist Martin Weitzman of Harvard University characterized the discounting of the distant future as the most critical problem in economics.[255]

The importance of the discount rate used is well illustrated by the calculation of the social cost of carbon which represents the marginal impact of GHG emissions. Knowledge of this cost makes it possible to adopt policies allowing for the internalization of negative externalities associated with activities that emit carbon.

The different estimates of the social cost of carbon are extremely divergent and rest essentially on the discount rate used, a controversial problem for which there is still no solution, according to William Nordhaus, an economist at Yale University.[256] In order to determine which environmental regulations have positive effects, the American government mandated a working group made up of several experts to calculate this cost. In 2007, using a 3% discount rate, they arrived at a result of $24 per tonne of CO_2 for the year 2015. When the study was updated, this cost was revised upward to $37. Indeed, this update illustrates the influence of the discount rate used. In calculating the social cost of carbon for the year 2050, the authors obtain an estimate of $26 with a 5% discount rate, but an estimate of $97 with a 2.5% discount rate.[257]

The degree of sensitivity of the social cost of carbon to the discount rate used is also well illustrated by a review of the 311 estimates in the literature. The average cost is $5 per tonne of CO_2 for an intertemporal preference rate[258] of 3%, compared to $75 for a rate of 0%.[259] It is therefore very difficult to determine which of all of these estimates is the most appropriate.

A High Degree of Uncertainty

As we can see, the different approaches of climate economists for determining the social cost of carbon are characterized by a high degree of uncertainty. This is all the more so given that the margins of error at each step

254. International Energy Agency, *Tracking Clean Energy Progress 2015*, 2015, p. 20.

255. Moritz Drupp *et al.*, *Discounting Disentangled: An Expert Survey on the Determinants of the Long-Term Social Discount Rate*, Centre for Climate Change Economics and Policy, Working Paper No. 195, June 2015.

256. William Nordhaus, *Estimates of the Social Cost of Carbon: Background and Results from the Rice-2011 Model*, Cowles Foundation for Research in Economics, Discussion Paper No. 1826, Yale University, October 2011.

257. In 2007 US dollars. Interagency Working Group on Social Cost of Carbon, *Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis*, Executive Order 12866, February 2010, p. 1; Interagency Working Group on Social Cost of Carbon, *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis*, Executive Order 12866, May 2013, p. 3.

258. The intertemporal preference rate is a component of the discount rate.

259. Richard S. J. Tol, "The Social Cost of Carbon," *The Annual Review of Resource Economics*, Vol. 3, October 2011, p. 432. The values found by the author are $19 and $276 per tonne of carbon. We obtain the equivalent in tonnes of CO_2 by multiplying these numbers by 0.2727.

of the calculation increase the uncertainty associated with each of the other steps. For example, in the calculation of the damage caused by climate change, the standard deviation of the economic impact in terms of loss of GDP does not include all of the uncertainty associated with the preceding steps.[260]

Economist Robert Pindyck from MIT is highly critical of integrated assessment models. He states that they "create a perception of knowledge and precision that is illusory," and that the hypotheses associating climate change with economic losses are arbitrary. Thus, the models are close to useless in determining the social cost of carbon and the policies that should be adopted, according to him.[261] Martin Weitzman, for his part, declares that the uncertainty associated with climate change means that the cost-benefit analyses derived from the models are far from achieving the degree of precision of traditional cost-benefit analyses.[262]

The Results of the Cost-Benefit Analyses

Although the effects associated with climate change derived from the integrated assessment models are highly uncertain, they represent the best available estimates and should, at the very least, serve as guidelines in the adoption of public policies.

The most recent IPCC report compiles the results of integrated assessment models from different studies having quantified the socioeconomic damage associated with climate change. Unfortunately, very few studies quantify the damage associated with increases of more than 3°C above today's temperatures. Most of the studies measure the impact of a temperature increase of from 2.2°C to 3°C. For example, for studies estimating warming of 2.5°C, the average of the estimates of the damage caused is 1.1% in terms of loss of GDP.[263] While there is no timeframe associated with these temperature increases, it is generally accepted that these studies measure the economic impacts from now until the end of the 21st century.[264] For its part, the OECD estimates that GDP will be from 0.7% to 2.5% lower in 2060, and from 1.5% to 4.8% lower by the end of the century.[265]

