Alberta's Agriculture GHG Emissions and Canada's National Targets:

Where to Start?

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Abstract

Under the Paris Agreement, Canada has committed to reduce greenhouse gas (GHG) emissions by 40 to 45 percent by 2030. To meet these targets, significant reduction will have to occur in all sectors of the economy, including agriculture. This report provides an introduction for policy makers interested in agricultural emissions in Canada and Alberta and identifies areas of future research for the Carbon Program. The report seeks to answer three broad questions: first, how do agricultural emissions relate to current climate plans; second, how have agricultural emissions changed over time; and finally, how are agricultural emissions measured? By answering those three questions, this report provides a solid foundation for future work investigating which technologies or policies have the potential to help reach the target.

Alberta's Agriculture GHG Emissions and Canada's National Targets - Where to Start?

Since the signing of the Paris Climate Agreement, the Canadian government has taken steps to reduce emissions across the economy as part of an international effort to keep average global temperature increases to well below 2°C from pre-industrial levels (United Nations Framework Convention on Climate Change (UNFCCC), 2015). Following its commitments, plans to reduce emissions have targeted all areas of the economy, with the majority of effort focused on the *Oil and Gas*, *Transportation*, *Building,* and *Electricity* sectors (Environment and Climate Change Canada (ECCC), 2016c, 2020a). While the results of the climate measures have been mixed, there have been successes in Canada, most notably in the electricity sector which has decreased emissions by almost 50 per cent since 2005 (ECCC, 2021b).

At 8 to 10 per cent of total emissions (ECCC, 2021a, 2021b), agriculture in Canada comprises a small but significant share of national levels. This overall level has remained relatively unchanged since 2005, and is only projected to increase by 4 Mt to 77 Mt of CO_2 eq by 2030 given currently enacted climate measures (ECCC, 2020b). While the agricultural sector has remained relatively unaffected by Canada's current climate plans, it is likely to face more scrutiny if emissions follow their projected growth and Canada looks to miss its emission targets. To avoid onerous emission-related legislation and maintain greater freedom in production decisions, the sector as a whole should take a proactive approach to emission reductions. While large-scale emissions reductions are unlikely to occur without significant intervention from the federal government, there are existing opportunities to reduce greenhouse gas emissions from the agricultural sector that require only small changes to current practices.

This report provides an introduction to agricultural emissions in Canada, and the province of Alberta. Within the report three broad areas around agricultural emissions are examined: first, how do agricultural emissions relate to current climate plans; second, how have agricultural emissions changed over time; and finally, how are agricultural emissions measured? By answering these questions, the report aims to identify areas in which emissions can be reduced and clearly identify areas in which further research is needed.

Agricultural Emissions and Canada's Climate Plan

Motivating Canada's current climate plans is its commitment under the Paris Climate Agreement. The agreement, ratified in Canada on October 5, 2016, is an international treaty on climate change that seeks to keep global average temperatures to well below a 2°C increase from pre-industrial levels (UNFCCC, 2015). A central component of the treaty is the Nationally Determined Contributions (NDCs), which sets forth the country's emission reduction targets and adaptation to climate change strategies (UNFCCC, 2021). The NDCs are intended to be updated on a five-year cycle starting in 2020 and should reflect increasingly ambitious climate actions (UNFCCC, 2021). The UNFCCC also provided recommendations to the signatories of the Paris Agreement to submit a *Long-Term Low Greenhouse Gas Emission Development Strategies* (LT-LEDS) to provide long-term guidance for planning beyond 2030, which Canada submitted in 2016 (ECCC, 2016b).

Canada's first NDC was submitted in May 2016 and committed Canada to reducing greenhouse gas (GHG) emissions by 30 per cent below 2005 levels by 2030 (ECCC, 2016).The emission reduction targets were to be economy-wide, covering all *Intergovernmental Panel on Climate Change* (IPCC) sectors and using the 2006 IPCC methodologies. To achieve the NDCs targets initially, Canada was to rely on the *Canadian Environmental Protection Act* and take a sector-by-sector regulatory approach to reduce GHG emissions (ECCC, 2016).

On December 9, 2016, Canada's First Ministers adopted the *Pan-Canadian Framework on Clean Growth and Climate Chang*e (PCF). The PCF provided Canada with its first national climate plan and was explicitly designed to meet Canada's initial NDC commitments (ECCC 2016c). Central to the PCF was adopting a carbon pricing system that the federal government believed to be a more transparent and efficient policy instrument to reduce GHG emissions than a sector-by-sector regulatory approach (ECCC 2016c). Carbon pricing had the additional advantage of being easily scalable and could be implemented predictably and gradually, characteristics that are desirable given the requirements of increasingly ambitious emission reduction targets.

Complementing the carbon pricing program, the PCF also outlined several complementary climate actions, investments, and infrastructure projects designed to further reduce GHG emissions and climate change associated risks. While there were sections of the framework that discussed agriculture, the PCF did not provide specific emission targets, climate plans, or investments directed directly towards it. Instead, it highlighted several areas where mitigation could occur, such as carbon storage in agricultural soils, generating renewable fuel from biomass, and investing in innovation (ECCC 2016c). Canada's initial NDC was subsequently updated in May 2017 to reflect Canada's emission reduction strategies under the PCF (ECCC, 2017).

The Greenhouse Gas Pollution Pricing Act (GGPPA) went into force on June 21, 2018, creating the federal carbon pricing backstop proposed in the PCF. Starting January 1, 2019, a tax of $20 per tonne of greenhouse gas emissions (CO_2eq) would be applied to the combusting of fuel or waste. The tax was set to increase by $10 per tonne CO_2eq a year until reaching $50 per tonne CO_2eq in 2022 (Department of Finance Canada, 2018). Under the GGPPA, emissions from biological processes, which accounted for 81% of total agricultural emissions in 2018 (ECCC 2021c), were exempt. Additionally, fuel used for on-farm activities was, for the most part, exempt under the federal program (Parliament of Canada, 2018). However, the extent of the exemptions is an area of ongoing concern for many producers, as some farming activities (e.g., grain drying, heating) and fuels (e.g., propane and natural gas) are not covered under the exemptions (Parliament of Canada, 2018). Concerns about the extent of the exemptions were highlighted in 2019 when above-average precipitation during harvest resulted in significant increases in grain drying cost. This led some farmers and organizations to question the validity of a 2018 Agriculture and Agri-food Canada (AAFC) report which estimated the effect of the GGPPA on annual grain drying costs in provinces subject to the national backstop (Rabson 2020; National Farmers Union 2019).

Canada took several significant steps in 2020 to strengthen its climate plans. First, the federal government introduced the *Net-Zero Emissions Accountability Act*. The *Act* would commit the federal government to set a target of net-zero emissions by 2050 as well as to develop intermediate targets and corresponding climate plans (ECCC 2021h). On June 29, 2021, the *Act* received royal assent and set its initial intermediate climate target for 2030 to align with its commitments under the Paris climate agreement (ECCC 2021h).

