ECONOMIC VIEWPOINT

Global Warming: What Are the Economic Implications?

An Overview of the Estimated Costs of Climate Change Found in Scientific Literature

Many countries are increasingly concerned about how their economies will respond to climate change as a number of major institutions are sounding the alarm about global warming. A review of the literature on the possible economic costs of greenhouse gas (GHG) emissions provides insight into not only the possible negative impact on the global economy, but also the level of uncertainty that surrounds climate models and their effect on the economy.

Society appears to be increasingly preoccupied by the issue of global warming and climate change, with several major institutions identifying climate change as one of the greatest economic threats. The World Economic Forum, which has been publishing a list of the biggest threats to the global economy annually since 2006, has mainly indicated environmental threats as being the most likely to occur since 2011. Recently, the Bank of Canada also decided to include a section on climate change in its *Financial System Review*.

As GHG Emissions Rise, So Does the Thermometer

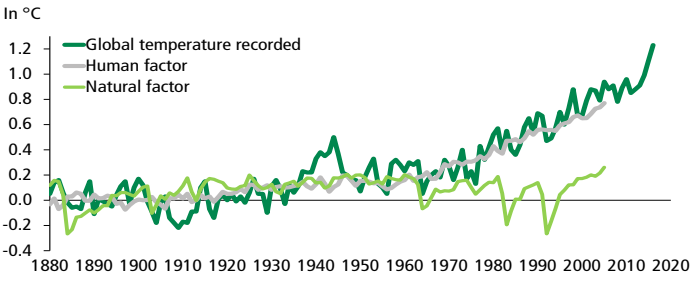
The source of this concern is the unrelenting upward trend of Earth's average temperature noted since the industrial age. The major scientific institutions attribute most of this warming to the GHG emissions resulting from human activity (graph 1).

Significant gains have been made around the globe in terms of the economies' carbon intensity since 1990, as GHG emissions in relation to global real GDP, adjusted for purchasing power parity (PPP), have fallen by 0.25 kg/US$ of GDP. Still, total GHG emissions are continuing to increase at a steady pace (graph 2) as global GHG emissions per capita are rising. The atmospheric concentration of carbon dioxide (CO2), which is now at a historic high, is a testament to this sharp increase in GHG emissions. Prior to the Industrial Revolution, the average atmospheric concentration of CO2 worldwide was approximately 280 ppm (parts per million). In other words, 280 of every 1,000,000 gas particles in the atmosphere were CO2. Since 2015, this concentration has constantly surpassed 400 ppm, a level never reached in the previous 800,000 years according to National Aeronautics and Space Administration (NASA) data.

GRAPH 1

The human factor largely explains the rise in temperatures since 1950

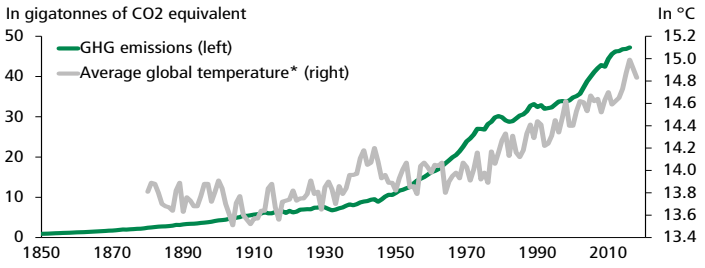
Relative average deviation from 1880–1910 and the contribution of various factors



Note: The contribution represents the temperature deviation anticipated according to various factors.
Sources: International Monetary Fund and Desjardins, Economic Studies

GRAPH 2

GHG emissions have rapidly increased since 1950, consistent with the rise in global temperature



CO2: Carbon dioxide; GHG: Greenhouse gases; * Land and ocean surface temperature.
Sources: Potsdam Institute For Climate Impact Research, NASA Earth Observatory and Desjardins, Economic Studies

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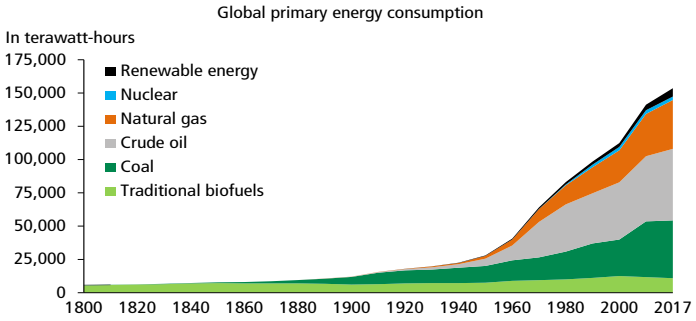
The situation seems to be far from reversing, with the energy consumed still largely coming from fossil fuels (graph 3). Furthermore, in 2017, CO2 emissions worldwide began to climb once again after remaining stable for three years. Despite the rise in renewable energy and efficiency gains, emissions still seem to depend on economic growth.

