Greenhouse Gases

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Chem 300A

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Introduction

The gaseous compounds known as “Greenhouse Gases” (GHGs) are so named for their properties in the upper atmosphere where they are able to trap radiation that would otherwise be projected out into space, heating the Earth’s atmosphere much like a greenhouse keeping plants warm. These gases are necessary for life on the planet as we know it, keeping the average global temperature at a moderate 15°C instead of a frosty -18°C (Ma and Tipping, 1998). With these gases having accumulated beyond pre-industrial levels and noticeably affected the climate, we as academics must closely monitor their concentrations, and consider the global environmental, social, economic, and political repercussions of the Greenhouse Effect.

Greenhouse gases can absorb and re-emit energy as infrared radiation due to the dipole moments afforded to them by their asymmetrical structure, which is why common air-borne diatoms like Oxygen and Nitrogen do not contribute to the greenhouse effect (Hertzberg and Siddons, 2017). The three most common greenhouse gases in order of abundance are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (Figure 1). All three of these gaseous compounds are present due to natural processes in the environment, but also by modern human enterprises, and have been increasing since the industrial revolution with the exponential growth of the human population (Martinez, 2005).

Major Greenhouse Gases

Carbon dioxide, CO_2, is the most abundant GHG because it is a product of all hydrocarbon combustion reactions as well as aerobic cellular respiration. It is also released naturally from volcanoes, forest fires, melting ice-masses, and biological decay of organics (Yao *et al.,* 2020). Anthropogenic CO_2 emissions within the atmosphere can be mainly attributed to the burning of fossil fuels and refined petroleum like gasoline, jet fuel, diesel, coal, peat, and natural gases (Ma and Tipping, 1998). As a gas it has a very low Global Warming Potential (GWP) and serves as the reference GHG with a value of only 1 but being the most plentiful of the gases at 385 ppm in the troposphere, it makes the greatest contribution to the greenhouse effect (Fig. 1).

Table 3.3 Global Warming Potential for Three Greenhouse Gases

Substance	Global Warming Potential (GWP)*	Tropospheric Abundance (ppm)
CO_2	1	385
CH_4	23	1.8
N_2O	296	0.31

*GWP values are given for the estimated direct and indirect effects over a 100-year period and are relative to the assigned value of 1 for CO_2.

Figure 1. Table 3.3 shows the major greenhouse gases and their respective GWP values, as well as average abundance in the troposphere (ppm). By multiplying the values GWP and Abundance for each gas, we can calculate the net contribution to the greenhouse effect by CO_2, CH_4, and N_2O as 385, 41.4, and 91.76 respectively (Chemistry in Context 6th Edition. ACS, McGraw-Hill).

Methane, CH_4, is the second most common GHG, emitted by organics breaking down under anoxic high pressure, and makes up 70-90% of natural gas (Lan *et al.,* 2015). Methane is naturally released from melting permafrost, benthic hydrothermal vents at continental shelves, and expelled by ruminant animals as digestive gases (Smith *et al.,* 2008). Anthropogenic sources include livestock farming, especially cattle, and fossil fuel extraction. The atmosphere acts as a natural sink for CH_4 as it will combine with a hydroxyl radical to form either a carbon dioxide or water vapour molecule, both GHGs themselves (Encyclopedia Britannica, 2019). CH_4 has a GWP value 23-28x greater than that of CO_2 but is only present in the troposphere at 1.8 ppm, and so it accounts for a smallest contribution to the greenhouse effect. It has a relatively short turnover period in the atmosphere, being fully reduced in about 4-7 years (Ehhalt and Schmidt, 1978).

