ASSESSMENT OF GREENHOUSE GAS EMISSIONS FROM AGRICULTURE IN CANADA: A COMPARATIVE ANALYSIS

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THE ISSUE

Climate change is a serious global issue today. Agriculture is one of the most vulnerable sectors to be affected by the impacts of climate change. Meanwhile, agriculture is one of the major GHGs contributors. Globally, agricultural GHG emission has doubled since 1961.

Global agricultural GHG emissions: 9.3 Gt CO_2 eq in 2018

AGRICULTUREAL GHG EMISSIONS IN CANADA

- Agriculture was responsible for about **8.2%** of Canada's total emissions in 2020, **34%** higher than the 1990 level
- Cattle production systems are the highest GHG emission contributors, followed by N_2O from soils

MAJOR AGRICULTUREAL GHGS IN CANADA

Methane (CH_4) from enteric fermentation of ruminant animals

6% increase from 1990 to 2020

Methane (CH_4) and nitrous oxide (N_2O) from manure management

82% increase from 1990 to 2020

Nitrous oxide (N_2O) from agriculture soils

28% increase from 1990 to 2020

GHG EMISSIONS BY SELECTED PROVINCES

British Columia
has the most diverse agricultural systems

Agricultural GHG emissions: 3%

2200 Kt CO_2 eq in 2020

Alberta
has the largest agricultural lands

Agricultural GHG emissions: 7%

16000 Kt CO_2 eq in 2020

Ontario
has the greatest agricultural products

Agricultural GHG emissions: 5%

10000 Kt CO_2 eq in 2020

GHG EMISSIONS BY ENTERPRISES

Cattle

Canada's GHG emissions per kg of live weight beef was **12** kg CO_2 eq in 2020

Wheat

0.22 kg CO_2 eq/kg in Canada in 2020

Canola

0.38 kg CO_2 eq/kg in Canada in 2020

Soybean

Soybeans are most grown in Ontario. In 2013, the emissions were **0.506** kg CO_2 eq per tonne production

Vegetable

Among field grown vegetable, **tomatoes** have the highest GHG emissions, followed by **cabbage** and **carrots.**

RECOMMENDATIONS

Fertilizer BMPs

4R

Right source
matching the types of fertilizer with crop needs

Right time
applying fertilizers when the plants most need it

Right rate
applying fertilizers as the recommended rates

Right place
applying fertilizers at which the crops can get better access

Livestock and Manure Management BMPs

High quality diet
adding more fat or grain on the feed could prevent energy lost as methane

Straw cover/ Emptying the tank
covering liquid manure with straw allows microbes to contact with oxygen to break down methane

Feed additives
adding plant extracts and rumen modifiers could improve fiber digestion

Anaerobic digester
bacteria break down organic matter in the absence of oxygen and produce biogas for energy use

Assessment of Greenhouse Gas Emissions from Agriculture in Canada: A Comparative Analysis

LWS 548 Major Project

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August 2022

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1. Executive Summary

Climate change has become one of the most critical concerns globally today. Evidence includes the increase of surface temperature, the increase of extreme climate events, changes in freshwater availability, the rise of sea level, the decrease of snow cover and ice across the world. In Canada, climate change effects are projected to continue in the future. Agriculture is one of the most vulnerable sectors to be impacted by climate change. Changes in climate can affect crop yield, livestock health, and economies of countries. On the other hand, agriculture is one of the major contributors to climate change, producing a significant amount of greenhouse gases (GHGs). Carbon dioxide, methane, and nitrous oxide are three main GHGs from agricultural crop production and livestock activities, all of which have great warming effects to the atmosphere. Canada has committed to reduce GHG emissions by 40% - 45% below the historical level in 2005 by 2030, and net-zero emission by 2050 (Government of Canada, 2021).

Canada's agriculture is an important part of Canadian economy, which generated 2.1 % of Canada's gross domestic product (GDP) in 2020 (Government of Canada, 2021). British Columbia, Alberta, and Ontario are three provinces with distinguished agricultural features. Agriculture plays significant roles in these provinces' economies. However, agricultural GHG emissions from these regions are also high. Governments should develop relevant policies and encourage more efficient management practices with a focus on reducing GHGs from the agricultural sector.

This white paper focuses on the GHG emissions within the farm gate, excluding the emissions from burning of fossil fuel for on-farm machinery and land use/land use change/forestry, while assessing major sources of GHG emissions from various sectors in Canada by provinces and enterprises, and providing recommendations for climate change adaptation and mitigation.

2. Introduction

2.1 Background

According to the Sixth Assessment Report from the Intergovernmental Panel on Climate Change, (IPCC), climate change effects have been amplifying since 1850 and greenhouse gases (GHGs) have increased at an unprecedented rate (Gulev *et al*., 2021). Climate change is one of the biggest issues around the world today because the current changes are mainly due to human activities (Gulev *et al*., 2021). Gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs) produced by human activities affect the atmosphere by preventing heat from escaping the earth (NASA, 2022). The earth's temperature has been increasing at an average rate of 0.08 degrees Celsius (°C) every decade since 1880 (NOAA, 2021). Although a 0.08 °C increase in surface temperature per decade may seem small, the accumulated heat effect is significant (NOAA, 2021). In 2021, the land surface temperature of the Northern Hemisphere was 1.54 °C higher than average (from 1880 to 2021) (NOAA, 2021). The year of 2021 was the sixth warmest on record (NOAA, 2021). According to the NOAA's 2021 Annual Climate Report, significant below-average and above-average annual precipitation occurred across the globe. Extreme weather events such as floods and droughts are predicted to continue to increase. Snow cover has decreased drastically over the past five decades and sea level has risen by approximately 20 cm over the last century (NASA, 2022).

Agriculture is extremely vulnerable to climate change. Farmers are on the frontline facing climate change (FAO, 2022). The effects of climate change are nearly irreversible on the timescale of people alive today and are worsening (NASA, 2022). Higher concentrations of carbon dioxide may increase plant growth in some regions; however, changes in temperature and climate extremes (such as floods and droughts) can cause losses of crop and threaten the livelihoods of farmers and food security (NASA, 2022). In addition, weeds, pests, and diseases will thrive under warmer and wetter conditions (NASA, 2022). New patterns of pests and diseases can influence crops, animals, and human health.

The climate of Canada has changed and will warm further in the future, according to Canada's Changing Climate Report (Bush and Lemmen, 2019). In Canada, the mean annual temperature has increased by 1.7 °C over the past seven decades and is projected to increase by 1.8 °C - 6.3 °C this century (Government of Canada, 2019). Canada's mean annual precipitation has increased from 1984 to 2012 and is projected to increase everywhere in the country in every season (Government of Canada, 2019). Ice sheets in Canada have been shrinking rapidly at a rate of 7% per decade on average since 1968 (Government of Canada, 2019). Snow cover has also been decreasing at a rate of 5%-10% per decade since 1981, which leads to the decrease of snow water, and it is projected to be a significant reduction in the future (Government of Canada, 2019). British Columbia is expected to experience the greatest impacts (Government of Canada, 2019). The agriculture sector is one of the most sensitive sectors to climate change. For example, in British Columbia, Canada, a total of 100.4 mm precipitation, which was 51.5 mm higher than the 1998 record, led to disastrous floods and landslides and destroyed important farmlands in the area of Abbotsford (NOAA, 2021).

Agriculture is not only one of the most vulnerable sectors affected by climate change, but also a great contributor to climate change. The main GHGs from agriculture are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). GHG emissions from crop production and livestock activities (within the farm gate) and related land use/land change contribute about 10 billion tonnes of CO_2 equivalent (CO_2 eq) each year, which is about 11% of the total global GHGs (Tubiello, 2019). Globally, agricultural GHG emissions have doubled from 1961 to 2016 (Tubiello, 2019). In Canada, GHG emissions reached 729 Mt CO_2 eq in 2018 (Fouli *et al.*, 2021). About 80% was released in the form of CO_2. The CH_4 emissions come mainly from gas systems, coal mining, agriculture and animal waste management, landfills and wastewater, and the N_2O emissions mostly come from agricultural soil management, energy and fuel, industrial activities and waste management (Fouli *et al.*, 2021). The agricultural sector produced about 10% of GHG emissions in the country in 2018, which was 59 Mt CO_2 eq, 15 Mt higher than that in 1990 (Fouli *et al.*, 2021). Agriculture also plays a significant role in addressing climate change as GHG emissions can be reduced through the application of more efficient management in agricultural systems (FAO, 2022; B.C. Ministry of Agriculture and Food, *n.d.*).

2.2 Objectives

This study focuses on GHG emissions from agriculture within the the farm gate in Canada by comparing GHG emissions from three select provinces, excluding GHG emissions for energy and LULUCF (Land-Use, Land-use Change, and Forestry). The purpose of the project is to assess the contribution of agricultural activities to greenhouse gas production in Canada, to elicit adaptation strategies to climate change, and to emphasize the role of Beneficial Management Practices (BMPs) in climate change mitigation.

The primary objectives of the project are:

1. To conduct a systematic review of greenhouse gas emissions (GHG) within the farm gate in Canada and around the world;
2. To identify the major sources of GHG from agriculture in Canada;
3. To assess and compare GHG emissions from agriculture among three agriculturally important provinces: British Columbia, Alberta, and Ontario;
4. To assess the GHG emissions produced by different agricultural enterprises in Canada;
5. To propose benefit management practices that has the potential to reduce GHG emissions from Canada's agriculture sector.

2.3 Methods

Systematic Review

The main methodology of this study is a systematic review of academic literature and government publications to gather information on the causes of climate change, the effects of climate change, the relationship between climate change and agriculture, and to assess global agricultural GHG emissions and Canada's agricultural GHG emissions.

Reports by the Intergovernmental Panel on Climate Change (IPCC), the Food and Agriculture Organization (FAO), the United States Environmental Protection Agency (EPA), and the Government of Canada provide key statistical data for this report, including climate change historic data, future projection, major local and global agricultural GHG emissions, GHG emissions by provinces and by sectors, the climate action plan, and climate change adaptation and mitigation strategies. Canada's official greenhouse gas inventory report by Environmental and Climate Change Canada (ECCC) contains the latest data of GHG emissions and provide important data for anthropogenic emissions by sources and annual emissions from 1990 to 2020.

3. Canadian Agriculture and its Economic Significance

Canada's agriculture and agri-food industries are important parts of the Canadian economy. The primary agriculture sector, defined as activities within the boundaries of a farm, contributed 39.8 billion Canadian dollars to the GDP (2.1%) and provided 269,300 jobs in 2020 (Government of Canada, 2021). Currently, there are about 193,492 farms, covering 68.9 million hectares (6.9%) of Canada's land area (Government of Canada, 2021).

