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The Climate Change Threat: Why Reduce GHG Emissions?

The prospect of climate change is an enormous environmental challenge. What are the unique qualities of the Earth and its atmosphere that make them so amenable to life as we know it and so potentially fragile and susceptible to changes? What are the sources of the gases said to alter climate, and how will the Earth be affected by climate change? How can we deal with this prospect? As a nation of 30 million people in a world of six billion, to what degree are Canadians responsible for these emissions, and how are we participating to remedy them? What price should we be willing to pay?

This chapter reviews climate change science and the resultant policy response in order to provide the overall context for estimating the cost of GHG emission reductions. First we look at the nature of the Earth and its atmosphere, in particular why changes in the concentration of GHGs in the atmosphere could impact the Earth. Sources and types of GHGs are described, as is the history of the human-induced changes to atmospheric GHG concentrations that have led to the present concerns. Then we turn to the history of international policy responses and negotiations and a review of the initiatives that Canada has undertaken since 1990. Finally, we describe in detail Canada's current process to assess its GHG policy options.

After reading this material, one may agree that human-induced climate change is occurring. However, agreement with this position is not necessary for one to see the value of estimating reduction costs. The world is engaged in a classic exercise of decision making under uncertainty, indeed a chronic uncertainty in that, even for those who are confident that we are changing the climate, many specific impacts are unpredictable. Understanding the cost of action is critical information for such a decision-making endeavour.

What Is Climate Change?

The Earth and Its Atmosphere

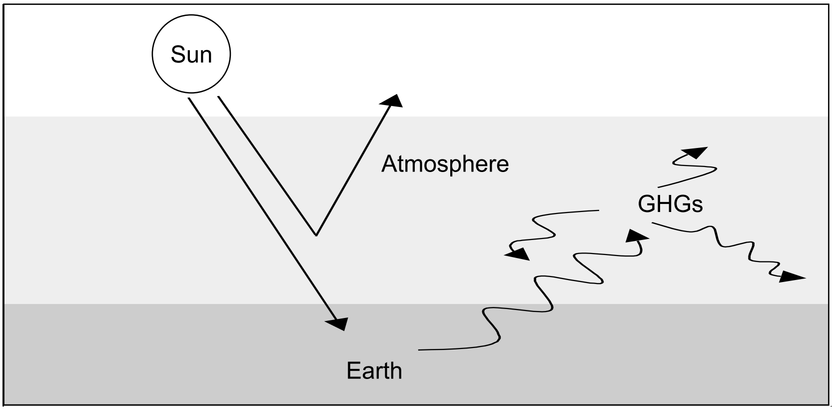
The Earth has a livable region, known as the *biosphere*, that is extremely thin relative to its 12,000 km diameter. We have little evidence of any other place that could sustain Earth's life forms. What makes our planet unique?

The Earth's distance from the Sun is critical. A difference of 5% in the Earth-Sun distance would lead to a runaway greenhouse effect or runaway glaciation, consigning the Earth to Venus-like high temperatures or Mars-like constant subzero conditions.[1] The Earth's mean temperature of 15°C seldom varies more than 40° to 60° in either direction, and the Earth has sustained temperatures in this range for much of its history. Two of the Earth's characteristics are primarily responsible for maintaining this stability. First, about 70% of its surface is covered by water, whose mean temperature is about 5°C. This massive body of water moderates the Earth's temperature by acting as a heat sink during daylight hours and a heat source at night and by reducing heat concentrations as its currents distribute heat from warmer to cooler areas. Second, the Earth's gravitational field maintains a thin band of gases, known as the atmosphere, that acts as a thermal blanket regulating both incoming and outgoing solar energy during day and night. The interaction between the Earth's bodies of water and its atmosphere regulates its climate. Alter the characteristics of either and climate conditions can also be expected to change.

Figure 1.1 depicts the interactions between the Earth, its atmosphere, and solar radiation. The atmosphere, a layer of gas about 150 km thick, permits most forms of solar electromagnetic radiation to reach the Earth's surface in varying amounts.[2] Upon striking the Earth, the radiation, including its shorter waves known as visible light, is generally converted to heat and

Figure 1.1

Greenhouse effect



Note: The solid lines represent solar radiation; the curved lines represent infrared radiation.

re-emitted in the form of infrared radiation. The atmosphere does not let infrared radiation leave as readily as visible light radiation enters, so heat energy is retained near the Earth's surface. This *greenhouse effect* maintains the Earth's temperature about 33°C higher than it otherwise would be.[3]

The greenhouse effect is a result of the atmosphere's chemical constituents. Composed primarily of nitrogen and oxygen, the atmosphere also contains trace gases: argon, neon, helium, krypton, xenon, ozone (O_3), hydrogen, carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and water vapour, a gas whose local proportion varies considerably from day to day. Table 1.1 defines these constituents and shows how concentrations have changed over time. While their proportion of the Earth's atmosphere may be small, the trace gases play important roles in maintaining the Earth as a livable region.[4] A number of these gases – CO_2, CH_4, N_2O, and a few other gases generated by human activity – trap infrared radiation (heat) and then re-emit it as infrared energy in all directions.

Sources and Types of GHGs, Natural and Human-Induced

The surface of the Earth and its atmosphere are constantly changing. A number of geological and chemical cycles ensure the supply and replenishment of many of the elements and compounds needed to sustain life: key cycles are water, nitrogen, and carbon. Our interest is primarily in the carbon cycle (Figure 1.2), which explains the flow of carbon in its gaseous form, in association with oxygen as CO_2, to fixed organic material known as biomass. When carbon is fixed, it is said to be *sequestered*. The medium in which it is captured and fixed is generally referred to as a *sink*. Thus, one may refer to the forest sink or the ocean sink. The arrows in the diagram show the transfers of carbon between different forms. Most carbon in biomass gets released back to the atmosphere again as CO_2. However, over geological time, the fixation of carbon has exceeded its release as CO_2 because some organic material gets trapped underground in sedimentary strata and, after long periods of sustained pressure, is transformed into fossil fuels – coal, oil, and natural gas. Certain forms of sea life also biologically fix bicarbonate with calcium, ultimately producing limestone and dolomite.