The Federal government also introduced *A Healthy Environment and a Healthy Economy, Canada's Strengthened Climate Plan* (SCP) in 2020. The SCP builds upon the PCF to exceed Canada's initial NDC commitments (ECCC, 2020a). A significant aspect of the SCP is the continuation of the annual price of carbon increases beyond 2022. Starting at $65 per tonne CO_2eq in 2023, the carbon price will increase at a rate of $15 per tonne CO_2eq a year until 2030, when it will reach $170 per tonne CO_2eq (ECCC, 2020a). Unlike the PCF, the SCP provides more concrete plans for the agricultural sector. On top of current climate-smart programs, the federal government announced $167 million over seven years to support the agriculture industry in developing and adopting clean technology. The SCP also proposed introducing a national emissions reduction target for emissions originating from fertilizers. The target would aim to decrease emissions by 30 per cent from 2020 levels to partially offset a 60 per cent growth in synthetic nitrogen fertilizer use since 2005 (Environment and Climate Change Canada, 2020a). This is the first mention of an explicit agriculture sector emissions reduction target in national climate plans.

The SCP also includes a commitment to complete the Federal Greenhouse Gas Offset System, which was introduced through the combination of PCF and the Pan-Canadian GHG offset Framework (Canadian Council of Ministers of the Environment, 2019; ECCC, 2016c). While not yet complete, the regulations are expected in the fall of 2021 (ECCC, 2020), and should include an offset protocol for enhanced soil organic carbon in its first phase of development (ECCC, 2021a).

In July 2021, Canada submitted its enhanced nationally determined contribution (eNDC) in line with its commitments under the Paris Agreement. The eNDC committed Canada to reducing GHG emissions to between 40 and 45 per cent of 2005 levels by 2030 (ECCC 2021d). The 40 to 45 per cent level was also incorporated Canada's first intermittent target for achieving Net Zero by 2050 (ECCC, 2021b).

What are Agricultural Emissions?

Canada's agricultural emissions range between 8 to 10 per cent (ECCC, 2021b, 2021c) of Canada's total GHG emissions. These differences in emissions arise from the methodologies used and the grouping of emission sources (ECCC, 2021c). Canada's official measurement is the National Greenhouse Gas Inventory, produced by Environment and Climate Change Canada (ECCC) and submitted annually to the UNFCCC secretariat (ECCC, 2021g). The National

Greenhouse Gas Inventory follows the *2006 IPCC Guideline for National Greenhouse Gas Inventories* and subsequent updates to the methodologies, such as the *2019 Refinement* (ECCC, 2021g). Within the agricultural sector, the IPCC guidelines generally take a top-down approach in which activity data, such as head of cattle or kilograms of nitrogen fertilizer, multiplied by an estimated emission factor (ECCC, 2021a). Emission factors are specific to the source of emissions (e.g., *Manure Management, Agricultural Soils*), gas produced (e.g., CO_2, CH_4, N_2O), and are either set to an international standard (TIER 1) or region-specific (TIER 2) (ECCC, 2021a). Agricultural emissions are estimated using an integrated system of equations, which begins with estimating emissions from animal production before linking it to crop production through the availability of nitrogen found within animal manure (ECCC 2021a). We discuss below for comparison the IPCC and two other alternative methodologies, namely the Canadian Economic Sector measurements and the Physical Flow Accounts.

IPCC:

Under the IPCC guidelines, emissions from the agricultural sector do not include emissions from on-farm fuel use (found in the energy and *Industrial Processes and Product Use* sectors) or CO_2 emission and removal from land management and land-use change (*Land use, Land Use Change and Forestry Sector*) (ECCC, 2021b). Instead, it solely accounts for emissions directly related to agricultural production. Agricultural emissions can be grouped into the following categories based on the source of emissions: *Enteric Fermentation*, *Manure Management*, *Agricultural Soils*, *Field Burning of Agricultural Residues*, and *Liming, Urea Application, and Other Carbon-containing Fertilizers*. Combined, the IPCC agricultural measurement accounted for 8 per cent of total emissions (ECCC, 2021b).

Canadian Economic Sector:

Canada's submission of the National Inventory Report voluntarily includes a recategorization of emissions, referred to as the Canadian Economic Sector (CES) measurements, a second method of categorizing emissions. The CES follows the same methodologies as the IPCC guidelines but reallocates emissions by economic activity instead of emissions sources (ECCC, 2021c). *Crop Production* under the CES measures comprises of emissions from *Agricultural Soils*, *Field Burning of Agricultural Residues*, and *Liming, Urea Application, and Other Carbon-containing Fertilizers,* while *Animal Production* consists of *Enteric Fermentation* and *Manure Management.* The CES measurement also includes a third category, *On-farm Fuel Use*, based on emissions from *Off-Road Transportation*, *Stationary Combustion,* and other *Energy* and *Industrial Processes and Product Use* sources. Differences in total emissions between the underlying source and economic sectors can be attributed to the reallocation of manure on pasture and rangeland from agricultural soil emissions to the Animal Production sector (ECCC, 2021c). Under the CES measure, agriculture accounts for 10 per cent of total emissions.