Nitrous oxide, N_2O, is the least abundant of the GHGs, and is naturally produced by the deterioration of nitrogen-rich organic material via oxidation of ammonia (Ma *et al.,* 2019). Anthropogenic sources account for roughly a third of nitrous oxide emissions, and include livestock manure, human sewage, heavy industry, burning fossil fuels, and agriculture, specifically leaching from soils artificially fertilized with excessive nitrogen (Smith *et al.,* 2008). It has a GWP value 296x more potent than that of CO_2 due to its very strong dipole moment in the shifting N-N bond but is the least abundant of the gases at only 0.31 ppm in the troposphere (Figure 1). It is therefore the second most culpable of the GHGs for the Greenhouse effect.

Other Greenhouse Gases

In addition to these gases, it is also worth noting the various effects of water vapor and ozone at various heights in the atmosphere. Water vapor, $H_2O_{(g)}$, is present in the lower atmosphere as clouds and closer to the ground as fog or air humidity, especially in wet climates. Water molecules are extremely polarized, and as a result have a very high heat capacity. This heat capacity is what makes coastal climates more moderate as it takes more energy to evaporate or freeze (Gao, Zhang and Hader, 2018). In this way, the ocean serves as a heat sink as well as a carbon sink, absorbing much of the extra energy in the biosphere due to climate change (Doney *et al.,* 2016). Even so, the climbing temperatures of the earth and ocean have deposited enough excess infrared energy to evaporate large bodies of water like lakes and oceans, putting more water vapor into the air. As atmospheric vapor, water molecules can absorb and trap radiant energy, acting as greenhouse gases.

Ozone (O_3) is considered to be a GHG for its properties but acts on a different level of the atmosphere than those responsible for the Greenhouse effect. In the upper atmosphere, the "ozone layer" absorbs ultraviolet radiation from the sun, protecting us from dangerous wavelengths that can damage living tissues and potentially cause double stranded breaks in DNA (Iglesias-Suarez *et al.,* 2020). In the lower atmosphere ozone is highly reactive with everyday air-borne compounds. Ozone is considered a secondary pollutant as it is not directly emitted by humans, but when an oxygen (O_2) breaks into a single oxygen it can create ozone (O_3) by the reactions associated with carbon monoxide (Encyclopedia Britannica, 2019).

Trends in Canada

Worldwide, there has been an indisputable increase in greenhouse gas levels, and the numbers are only increasing (Figure 2; NOAA, 2020). In Canada alone, CO_2 emissions have risen by 18.9% due to three main industries: mining, oil and gas production, and transport (Government of Canada, 2019). As we compare the data from 2005 (Figure 3), we can see that Canada's CO_2 emissions have decreased on average in the past 15 years, and we can attribute this to lower emissions from public electricity and heat production utilities.

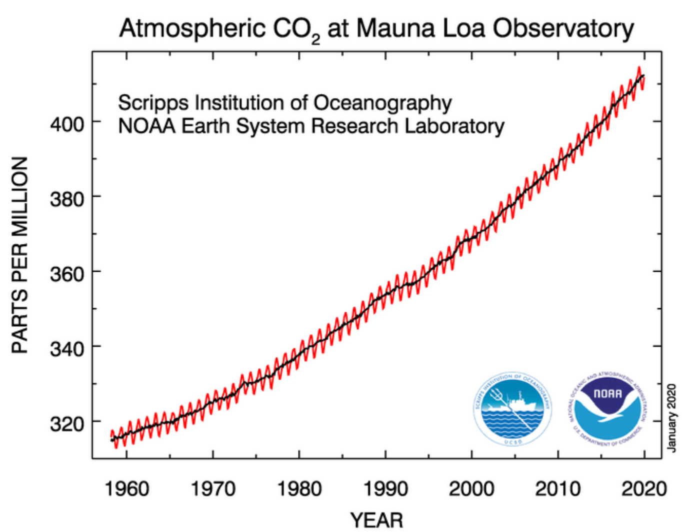

Figure 3. Atmospheric levels of Carbon Dioxide in ppm from 1960 until present, recorded at Mauna Loa Observatory by NOAA in Hawaii. Fluctuations throughout the year depicted in red with annual averages designated by black trend line. (NOAA Earth System Research Laboratory, 2020).