The economic cost associated with a stabilization of atmospheric concentrations of GHGs at 430-480 parts per million of CO_2e—necessary in order to have a greater than 66% chance of respecting the 2°C limit—is equivalent to a loss of consumption of 4.8% in 2100, according to the IPCC.[266]

Based on these figures, we could be tempted to conclude that the economic cost of mitigation policies will be as high as the benefits that we think will result from a lower global temperature. However, the IPCC's estimates of the costs of mitigation policies are based on the least expensive scenario, namely that of a single carbon price imposed on a global scale. Given the difficulties of reconciling the interests of rich countries with those of developing countries (see Chapter 1), it is unlikely that this will be the case. Indeed, William Nordhaus calculated that if only 50% of countries participate, the economic costs associated with the tax would be 250% higher than an optimal tax.[267] Moreover, the IPCC bases its estimate on very strong hypotheses regarding the widespread availability of certain technologies, like carbon capture and storage. The IPCC recognizes, though, that without this technology, the cost of mitigating GHGs could increase by 138%.[268]

These strong hypotheses, combined with the high adaptive capacity of human beings, suggests that GHG reduction efforts to limit the temperature increase to 2°C will in all likelihood cost more than the benefits. Nonetheless, this does not constitute a reason not to act. The lack of studies measuring the impact of an increase greater than 3°C—which surely underestimates the weight accorded to the possibility of irreversible catastrophes—can justify the adoption of mitigation policies.

From this perspective, it is appropriate to bear the cost of mitigation policies, just as it is logical to insure oneself in one's daily life against events whose probability is low, but whose occurrence would entail considerable damage, like a fire in one's home.[269] This is an entirely separate discussion, however.

It would be very sensible, though, for the political debate to take into consideration all of the costs and benefits associated with climate change, and integrate

260. *Ibid.*, p. 425.
261. Robert S. Pindyck, "The Use and Misuse of Models for Climate Policy," NBER Working Paper No. 20900, April 2015.
262. Martin Weitzman, *op. cit.*, footnote 253.
263. Richard S. J. Tol *et al.*, "Key Economic Sectors and Services: Supplementary Material," in Field, C.B. *et al.* (eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2013, p. SM10-4.
264. Richard S. J. Tol, *op. cit.*, footnote 250, p. 44.
265. Rob Dellink *et al.*, "Consequences of Climate Change Damages for Economic Growth: A Dynamic Quantitative Assessment," OECD Economics Department Working Papers No. 1135, 2014, p. 3.
266. Ottmar Edenhofer *et al.*, "Summary for Policymakers," in Ottmar Edenhofer *et al.* (dir.), *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2014, p. 15.
267. William D. Nordhaus, *A Question of Balance: Weighing the Options on Global Warming Policies*, Yale University Press, 2008, p. 19.
268. Ottmar Edenhofer, *op. cit.*, footnote 266.
269. Martin Weitzman, *op. cit.*, footnote 253; Robert S. Pindyck, *op. cit.*, footnote 236, p. 16.

the latest developments in economics. The *Stern Review*, heavily criticized for its overestimation of the harm caused by climate change and its choice of a zero discount rate (see Chapter 2), arrives at the conclusion that we must stabilize the atmospheric concentration of GHGs at 500-550 parts per million of CO_2e.[270] Since then, estimates of the harm due to climate change have fallen as the economic research on this question has improved.[271]

In sum, the optimal level of atmospheric concentrations of GHGs—still based on a carbon tax imposed at the planetary level—would be around 550 parts per million of CO_2e for an intertemporal preference rate of 1%, and of 625 for an intertemporal preference rate of 3%.[272] The United Nations Framework Convention on Climate Change, during the Conference of the Parties in Copenhagen in 2009, instead retained the 2°C target and an atmospheric concentration of around 450 parts per million of CO_2e.

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270. Nicholas Stern, *op. cit.*, footnote 237, "Summary of conclusions."
271. Robert Mendelsohn, "Climate Change and Economic Growth," Commission on Growth and Development, Working Paper No. 60, 2009, pp. 10-11.
272. Richard S. J. Tol, "Targets for Global Policy: An Overview," *Journal of Economic Dynamic and Control*, Vol. 37, No. 5, 2013, p. 918.

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ISBN 978-2-922687-63-7