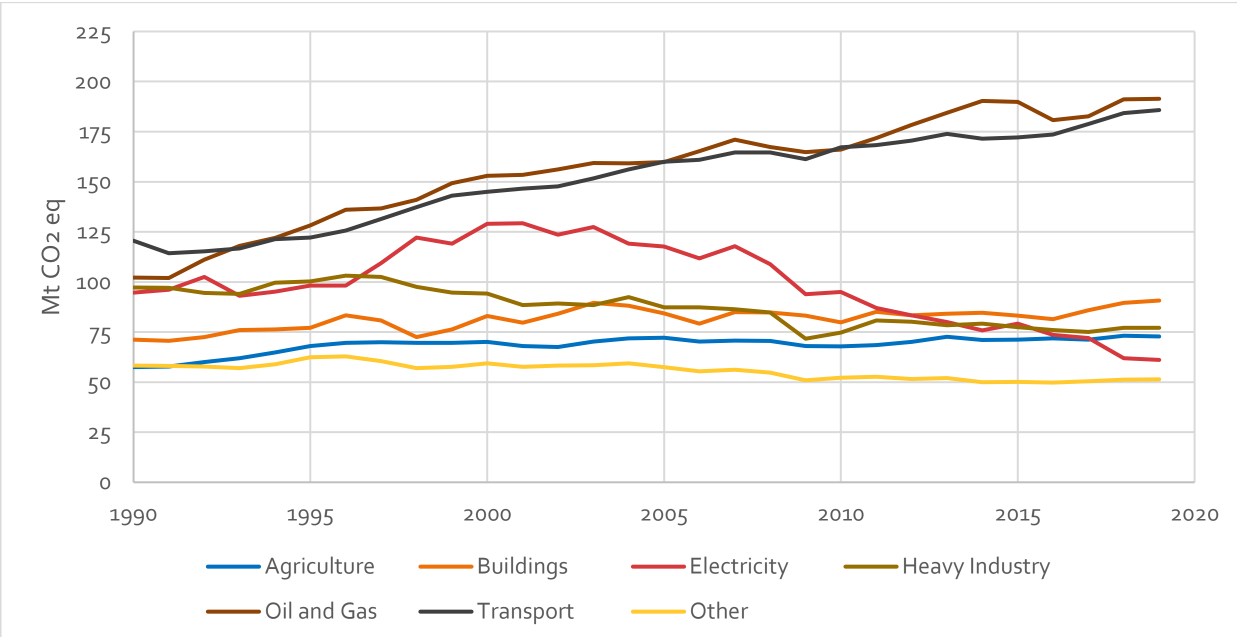
Physical Flows Accounts

Canada's Physical Flows Accounts (PFA) is a complementary measure of greenhouse gas emissions in Canada, and represents a third method of categorizing emissions (Statistics Canada, 2020b). It is produced by Statistics Canada and follows the United Nations System of Environmental-Economic Accounts (SEEA) (Statistics Canada, 2020a). The PFA and the IPCC measures are similar, and share many data sources and methodologies for estimating GHG emissions (ECCC, 2021g; Statistics Canada, 2016). Differences arise in the period under analysis as the PFA only accounts for current emissions and does not factor in reabsorption at a future time, such as in the production and combustion of biofuels (Statistics Canada, 2020b). These differences in accounting for emissions bring the PFA in line with the System of National Accounts (SNA), an international standard to measure economic activity, and allows for a direct comparison between emissions and economic measures (Statistics Canada, 2020a). The PFA also differs in the classification of emissions; instead of the nine CES sectors or five IPCC sectors, the PFA accounts for emissions in 110 different industries and two household groups. Agricultural emissions under the PFA account for 9 per cent of total emissions and in 2018 was equal to 71 Mt CO_2eq (Statistics Canada, 2021).

Canadian Emissions Trends

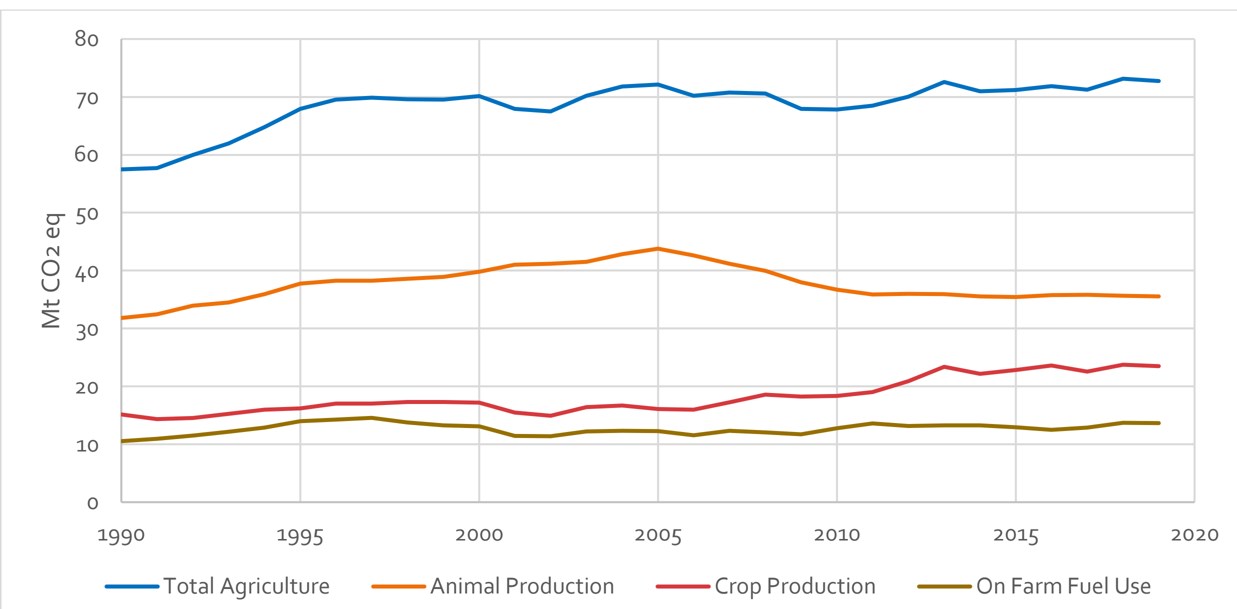
Starting with the CES measurements, from 2005 to 2019, GHG emission in Canada decreased from 739 Mt to 730 Mt CO_2eq (ECCC, 2021c). By sector, *Oil and Gas* and *Transportation* were the largest emitters, emitting 191 and 186 Mt CO_2eq, respectively. Emissions from the *Electricity* sector experienced the most significant decrease, falling from 118 Mt CO_2eq in 2005 to 61 Mt CO_2eq in 2019. Emissions from the *Agricultural* sector remained relatively constant, only increasing by 1 Mt CO_2eq since 2005 to 73 Mt CO_2eq in 2019. While overall emissions in the ag industry in general remained constant from 2005 to 2019, underlying sectors experienced different emission trends. The largest emitting *Agricultural* subsector, *Animal Production*, decreased emissions from 44 to 36 Mt CO_2eq from 2005 to 2019 (ECCC, 2021c). The decrease in emissions was primarily driven by a fall in the size of the national cattle herd from 2005 to 2010 due to market pressures following the 2003 bovine spongiform encephalopathy (BSE) outbreak (ECCC 2021f). Decreases in *Animal Production* emissions have been offset by growth in emissions from *Crop Production*. From 2005 to 2019, emissions increased from 16 Mt to 24 Mt CO_2eq (ECCC, 2021c), primarily due to the increasing use of nitrogen fertilizer (ECCC, 2021h). The remaining emissions have been attributed to *On-Farm Fuel use,* which increased by 12 Mt to 14 Mt CO_2eq (ECCC, 2021c).

Figure 1: Canadian GHG Emissions by Economic Sector from 1990 to 2019



Source: Environment and Climate Change Canada. (2020, April 31). Canada's Official Greenhouse Gas Inventory . Retrieved September 21, 2021, from https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b

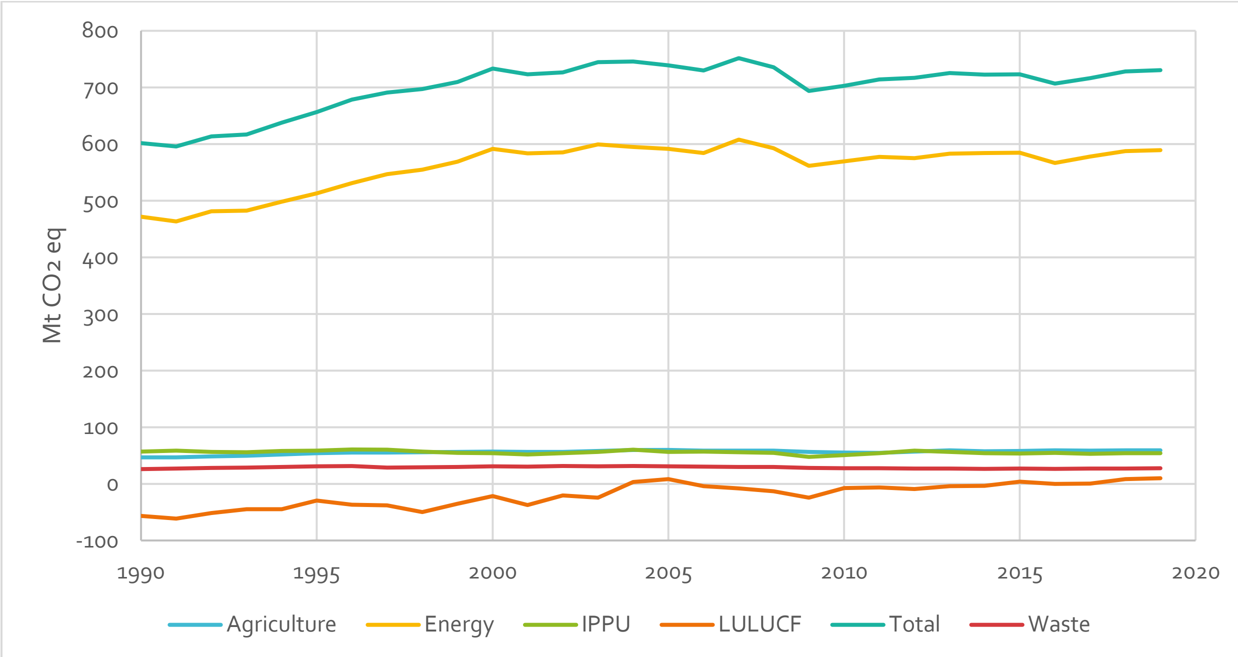
Figure 2: Canadian Agricultural Emissions by Economic Sector from 1990 to 2019