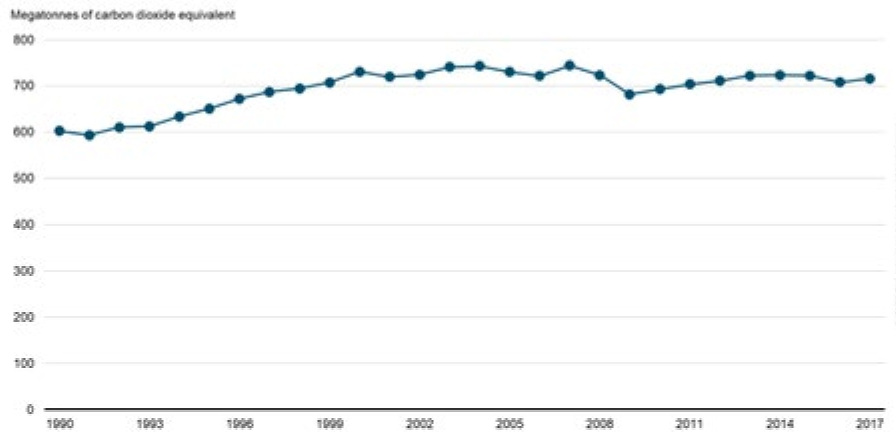

Figure 2. Canadian Greenhouse gas emissions from 1900-2017. (Government of Canada, 2017)

There has been a 10% decrease in greenhouse gas emissions per person between 1990 and 2017. Additionally, greenhouse gas emissions per unit of gross domestic products have decreased by 36% within those same years (Government of Canada, 2019). Decreased GHG emissions in these two areas are due to various factors, such as the development of efficient industrial practices, movement towards a service-based economy, and energy generation.

Greenhouse gas trends vary among different sectors. In Canada, the oil and gas development and transportation sectors are responsible for 52% of total anthropogenic emissions. The total greenhouse gas emission increase between 1990 and 2017 was largely due to the 84% and 43% emission increase of the oil/gas sector and transportation sectors, respectively.

In the oil and gas industry alone was responsible for 27% of total Canadian GHG emissions. The Government of Canada (2019) stated that there has been an 84% increase in emissions from this sector since 1990, which can be linked to increased production of crude oil, and growth of oil sands projects and infrastructure. Between 1990 and 2017, emissions from oil sands increased by 423%. In 2017, crude oil processing doubled the GHG emissions seen in

1990, which can be accounted for by the increased production of refined petroleum from oil sands.

The transportation sector was the second largest contributor to the total amount of greenhouse gas emissions in Canada. The 43% increase of emissions in this sector was predominantly caused by the augmented use of freight and passenger-light trucks (vans and sport utility vehicles). Modes of transportation have changed since 1990, as reflected in the increase of emissions in this sector; personal vehicle emissions declined by 18%, but as previously mentioned, vehicular emissions increased overall as passenger-light trucks and freight emissions grew by 122%. The Government of Canada (2019) reports that the modes of transportation were influenced by factors like population, economic growth, vehicle type, fuel efficiency or type, and personal preference.

The electricity sector also accounts for much of Canadian greenhouse gas emissions. This sector produces 10% of national emissions, however, between 1990 and 2017 combustion-based electricity generation decreased its emission output by 21%. This decline was due to the increasing use of hydro, nuclear and other renewable energy sources. Additionally, using fuels that were not as contaminated with heavy pollutants and greenhouse gases as coal have aided the decline (Government of Canada, 2019).