Canada's primary agriculture enterprises are concentrated in the Prairies, Québec, and Southern Ontario (Government of Canada, 2021). The Prairies account for about 80% of the farmland in Canada, containing important grassland, cropland (mainly to produce canola, wheat, barley, oats, flax, lentils, peas, sunflowers) and livestock (Desjardins *et al.,* 2019). Corn and soybeans are produced in Ontario and Québec (Desjardins *et al.*, 2019). Potatoes, tree fruits, and wine are grown mainly in the Maritime provinces, British Columbia, Niagara Peninsula of Ontario and southwestern Québec. Vegetables are produced in suburban areas across the country. Moreover, animal husbandry occurs in every province, with a total of 12.5 million head of cattle (0.9 million of the total were dairy cows), 14 million hogs, 145 million poultry, and 1 million sheep and lambs (Desjardins *et al.*, 2019). Canola and wheat are the top 2 crop commodities in Alberta, Saskatchewan, and Manitoba between 2016 to 2020 (Table 1). Dairy is the top livestock commodity in British Columbia, Ontario, and Québec, and cattle is the top livestock commodity in Alberta (Table 1).

Crop and animal production are two major contributors to the economy in Canada. According to the Government of Canada database, there are about 63,628 reporting farms growing crops across the country. Principle crop production contributed $34.4 billion to the GDP (Government of Canada, 2021). Farm market receipts of crop production, which represents the revenues of farmers from the sale of agricultural products, has reached $28.5 billion, and crop export has reached $24.1

billion (Government of Canada, 2021). 77,594 reporting livestock farms contributed $5.4 billion to GDP and generated $26.3 billion and $11.6 billion from farm market receipts and export, respectively (Government of Canada, 2021).

Table 1. Top three crops and livestock commodities by average 2016-2020 farm receipts (Source: Government of Canada, 2021).

Provinces	Top 3 crop and livestock commodities	Provinces	Top 3 crop and livestock commodities
British Columbia	Dairy: $646 million Vegetables: $593 million Floriculture, nursery and sod: $488 million	Québec	Dairy: $2.4 billion Hogs: $1.3 billion Poultry: $781 million
Alberta	Cattle and calves: $4.9 billion Canola: $2.7 billion Wheat: $2.1 billion	New Brunswick	Potatoes: $157 million Dairy: $112 million Floriculture, nursery and sod: $47 million
Saskatchewan	Canola: $5.3 billion Wheat: $3.2 billion Cattle and calves: $1.4 billion	Newfoundland and Labrador	Dairy: $47 million Eggs: $18 million Floriculture, nursery and sod: $9 million
Manitoba	Canola: $1.4 billion Wheat: $1.1 billion Hogs: $1 billion	Prince Edward Island	Potatoes: $242 million Dairy: $87 million Cattle and calves: $32 million
Ontario	Dairy: $2.1 billion Vegetables: $1.9 billion	Nova Scotia	Dairy: $144 million Fruit: $60 million Vegetables: $43 million

	Soybeans: $1.7 billion		

4. Agricultural GHG Emissions

4.1 Types of Agricultural GHG Emissions

Agricultural activities release a significant amount of GHGs into the atmosphere. The major gases emitted from agriculture include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), all of which have the potential to increase global warming by trapping heat. The ability of CH_4 and N_2O to trap heat is more than 20 times and 300 times as effective as CO_2, respectively (Government of Canada, 2020). The average atmosphere residence lifetime of methane is about 12.4 years while nitrous oxide has a lifetime of 121 years (EPA, 2022). Atmosphere residence lifetime is the average time that takes for these gases to be removed from the atmosphere. Carbon, as an essential element on Earth, is found in the air, animals, plants, soils, rocks and oceans (Fouli *et al*., 2021). In order to compare these gases, CO_2 equivalent (CO_2 eq) is used (Agriculture and Agri-Food Canada, 2020). One kg of CO_2 equivalent equals the effect of one kg of CO_2 being emitted, while 1 kg of nitrous oxide equals 298 kg of CO_2 equivalents, and the emission of 1 kg of methane is equal to 25 kg of CO_2 equivalent.

In agricultural systems, carbon is stored in organic matter in soils (Agriculture and Agri-Food Canada, 2020). Carbon dioxide is constantly exchanging between the atmosphere and the soil (EPA, 2022). The changes in the amount of carbon stored in soil depends on the balance of rates of carbon input from microorganisms, plants, and animals and the rate of organic matter decomposition (Agriculture and Agri-Food Canada, 2020). Soils are carbon sinks and can store carbon while soils can also be carbon sources if the rate of carbon input is lower than the that of carbon loss (Agriculture and Agri-Food Canada, 2020).

Methane comes mainly from domestic livestock, namely cattle, sheep, and goats, through enteric fermentation and manure storage (Agriculture and Agri-Food Canada, 2020). Enteric fermentation is a part of the digestive process of livestock and allows livestock to convert indigestible carbohydrates to be broken down by microorganisms into usable energy (Agriculture and Agri-Food Canada, 2020). Moreover, when manure is stored in a wet environment, the high water content will prevent reaction with oxygen; therefore, CH_4 is produced and released from the site (Agriculture and Agri-Food Canada, 2020).

Nitrous oxide comes mostly from agricultural soil management activities and it accounts for approximately half of the global warming effect of agricultural emissions (EPA, 2022; Agriculture and Agri-Food Canada, 2020). Soil management activities include the use of synthetic and organic fertilizers, farming and cropping practices, and manure management (EPA, 2022). These agricultural activities lead to increases of nitrogen content in soils, and are the largest source of N_2O (EPA, 2022). Extra nitrogen will leach to the adjacent environment and can be converted and emitted as N_2O (Agriculture and Agri-Food Canada, 2020).

4.2 Overview of Global Agricultural GHG emissions

Globally, agricultural GHG emissions has doubled from 1961 to 2016, from 2752 to 5294 Mt CO_2 eq yr^{-1} (Tubiello, 2019). Between 1960s and 2010s, the world's total agricultural GHG emissions has been continuously increasing (Figure 1).

In 2018, the world's total agriculture GHG emissions from crop and livestock activities and the emissions from related land use/land use change have reached 9.3 Gt CO_2 eq. Crop and livestock activities generated 5.3 Gt CO_2 eq of GHG emissions (FAO, 2020). The amount of methane and nitrous oxide emissions from agriculture have grown by 14% from 2000 to 2018 (FAO, 2020). In 2020, the crop and livestock activities has released 4.6 Gt CO_2 eq (FAO, 2020), which shows a slight decrease, a result of emissions from other economic sectors such as electricity and transportation growing at a relatively faster rate during this period (FAO, 2020).

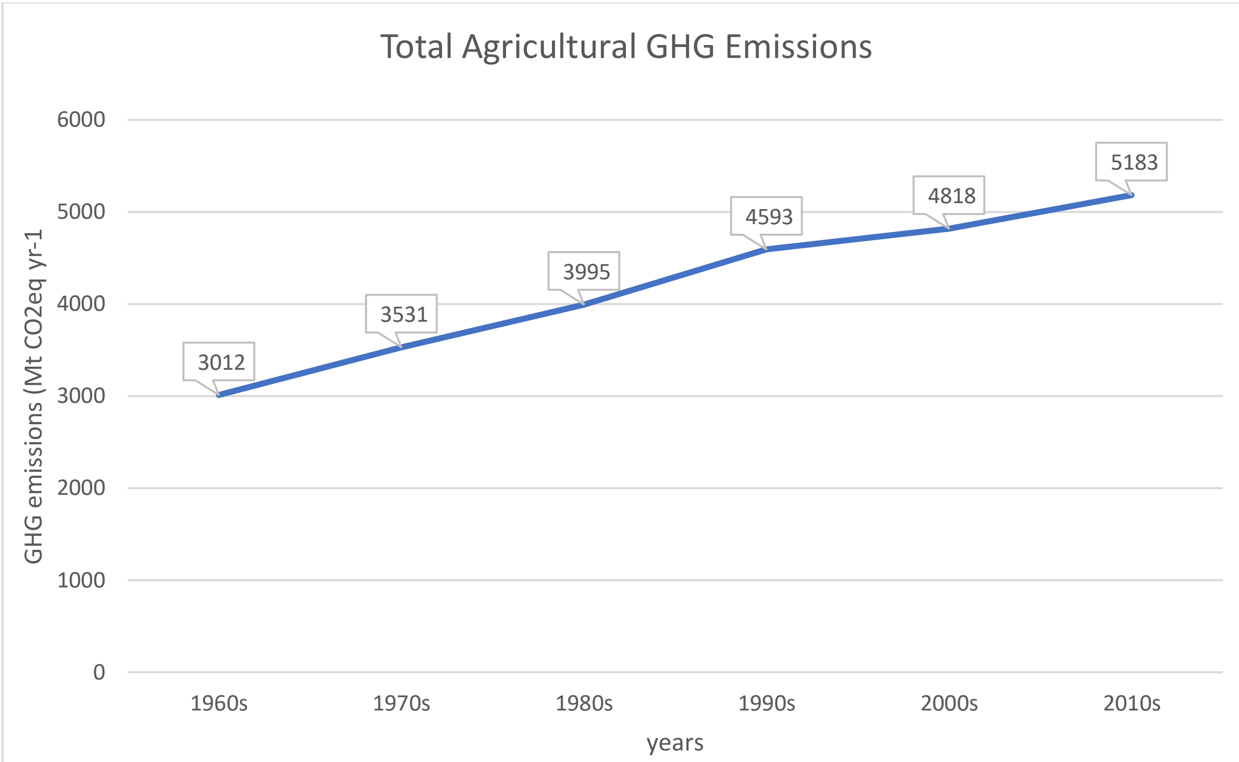

Figure 1. Decadal averages of world total GHG emissions from agriculture (Source: Tubiello 2019).

Methane and nitrous oxide are two powerful GHGs contributing two-thirds of the total agricultural GHG emissions. In 2010s, the relative shares of CH_4 and N_2O in total agricultural GHG emissions are about 55% and 45%, respectively (Tubiello, 2019), which did not show a significant difference. However, in the 1960s, CH_4 emissions were more than double that those of N_2O (Tubiello, 2019). This rising trend of nitrous oxide emissions reflects that the use of synthetic fertilizers on cropland has increased and that livestock numbers have been growing during these years (Tubiello, 2019).