Source: Environment and Climate Change Canada. (2020, April 31). Canada's Official Greenhouse Gas Inventory . Retrieved September 21, 2021, from https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b

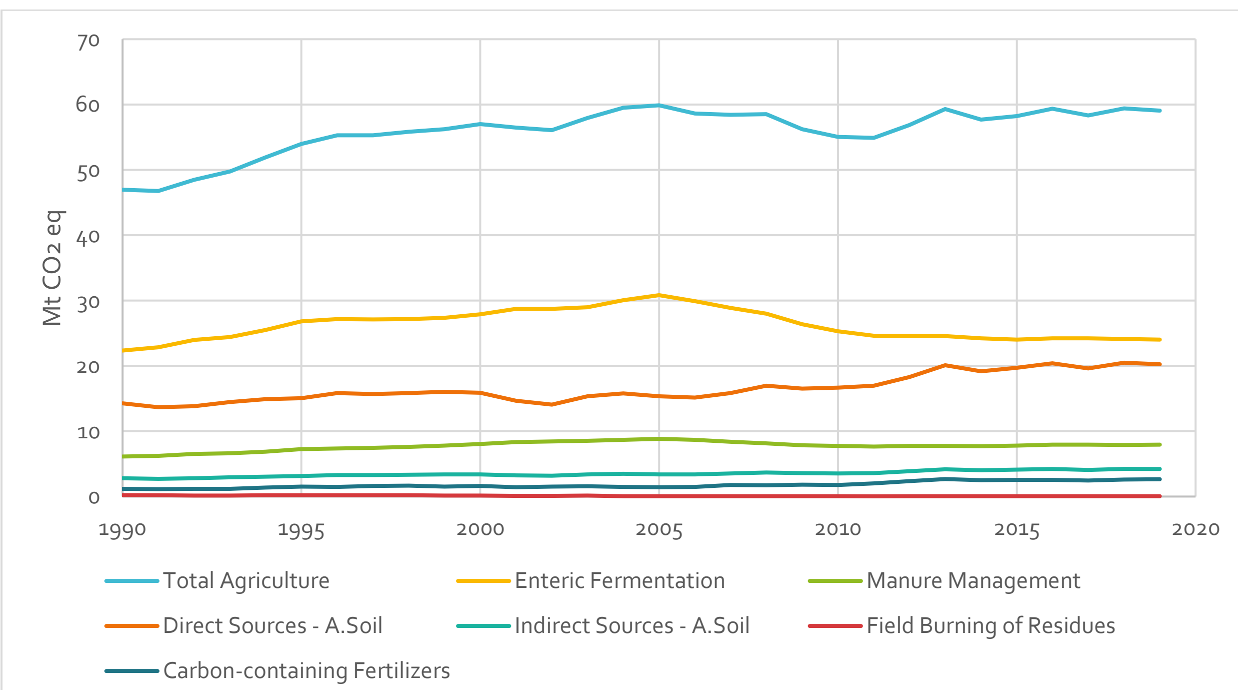
Following the IPCC measurements, agricultural emissions have decreased from 2005 to 2019 by 1 Mt to 59 Mt CO_2eq (ECCC, 2021b). The largest emitting agricultural source is *Enteric Fermentation* which has decreased from 30 to 24 Mt CO_2eq and comprises the majority of emissions classified under *Animal Production*. *Enteric Fermentation* is primarily driven by the beef and dairy industry and is a biological process in the digestive tract of ruminant animals such as cattle and sheep (Hatfield, Johnson, Bartram, Gibb, & Martin, 2006). *Manure Management* has also experienced a decrease in emissions from 2005 to 2019, decreasing from 8.7 Mt to 7.9 Mt CO_2eq (ECCC, 2021b). The *Manure Management* category accounts for emissions during the storage and handling and animal waste. It is dependent on the quantity of manure produced and the animal waste management system used (ECCC, 2021a). *Agricultural Soil* emissions result from nitrification and denitrification occurring naturally in the soil. These emissions are heavily influenced by the quantity of nitrogen fertilizer used, temperature, moisture, topography, and land management practices (ECCC, 2021a). From 2005 to 2019, *Agricultural Soil* emissions increased from 19 to 24 Mt CO_2eq and accounted for most emissions originating in crop production (ECCC, 2021b, 2021c). Combined *Field Burning of Agricultural Residues* and *Liming, Urea Application, and Other Carbon-containing Fertilizers* accounted for 3.1 Mt CO_2eq in 2019 up from 1.8 Mt CO_2eq in 2005 and made up the remainder of *Crop Production* emissions (ECCC, 2021b).

Figure 3: Canadian GHG Emissions by IPCC Sector from 1990 to 2019



Source: Environment and Climate Change Canada. (2020, April 31). Canada's Official Greenhouse Gas Inventory . Retrieved September 21, 2021, from https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b

Figure 4: Canadian Agricultural Emissions by Emission Source from 1990 to 2019



Source: Source: Environment and Climate Change Canada. (2020, April 31). Canada's Official Greenhouse Gas Inventory . Retrieved September 21, 2021, from https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b