Carbon is returned to the atmosphere in different ways. Oxidative combustion of any carbonaceous compound (wood, oil, methane, coal) generates CO_2 as a by-product. Respiration, the process of obtaining energy from the oxidation of sugars in living systems, generates CO_2 as well. Living systems release CO_2, whether bacteria decomposing organic material, yeast generating alcohol from sugar, or humans metabolizing their lunch. Other noncombustive sources include deforestation and land use change, volcanoes and similar geological activities, and certain chemical reactions such as the calcination of limestone to make cement or lime.

Table 1.1

Atmospheric gases, global warming potentials, and sources

Gases	Concentration, 1992[a]	Concentration, pre-industrial[a]	CO_2e rating	Lifetime in atmosphere, remarks
Nitrogen (N_2)	78.084%			
Oxygen (0_2)	20.946%			
Argon (Ar)	0.934%			
Neon (Ne)	0.182%, 182 ppmv			
Helium (He)	0.0524%, 52 ppmv			
Water vapour (H_2O)[b]	0 to 2%		–	
Carbon dioxide (CO_2)[b]	0.35%, 350 ppmv	0.28%, 280 ppmv	1	Variable, normally 200 years, increase almost entirely of human origin
Ozone (O_3)				Not emitted directly by humans but influenced
In troposphere[b]	0.02 to 0.1 ppmv		–	by human activity. Increased tropospheric O_3
In stratosphere[b]	0.1 to 10 ppmv		–	concentrations contribute to warming, while stratospheric O_3 depletion has a net cooling effect.
Methane (CH_4)[b]	1.74 ppmv	0.70 ppmv	21	12.2 years, natural and human origin
Nitrous oxide (N_2O)[b]	0.311 ppmv	0.275 ppmv	310	120 years, natural and human origin
CFC-12 (CF_2Cl_2)[b]	0.503 ppbv	0.0 ppbv	8,500	102 years, entirely human origin
CFC-11 ($CFCl_3$)[b]	0.3 ppbv	0.0 ppbv	4,000	Entirely human origin
Sulphur hexafluoride (SF_6)[b]	0.032 ppbv	0.0 ppbv	23,900	3,200 years, entirely human origin
Halon-1301 ($CBrF_3$)[b]	2.0 pptv	0.0 pptv	5,600	Entirely human origin
Halon-1211 ($CBrClF_2$)[b]	1.7 pptv	0.0 pptv	–	Entirely human origin
Nitric oxide (NO)				
In troposphere	0 to 1 ppbv			
In stratosphere	Up to 0.02 ppmv			

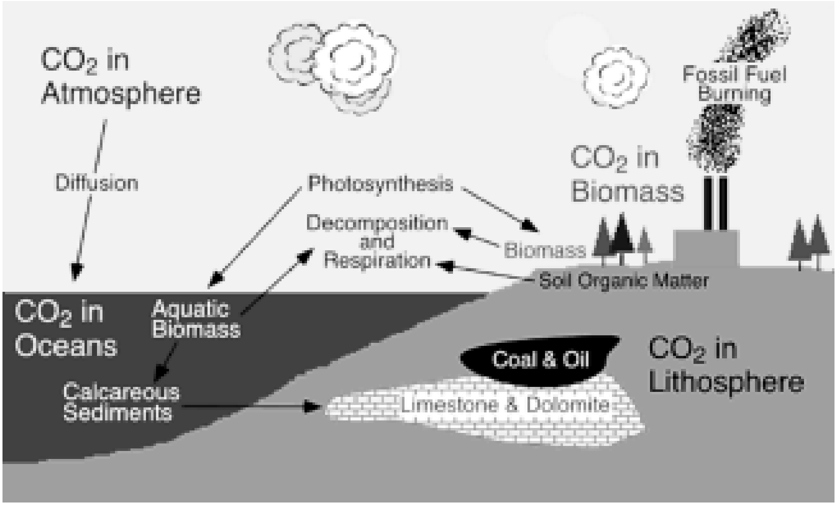
a The concentrations of atmospheric gases are given in either percentage by volume (which is the same as parts per hundred by volume), parts per million by volume (ppmv), parts per billion by volume (ppbv), or parts per trillion by volume (pptv).

b These gases have GHG properties of heat retention. Their global warming potentials are indicated by a CO_2 equivalency (CO_2e) rating as of 1995, except for ozone and water vapour, whose radiative role is complex and less understood.

Source: Statistics Canada, *Human Activity and the Environment 2000* (Ottawa: Statistics Canada, 2000).

Figure 1.2

The carbon cycle



Source: M. Pidwirny, Department of Geography, Okanagan University College, Figure 9r-1, *Fundamentals of Physical Geography* (1996-2000), <www.geog.ouc.bc.ca/physgeog>.

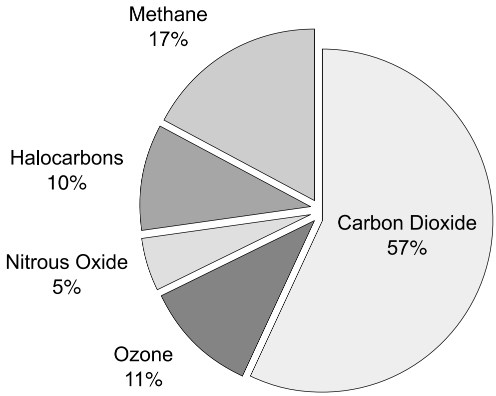
The carbon cycle is generally found to be in equilibrium, and it dwarfs the changes caused by human-induced, or *anthropogenic,* carbon releases to the atmosphere. Indeed, some skeptics point to the relatively small anthropogenic contribution as evidence that humans are not causing climate change. However, according to climate specialists, small changes in atmospheric concentrations of GHGs, carbon dioxide in particular, can have significant impacts on the atmosphere's greenhouse function. But just how significant is an uncertainty likely to remain for some time.