In 2018, among the total 5.3 Gt CO_2 eq GHGs, CH_4 emissions from enteric fermentation contributed 40 percent to the total (2.1 Gt CO_2 eq) (Figure 2). The enteric fermentation in the digestive systems of livestock continued to be the largest component of GHG emissions within the farm gate (FAO, 2020). The second largest component are N_2O emissions from livestock manure left on pastures and manure applications on croplands, which contribute 20 percent to the total (1 Gt CO_2 eq). Moreover, synthetic fertilizers contributed to 13 percent of the total emissions (0.7 Gt CO_2 eq) (FAO, 2020). Rice cultivation generated CH_4 emissions, contributing an additional 10 percent to the total (0.5 Gt CO_2 eq) (FAO, 2020). Agricultural N_2O emissions are projected to increase by 35%-60% by 2030 because of the increased use of manure application and nitrogen fertilizers, and CH_4 emissions are projected to increase by 60% due to the increase in livestock numbers (Smith *et al*., 2007).

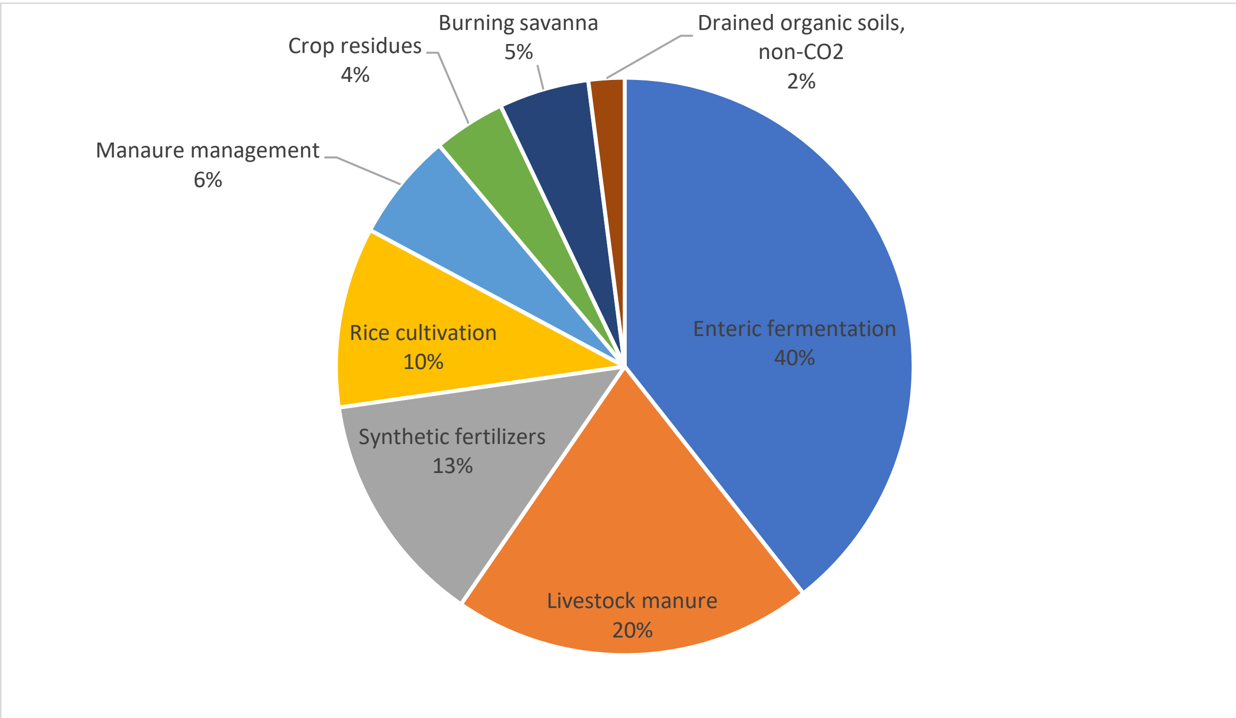

Figure 2. Contribution of crops and livestock activities to total non-CO_2 emissions from agriculture in 2018 (Source: FAO, 2020).

4.3 Overview of Canada's Agricultural GHG Emissions

In Canada, agricultural GHG emissions have been rising since 1990. Agriculture was responsible for approximately 8.2% (55 Mt CO_2 eq) of Canada's total GHG emissions in 2020. The use of nitrogen fertilizers has more than doubled from 1990 to 2020 (Figure 3). The increasing GHG emissions from the use of synthetic fertilizer drove up the total GHG emissions (National Farmers Union, 2022). Without interventions, the emissions from chemical fertilizers could double again by 2050 (National Farmers Union, 2022). Furthermore, the fluctuation in livestock populations is also a main driver of the increased emission trend (ECCC, 2022). The numbers of beef, swine and poultry in 2020 are 4%, 38%, 52% higher, respectively, than in the 1990 level (ECCC, 2022).

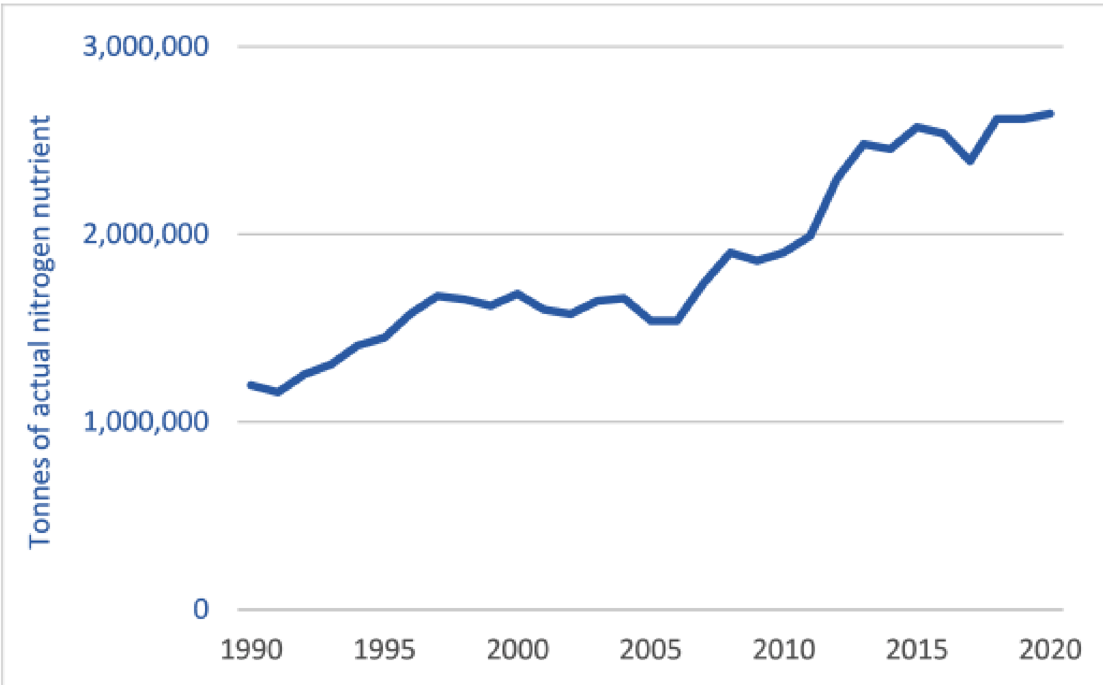

Figure 3. Use of nitrogen fertilizers in Canada between 1990 and 2020 (NFU, 2022).

Compared to the global agricultural GHG emissions, Canada does not produce rice and apply the practices of burning savanna. GHG emissions from Canadian agricultural activities mainly come from three major sources (Figure 4). The largest source is CH_4 from enteric fermentation during the digestion of plants by ruminant livestock. The second highest source is N_2O from soils. Direct N_2O emissions are from nitrogen fertilizers, manure or biosolid that applied on cropland, tillage, summer fallow, irrigation, crop residue, and organic soil cultivation (ECCC, 2022). Other emitters include N_2O and CH_4 from manure management and indirect emissions of N_2O from soil (Agriculture and Agri-Food Canada, 2020). Microbial activities occur during the storage of feces, urine and bedding materials and release GHGs (ECCC, 2022). Indirect N_2O emissions may come from the evaporation and leaching of manure and nitrogen fertilizers and crop residue nitrogen

(ECCC, 2022). Figure 5 indicates the trends of GHG emissions from Canada's agricultural sources, with a peak in the year of 2005. The emissions in 2005 is used as a baseline for comparison.

In 2020, the emissions (8.2%) from Canada's agriculture sector were 2% higher than the 2005 levels and 34% higher than the 1990 levels (Table 2). Figure 6 shows the trends of the contribution of crop production and animal production to total agricultural emissions. Since 2005, the proportion of the contribution of animal productions (Mainly CH_4) to total agricultural emissions dropped to the lowest from 78% in 2005 to 62% in 2020, while the proportions of N_2O from crop production increased.

Emissions from enteric fermentations increased by 6% from 1990 to 2020 (ECCC, 2020) while there was a 23% decline between 2005 and 2020. This trend was due to changes in the livestock population between 1990 to 2020. The population of beef cattle, swine and poultry increased from 10.5 million head, 10 million head, and 101 million head respectively to 15 million head each in 2005 (ECCC, 2022). Since 2005, the beef cattle population has decreased to 11 million head while the swine population first decreased to 12.5 million head and then increased to 14 million head in 2016 (ECCC, 2022). Dairy cow decreased from 1.4 million head to less than 1 million head in 2020 (ECCC, 2022). Although the emissions associated with dairy cow declined, they were offset by a 24% increase in per-animal emissions (ECCC, 2022). This is because dairy cow emits more GHGs than in 1990, a result of changes in feeding, improvements in genetics and/or management practices (ECCC, 2022). Moreover, emissions from manure management systems increased 28% between 1990 and 2020 (Table 2) due to the increased number in beef cattle, swine and poultry. The storage of beef and poultry manure produces N_2O while swine manure produces CH_4 (ECCC, 2022). Due to the changes in management practices, dairy manure emits more CH_4 than N_2O today (ECCC, 2022). Also, beef cattle weights increased, thereby contributing more N_2O emissions from their manure (ECCC, 2022). As a result, CH_4 emissions are associated with the trend of dairy and swine populations while N_2O emissions follow the trend of beef cattle populations (ECCC, 2022). Based on Figure 5, emissions from manure management and enteric fermentation were fairly stable in the most recent years, from 2015 to 2020. What's more, emissions from agricultural soils increased 82% from 1990 to 2020 due to the application of synthetic and organic nitrogen fertilizers to cropland. Meanwhile, canola, corn, and soybean production increased from 3.3 Mt, 7

Mt, and 1.3 Mt in 1990 to 19Mt, 14Mt, 6.4 Mt respectively in 2020 (ECCC, 2022). The increase in nitrogen fertilizer between 1990 and 1997 was a result of the intensification of cropping systems and summer fallow reductions in the Prairies provinces (ECCC, 2022). The second increase in nitrogen fertilizers was between 2007 and 2020 due to the increase in grain prices, which prompted farmers to apply more nutrients to the croplands (ECCC, 2022).