Greenhouse gas emissions can further be divided by comparing contributions by province. The top five provinces, in order from greatest to least GHG producers, are Alberta, Ontario, Quebec, Saskatchewan and British Columbia. Alberta and Ontario are the two largest contributors accounting for 38% and 22% of national emissions, respectively. Alberta's elevated emissions are due to its heavy investment in the management and production in the oil and gas industry, particularly in Northern Alberta. Around 1990, Ontario's GHG emissions were largely due to their manufacturing industry, however, Ontario's emissions have declined since then as a result of closing their "coal-fired electricity generation plants" (Government of Canada, 2019). Provinces like Quebec and British Columbia have seen a decrease in emissions because they are shifting their reliance on fossil fuels in favor of hydroelectric resources for electricity generation. Conversely, Saskatchewan has seen a 14% increase of emissions. This increase is assumed to be attributable to the transportation, oil and gas, and mining sectors.

Greenhouse gas trends have fluctuated between 1990 and 2017, and the trends mentioned above have been discussed at national, industry, and provincial levels. Each province has different ties to sectors that increase the amount of greenhouse gases emitted by Canada.

Impacts of Greenhouse Gases

Changes to the environment and climate as a result of excess greenhouse gas emissions both directly and indirectly affect human social, political, and financial endeavors. The most immediate and direct concern of GHGs is their effects on the natural environment. The primary consequence of increasing greenhouse gas emissions is that of climate change and global warming.

CO_2 is a waste product of combustion reactions as well as cellular respiration and is converted back to breathable oxygen by photosynthesis. The conversion of carbon dioxide back to oxygen by marine photosynthetic microorganisms effectively makes the ocean a "carbon sink" in the carbon cycle, with the ocean storing an estimated 30% of human made CO_2 (Dutkiewicz *et al.,* 2015). As the ocean continues to absorb more CO_2 dissolved as weak carbonic acid, it lowers the pH, usually slightly basic (>7), towards being closer to a neutral 7.0. Phytoplankton are especially susceptible to changes in their habitat, and thus will be less effective in their role as

CO_2 recyclers as the ocean absorbs more of the excess atmospheric carbon (Doney *et. al.,* 2016; Gao *et al.,* 2018). Zooxanthellae, zooplankton that give living corals their bright colours, are just as, if not more vulnerable to a changing habitat as phytoplankton as they are fixed in their reefs. The now-worldwide “coral bleaching” phenomenon that is turning coral reefs from vivids to white is caused by the expulsion of the zoothanthellae from the corals in water that is too warm, as well as the deterioration of the reefs’ hard calcium carbonate structure due to increasing ocean acidity (Pacific Marine Environmental Laboratory, 2020; Sully *et al.,* 2019). Furthermore, warmer water holds less dissolved CO_2 than colder water, and encourages the conversion of carbonic acid back into CO_2, and so warmer oceans will be less effective carbon sinks as the Greenhouse effect intensifies (Yao *et al.,* 2020).

Another adverse impact of the global temperature increase is that polar ice and glaciers have begun and continuing to melt (University Center for Atmospheric Research, 2020). This initiates a positive feedback loop effect, as the more ice that melts, Earth’s albedo will decrease and less solar radiation will be reflected off of the planet’s surface, thus more solar energy will be absorbed by the polar marine systems. Additionally, melting ice masses release stores of methane and CO_2 that were once trapped in the ice into the atmosphere, again increasing greenhouse gases and contributing to this positive feedback (Ma and Tipping, 1998). As these glaciers thaw, their runoff causes the sea level to rise, and as such, flooding has become a major concern for coastal cities and habitats all over the world (University Center for Atmospheric Research, 2020).

Global warming also has the effect of weakening the jet stream. Jet streams are fast flowing air currents that occur between zones of the atmosphere. One of their primary functions is separating the different regions of air, and in the case of the polar jet streams, they keep the cold polar air away from the warm air of lower latitude regions. As the absolute temperature of the world increases, the relative difference in temperature between the arctic and lower latitudes diminish, which is a key factor defining the strength of a jet stream. This weakens the jet stream, which is wavy, and not able to bottle up arctic weather (Mann *et al.,* 2018). The result is often unseasonably severe weather in mid latitude areas, as frigid arctic air cells are carried South, unhindered by this weakened jet stream that used to keep that air confined in the North (Mann *et al.,* 2018).