Some skeptics suggest that we need not take action to reduce our emissions because natural sinks will absorb the extra carbon in the atmosphere. Thus, sinks can act like buffers or negative feedback loops if their rate of CO_2 uptake increases as the atmosphere becomes more CO_2 enriched. This might especially be the case for oceans, the largest CO_2 sink, which are teeming with microscopic organisms and hold vast amounts of CO_2 in solution. However, many scientists working in this area believe that only about half of anthropogenic CO_2 is absorbed in this way, while the rest remains in the atmosphere – which explains the steady increase of atmospheric CO_2 concentrations.

It is not only CO_2 that acts as a thermal blanket. A number of other GHGs are even more efficient at retaining heat. They include common gases such as methane (CH_4) nitrous oxide (N_2O) and a long list of less common, human-produced compounds such as halocarbons: compounds of carbon

Figure 1.3

Contribution of human-induced gases to the greenhouse effect



Sources: Calculations based on information in Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change* (Cambridge: Cambridge University Press, 1996); Pembina Institute, "Greenhouse Gases," <www.climatechangesolutions.com/english/science/gases.htm>.

with fluorine, chlorine, or both. Each compound has been analyzed in terms of its ability to retain heat (*radiative forcing*) compared with CO_2; this is described as a *CO_2 equivalency (CO_2e) rating* or *global warming potential*. For example, CH_4 has a CO_2e rating of 21, meaning that one tonne of CH_4 has the same global warming potential as 21 tonnes of CO_2. The estimations are based not only on ability to retain heat but also on life span in the atmosphere and other characteristics. Table 1.1 includes CO_2e ratings for different GHGs.[5]

Although there are only small amounts of GHGs in the Earth's atmosphere, they trap a significant part of the heat that is emitted as radiation by the Earth's surface. Water vapour is the most abundant and important GHG and is responsible for about 60% of the total greenhouse effect. The remaining 40% is due to the gases discussed above that are closely linked with human activity: CO_2, CH_4, N_2O, halocarbons, and ozone. Their respective contributions to the human-induced greenhouse effect are shown in Figure 1.3. Although ozone is better known for the role that it plays in the ozone layer, human-induced changes in the concentration of tropospheric (ground-level) ozone relative to stratospheric ozone may be strengthening the greenhouse effect.

History of GHGs and Human Activity

Prior to the industrial revolution, people depended primarily on renewable sources of energy: muscle power (human or domesticated animal), flowing water, wind, and the combustion of plant and animal wastes. But with the development of the steam engine at the birth of the industrial revolution, the use of coal and eventually other fossil fuels contributed to profound changes in production processes, farming, and domestic activities. Since 1750, and especially during the past 100 years, the use of fossil fuels has increased dramatically. Today fossil fuels provide 83% of the energy used by member countries of the Organization for Economic Cooperation and Development, releasing roughly 28 billion tonnes of CO_2 into the atmosphere in 2000. Ice core samples that go back 400,000 years indicate that levels of CO_2 are at a peak today and that the rate of increase in the Earth's atmospheric concentration is the fastest ever. In fact, the increase over the past 150 years equals that which occurred from the height of the last ice age 20,000 years ago to the year 1750.

Researchers using models to predict future atmospheric concentrations of CO_2 estimate that by the year 2100 the CO_2 content of the atmosphere will have doubled or tripled over pre-industrial levels. The margin of error around these values is estimated to range from 10% to 30% because of the high uncertainty about the buffering effect of sinks.

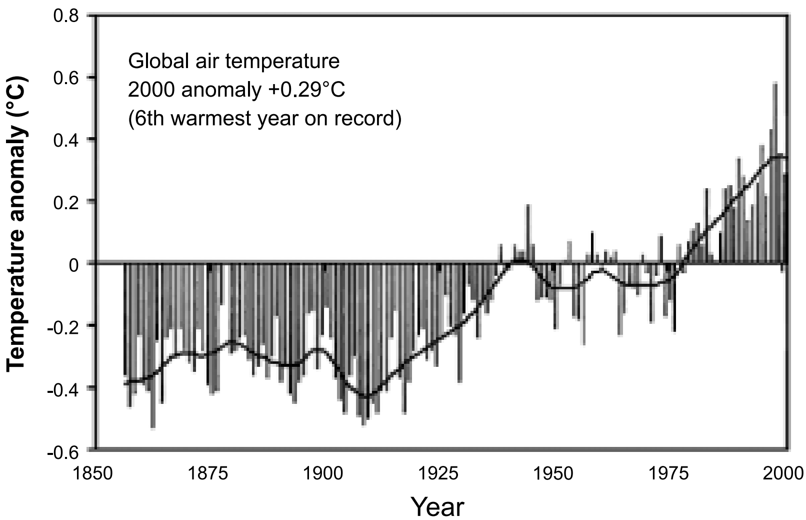
Fossil fuel use as well as industrial and agricultural activities generate other GHGs. The atmospheric concentration of methane has increased 151% since 1750 and the concentration of nitrous oxide by 17% to its highest level in at least the past 1,000 years. While CO_2 emissions are closely linked to the carbon in fuels, these other GHG emissions depend on a variety of factors such as industrial process or combustion technology. Nitrogen, by far the largest component of the atmosphere, combines with oxygen quite readily under heat and pressure, typical of internal combustion engines and some boiler systems. Industrial processes also release chlorofluorocarbons (CFCs), hydro-chlorofluorocarbons (HCFCs), per fluorocarbons (PFC), and sulphur hexafluoride (SF_6), each a potent GHG. Many of these gases remain in the atmosphere for a long time, giving them CO_2e indices in the thousands (Table 1.1).