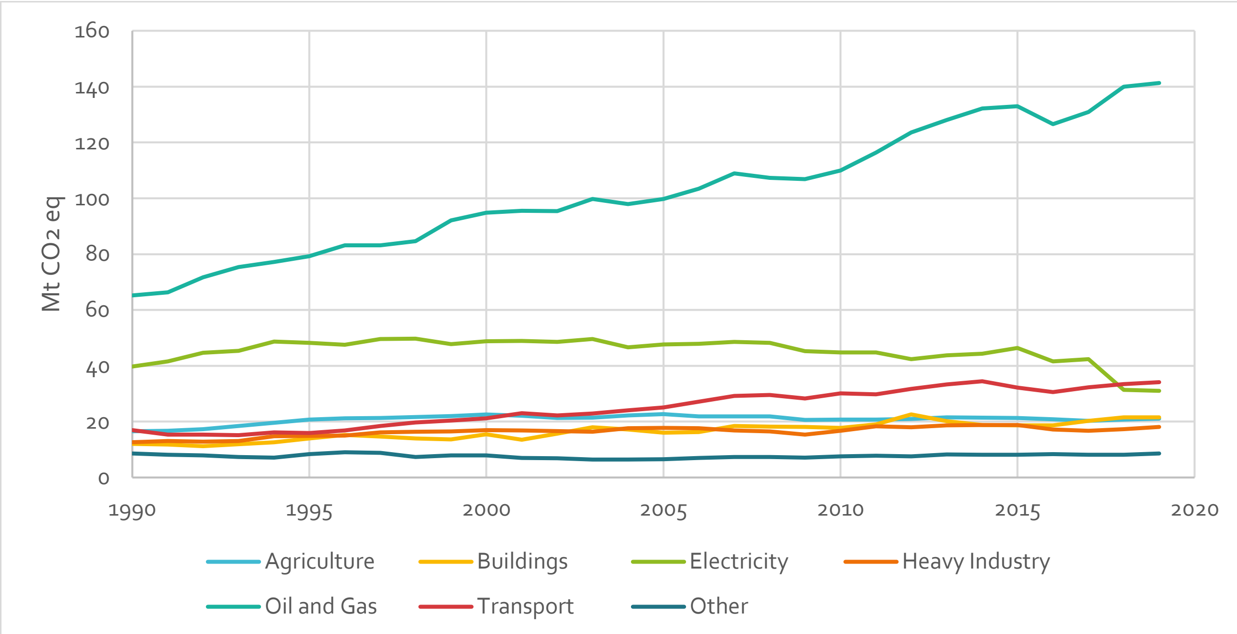
Alberta Emission Trends

Alberta is the largest provincial emitter of GHG emissions from 2005 to 2019; in that period, emissions increased from 236 to 276 Mt CO_2eq and accounted for 38 per cent of total Canadian emissions (ECCC, 2021c, 2021d). Emissions are heavily concentrated in the *Oil and Gas* sector, 51 per cent, followed by *Transportation*, 12 per cent, and *Electricity*, 11 per cent (ECCC, 2021d). *Agriculture*, the fifth largest emitting sector, accounted for 21 Mt CO_2eq, 7.6 per cent, down from 22.7 Mt CO_2eq in 2005.

While *Agriculture* comprises a small share of provincial emissions, it accounts for a significant share of the national agricultural measure at 29 per cent (ECCC, 2021c, 2021d). Alberta's emissions from *Animal Production* fell from 15.2 Mt to 11.9 Mt CO_2eq between 2005 and 2019, which corresponded with the decrease in national emissions from *Animal Production* during that period (ECCC, 2021d). Like national trends, provincial emissions from *Crop Production* increased from 2005 to 2019 from 4.0 Mt to 5.9 Mt CO_2eq. *On-Farm Fuel Use* remained relatively constant 3.5 to 3.3 Mt CO_2eq.

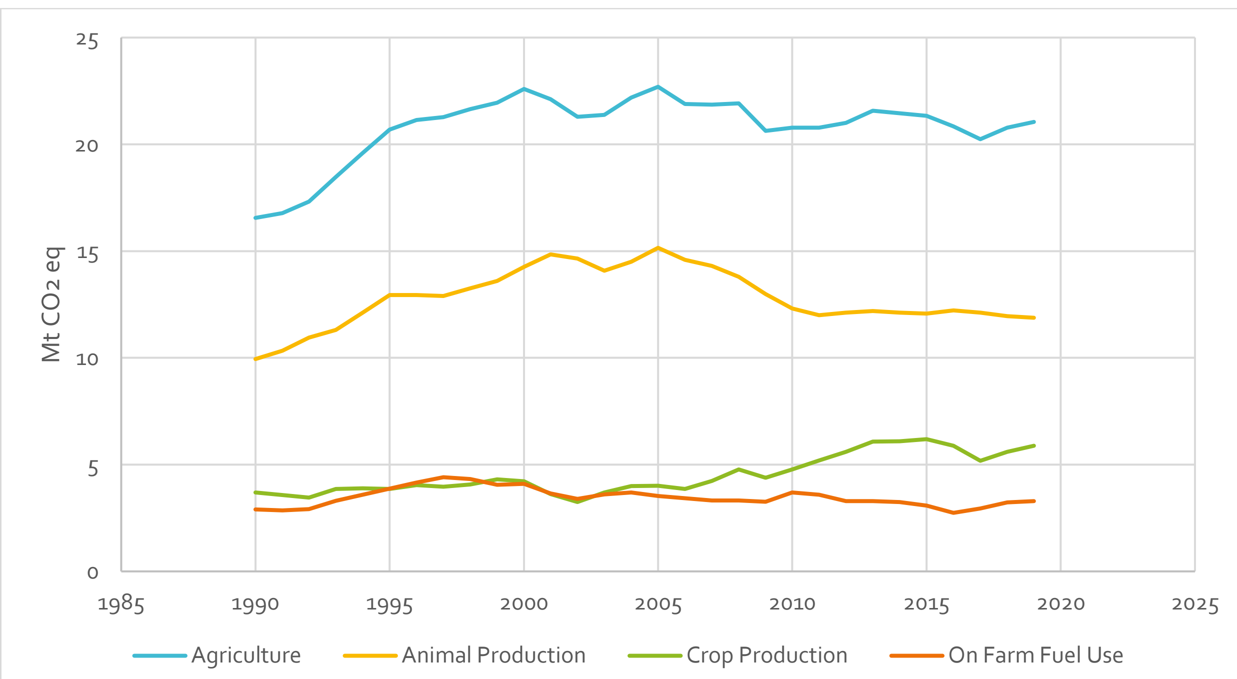
Using the IPCC categories, Alberta's emissions from *Enteric Fermentation* decreased from 12 Mt to 9.2 Mt CO_2eq, while *Manure Management* decreased by 2.4 Mt to 2 Mt CO_2eq in 2019 (ECCC, 2021e). *Agricultural Soils,* which experienced the largest total growth in emissions, increased from 4.6 Mt to 5.8 Mt CO_2eq. The remaining categories, *Field Burning of Agricultural Residues* and *Liming, Urea Application, and Other Carbon-Containing Fertilizers,* increased from 0.37 Mt to 0.76 Mt CO_2eq.