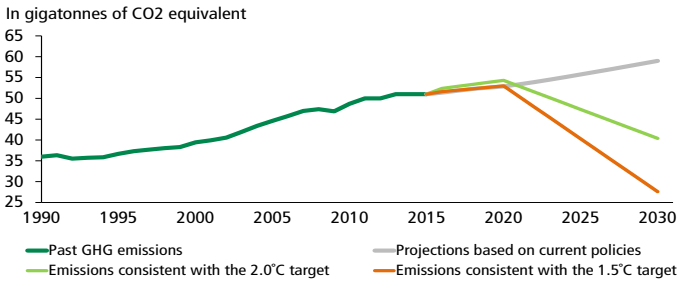
GRAPH 3
Fossil fuels still meet most energy needs



Sources: Our World in Data and Desjardins, Economic Studies

The average global temperature has risen 1°C since the pre-industrial period of 1850–1900 based on the data of the Intergovernmental Panel on Climate Change (IPCC). Still, the level of warming varies according to regions. Low-income countries, which already have higher temperatures, warmed by 0.7°C since the beginning of the last century, whereas advanced countries have seen temperatures rise an average of 1.4°C. Canada is warming at one of the fastest rates, with the temperature already 1.7°C higher since 1948, which is the beginning of the series. While it is true that Earth has gone through several climate cycles, the current warming exceeds previous occurrences in terms of both speed and level, especially since the planet's natural cycle should, in theory, be in a period of cooling. The IPCC's climate models estimate that, should GHG emissions continue to grow at the pace seen in recent decades, the planet's temperature could rise between 2.8°C and 7.8°C compared with the average for 1850–1900. Quebec could heat up between 5.3°C and 6.9°C, while the temperature in Canada as a whole could increase up to 7.7°C compared with the period from 1986 to 2005 according to a study by the Government of Canada. Given the later reference period for Canada, the expectation is for estimates to be even higher if the 1850–1900 period was used. Without a doubt, this scenario corresponds to a more negative outcome in which GHG emissions remain high, but it is also the scenario that best reflects the trends of the last 15 to 20 years according to the IPCC and the U.S. Global Change Research Program. A significant drop in emissions could contain the level of warming closer to the 1.5°C and 2.0°C targets of the Paris Agreement (graph 4).

GRAPH 4
A significant reduction in GHG emissions would be required to keep warming below 2°C



CO2: Carbon dioxide; GHG: Greenhouse gases
Sources: Climate Action Tracker and Desjardins, Economic Studies

With global warming of 1°C, some climate changes may have already started to appear. Natural disasters[1] seem to be occurring more often, and the scientific community frequently associates this phenomenon with global warming. Extreme climate events, such as hurricanes, heat waves, flooding and drought, are not the direct result of global warming, but they may be more likely to occur because of it, as it disrupts precipitation patterns and leads to increasingly hotter and more frequent heat waves. Warmer oceans may also give rise to stronger winds during tropical storms. The higher temperatures also contributed to glaciers and the ice sheet melting, thus leading to higher sea levels. Since 1900, the average sea level has risen between 16 cm and 21 cm, with nearly half of this increase occurring since 1993. The number of days of extreme heat, during which the temperature exceeds 30°C, is increasing. In southern Canada, the number of extreme heat days has gone up from one to three days per year between 1948 and 2016. In the United States, the number of heat waves—defined as two or more consecutive days of extreme heat—rose from two to six in the 50 largest cities between 1960 and the past decade, and the heat-wave season has grown by 45 days. The higher temperatures also extended the growing season in Canada by 15 days between 1948 and 2016. With hotter summers and extreme heat days occurring more often, heat-related health issues and mortality may also increase. The effects also include ocean acidification, abnormal precipitations and biodiversity disruptions.