Possible Impacts of a Change in GHG Concentration in the Atmosphere

At first glance it appears unlikely that such minor changes in the composition of the Earth's atmosphere (fractions of a percent) would have significant effects. However, global temperature estimates over the past five centuries indicate a rising trend (Figure 1.4), and it is estimated that temperatures have increased by 0.6°C over the past century. In its 1995 report, the Intergovernmental Panel on Climate Change (IPCC) stated that "the balance of evidence suggests a discernable human influence on global climate," and it strengthened that statement in its 2000 report by stating that "there is now new and stronger evidence that most of the warming observed

Figure 1.4

Trend in the Earth's average annual temperature



Note: Further details about the development of the data set are available in P.D. Jones et al., "Surface Air Temperature and Its Changes over the Past 150 Years," *Review of Geophysics* 37 (1999): 173-99.
Source: Climatic Research Unit, University of East Anglia, <www.cru.uea.ac.uk/cru/info/warming/>.

over the last 50 years is attributable to human activities."[6] The IPCC goes on to forecast a further increase in average global temperatures of 2°C by 2100, although with uncertainties this increase could range from 1°C to 4°C.

What would be the effects of such temperature changes? An increase of 2°C appears small to a Canadian, who might experience temperatures that vary by 60°C through the seasons of a typical year. However, it is estimated that at the depth of the last ice age average global temperatures were only 3.5°C to 5°C colder than at present. Many climate and ecology experts believe that increases in the average global temperature of 1°C to 4°C in the short span of a century could have profound impacts on climate and ultimately ecosystems.

Climate change is likely to impact the hydrological cycle, thus affecting the patterns and intensities of precipitation and drought, the conditions for agriculture and forestry, freshwater availability, and overall ecosystem viability. There is a potential for coastal flooding and even submerging of island states as sea levels rise. More subtly, changed moisture regimes could expand forested regions and transform semi-arid regions into deserts, causing the extinction of species and increasing the abundance of others, including the expansion of disease-causing organisms into new areas.[7] Of particular interest to Canadians is that permafrost zones are predicted to move steadily northward and detrimentally alter the habitat and perhaps the survival of caribou and other inhabitants of the tundra. Additionally, warming oceans could negatively impact salmon populations while extending the range of species such as mackerel.

The rate of such change could be many times greater than the rate at which species can adapt. Higher global temperatures may also increase the likelihood of extreme climatic events. While evidence is not conclusive, some climatologists consider it likely that the world will see increased intense precipitation events in the northern hemisphere and increased cyclone activity in tropical regions.

The impact on humans is controversial and not well understood. Many of these events could result in considerable economic burden for a nation, region, or local population. Others could result in significant benefits. For example, the impact on food crops is not well understood, and estimates vary greatly; some studies suggest declines of 80% or more, while others forecast increases of over 200%.[8] Flooding and higher sea levels could force internal or international migrations of human populations. Human health could be affected because of harsh changes in the local climate (heat waves, levels of precipitation, drought, extreme weather events) and ecological disturbances that include the spread of tropical diseases, parasites, and crop pests.

Dealing with Climate Change

Governments are increasingly convinced by those who argue that we must take seriously the threat of climate change. Many have decided that the risk of negative impacts is real and that we must act now to reduce the risk; the perspective is changing from one of "Should we act?" to one of "How should we act?" In essence there are two ways of acting: either to adapt to the changes or to mitigate them.

Adaptation

Adaptation is a response to change in the environment in an effort to minimize adverse effects. The ability to adapt depends on the extent to which climate change can disrupt the system and the extent to which the system can be modified to avoid damage from disruption.

Adaptation could include more efficient management of resources; construction of dikes; improved monitoring and forecasting systems for floods and droughts; construction of new reservoirs to capture and store excess flows produced by altered patterns of snowmelt and storms; changes of individual crops and crop mixes; improved water management and irrigation systems; and changes in planting schedules and tillage practices. The extent of adaptation will depend on the affordability of such measures, access to know-how and technology, the rate of climate change, and biophysical constraints such as water availability, soil characteristics, and crop genetics.

Mitigation

Mitigation is an effort to maintain the existing or historical state by stopping or counteracting the source of a change. Examples are to stop combusting fossil fuels and to sequester CO_2 emissions from such combustion.

While it is not clear what an acceptable level of GHGs in the atmosphere might be, atmospheric scientists claim that simply to stabilize the atmospheric concentration of CO_2 would require a decrease of at least 70% in the release of anthropogenic emissions, an achievement that clearly would take decades at best.[9] Because of time lags in the absorption processes of sinks, the greenhouse effect would intensify during this period and for some time after the targeted reduction has been achieved. International agreements that stabilize global anthropogenic emissions (as opposed to atmospheric concentrations) can only slow climate change because current emissions are already at levels that cause rapid increases in atmospheric concentrations. The Kyoto agreement would have even less effect because it stabilizes only the emissions of developed countries and a few others, so this stability would be offset by rising emissions from developing countries, China and India in particular.

In developing a mitigation strategy, it is important to specify the key factors that determine the level of emissions. A useful tool is a *decomposition equation* that explains changes in GHG emissions in terms of changes in specific factors. A common term for this in the GHG literature is the *Kaya Identity,* shown in Figure 1.5. Each term provides insight into how one might reduce emissions.

The first term relates GHGs to energy use (GHG/E). A change in this term may occur if the share of fossil fuels has declined in the energy mix, say through the greater use of renewables or nuclear power. It may change if there is a shift among fossil fuels such as from coal toward natural gas. It may also change if technologies are used to separate CO_2 emissions from fossil fuels (either before or after combustion) and prevent them from entering

Figure 1.5

Kaya Identity decomposition equation

$$\%\Delta GHG = \%\Delta \frac{GHG}{E} + \%\Delta \frac{E}{Q} + \%\Delta \frac{Q}{P} + \%\Delta P$$

Note: GHG = greenhouse gas, *E* = energy, *Q* = output of the economy, and *P* = population.

the atmosphere. Carbon can be captured and sequestered by injection into exhausted oil and gas reservoirs, active wells to enhance oil and gas recovery, coal beds to release methane, or deep saline aquifers. Forestry and agricultural carbon sinks can also be enhanced through forest management, cropland management, and revegetation actions.