Cattle production systems still are the highest GHG emission contributors in Canada, followed by the use of nitrogen fertilizers and manure management. This result shows a similar pattern as the global agricultural GHG emissions. Canada has committed to reduce GHG emissions from synthetic fertilizer and livestock production to 30% and 75% below 2020 levels and 2012 levels, respectively, by 2030 (National Farmers Union, 2022). The high emissions from these sources mean that changes must be made if the country is to reduce GHG emissions from the agriculture sector by 2030 (National Farmers Union, 2022).

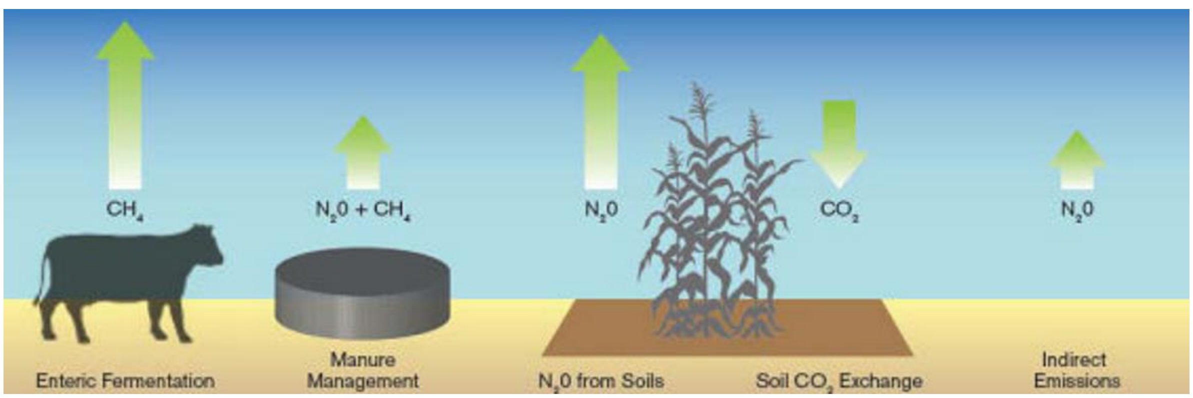

Figure 4. Sources of GHG emissions from Canadian agriculture (Source: Agriculture and Agri-Food Canada, 2020).

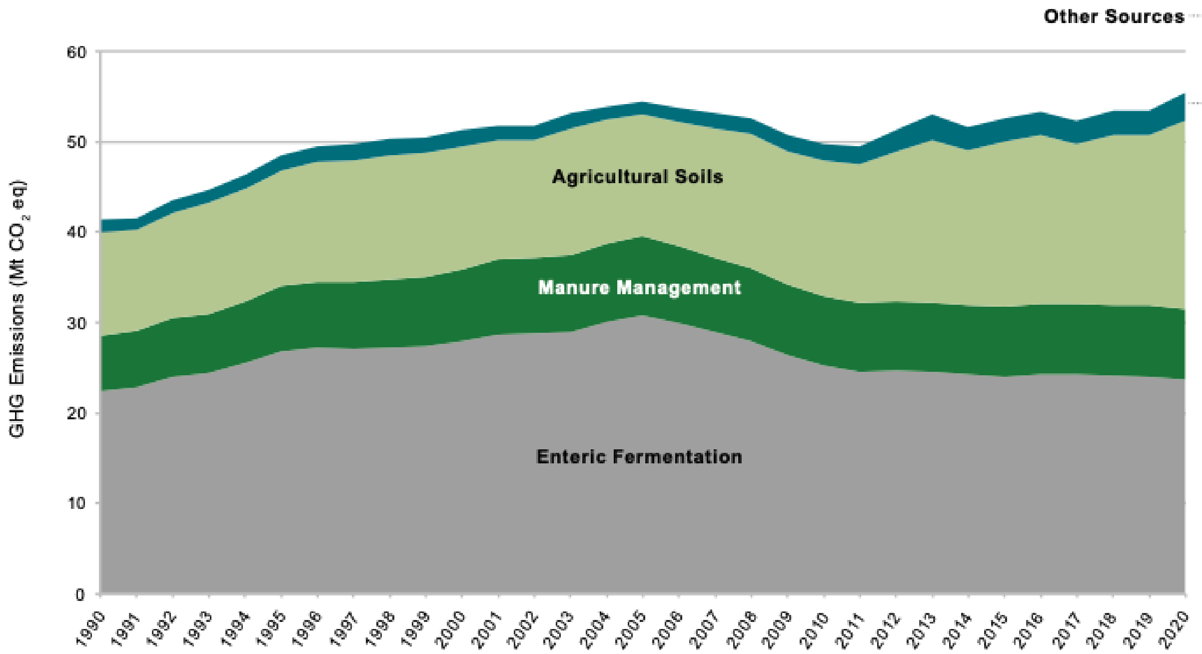

Figure 5. Trends in Canadian GHG Emissions from Agriculture Sources, 1990-2020 (ECCC, 2022)

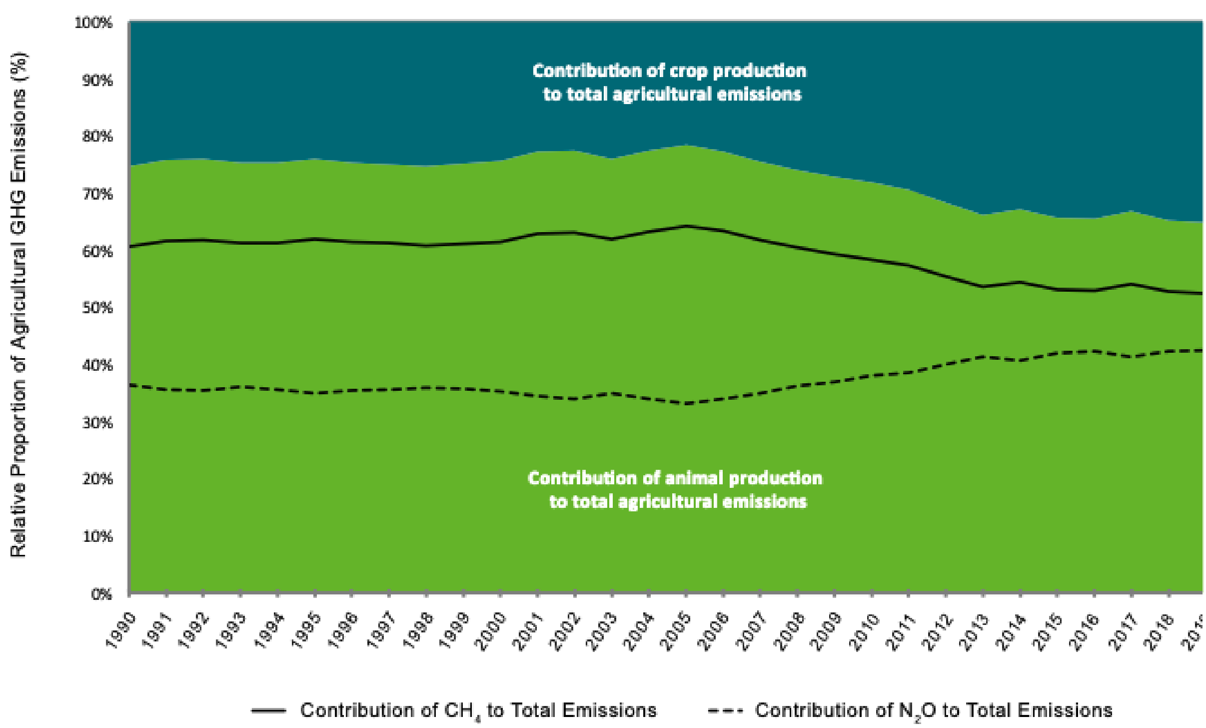

Figure 6. Proportions of Agricultural GHG Emissions emitted as CH_4 and N_2O, 1990-2020 (ECCC, 2022)

Table 2. GHG Emissions from Agriculture (selected years) and Changes.

GHG Source Category	GHG Emissions (Mt CO_2 eq)			Change (%)	
	1990	2005	2020	1990-2020	2005-2020
Agriculture	**41**	**54**	**55**	**34%**	**2%**
Enteric Fermentation	**22**	**31**	**24**	**6%**	**-23%**
Manure Management	**6.1**	**8.7**	**7.8**	**28%**	**-11%**
Agricultural Soils	**11**	**13**	**21**	**82%**	**56%**
Field Burning of Agricultural Residues	0.22	0.04	0.05	-76%	25%
Liming, Urea Application and other Carbon-Containing Fertilizers	1.2	1.4	3	155%	114%

(Source: National Inventory Report by ECCC, 2022)

4.4 Canada's Agricultural GHG Emissions by Select Provinces

Figure 7 shows the agricultural GHG emissions from all provinces and territories in 2005, 2015, and 2020. Agricultural GHG emissions in Canada are mainly from southern British Columbia (B.C.), the Prairies, and southern Ontario and Québec. These areas each contributed more than 2000 Kt CO_2 eq each year. Alberta is the largest agricultural GHG emission contributor in the country, emitting more than 16000 Kt CO_2 eq on average, followed by Saskatchewan, Ontario, Québec, Manitoba, and B.C. B.C., Alberta, and Ontario are selected for comparison for this study as they represent three of Canada's different agriculture regions. B.C. has a wide range of agricultural activities, Alberta has the largest agricultural lands, and Ontario has the largest number of agricultural products.