Differing and Uneven Economic Consequences

The scientific community seems to agree on the overall economic consequences of climate change. Recurring damage to infrastructure due to more frequent natural disasters could discourage investment in affected areas. Even if part of these investments could be redirected to other regions, several experts

[1] A natural disaster meets at least one of the following criteria: 10 or more deaths, 100 or more persons affected, the declaration of a state of emergency, an appeal for international aid.

still expect a net loss on a global scale. Rising temperatures would reduce economic productivity, in terms of agriculture and labour, in countries where the climate is already warmer, but they could have the opposite effect in cold countries such as Canada. A research conducted by three economists estimates that the economy's response to temperature would be non-linear and that there would be an optimal average annual temperature for economic activity. According to them, an average temperature higher than 13°C would lead to significant losses in productivity. This drop in productivity would be the result of, among other things, lower agricultural yields, more heat-related health issues and a decrease in the capacity of employees who work outdoors or in locations with no air conditioning. Another research attempted to quantify the productivity losses in the United States caused by heat. It estimates that a single day hotter than 30°C would cost approximately US$20 per person in an average county in the United States. For example, Japan, China and the United States would currently be close to the optimal temperature and could increasingly feel the harmful effects as the average temperature rises. Although it is heating up faster than other countries, Canada still lies very much below the 13°C threshold. Therefore, it could potentially benefit from a few additional degrees, but researchers warn that this conclusion is premature. The effects differ greatly between regions within Canada, and some of the negative impacts have not been taken into account because of the lack of information on such things as the thawing of the permafrost and the impact on global trade and biodiversity. Even if some economic gains are possible in the short term in colder countries, researchers seem to have concluded that the effects will probably be negative in the longer term.[2]

Nonetheless, there is still a lot of disagreement on the long-term monetary value of the damage of global warming. According to the studies reviewed during this analysis, the economic losses worldwide in 2100 caused by a 4°C rise in temperature, i.e., the median of the business-as-usual scenarios, would vary between 2.6% and 50% of GDP compared to a scenario with no climate change (table 1). These estimates were all published by renowned experts in the field.

However, the costs associated with climate change are not distributed equally across all countries. Three researchers estimated the cost of climate change per country. According to them, the impact on Canada's GDP should be positive up to a certain point. If temperatures were to rise 3°C, GDP could be 0.15% higher in 2050 compared to a scenario involving no climate change. Still, in the long run, the effect turns negative, with a loss of 0.22%. As for the United States, it could be negatively affected as early as the next decade and experience

TABLE 1
Researchers do not agree on the economic costs of climate change

AUTHORS	TITLE AND YEAR PUBLISHED	ECONOMIC LOSSES IN 2100*
William D. Nordhaus and Andrew Moffat	*A Survey of Global Impacts of Climate Change: Replication, Survey Methods, and a Statistical Analysis*, 2007	2.6%
Marshall B. Burke, Solomon M. Hsiang and Edward Miguel	*Global non-linear effect of temperature on economic production*, 2015	23%
Keith Wade	*The impact of climate change on the global economy*, 2016	4%, 9%, 50%
William D. Nordhaus	*Projections and Uncertainties About Climate Change in an Era of Minimal Climate Policies*, 2017	3.2%
Marshall B. Burke, W. Matthew Davis and Noah S. Diffenbaugh	*Large potential reduction in economic damages under UN mitigation targets*, 2018	30%

* Compared to a scenario with no climate change.

a long-term loss of 0.62%. Low-income countries would be hit the hardest, with a long-term GDP loss up to 17%. This trend was highlighted by several other studies. Emerging and low-income countries often have fewer resources to develop policies to adapt to or mitigate the impact and are more concentrated in climate-sensitive sectors such as agriculture and tourism. In addition, their temperatures are often already higher. An International Monetary Fund (IMF) research estimates that, should GHG emissions continue at the current rate, GDP per capita in low-income countries in 2100 could be 9% lower on average than if temperatures did not rise. The results of a study published in *Nature* are even more drastic: GDP per capita in 40% of the poorest countries could be roughly 75% lower in 2100 compared to a scenario in which there is no climate change, whereas the richest 40% could record gains. Nonetheless, those gains are wiped out once the long-term effects are included.