Figure 5: Albertian GHG Emissions by Economic Sector From 1990 to 2019



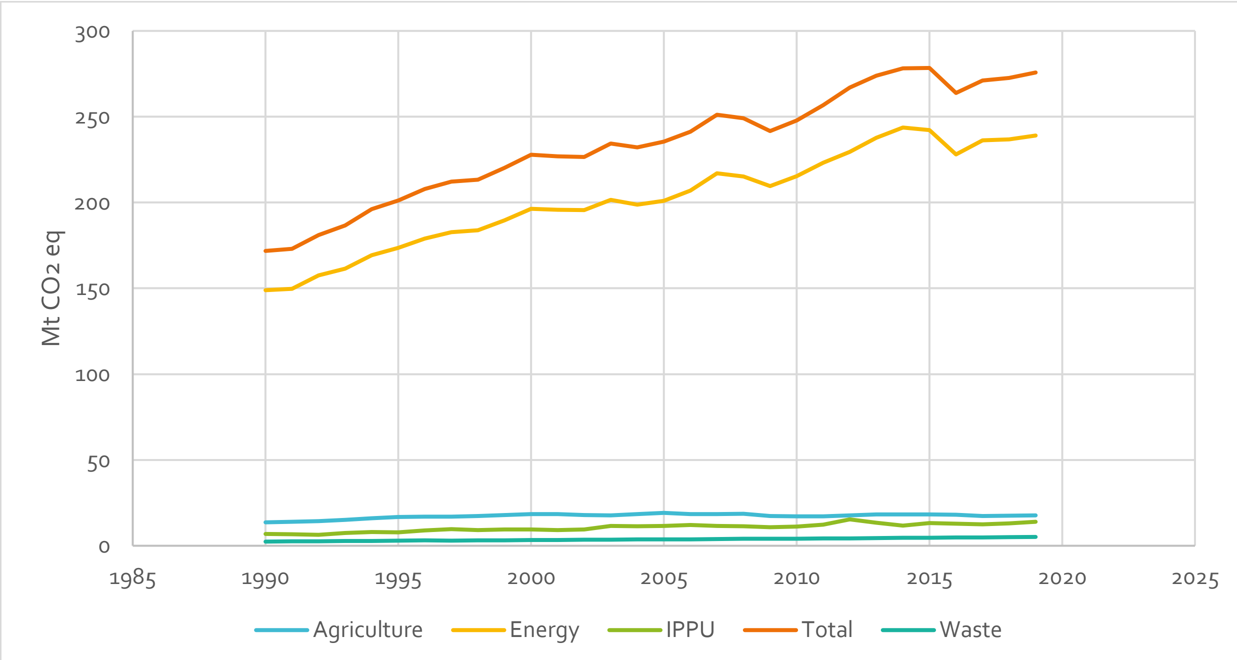
Source: Source: Environment and Climate Change Canada. (2020, April 31). Canada's Official Greenhouse Gas Inventory . Retrieved September 21, 2021, from https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b

Figure 6: Albertian Agricultural GHG Emissions by Economic Sector From 1990 to 2019



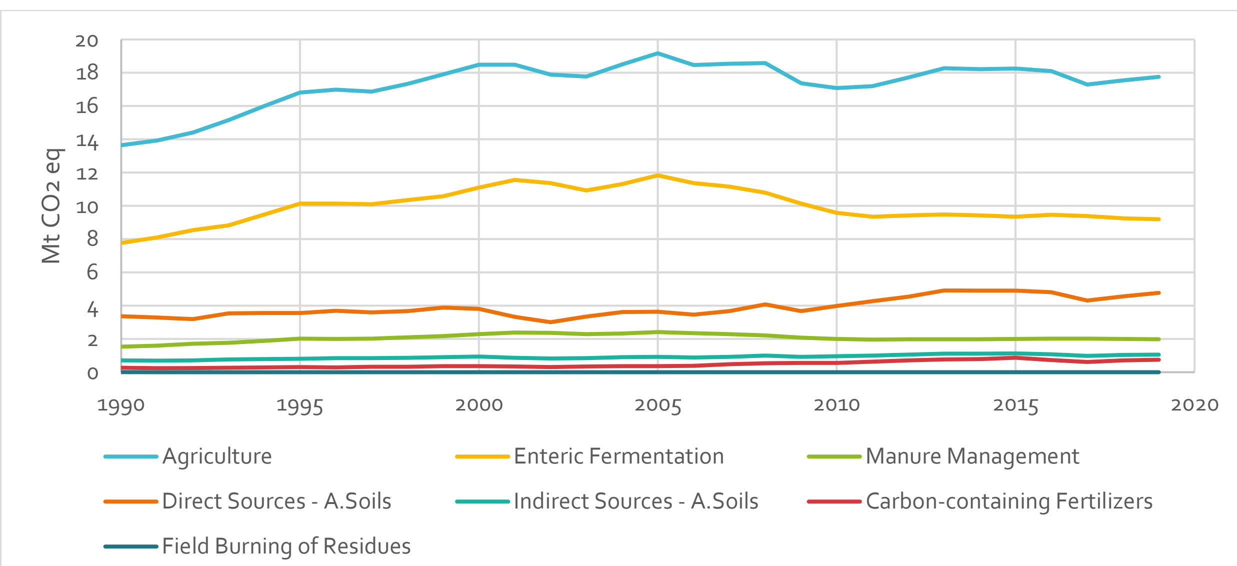
Source: Environment and Climate Change Canada. (2020, April 31). Canada's Official Greenhouse Gas Inventory . Retrieved September 21, 2021, from https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b

Figure 7: Albertian GHG Emissions by IPCC Sector From 1990 to 2019 (Excluding LULUCF)



Source: Source: Environment and Climate Change Canada. (2020, April 31). Canada's Official Greenhouse Gas Inventory . Retrieved September 21, 2021, from https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b

Figure 8: Albertian Agricultural GHG Emissions by Emission Source From 1990 to 2019

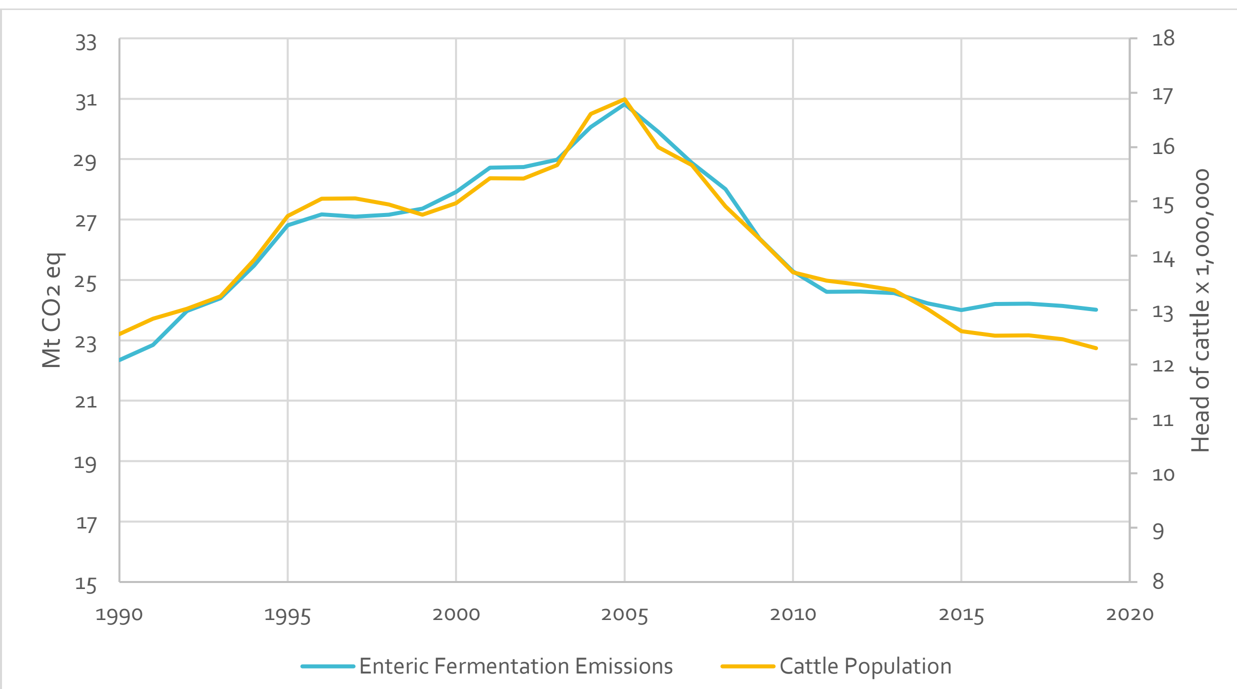


Source: Source: Environment and Climate Change Canada. (2020, April 31). Canada's Official Greenhouse Gas Inventory . Retrieved September 21, 2021, from https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b