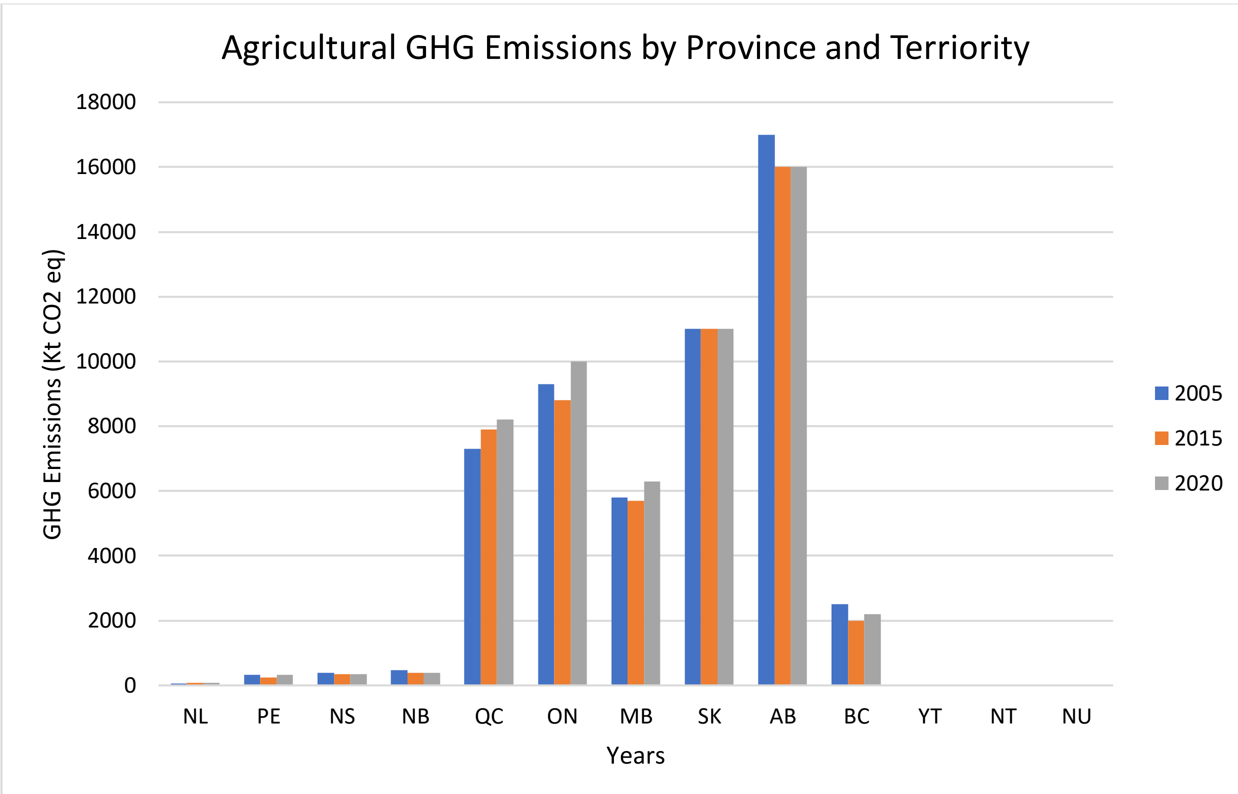

Figure 7. Agricultural GHG Emissions by Province and Territory in 2005, 2015, and 2020 (Source: National Inventory Report by ECCC, 2022)

4.4.1 British Columbia

Thanks to the province's mild maritime climate, a wide range of agricultural activities take place in southern B.C. year-round, especially dairy farming. Other farming activities may include cattle-ranching, poultry-raising, the growing of small tree fruits, berries, grapes, vegetables, mushrooms, and ornamental flowers (BCAITC, 2014). In B.C., there are more than 20,000 agricultural farms, producing more than 200 agricultural commodities (BCAITC, 2014). Agriculture in B.C. can generate more than $2.8 billion farm market receipt each year (BCAITC, 2014).

In B.C., less than 5% of total provincial land is suitable for farming. Up to 30% of the total land area has the potential for agricultural activities (Ministry of Agriculture, Food and Fisheries, 2004).

Farmlands that are producing crops and used for grazing or pasture cover 1.5 million acres and 3.4 million hectares, respectively (Ministry of Agriculture, Food and Fisheries, 2004). There are another 21 million acres of Crown land (lands that owned by provincial government) for grazing or pasture (Ministry of Agriculture, Food and Fisheries, 2004). B.C.'s total agricultural GHG emission accounts for about 3 % of the total GHG emissions annually (Fouli *et al*., 2022).

According to the National Inventory Report conducted by ECCC, emissions from all sources remained stable but increased slightly in the most recent three years, between 2017 and 2020 (Figure 8). GHG Emissions from enteric fermentation were much higher than emissions from manure management and agricultural soils and peaked in 2005. The average emissions from enteric fermentation, manure management, and agricultural soils between 2015 and 2020 were 1450 Kt CO_2 eq (68%), 415 Kt CO_2 eq (20%), and 257 Kt CO_2 eq (12%), respectively. The proportions of GHG emissions between 2015 and 2020 are shown in Figure 9.

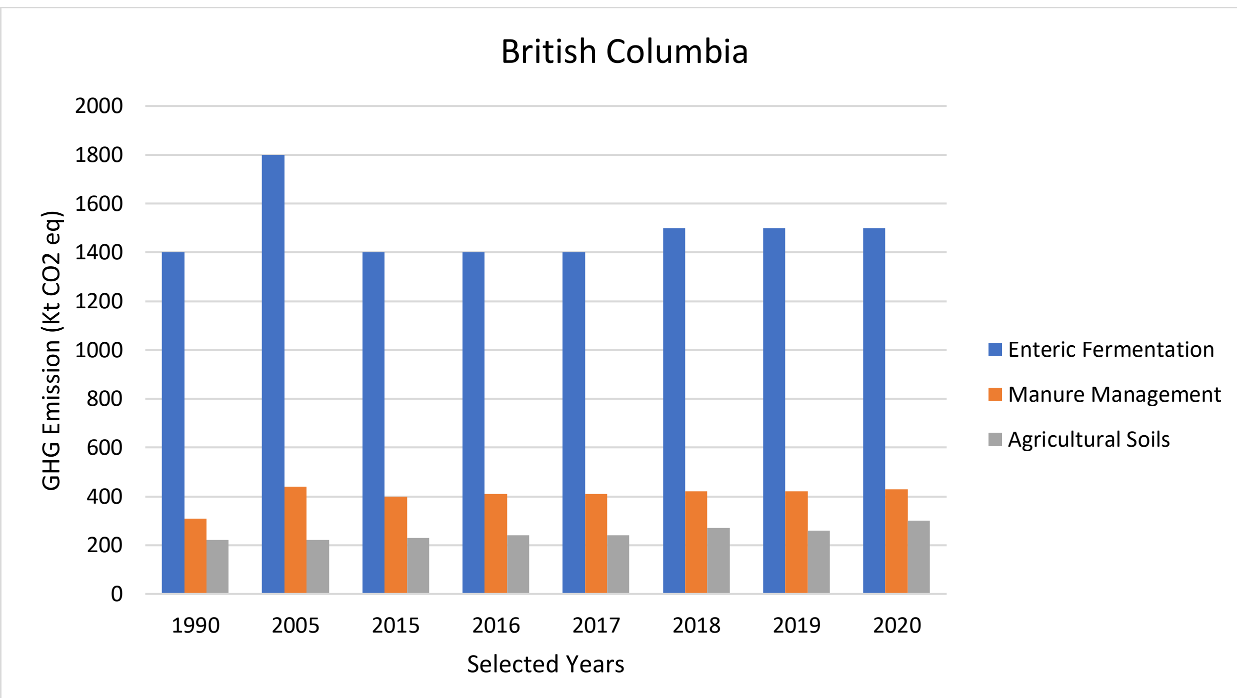

Figure 8. Agricultural GHG Emission for British Columbia, Selected Years (Source: National Inventory Report by ECCC, 2022)

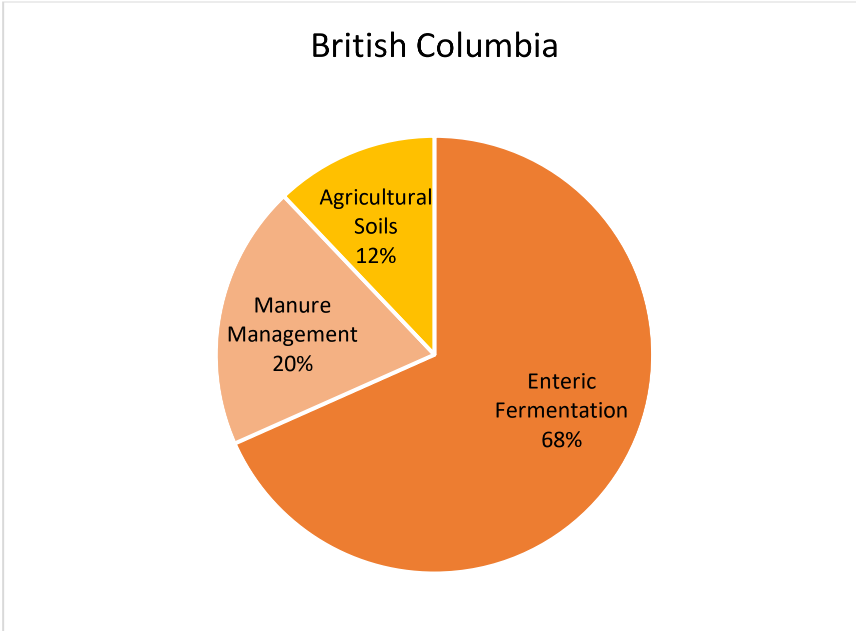

Figure 9. Average agricultural GHG emission breakdown by sectors for B.C., 2015-2020 (Source: National Inventory Report by ECCC, 2022)

4.4.2 Alberta

Unlike B.C., whose agriculture is distinguished by its diversity, Alberta has the largest arable lands to produce primary agricultural products and it is a leading producer of canola, wheat, barley. The province is also leading in livestock market, especially beef cattle. According to the Agriculture Statistics Yearbook by Alberta Agriculture Forestry and Rural Economic Development (2021), in 2020, the total farm market receipts of Alberta was $15.4 billion, which was a 10.7% increase from the recent 5-year average and accounted for 21.4% of the Canadian total. Crop market receipts and livestock market receipts accounted for 48.2% and 43.9% of the total farm market receipts.

In 2021, the reported total farm area of Alberta was 49.2 million acres, of which 46.4% was for oilseed and grain and 39.6% was classified as beef and feedlots (St. Pierre & McComb, 2022). Agricultural GHG emissions accounted for about 7% of the total annual emissions in Alberta (Government of Alberta, 2022; Fouli *et al.*, 2022). Trends of emissions from three sources for Alberta follow the trend of Canada's emissions (Figure 10 & Figure 5). Emissions from enteric fermentation has stabilized and has observed a slight decreasing trend in recent years between 2017 and 2020, while emissions from agricultural soils, the second highest source, have been rising since 2017. Emissions form manure management remained stable in the last five years. Average emissions between 2015 and 2020 for enteric fermentation, agricultural soils, and manure management were 9283 Kt CO_2 eq (61%), 4050 Kt CO_2 eq (27%), and 1883 Kt CO_2 eq (12%), respectively (Figure 11).