In areas that currently are already consistently warm, the greenhouse effect can cause "desertification" as soil and arable land becomes barren; many areas that already see very little rain are likely to see even less in the future. As the average global temperature continues to rise, and seasonal weather patterns become less reliable, areas suitable for crops and the time window for growing become smaller (World Meteorological Organization, (n.d.); Smith *et al.,* 2008).

Economic Impacts

Climate change poses a potentially large threat as it brings climate and environmental changes, ultimately affecting the economy and the financial system. Scientists estimate that, through the emission of greenhouse gases, human activities have caused about a 1.0°C average global temperature increase above pre-industrial levels, and if human emissions continue at this current rate, global warming is likely to reach 1.5°C between 2030 and 2052 (IPCC, 2018). Since 1980, extreme weather destruction has cost national governments $1.6 trillion, and if temperatures were to rise 3°C above the pre-industrial average, global GDP is estimated to fall by 25% (NCEI, 2020). At the current rate with no interference, temperatures will rise 4°C by

2100 and global GDP would decline by more than 30%, worse than even the Great Depression, when global trade fell 25% (The Balance, 2020).

Munich Re Group, the world's largest reinsurance firm (Germany), blamed climate change for $24 billion of losses during the recent California wildfires (Nelsen, 2019). The firm warned that insurance companies will have to raise premiums to cover the rising costs from extreme weather, charging insurance premiums that may be too expensive for the average property owner (Cho, 2019). In Canada, costs associated with climate change could escalate from roughly $5 billion per year in 2020, to between $21-43 billion per year by the 2050s (National Round Table, 2013). By the 2050s, the impacts of climate change on the timber supply are expected to cost the Canadian economy between $2 -17 billion per year due to changes in pests, forest growth, and the frequency and spread of fires themselves. As a result of climate change, sea-levels will rise and cause more flooding in coastal areas, posing a severe risk to coastal homeowners in Canada and Worldwide (University Center for Atmospheric Research, 2020). Across Canada, provinces will also experience more severe weather by the 2050s, raising the costs of flooding from climate change to $1-8 billion per year (National Round Table, 2013). Additionally, climate change will lead to warmer summers and poorer air quality, resulting in a rise in deaths and illnesses in the four cities studied: Montréal, Toronto, Calgary, and Vancouver. Illnesses associated with climate change-related air contamination in turn will impose costs on the health care system; in Toronto these costs could be between $3 million and $11 million per year by the 2050 (National Round Table, 2013).

The costs of climate change on people, places, and prosperity will vary and be uneven across the country. As previously mentioned, climate change may *sap* $2-17 billion per year from the timber supply sector of the Canadian economy by 2050. Timber supply in Western

Canada will likely be more affected than in the East. British Columbia's forest-reliant economy will suffer more than many others, while Ontario's economy, due to its size, will see the largest total economic impact. The coastal regions that skirt Canada are also affected differently by climate change, namely rising sea levels (Cho, 2019). Relative to the total land area of each province/territory, Prince Edward Island's coastal areas are most at risk. Many dwellings in the Lower Mainland of British Columbia are likely to be impacted, given that these areas are low-lying and have a high housing density. The costs of dwelling damage per capita will be highest in British Columbia and Nunavut. Human health impacts and increased healthcare costs from climate change vary across the four cities. The cities that will experience the greatest increases in temperature are Toronto and Vancouver therefore, they will experience the greatest repercussions of climate change (National Round Table, 2013).

The oil and gas sector, as well as other carbon-intensive sectors are important to the current structure of the Canadian economy. Changes in preferences, technology, and policies along the transition path, including the climate policy, are expected to lead to significant shifts in relative prices. These price changes could lead to reallocating resources across sectors and alteration in cross-country comparative advantages, patterns of trade and specialization, balance of payments, and exchange rates (Bank of Canada, 2020).

When applied regionally, the economic impact of climate policies strongly depends on interactions with other regions in the world. Lasting shifts in the energy industry are also expected to persistently change energy prices, which could feed into inflation expectations and wages, creating inflationary pressures (McKibbin, 2017).