How Emissions Are Measured - Emissions Factors

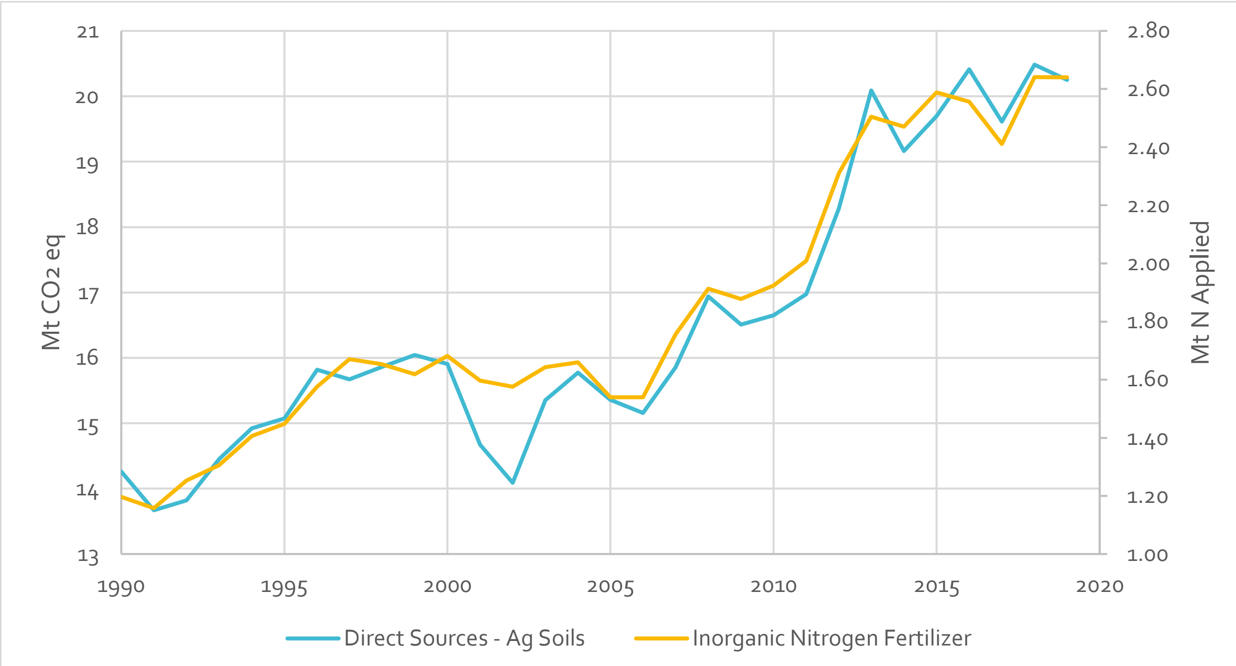
Simply put, emissions are estimated by multiplying together activity data by an emission factor, which can be interpreted as emissions per unit of activity (ECCC, 2021a). Given this structure, emissions can either be lowered by decreasing activity or decreasing the factor itself. Historically, in Canada, it appears that changing levels of emissions are driven primarily by changes in activity and not from improvements in the emission factor (see Figures 7 and 8). While reducing emissions by reducing activity data is not inherently bad, if Canada wants to maintain its role as a major exporter of agricultural goods, policies need to focus on improving the emission factor to avoid large-scale production decreases. This section examines how the emission factors are estimated and how the factors have changed over time to identify areas in which reductions may be able to occur, and improvements can be made.

Figure 9: Enteric Fermentation and Cattle Population Trends from 1990 to 2019



Source: Source: Environment and Climate Change Canada. (2020, April 31). Canada's Official Greenhouse Gas Inventory . Retrieved September 21, 2021, from https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b Environment and Climate Change Canada. (2021l, April 12). Table 3.A Sectoral Background Data for Agriculture: Enteric Fermentation. National Inventory Submissions 2021. Government of Canada. Retrieved from https://unfccc.int/sites/default/files/resource/can-2021-crf-12apr21.zip

Figure 10: Direct Soil emissions and Inorganic Nitrogen Fertilizer Use Trends from 1990-2019



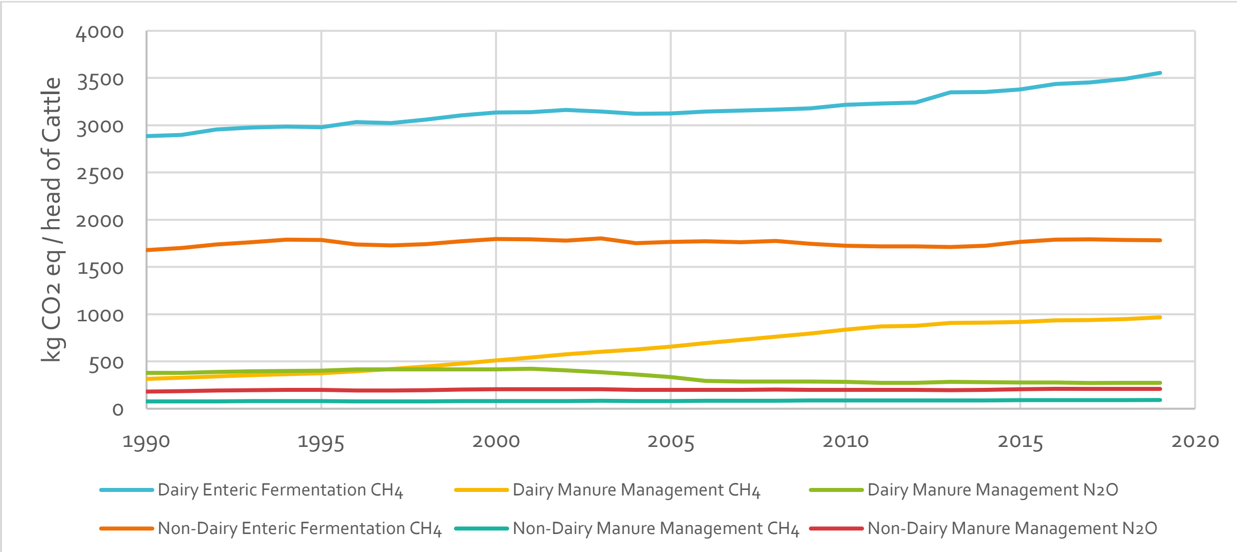
Source: Environment and Climate Change Canada. (2020, April 31). Canada's Official Greenhouse Gas Inventory . Retrieved September 21, 2021, from https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b;Environment and Climate Change Canada. (2021m, April 12). Table 3.D Sectoral Background Data for Agriculture: Direct and indirect N2O emissions from agricultural soils. National Inventory Submissions 2021: CRF Tables. Gatineau: Government of Canada. Retrieved from https://unfccc.int/sites/default/files/resource/can-2021-crf-12apr21.zip

Animal Production

Emissions from animal production, enteric fermentation and manure management comprise 54 per cent of Canada's agriculture based GHG emissions in 2019 (ECCC, 2021b). The activity data used for estimating emissions from animal production is the population of each type of livestock produced in Canada. The population data is then multiplied by the corresponding emission factor for each emission source (i.e., enteric fermentation and manure management), gas type (i.e., CH_4 and N_2O), and emission type (i.e., direct or indirect emissions) (ECCC, 2021a). For animal production, many emission factors use a tier 1 estimate, limiting the ability to reduce measurable emissions as they are set at international benchmarks. However, prominent sources of emissions, such as enteric fermentation with cattle and manure management with swine, use Tier 2 emission factors (ECCC, 2021a).