The trends of GHG emissions in Alberta's agriculture reflect that the emissions from livestock production have declined because of improvements on management and lower cattle populations (Government of Alberta, 2022). The trends also indicate that more fertilizer and manure use has increased both crop yields and N_2O.

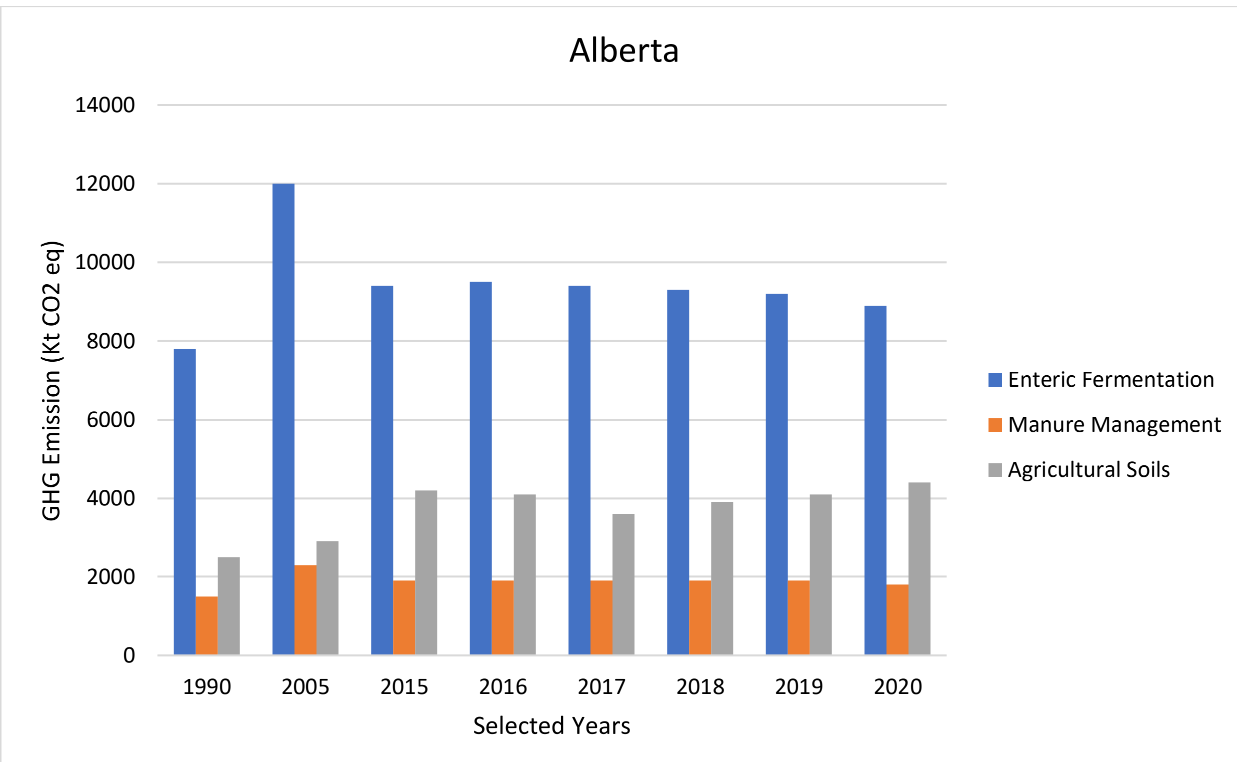

Figure 10. Agricultural GHG Emission for Alberta, Selected Years (Source: National Inventory Report by ECCC, 2022)

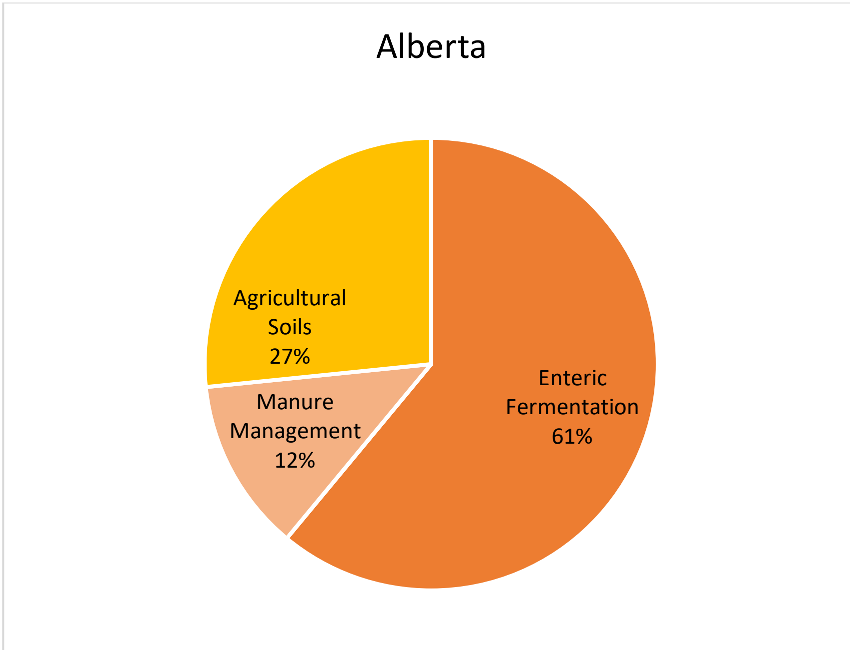

Figure 11. Average agricultural GHG emission breakdown by sectors for Alberta, 2015-2020 (Source: National Inventory Report by ECCC, 2022)

4.4.3 Ontario

As Canada's second largest province, Ontario is known for its largest number of agricultural products and largest national share of farms and farm operators (Chen, 2022). Ontario is also leading the production of soybean and corn among all provinces. In 2021, Ontario represented 54.4% of Canada's soybean area and 59.9% of Canada's total corn area, both of which increased from the previous census due to their strong prices (Chen, 2022). Ontario also has over one-third of Canada's dairy cows (Chen, 2022).

The agriculture sector in Ontario is responsible for about 5% of the province's GHG emissions annually (Fouli *et al.*, 2022). The trend of emissions from enteric fermentation is quite stable, maintaining at around 3400 Kt CO_2 eq in the most recent 5 years (*i.e.*, between 2015 and 2020) (Figure 12). The trend of emissions from manure management in Ontario has also stabilized. However, emissions from agricultural soils has been increasing slowly since 2005 and has been soaring quickly since 2019, making agricultural soils the biggest GHG emission contributor. The average emissions between 2015 and 2020 from agricultural soils, enteric fermentation, and manure management were 3716 Kt CO_2 eq (42%), 3317 Kt CO_2 eq (37%), and 1900 Kt CO_2 eq (21%), respectively.

The farm product price index of grains has a 38% increase, from 114.8 in 2007 to 159.1 in 2021 (Statistic Canada, 2022). This increase drove the rise of soybean and corn area in Ontario; thus, the emissions from agricultural soils has increased in the recent years.

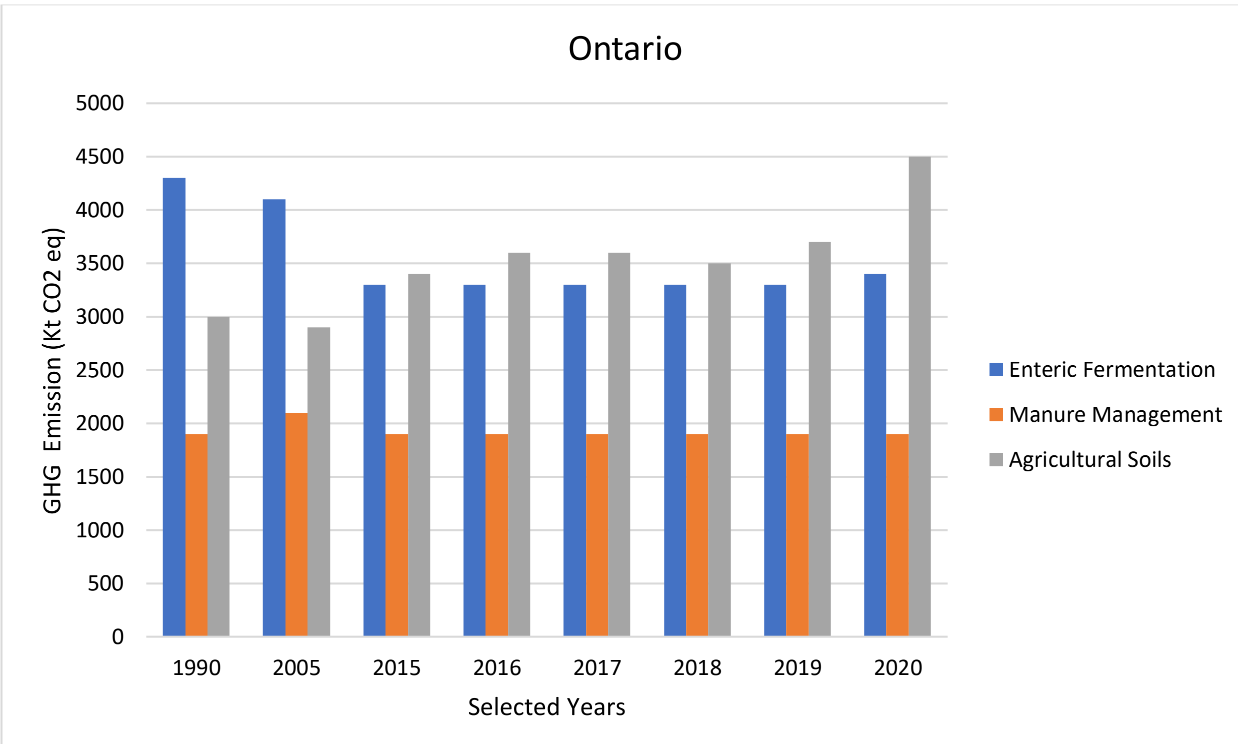

Figure 12. Agricultural GHG Emission for Ontario, Selected Years (Source: National Inventory Report by ECCC, 2022)