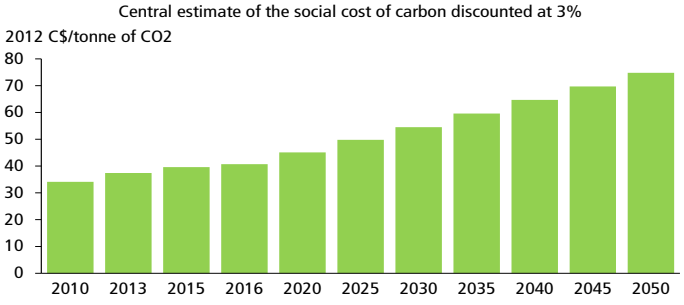
The literature often refers to another measurement of the impact of climate change. The social cost of carbon (SCC) measures the marginal cost of a tonne of CO2 consumed in a specific year and takes into account the damage inflicted on the global economy over a long period of time that can extend as far as 2300. This measurement is useful because it directly illustrates the cost of CO2 consumption and helps assess which climate change mitigation technologies or policies could be worth implementing from an economic point of view. As a result, the way it interprets climate change is simpler and more practical. The U.S. Environmental Protection Agency (EPA) estimates that a tonne of CO2 emitted in 2020 would cause US$42[3] in damage worldwide, whereas the same tonne emitted in 2050 would cost US$69. The SCC tends to increase each year as additional emissions contribute to the damage of an increasingly fragile ecosystem. Environment and Climate Change Canada puts the

[2] Nicholas STERN, *The Economics of Climate Change: The Stern Review*, Cambridge University Press, 2007, ch. 3 and 5; Katharine RICKE et al., *Country-level social cost of carbon*, Nature Climate Change, vol. 8, 2018, p. 895-900.

[3] In 2007 constant U.S. dollars with a 3% discount rate.

[4] In 2012 constant Canadian dollars with a 3% discount rate.

GRAPH 5
Canada estimates the benefits of eliminating a tonne of CO2 at C$45 in 2020



CO2: Carbon dioxide
Sources: Environment and Climate Change Canada and Desjardins, Economic Studies

SCC at a similar level, i.e., C$45[4] in 2020 (graph 5 on page 4). Still, some experts claim that these estimates are much too low. One study in particular estimates that the global SCC would instead lie between US$177 and US$806 per tonne of CO2. The authors went one step further by calculating an SCC for each country individually and found that the biggest emitters of CO2, i.e., the United States, China and India, are among those that would have the most to lose. However, they also emphasize that some countries, such as India, would also pay a disproportionate price compared to their share of global pollution. For example, according to this study, India's share of the global SCC would be four times greater than its share of GHG emissions. The study concluded that Canada would have an SCC of -US$8 per tonne of CO2 in a business-as-usual scenario. In this case, the minus sign for the SCC would represent a gain. However, when the long-term effects are included, the SCC jumps to nearly US$16.

A review of the literature provides insight into the SCC estimates, which range from US$10 to US$1,000 (table 2). The SCC also varies greatly for a given author. William D. Nordhaus, a recipient of the Nobel Prize in economics for his work on climate change, revised his SCC estimate for 2015 upwards over the years, as it went from approximately US$13 per tonne of CO2 in 2011 to US$30 in 2017 (in 2010 constant dollars).[5] This reflects the updates made to economic and climate models as well as the latest data.

TABLE 2
Estimates of the damage caused by CO2 emissions vary greatly

AUTHORS	TITLE AND YEAR PUBLISHED	SOCIAL COST OF CARBON (US$/TONNE OF CO2)*
David Anthoffa and Richard S.J. Tol	*The Uncertainty about the Social Cost of Carbon: A Decomposition Analysis Using FUND*, 2011	From US$19 to US$2,720 in 2010
Frances C. Moore and Delavane B. Diaz	*Temperature impacts on economic growth warrant stringent mitigation policy*, 2015	US$220 in 2015
Ravi Bansal, Dana Kiku and Marcelo Ochoa	*Price of Long-Run Temperature Shifts in Capital Markets*, 2016	US$28 in 2015
U.S. Environmental Protection Agency (EPA)	*The Social Cost of Carbon*, 2016	From US$12 to US$62 in 2020
Katharine Ricke, Laurent Drouet, Ken Caldeira and Massimo Tavoni	*Country-Level Social Cost of Carbon*, 2018	From US$418 to US$781 in 2020

CO2: Carbon dioxide; * Expressed in real dollars for different baseline years.