The energy intensity term (E/Q) reflects changes in energy used per unit of economic output. If the energy efficiency of equipment, buildings, and infrastructure changes, then it will show up in this term. However, other factors – not specifically related to technical energy efficiency – can also cause this ratio to change, which is why the preferred term is *energy intensity* instead of energy efficiency. The measure of output (Q) may change even though it has not changed in physical terms. Output is usually measured in monetary units, corrected for inflation, in order to estimate changes in physical output. However, if the value of the sector's output has changed at a different rate than inflation, then this term can change even when the physical product does not change.[10] When it comes to personal energy uses, such as home heating or vehicle travel, even lifestyle changes can show up in this term. A deliberate lowering of home heating temperatures, or reduced vehicle use for short, less efficient urban trips, can lead to changes in energy intensity. Because some sectors are more energy intensive than others, structural shifts in the economy will also change energy intensity and thus GHG emissions. For example, a shift toward a more service-oriented economy would reduce energy intensity and GHG emissions.[11]

The economic output per capita term (Q/P), referred to as income or standard of living, is conventionally measured as the monetary value of economic output divided by population. Generally, one assumes that greater income is associated with greater physical output, greater energy use, and thus greater GHG emissions. However, increases in Q/P may not lead to proportionately higher GHG emissions if the higher incomes are linked to advanced, energy-efficient technologies and a structural change toward a services and information economy, both of which reduce E/Q. In other words, the terms in the Kaya Identity are not necessarily independent of each other.

Finally, if all other terms in the identity are held constant, then increases in population will lead to corresponding increases in GHG emissions.

We have been describing thus far an energy-focused decomposition equation. But GHG emissions are not just associated with energy use. One could add functions to isolate emissions related to other GHG-producing activities. For example, there could be a similar identity for forestry or agricultural GHG emissions and sinks and yet another for solid-waste-related GHG emissions.

Mitigation or Adaptation?

Adaptation and mitigation approaches are not mutually exclusive; we may

Table 1.2

Time scales of processes that influence or are influenced by the climate system

Process	Time scale
Turnover of capital stock	Years to decades
Stabilization of long-lived GHGs	Decades to millennia
Equilibration of the climate system	Decades to centuries
Equilibration of sea levels	Centuries
Restoration/rehabilitation of disturbed ecosystems[a]	Decades to centuries

a Some changes such as species extinction are not reversible.
Note: These estimates assume stabilization of GHG emissions.
Source: Intergovernmental Panel on Climate Change, *IPCC Second Assessment: Climate Change 1995* (Cambridge: Cambridge University Press, 1996), 28.

require both adaptive and mitigative strategies given that we have already changed the atmosphere significantly. Indeed, adaptive approaches are already under way, as witnessed by the growing focus on climate change factors by insurance companies in their claims forecasting and premiums setting.

One reason that adaptation must be considered seriously is that GHGs can continue to have an effect for many years after entering the atmosphere. First, any increased uptake of GHGs by the biosphere from the GHG-enriched atmosphere can take a long time depending on a variety of factors. Second, the deep oceans are slow to adjust to temperature change simply because of their large mass.[12] Third, the response of ice sheets to changes in the average global temperature is also slow. These processes will be responding to previous and upcoming temperature changes long after humankind has managed to reduce emissions or even to stabilize atmospheric concentrations.

Table 1.2 provides estimates of the time scale of the processes that influence or are influenced by the climate system. Given this inertia, it is likely that climate policies must be a combination of adaptation and mitigation. Adaptation strategies are more a challenge for the future as the more significant impacts of climate change emerge. Mitigation, in contrast, requires action now if it is to have the effect of reducing some of the more extreme risks associated with climate change. This is the motivation for current research on the costs of mitigation and for international and national negotiations to reduce emissions. It is the rationale for this book.

Responsibilities for Human GHG Emissions: The World and Canada

Action at an international level to mitigate climate change has involved significant wrangling over the responsibility for and the allotment of emission reductions among the world's nations. Countries can be ranked differently

Table 1.3

Cumulative and average CO_2 emissions of major emitters

Region	Cumulative CO_2 emissions (1950 to 1995 Gt)		1995 CO_2 emissions (Gt)		CO_2 emissions per capita (1995 t/capita)	
World	662.24		22.32		4.62	
United States	180.24	1	5.16	1	19.4	1
European Union	125.22	2	2.98	3	9	7
Russia	66.69	3	1.82	4	12.1	3
China	54.03	4	3.19	2	2.6	10
Germany	41.78	5	0.84	7	10.3	4
Japan	29.74	6	1.13	5	9.2	5
United Kingdom	26.67	7	0.54	8	9.2	5
Ukraine	20.93	8	0.44	9	8.4	8
France	16.44	9	0.34	11	5.9	9
India	14.51	10	0.91	6	1.1	11
Canada	14.47	11	0.44	10	14.7	2

Source: E. Claussen and L. McNeilly, *Equity and Global Climate Change: The Complex Elements of Global Fairness* (Arlington, VA: Pew Center on Global Climate Change, 1998), Appendix.

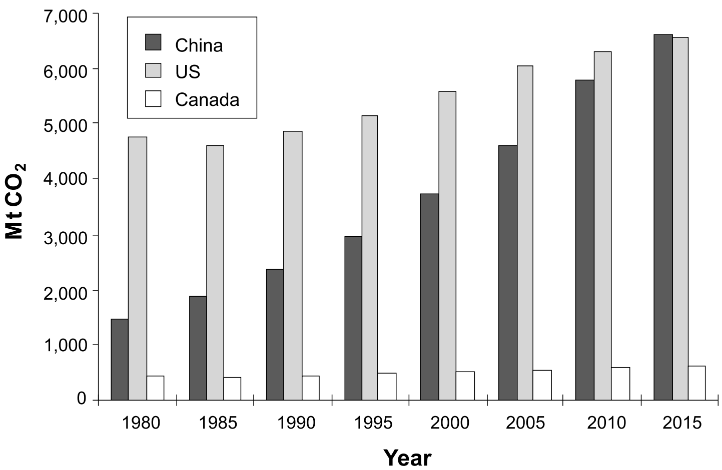
according to whether one considers their cumulative CO_2 emissions over a common historical period, their share of current global CO_2 emissions, or their CO_2 emissions on a per capita basis. Table 1.3 ranks major emitters according to these categories. Canada ranks 11th in terms of cumulative emissions and 10th when annual emissions in 1995 are considered. Although Canada is ranked second in per capita CO_2 emissions among the major emitters in this table, its ranking is 10th when all countries of the world are included (ranking behind countries such as Australia, Singapore, Norway, and Luxembourg).