Discussion, Methods for Management, and Potential Solutions

The rapid warming of the Earth's atmosphere presents many negative consequences to the natural equilibrium of various climates and causes direct harm to both their animal and human residents. The greenhouse effect creates a "blanket" over the atmosphere that significantly reduces the release of radiation from the Earth's surface and results in a net warming effect. With the dramatic increase in surface warming trends, it is imperative that individuals, governments, and large-scale companies work collaboratively to reduce our impacts associated with the greenhouse effect.

Although it may seem inconsequential, any individual can contribute to the reduction of GHG emissions. If societies as a collective embrace this ideology that every individual can make a difference for the better, great strides can be made as a whole. A common but effective strategy that can be implemented is the 3 R's; reduce, reuse and recycle. This saying has been consistently reiterated for a good reason as it proves to have positive impacts if all individuals embrace this strategy. Using reusable materials will decrease the amount of waste that travels to landfills and will lessen the amount of energy needed at these landfills. Within the home, reducing the use of excessive air conditioning and heating, using energy efficient alternatives like eco-friendly light bulbs, can reduce a family's carbon footprint and their energy bill. In terms of travel, reducing the amount an individual trip will reduce the amount of CO_2 released into the atmosphere. Other alternatives such as carpooling, public transit, walking, or riding a bike are beneficial alternatives. As stated previously, if individuals adopt the ideology that every action made can largely contribute to a positive change in the environment, small changes such as using the 3 R system (reduce, reuse and recycle) can affect how much pollution is produced and how much energy is used.

According to the Government of Canada (2019), transportation is the second leading cause of greenhouse gas emissions (only behind oil and gas), at 24% of the country's total emissions. Other sources of Candian emissions are electricity (10%), homes and buildings (12%), forest/agriculture/waste (13%), industry (13%) and oil and gas at 27% (Government of Canada, 2019). The Canadian government is focusing on several key factors to tackle just this one portion of their greenhouse gas emissions. Public transit investments will be significantly increased in order to lower the incentive for individuals to drive their own vehicles (Government of Canada, 2019). Furthermore $182 million will be put towards funding of electric and alternative fuel vehicles. In order to increase the popularity of electric vehicles, a purchase incentive of up to $5000 is eligible for certain zero emission vehicles, as well as increasing the guidelines to emissions for regular combustion vehicles, especially trucks (Government of Canada, 2019). Although there are many other contributors to the Government of Canada's GHG emissions, as well as many other strategies to combat the current rates of emissions, the example above provides a glimpse at how our government is attempting to deal with the current issue. The way in which the Canadian government is providing information to the public is reassuring, as it allows citizens to hold the government accountable for their promises.

An international effort has been put forward by the United Nations in order to fight a battle that everyone on the planet is facing. 187 countries, including Canada, but excluding the United States, have signed an agreement to decrease the global warming trend by setting goals and caps for individual country's greenhouse gas emissions (United Nations, 2020). The UN has committed to collectively combat the effects of climate change, as well as aid developing countries during this process (United Nations, 2020). The goal of the 2015 Paris Agreement is to keep the rise in global temperature below a 2°C threshold by the end of the century (United

Nations, 2020). The United Nations does not state the terms in which each country must reduce their emissions, instead the use the concept of Nationally Determined Contributions in which each country can set their own goals and be transparent with the United Nations (United Nations, 2020). Case studies such as the Paris Agreement highlight the global recognition and action taken in order to halt and reverse the impacts of climate change.

Taken together, this research highlights the impact of increased greenhouse gas emissions as a product of human industrialization and expansion. From data we cannot deny that we are negatively impacting the health and stability of the planet through our daily activities and our participation in economic sectors that benefit from the climate's degradation. As residents of the Earth, it is our responsibility to see that we hold ourselves and each other accountable for our impacts if we want life to continue beyond our own.

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