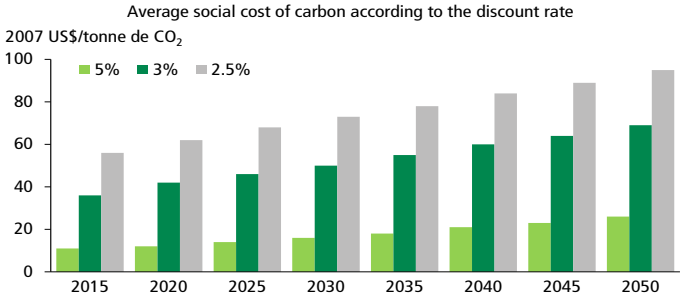
Large Gaps in Our Understanding Remain

The significant variability in the scenarios about global warming and its consequences arises mostly from the high degree of uncertainty surrounding the issue. Even when the unpredictability concerning technological innovation and changing environmental policies are excluded, several of the variables of climate change models depend on the researchers' assumptions. Forecasts about economic and demographic changes over the next 100 years are used to calculate the direction of future emissions. However, these forecasts are highly speculative given the vast horizon used to forecast. The relationships between the level of GHG emissions and the climate's response to it vary according to the hypotheses established and the latest data gathered, which, in turn, have an impact on quantifying the damage due to Earth's warming. Yet several mysteries remain regarding climate processes, as the current rate at which the globe has been warming is without precedent according to the available data. With no historical experience, it is difficult to establish firm correlations, all the more so since these processes are non-linear and that experts suspect the existence of tipping points with thresholds beyond which there will be no turning back. The economic response to climate change can also vary according to the factors taken into account and the type of model used. For example, the estimated costs of climate change vary when income differences between countries are considered, since these economies could react differently to climate change.[6] Including assumptions about the adaptation measures that may be introduced in the future can also cause the weight of the economic losses to fluctuate. These measures will largely depend on technological change, which is difficult to predict. However, according to some experts, the greatest source of divergent economic costs remains the discount rate selected (graph 6 on page 5), i.e., the present value assigned to future damage. The higher the discount rate, the lower the

[5] William D. NORDHAUS, *Estimates of the Social Cost of Carbon: Background and Results from the Rice-2011 Model*, National Bureau of Economic Research, 2011, p. 17-18; *Id.*, *Revisiting the social cost of carbon*, Proceedings of the National Academy of Sciences of the United States of America, 2017, vol. 114, no. 17, p. 1518-1523.

[6] Katharine RICKE et al., *op. cit.*; Marshall BURKE et al., *Global non-linear effect of temperature on economic production*, *Nature*, 2015, vol. 527, p. 235-239; *Seeking Sustainable Growth: Short-Term Recovery, Long-Term Challenges*, International Monetary Fund, World Economic Outlook, October 2017, ch. 3, p. 125-131.

GRAPH 6
The discount rate selected can significantly influence the cost of GHG emissions



CO2: Carbon dioxide; GHG: Greenhouse gases
Sources: U.S. Environmental Protection Agency and Desjardins, Economic Studies

weight of the damage incurred in the future. No consensus has yet been reached on the appropriate rate.

The huge uncertainty surrounding climate change also implies that the models are excluding, whether completely or partially, several effects that could have major consequences but are too unpredictable or difficult to quantify to be included in an analysis of the costs worldwide. These effects, such as higher mortality rates, decreased quality of life, the migration of communities threatened by climate change, new harmful organisms attacking people or crops, forest fires and shocks to biodiversity, are often not included, or only partially, in the estimates. Most of the studies also exclude the impact on global trade and food accessibility. Besides, the U.S. Department of Agriculture estimates that soybean and corn fields could be seriously affected should emissions remain high. Even when some of the adaptation measures that producers could adopt are included, production of these grains in the United States could fall between 10% and 60% by 2080. As a result, the risk that disruptions to food availability and accessibility could be extremely costly is very real. The threat of all of these effects remains unpredictable, but excluding the possibility that they could occur leads to a downward bias in the economic cost of climate change.

So What's the Takeaway?

At this point, it's important to take a step back and reflect on the different issues raised. The vast range of the estimated costs of climate change would cause anyone to be confused and puzzled. Experts are still debating the matter, and it may not be possible to reach a consensus on the exact number. However, all of these efforts are not in vain, since the message is clear: It is impossible, with the tools at our disposal, to determine the exact amount of the damage that will be caused by global warming, but it is almost certain that the impact worldwide will be significantly negative.[7] In addition, the later climate change mitigation and adaptation measures are identified and implemented, the more turbulent the transition to a society less dependent on fossil fuels will be for the economy and the financial markets. Therefore, it is important to pursue mitigation efforts while relying on innovation in particular while advancing the research in this field to better understand this critical issue.

Carine Bergevin-Chammah, Economist

[7] Peter HOWARD and Derek SYLVAN, *Expert Consensus on the Economics of Climate Change*, Institute for Policy Integrity, 2015, p. 9-23.