There are several reasons for Canada's high per capita emission levels. Not only is Canada a world supplier of primary commodities, but also it has a small population living in a large country with a cold climate. Producing goods, travelling great distances, and keeping warm consume a lot of energy. Canada has significant, high-quality energy resources, including substantial reserves of coal, oil, and gas, primarily in the western region.[13] With energy supply plentiful and relatively inexpensive, Canada has an energy-intensive economy and lifestyle even when compared with other countries with similar geographic and demographic characteristics. For example, Canada uses significantly more energy per capita than equally cold and thinly populated Scandinavian countries such as Sweden and Finland.

One must consider a number of factors in determining how responsibility for emission reduction is allocated.

Figure 1.6

Forecast of CO_2 emissions to 2015 in China, the United States, and Canada



Source: US Energy Information Administration, *China: An Energy Sector Overview,* 1997, <www.eia.doe.gov>.

Historical sources: Developing countries point out that in most cases they have not contributed to the problem as much as the industrialized world has, and one of the means to become developed would be denied them if fossil fuel use were restricted. Thus, it would be inequitable to saddle developing countries with the same criteria and restrictions that one would apply to developed nations.

Future sources: If present trends continue, where will GHGs be produced in the future? CO_2 emission growth appears to be dropping in developed countries and rising in developing countries. According to recent US Department of Energy studies, China will surpass the United States in CO_2 generation by 2015 to become the single largest contributor of CO_2 emissions in the world. Figure 1.6 provides a forecast of emissions.

Geography and geology: What roles do climate and resource characteristics play? Colder climates obviously require greater use of energy for space heating. However, as developing countries in hot climates become wealthier, they will experience a dramatic increase in energy use for air conditioning, just as this is an important energy service today in the southern United States. In terms of resources, countries such as Canada and Australia, with small populations, exploit significant quantities of the world's raw materials. Extraction and upgrading of these resources for export as manufacturing inputs (aluminum, pulp, metals) tend to be energy intensive. In contrast, Japan has few natural resources, has a large population, and is engaged in processing these inputs into finished manufactured goods, an activity that is much less energy intensive. This contrast is significant in explaining country differences in emission intensities. Another factor is whether fossil-fuel-rich countries are endowed with coal, oil, or natural gas. China, for example, has immense reserves of coal (12% of total world reserves) but limited supplies of natural gas.[14] Coal-using technologies today emit more CO_2.

International Response to the Climate Change Threat

In February 1979 the first World Climate Conference was held in Geneva. Organized by the World Meteorological Organization, it focused on how climate change might impact human activities. The conference led to the establishment of the World Climate Program. In 1985 a group of concerned scientists from 29 developed and developing countries met in Villach, Austria, on the initiative of the United Nations Environment Programme, the World Meteorological Organization, and the International Council of Scientific Unions, to discuss whether or not human activity was affecting the Earth's climate. They concluded that the evidence pointed to a significant probability that human activity was indeed changing the Earth's climate.

This was followed by a series of conferences and workshops attended by politicians as well as scientists and international organizations. At a conference in Toronto in 1988, attendees established a target to reduce global CO_2 emissions by 20% of 1988 levels by 2005. The same year, the UN General Assembly approved the establishment of the Intergovernmental Panel on Climate Change (IPCC). The IPCC produced its first assessment report in 1990, concluding that the possibility of global warming had to be taken seriously.

In 1992 at the Rio de Janeiro Earth Summit, the United Nations Framework Convention on Climate Change was signed by 165 states, including the United States. It set a voluntary goal to cut CO_2 emissions to the 1990 level by the year 2000, with the ultimate objective of achieving stabilization of GHG concentrations at a level that would prevent dangerous anthropogenic interference with the climate system. Article 4 of the convention stated that both developed and developing countries should adopt mitigation strategies and promote further analyses of global warming and climate change, although industrialized countries should take the lead. In 1995 in Berlin, the first Conference of Parties decided to relieve developing countries of obligatory actions. The IPCC's reports in 1995 and 2001 supported the position that humans are influencing the climate, and mitigation action should therefore be undertaken.

The Kyoto Protocol

In December 1997 over 160 countries met in Kyoto, Japan, for the third Conference of Parties, and 84 of those countries negotiated an agreement

Table 1.4

Emissions limitation or reduction commitment of different regions under the Kyoto Protocol (1990 emissions = 100%)

Region	Commitment (%)	Region	Commitment (%)
Australia	108	New Zealand	100
Canada	94	Norway	101
European Union	92	Poland	94
Hungary	94	Russian Federation	100
Iceland	110	Ukraine	100
Japan	94	United States	93

Source: United Nations, *Kyoto Protocol to the United Nations Framework Convention on Climate Change,* Conference of the Parties, Third Session, 1998, Annex B.

that would reduce their aggregate GHG emissions to 5.2% below 1990 levels by the period 2008-12. Annex I countries were allotted different targets (Table 1.4).[15] The European Union received a target of 8% below 1990 emissions, the United States 7% below, Canada 6% below, and Australia 8% above.[16] International agreements made by negotiators require domestic ratification. It was agreed at Kyoto that the protocol would not come into effect until ratified by 55 countries that collectively account for 55% of Annex I emissions.

The protocol specifies a number of mechanisms through which the targets may be attained.