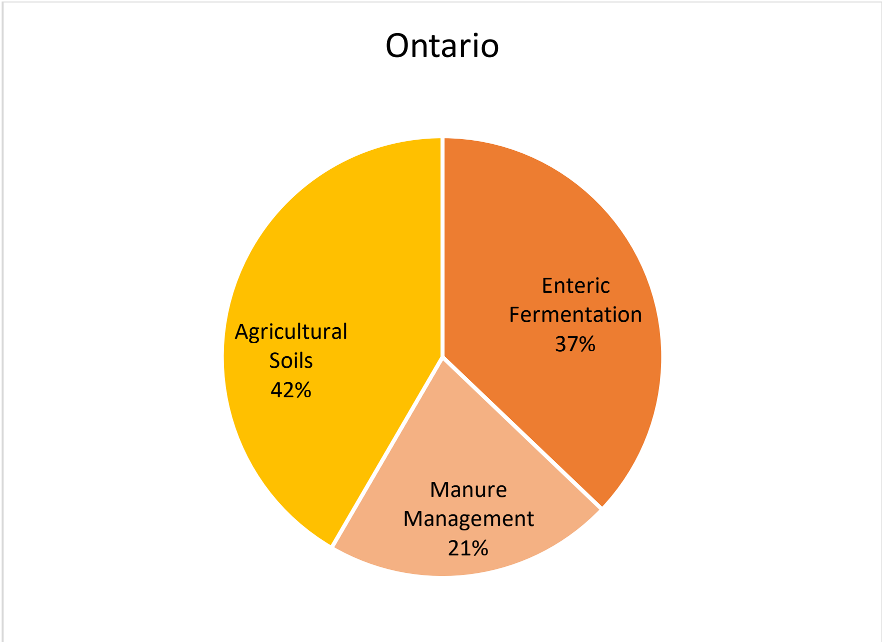

Figure 13. Average agricultural GHG emission breakdown by sectors for Ontario, 2015-2020 (Source: National Inventory Report by ECCC, 2022)

4.4.4 Comparison

Agricultural GHG emission trends for all of B.C., Alberta and Ontario have stabilized since 2015, except for the emission trend of agriculture soils of Ontario. Due to limited resources, the comparison in Table 3 used both farm area and total agricultural GHG emission data from the same year (2016) for consistency. In Canada, one acre of land emitted 0.315 t CO_2 eq in 2016. One acre of farmland in B.C. and Alberta emitted 0.328 CO_2 eq and 0.318 CO_2 eq, respectively. Although B.C. has the smallest farmland area and Alberta has the largest farm area among these three provinces, B.C.'s farmland emitted more GHG emissions per acre than Alberta's farmland. Moreover, B.C.'s average emission per acre was higher than the Canadian average. Ontario's average emission was the highest among all three provinces and was also higher than the average of the country. Ontario has less farmland than Alberta but emitted more GHGs, indicating a more intensive agriculture system in the former.

Table 3. Agricultural GHG Emissions per acre of land in 2016 in B.C., Alberta and Ontario.

Provinces	Farm Area (acres)	Total Agriculture GHG Emissions (t CO_2 eq)	Average GHG Emissions (t CO_2 eq per acre)
Canada	158,700.0	50,000.000	0.315
British Columbia	6,400.5	2,100.000	0.328
Alberta	50,250.5	16,000.000	0.318
Ontario	21,348.5	9,100.000	0.426

(Source: National Inventory Report by ECCC 2022; OMAFRA, 2021; Statistic Canada: 2016 Census of Agriculture; Agriculture and Agri-Food Canada, 2021)

4.5 Canada's Agricultural GHG Emissions by Enterprises

According to Table 1, the major crop and livestock production were dairy and vegetable in B.C., cattle, calves, canola, and wheat in Alberta, and dairy, vegetable, and soybean in Ontario. This section assesses GHG emissions from these enterprises.

Cattle

In Canada, the greatest contributor from cattle enterprise is enteric fermentation (accounting for about 94% of the total), followed by manure management. Table 4, Table 5, and Table 6 show the latest numbers of cattle on farms in the three provinces. In B.C., cattle farms cover around 5 million acres of private land and 21.5 million acres of crown range-land (British Columbia Cattlemen's Association, 2015). In 2015, enteric fermentation GHG emissions by dairy and beef cattle in B.C. were 312 kilotonnes CO_2 eq and 1025 kilotonnes CO_2 eq, respectively (Investment Agriculture Foundation, 2021). B.C.'s manure management GHG emissions by dairy and beef were 103 kilotonnes CO_2 eq, and 157 kilotonnes CO_2 eq, respectively (Investment Agriculture Foundation, 2021). In Alberta, beef production accounted for about half of the province's agricultural GHG emissions (Government of Alberta, 2022). Alberta leads the beef cattle enterprise. In 2011, one kilogram of Canadian beef production was associated with about 9 CO_2e of enteric CH_4, 2 CO_2e of manure N_2O, and less than 1 CO_2e of soil N_2O and manure CH_4 (Legesse *et al*., 2016). Compared to the total GHG emissions from production of one kilogram of beef from 1981, the emissions have been reduced by 15% (Government of Alberta, 2022). Alberta's estimated cattle enterprises GHG emissions in 2020 was 15.6 Mt CO_2 eq. Cattle enterprises in Eastern Canada produce both milk and meat and are more significant than in Western Canada; therefore, Eastern Canada has a lower carbon footprint for meat (Desjardins *et al*., 2019). Canada's GHG emissions per kilogram of live weight beef was 12 kg CO_2 eq (The Simpson Centre, 2022). The live weight of the cattle represents the highest weight of the cattle. In comparison, the European Union, Australia, the United States, and Brazil's GHG emissions per kilogram live weight were 12.3 kg CO_2 eq, 13.1 kg CO_2 eq, 14.4 kg CO_2 eq, and 22.1 kg CO_2 eq, respectively (The Simpson Centre, 2022).

Table 4. Number of Cattle on Farms in B.C. as of Dec 2019

Bulks	Beef cows	Dairy cows	Dairy heifers	Beef heifers (breeding and slaughter)	Steers	Calves	Total (Head)
12,600	208,300	85,200	43,200	62,400	22,800	175,500	610,000

(Source: British Columbia Cattlemen's Association, 2022)

Table 5. Numbers of Cattle on Farms in Alberta as of Jan 2020

Bulks	Beef cows	Dairy cows	Dairy heifers	Beef heifers (breeding and slaughter)	Steers	Calves	Total (Head)
81,200	1,464,200	79,900	39,400	650,800	589,300	1,600,200	4,505,000

(Source: Statistics Canada, Government of Alberta, 2022)

Table 6. Number of Cattle on Farms in Ontario as of Jan 2022

Bulks	Beef cows	Dairy cows	Dairy heifers	Beef heifers (breeding and slaughter)	Steers	Calves	Total (Head)
16,900	234,600	322,000	150,400	184,500	250,800	458,700	1,617,900

(Source: Statistics Canada, Government of Ontario, 2022)

Wheat and Canola

Based on the Government of Alberta data, wheat remains the crop with the highest production at about 11 million tonnes, followed by canola, whose production was about 5 million tonnes in 2020 (Table 6). All wheat includes winter wheat, spring wheat, and durum wheat. The production of wheat has increased while canola production has declined since 2014. The 2020 Agriculture Statistics Yearbook reported that the seeded area in 2020 was about 7.4 million acres for all wheat and around 5.9 million acres for canola. Alberta's estimated GHG emission for wheat enterprise was 2.4 Mt CO_2 eq in 2020 (The Simpson Centre, 2022). The estimation by the Simpson Centre ends at the farm gate. Canada only contributed 0.22 kg CO_2 eq per kilogram of wheat, compared to 0.27 kg CO_2 eq/kg in the United States, 0.29 kg CO_2 eq/kg in Italy, and 0.75 kg CO_2 eq/kg in China (The Simpson Centre, 2022). Moreover, Alberta's estimated canola enterprise GHG emission was 2 Mt CO_2 eq in 2020. Compared to 0.5 kg CO_2 eq per kilogram of canola in Australia and 0.3-0.7 CO_2 eq/kg in Iran, Canada's canola enterprises only produce 0.38 CO_2 eq/kg (The Simpson Centre, 2022).

Table 7. Top 2 Crop Production in Alberta ('000 tonnes)

Crops	2014	2015	2016	2017	2018	2019	2020
All Wheat	9,372.8	8,290.0	10,106.6	9,980.1	10,006.1	10,263.2	11,041.0
Canola	5,797.9	5,851.3	6,157.5	6,826.6	5,870.6	5,320.1	5,212.1

(Source: Alberta Agriculture Statistic Yearbook 2020, prepared by the Government of Alberta in 2021)

Soybean

In Canada, soybeans are mostly grown in Ontario. In 2021, over half of Canada's soybeans were produced in Ontario (Chen, 2022). Table 8 indicates that the soybean area has increased since 2005 and that soybean production has more than doubled between 2005 and 2015 in Ontario. Based on the Ontario Data Catalogue (2022), soybean production decreased between 2015 and 2021 while the area of soybeans increased. N_2O emissions from agricultural soils are the greatest source for soybean. In 2013, the GHG emission from Ontario's soybean production was about 506 kg CO_2 eq per tonne production (CRSC, 2017). Soybeans can fix nitrogen and have a smaller carbon footprint than other crops such as potatoes and corns (Desjardins *et al.*, 2019).

Table 8. Total Soybean Area and Production in Select Years in Ontario.

Soybean	2005	2015	2021
Seeded Area (acre)	2,325,000	2,900,100	2,936,000
Production ('000, tonnes)	2,585.5	5,987.5	4,080.0

(Source: Ontario Data Catalogue, 2022)

Vegetable

According to Desjardins *et al*. (2019), vegetables in Table 9 are exclusively for field-grown products. The main source of GHG emissions from these vegetables are N_2O emissions from nitrogen fertilizers and crop residues. Among these vegetables, tomatoes have the highest GHG emissions, followed by cabbages and carrots. In 2015, agricultural soil GHG emissions from vegetables enterprises in B.C. were 6 kilotonnes CO_2 eq (Investment Agriculture Foundation, 2021), which accounted for 1% of B.C.'s total agriculture soil emissions.

Table 9. Average Carbon Footprints per unit area for vegetables in B.C. and Ontario, 2007-2016

Vegetables	British Columbia (kg CO_2 eq/ha)	Ontario (kg CO_2 eq/ha)
Carrots	3000	3400
Sweet corn	2600	2900
Tomatoes	4200	7000
Peas	1599	1500
Lettuce	3500	3100
Cabbage	3800	4000
Potatoes	2500	2600

(Source: Desjardins *et al.*, 2019)

5. Recommendations

Agriculture is undoubtedly a significant GHG emission contributor to Canada's total GHG emissions, accounting for at least 8% of the total emissions, which is 34% higher than in the 1990 levels. Based on the assessment in the previous sections, the major drivers are nitrogen fertilizer use, livestock population, and livestock manure management. Compared to many other countries, such as Ireland and New Zealand, which have set agriculture-related emission targets in their legislations and Germany, Netherlands and France that also have clear emission targets for their agricultural sectors, Canada is still far behind (Farmers For Climate Solutions, 2021). In 2020, the Government of Canada has committed to cooperate with farmers and enterprises to reduce GHG emissions from fertilizer use to 30% below the 2020 levels by 2030 and to reduce emissions from livestock production as they contribute a large amount of CH_4 emissions (National Farmers Union, 2022). Canada has committed to reduce its overall CH_4 emissions to 75% below the 2012 levels (National Farmers Union, 2022). There would be big changes for every Canadian economy sector, including the agriculture sector (National Farmers Union, 2022). There are many different Beneficial Management Practices (BMPs) for reducing GHG emissions in the agriculture sector, helping to minimize current emissions while simultaneously preparing farmers for the changes to come.