- *Domestic emission reduction:* This is action to reduce GHG emissions undertaken within a country's borders. Such actions tend to be fuel switching and energy efficiency but may include CO_2 emission capture and sequestration.
- *Augmentation of domestic sinks:* A country may augment the carbon storage potential of its natural sinks by changing management practices on forested and agricultural land.
- *Joint implementation:* This is a method of reducing GHG emissions in one country with the help of another country. The benefits of the reduction are shared between the two countries, both of which have emission obligations.
- *Clean development mechanism:* This is a modified version of joint implementation that gives credit to Kyoto signatories for undertaking GHG emission reduction projects in developing countries that are not signatories.
- *Emissions trading:* Signatory countries can develop GHG emissions-trading mechanisms that would serve not just for domestic implementation but also, ultimately, as a means for the cost-effective, international coordination of efforts to reduce GHG emissions. In this sense joint implementation

and the clean development mechanism are seen as specific prototypes to be replaced one day by a more general trading mechanism.

Since the signing of the Kyoto Protocol, the signatories have continued to meet to discuss the many complexities of constructing and ratifying an international agreement of this scope and to more precisely define the roles of the above mechanisms. Certain issues have received considerable attention and controversy.

The Kyoto Protocol gives countries such as Russia and Ukraine, which have closed many high-emission factories since 1990 in the transition to a market economy, pollution quotas that permit them emissions in excess of current levels. Some countries would like to buy these quotas and thus lower their domestic emission reductions while still meeting their targets. But some observers fear that cash-starved countries will sell their pollution quotas and then generate emissions anyway as their economies grow. They argue that safeguards are needed and that the total amount of reduction credit from this practice should be limited if meaningful global reductions are to be achieved.

The definition and the role of sinks have been controversial. What actually is a sink? Could one include the extra carbon stored in soils consequent to altered farming and forestry practices? How would one measure and credit such a change? The resolution of these issues has been important to countries, such as Canada, Australia, and the United States, that have large land areas and extensive potentials for greater absorption of carbon with altered land management. A broad definition of sinks greatly reduces the amount of emissions reductions needed from energy production and use.

A related issue is the role of flexibility mechanisms to meet national targets. Members of the European Union have argued that most reductions by wealthy countries should come from domestic actions, while the United States, Japan, Australia, and Canada have pushed for greater flexibility. The focus on domestic GHG reductions in Europe can be interpreted as coinciding conveniently with European countries' move away from domestic coal use since 1990. In Great Britain coal use has declined dramatically, particularly after much of the coal-mining industry and many coal-fired power plants were closed in the years following electricity market reform in 1989. Likewise, Germany has experienced a windfall reduction as the country's unification in 1990 led to the closure of inefficient industrial and coal-using electricity plants in the former East Germany. In response, the Europeans argue that, because their economies in 1990 were already much less carbon intensive than those of the United States and Canada, they face substantially higher incremental costs for making additional reductions.

Debate has also occurred about how the Kyoto Protocol will be enforced once it is ratified. What would occur if a nation does not attain its specified target? How does one induce compliance and punish noncompliance? The Europeans have promoted the use of trading constraints and other economic sanctions against noncompliant nations, while the United States has favoured a penalty of additional obligations in subsequent commitment periods.

The Bush administration's intention not to ratify the Kyoto Protocol is based on its concern with the overall scope of the agreement rather than with the specific implementation issues described above. More specifically, the United States argues that the Kyoto Protocol will incur high costs for a few countries like the United States without making much headway on global emissions. Without the inclusion of the entire global community, emission reductions by developed countries will be quickly offset by rapidly growing emissions from developing countries. The United States also points to significant competitive issues. How can a country burdened with the costs of reducing GHG emissions compete fairly with one having no such restriction? What would prevent industry from relocating to regions where GHG reduction is not required, a phenomenon known as leakage?[17] The United States has instead sought the reopening of international negotiations, which it hopes will lead to a more comprehensive global commitment.

Other Kyoto signatories have not turned against the protocol, but negotiations about implementation and verification continue. The Conference of Parties meeting in Bonn in the summer of 2001 reached agreement on many key issues, although important technical details remain to be resolved.

A critical concern for Canada and some other signatories was the ruling on how much of a country's emission reduction commitment could be achieved by nondomestic (supplemental) actions. At Bonn, parties agreed that with the use of flexibility mechanisms countries could meet a significant share of their commitments, although the exact amount was not specified. The Canadian government has interpreted this to mean that it should attain a minimum of 50% of its target domestically, which means that it might purchase the other 50% from other signatories via flexibility mechanisms. This interpretation may change.

Most activities claimed as sinks will be eligible for credits, as long as they have occurred after 1990. This eligibility includes forest management, cropland management, and revegetation. There is no overall cap on sink credits, though specific limits have been established for forest management.

Although progress has been made in addressing many outstanding matters, much remains to be done. The specific issues raised by the Kyoto Protocol are symptomatic of broader concerns facing any effort to achieve a global response to the climate change threat.[18] These concerns will need to be addressed in order to advance a multilateral international response and to negotiate more substantial reductions in the future.[19] Any progress in this direction must ultimately come to terms with two competing concerns:

recognition of the perils of human experimentation with the Earth's atmosphere and reluctance to take actions that may cause significant financial and lifestyle costs for the present generation without certainty of future benefits. Analyses such as the one presented in this book can illuminate the trade-offs between these two concerns and assist countries such as Canada in determining their positions as the world continues to grapple with this complex challenge.

Mitigation Initiatives in Canada

A broad spectrum of views characterizes Canadian reaction to the climate change threat. Not only does Canada face the challenging task of achieving cooperation between divergent interests, but also it must do so within the framework of Canadian federalism. Under the Constitution, the environment is a shared federal-provincial jurisdiction: the management of natural resources lies within the jurisdiction of the provincial governments, while international agreements are a federal responsibility. This division of powers makes it difficult for Canada to move forward with a major mitigation initiative.[20]

Canada's national effort is centred on the National Climate Change Process (NCCP) initiated in early 1998 at a meeting of federal, provincial, and territorial ministers of energy and the environment. It is a forum that provides overall leadership and guidance on Canada's response to the climate change issue.[21] In October 2000 all governments except that of Ontario approved a National Implementation Strategy on Climate Change based on the work of the NCCP. This strategy is composed of three phases, delineated by various degrees of uncertainty.[22] Phase 1, Action under Uncertainty, represents the period until Canada ratifies the Kyoto Protocol or some subsequent agreement. This phase contains cost-effective measures that deliver important ancillary health, economic, and environmental benefits and lay the groundwork for further action. Phase 2 defines additional measures that Canada should undertake, given the results of additional analyses, and Phase 3 will begin if Canada ratifies the Kyoto Protocol or some substitute commitment.

Many of the federal government's departments participate in and support the NCCP. Two have been allocated primary responsibilities: Natural Resources Canada is in charge of GHG evaluation and response, and Environment Canada is responsible for developing Canada's GHG inventory. As a signatory to the Kyoto Protocol, Canada must submit GHG inventories to the United Nations Framework Convention on Climate Change and establish a history of CO_2 and other GHG emissions back to 1990. Other federal agencies participate by reviewing climate change impacts and mitigation options in their particular fields. Thus, Agriculture Canada plays a major role in the assessment of soil sinks and the impact of agricultural practices on GHG capture and emissions. In a similar manner, the Canadian Forestry

Service has been assessing the relationship between forests and carbon sinks in soils and forestry products. Transport Canada participates in the assessment of transportation's impact on climate change.

Regional response to climate change varies. As of October 2001, three provinces and one territory – British Columbia, Ontario, Quebec, and the Northwest Territories – have produced climate change action or business plans. These plans outline specific actions taken during the first phase of the National Implementation Strategy. In addition, a number of provincial governments, in conjunction with two federal ministries, have developed a pilot project on emissions trading. Called the Greenhouse Gas Emission Reduction Trading Pilot, it started in June 1998 to provide experience with a market-based approach to emissions reduction.[23]

In general, voluntary approaches have dominated Canada's response to climate change. One of the government's first major initiatives, the Voluntary Challenge and Registry, encourages private and public sector organizations to voluntarily limit their net GHGs, not only as good citizens and for private economic benefit but also to avoid or at least delay more stringent government intervention. In this program, firms are asked to submit an action plan that contains senior management support, a commitment to regular reporting, and a base year calculation. The action plan can be much more detailed and provide specific activities to be undertaken in the future. Each company submits progress reports on its action plan. Table 1.5 displays the growth of the registry over time. The companies that submit are responsible for roughly 75% of all industrial GHG emissions. Registrants include about 75% of all pulp and paper firms, 95% of all cement producers, and 100% of all petroleum refineries.

A number of industry associations generate status reports that define the activities and progress made by their members. Each year, for example, the

Table 1.5

Progress report, industry submissions to Voluntary Challenge and Registry, Inc.

Year	Action plans	Progress reports
1995	94	4
1996	331	88
1997	354	112
1998	547	168
1999	681	258
2000	757	344

Source: Online table, see Voluntary Challenge and Registry, Inc., Website, <www.vcr-mvr.ca>.

Canadian Chemical Producers' Association publishes its *Responsible Care* report and its *Reducing Emissions 8* report, part of the National Emissions Reduction Masterplan under its Responsible Care program. These annual documents review member activities and track all emissions, including GHGs. The Canadian Petroleum Products Institute also publishes an annual *Environment and Safety Performance Report* that displays, among other things, its efforts to reduce GHG emissions since 1990.[24]

While participation in the Voluntary Challenge Registry may be high, its effectiveness is not universally accepted. In a review of the registry, the Pembina Institute, a nongovernmental environmental organization, determined that it was inadequate in terms of reaching Canada's Kyoto Protocol target and showed no sign of improving prospects.[25] The institute recommended that the reporting of GHG emissions by significant industrial emitters be mandatory in Canada and that complementary financial incentives and regulatory instruments be invoked to induce greater response.

The National Climate Change Process

Given the importance of the NCCP in shaping Canada's mitigation response, we provide more detail on its structure and role. As noted, the NCCP provides overall leadership and guidance in the national response to the climate change issue. It is managed by two key groups: the National Climate Change Secretariat and the National Air Issues Coordinating Committee on Climate Change.[26] The latter committee provides advice to energy and environment ministers and guides the overall direction of the NCCP, including analysis. This committee is composed of civil servants who are mainly from the energy and environment ministries of the provincial, territorial, and federal governments. The National Climate Change Secretariat is the executive arm of the NCCP.

The NCCP has been responsible for assessing the social, economic, and environmental implications of policies and programs in order to develop the National Implementation Strategy. For this task the NCCP created, in the spring of 1998, numerous sector- and issue-based working groups, known as Issue Tables, as part of a National Engagement Process to provide advice, obtain information, and assess implementation options available to Canada to reduce GHG emissions in order to meet a Kyoto-based target. The 16 Issue Tables were comprised of experts from industry, government, academia, and nongovernmental organizations. Over the subsequent two years, the Issue Tables outlined various alternatives and avenues of potential emissions reduction in *Options Papers*.[27] The Analysis and Modelling Group (AMG) consolidates and integrates different analyses in that process.

While there are advantages to splitting tasks among different groups, each addressing a particular facet of the problem, such compartmentalization can hinder interaction and integration. For example, if an Issue Table's proposed option affects energy demand, then energy supply quantities and prices are affected. These effects will in turn change the impacts of other proposed options. Also, changing the process and technological structure of a sector has more than just GHG and energy impacts. Local employment, education, ancillary health benefits, and general social welfare are all affected. Interaction between mitigation options can occur not only at the level of energy supply and demand but also where changes in the costs of products and commodities may affect their market value and their eventual demand.

Much of the analysis in this book issues from this national process of assessing GHG reduction actions and their costs. A key undertaking in this exercise is the definition of costs (Chapter 2) and the application of an integrated model that captures the multiple interactive effects of many actions undertaken simultaneously (Chapter 3).