Fertilizer BMPs

Fertilizer Canada has developed and promoted the 4R Nutrient Stewardship for more than a decade with Canadian farmers and fertilizer enterprises (Fertilizer Canada, *n.d.*). 4R practices demonstrate that the fertilizer use should be using the right source at the right time, at the right rate, and at the right place (IFA & WFO, 2016). 4R Nutrient Stewardship provides a framework for farmers to increase production, increase fertilizer use efficiency, and improve sustainability. The selection of BMPs is highly dependent on the location, the crops, soil type, climate, and management conditions (Nutrient Stewardship, *n.d.*); thus, the arid prairie regions and humid coastal regions need to be differentiated. The right source indicates that matching the types of fertilizer with the need of crops can enhance nitrogen efficiency (Burton, 2018). For example, nitrification inhibitors in combination with urease inhibitors have proven to give a greater reduction in N_2O emissions than the nitrification inhibitors alone in alkaline soils, in soils with coarse texture, or in irrigated systems, particularly in corn production in Ontario (Burton, 2018). In terms of the timing for nutrients application, the arid and cold prairie region should implement nitrogen application in the fall while humid agricultural regions such as B.C. are recommended to only apply fall nitrogen application for growing crops such as winter cereals (Burton, 2018). Moreover, splitting applications of nitrogen (initial amount of nitrogen in the early growing season and followed by applications in later season when crop nitrogen demand is high) can reduce N_2O emissions if there are potentials for N_2O losses in the period of the split (Burton, 2018). Furthermore, lowering the rate of fertilizer application has a great potential to reduce the emissions. A study conducted by Han *et al.* (2017) found out that applying nitrogen fertilizers above recommended rates could increase N_2O emissions by about 55%, compared to complying with the requirements (Burton, 2018). Applying nitrogen fertilizers at a lower rate can result in a 33% decline in emissions (Burton, 2018). What's more, placing the fertilizer at the right place where the plants can access the fertilizer better can increase nitrogen use efficiency and minimize nitrogen losses (Burton, 2018).

Livestock and Manure Management BMPs

CH_4 emissions from enteric fermentation of ruminant livestock can be reduced through selecting high quality feed and using livestock feed additives. According to the Agriculture and Agri-Food Canada (2019), dietary fat levels can be increased by crushing oilseeds, such as sunflower seeds, canola seeds or flaxseeds, or by drying corn distillers' grain. This can reduce energy losses as CH_4 emissions by up to 20%. Whole cottonseeds, plant oils, and some ethanol by-products added to the feed can also increase dietary fat. Diets with ionophores and antimicrobials can target ruminal bacteria, enhance production efficiency, and reduce CH_4 emissions (Agriculture and Agri-Food Canada, 2019). Moreover, maintaining the reproductive performance of cattle can result in a reduction in animal numbers on farms, thereby reducing emissions (Agriculture and Agri-Food Canada, 2019). This feeding strategy and management of animal population can be developed immediately and has an expected reduction in CH_4 emissions of 5% - 20% (Agriculture and Agri-Food Canada, 2019). In addition, feed additives such as plant extracts (*e.g.*, condensed tannins and essential oils) and rumen modifiers (*e.g.*, yeast and enzymes) can supplement the diet for cattle, improving fibre digestion, which has been proven to reduce CH_4 emissions (Agriculture and Agri-Food Canada, 2019). The development of feed additives can take up to 5 years, and the expected reduction in CH_4 emissions can be 5% - 20% (Agriculture and Agri-Food Canada, 2019).

BMPs to reduce GHG emissions from the livestock sector include straw cover on liquid manure, emptying manure storage tank, and anaerobic digestion. Firstly, applying straw cover on the liquid manure storage facility allows microbes to access oxygen to break down the methane at the bottom of the tank, which has proven to have the potential to reduce CH_4 emissions by up to 15% (University of Guelph, 2020). Secondly, emptying the manure storage tank completely has the potential to reduce CH_4 emissions by up to 40% (University of Guelph, 2020). These two BMPs are adaptable, inexpensive, and can be implemented immediately (University of Guelph, 2020). Another more effective but more expensive practice is anaerobic digestion (Figure 14), which has the potential to reduce up to 60% of CH_4 emissions (University of Guelph, 2020). Bacteria in an anaerobic digester break down the organic matter and produce resultant biogases and digestate (solid or liquid materials) (EPA, 2022). Biogases produce energy, which can be used to provide heat or electricity on farms (EPA, 2022). Solid digestate can be used in animal bedding, organic-rich compost, or soil amendment and liquid digestate can be used as a nutrient-rich fertilizer (EPA, 2022). As this strategy is expensive, it is suggested that farmers in the local area gather together and share an anaerobic digester so as to minimize monetary input while improving their manure management systems. This strategy helps with GHG mitigation and adaptation and helps farmers achieve economic stability.

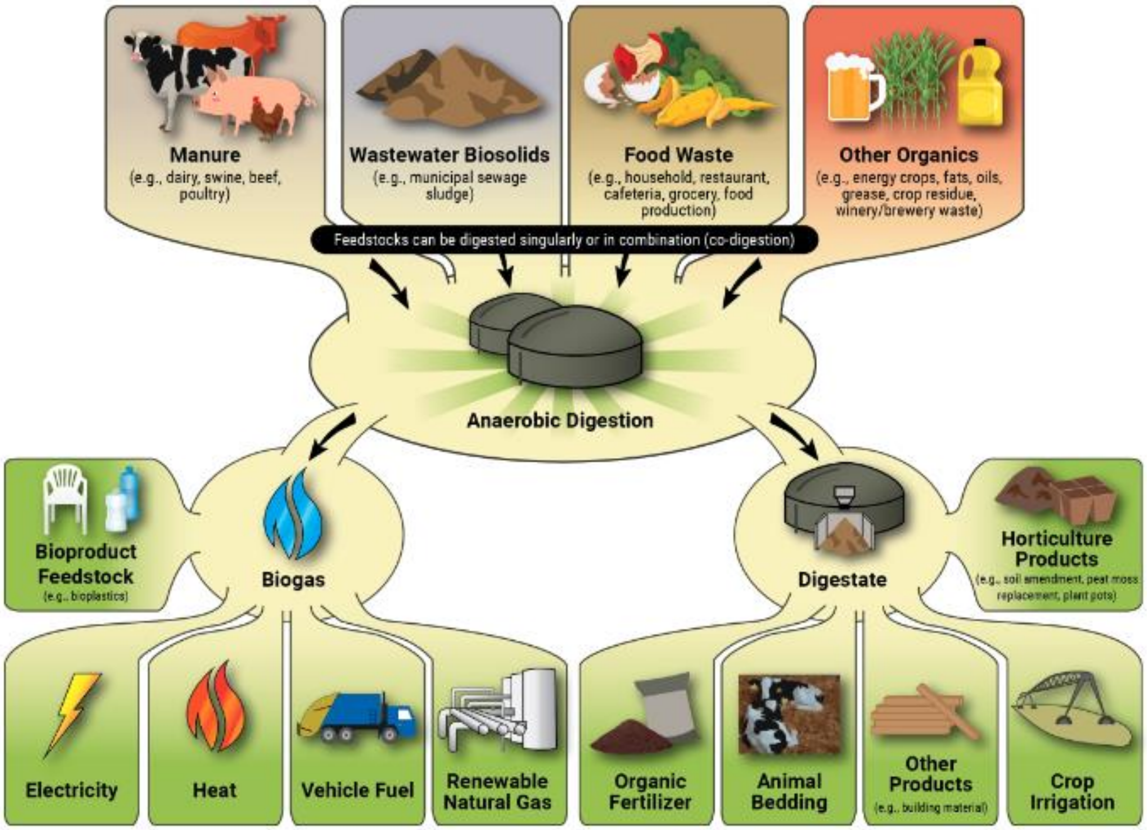

Figure 14. Anaerobic Digester Input and Output (EPA, 2022).

6. Conclusions

In conclusion, climate change is a serious global issue that requires attention and actions from all over the world. The main climate change impacts on agriculture are increasing temperatures, extreme weather events (*e.g.*, droughts and floods), and changing precipitation patterns. Both food security and farmers' livelihood can be influenced by climate change. Meanwhile, the agriculture sector is one of the major GHG emission contributor in the world and in Canada. In Canada, GHG emissions from the agriculture sector ranks at the fourth place, following the oil and, transportation and building sectors. Each economic sector is responsible for reducing GHG emissions. There is an urgent need for the agriculture sector to seek solutions to reduce GHG emissions and adapt to the changing environment as agriculture is associated with food supply. Dairy cattle enterprises in British Columbia and Ontario emit a large amount of CH_4 emissions. Wheat and canola are two major crops for Canada's farm market receipt and export receipt, but they have high carbon footprints. Although the GHG emissions per kilogram production of wheat and canola in Canada appear advantageous when compared to other countries, the Canadian government can still do more to mitigate GHG emissions from its agriculture sector. Numerous BMPs are available around the world that have proven reliable for climate change mitigation and adaptation. The key is to individually customize strategies as they are highly dependent on the location, soil types, the climate, and crops.

This major project provides agriculturists and government bodies with information that can contribute to future improvements in reducing national GHG emissions from the agricultural sector. Specifically, this project provides a comprehensive and systematic review for Canadian agricultural GHG emissions and provides a foundation and evidence for agricultural projects aspiring to implement more BMPs to reduce GHGs.

7. Acknowledgments

I am incredibly grateful to my supervisor Dr. Les Lavkulich, the academic director of the MLWS program, for giving me an opportunity to study in this program and his guidance and useful comments during my writing of this major project. His encouragement and endless patience play a key role throughout the duration of my program. I am fortunate to have such a professional and knowledgeable professor during my study.

I would also like to thank Julie Wilson for helping me shape this project, providing constructive feedback and support, and valuable discussions. Many thanks to my colleagues in the program and their valuable friendship.

Finally, I want to thank my parents for supporting my study in Canada. Their endless love and care for me are my motivation to explore the world.

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