The implied emission factors (IEF) are estimated for each source and livestock category. They can be found in the Common Reporting Format tables submitted annually as part of the National Inventory Submission to the UNFCCC. The IEF can be viewed as an average emission factor and is estimated by dividing total emission for each category and source by the activity data (ECCC, 2021i). Using cattle as an example, the IEF increased from 115.47 to 142.19 kg CH_4/head/year from 1990 to 2019 for enteric fermentation emissions from dairy cattle and 67.16 to 71.36 kg CH_4/head/year for non-dairy cattle (ECCC, 2021l). Methane emissions from manure management increased from 12.63 to 38.68 kg CH_4/head/year for dairy and from 3.09 to 3.69 kg CH_4/head/year for non-dairy. Nitrous oxide (N_2O) is also emitted when manure is handled or in storage (ECCC, 2021j), and the IEF for N_2O from dairy cattle decreased from 1.27 to 0.91 kg N_2O/head/year and increased for Non-dairy cattle from 0.61 to 0.70 kg N_2O/head/year (ECCC, 2021k). By converting each estimate into CO_2eq and adding across emission sources, it is possible to estimate the average total emissions for dairy and non-dairy cattle. From 1990 to 2019, emission per head of dairy cattle increased from 3579 kg CO_2e/head/year to 4796 kg CO_2e/head/year, an increase of 34 per cent, and the total average IEF increased from 1938 to 2086 kg CO_2e/head/year, or 8 per cent, for non-dairy cattle (ECCC, 2021i).

Figure 11: Comparison of Dairy and Non-Dairy Implied Emission Factors from 1990-2019



Source: Environment and Climate Change Canada. (2021i). Common Reporting Format (CRF) Tables. National Inventory Submissions 2021. Environment and Climate Change Canada. Retrieved from https://unfccc.int/sites/default/files/resource/can-2021-crf-12apr21.zip

To understand what is driving the changes in the IEF, the methodology can provide some clarification. Starting with enteric fermentation, the emission factor for a defined population, $EF_{(EF)T}$, is a function of the GE_p, the gross energy requirement for a given production stage, the methane conversion rate for cattle in a defined stage of production (m^3/kg), and time within a stage of production, TP_p (days/year) (ECCC, 2021a).

$$EF_{(EF)T} = \sum_T \left[\frac{GE_p * Y_{mP} * 365}{55.65} * TP_p\right] \quad (1)$$

Given the Emission factor estimate for each stage of production, emission can be decreased by decreasing, GE_p, Y_{mP}, or TP_p. When estimating for the whole population, TP_p gains greater importance, as each stage of production have different GE_p and Y_{mP} values (ECCC, 2021a). Optimizing time spent in each production stage may increase emissions for some production stages and decrease for others.

The methane conversion rate variable is treated as a constant with the value of 6.5 per cent for non-feedlot cattle, 3 per cent for feedlot cattle, and between 5.4 to 5.9 per cent for dairy cattle depending on productivity class of the farm (ECCC, 2021a). The gross energy requirement variable is also estimated annually and based on population characteristics. The GE variable is estimated as a function of net energy requirements for maintenance (NE_m), activity (NE_a), lactation (NE_l), pregnancy (NE_p), and growth (NE_g), the ratios of net energy available in a diet for maintenance (REM) and growth (REG) to digestible energy consumed, and the digestibility of the rations consumed (DE%).

$$GE = \left[\frac{\left[\frac{NE_m + NE_a + NE_l + NE_p}{REM}\right] + \left[\frac{NE_g}{REG}\right]}{\left[\frac{DE\%}{100}\right]} \right] \tag{2}$$

Holding all else constant, decreases in the net energy requirement variables or increases in the ratio variables would result in estimated decreases in the gross energy requirements and subsequent decreases in the emission factor.

Equations 3 through 8 provide the equations used for estimating the variables used in the GE estimate. Net energy for maintenance is a function of the animal's live weight ($Weight$) and a coefficient relating weight to energy requirements (Cf_i) (Hatfield et al., 2006). While the Cf_i is based on outside estimates and would typically be 0.35 (ECCC, 2021a). This value needs to be adjusted to account for Canada's environment, and a cold adjusted Cf_i is estimated. The cold adjusted Cf_i examples provided within the NIR found estimates ranged between 0.43 and 0.37 depending on the province, with Manitoba having the largest value due to temperature and wintering practices (ECCC, 2021a).

$$NE_m = Cf_i(Weight)^{0.75} \tag{3}$$

The net energy required for activity is dependent on the net energy required for maintenance and a coefficient for the animals feeding situation (C_a), which can be interpreted as the amount of energy required to acquire food (Hatfield et al., 2006). The coefficient for the feeding situation uses the IPCC default values and categorizes the animals into three groups, confined to a stall, confined to pasture, and grazing large areas, with the corresponding values being 0.00, 0.17, and 0.36, respectively (Hatfield et al., 2006).

$$NE_a = C_a * NE_m \tag{4}$$

Net energy requirements for lactation are based on the quantity and fat content of the milk produced, with increases in milk and increases in fat content resulting in higher estimates of NE_l (Hatfield et al., 2006). From 1990 to 2019, milk production in dairy cows increased by 52.46 per cent, from 21.37 kg/day to 32.58 kg/day (ECCC, 2021l). These changes in milk production are likely the primary cause of increases in the enteric fermentation emission factor for dairy and the differences between cattle types.

$$NE_l = Milk\left(1.47 + (0.40 * Fat)\right) \tag{5}$$

Net energy requirements for pregnancy are estimated by multiplying the net energy required for maintenance by a factor representing the increases in energy requirements from pregnancy. The estimate uses the IPCC default value of 0.10 (Hatfield et al., 2006).

$$NE_p = C_{pregnacy} * NE_m \tag{6}$$

Net energy requirement for growth is a function of the average live body weight (BW) of the cattle type, a coefficient for each of the following groups, Female, Steer, or Bull (C), mature live body weight (MW), and the average daily weight gain (WG) (Hatfield et al., 2006).

$$NE_g = 22.02 \left[\frac{BW}{C*MW}\right]^{0.75} WG^{1.097} \tag{7}$$

The ratios REM, and REG are a function of the digestibility of the ration consumed ($DE\%$) (Hatfield et al., 2006).

$$REM = \left[1.123 - [4.092 * 10^{-3} * DE\%] + [1.126 * 10^{-5} * DE\%^2] - \left[\frac{25.4}{DE\%}\right]\right] \tag{8}$$

$$REG = \left[1.164 - [5.164 * 10^{-3} * DE\%] + [1.308 * 10^{-5} * DE\%^2] - \left[\frac{37.4}{DE\%}\right]\right] \tag{9}$$

From the methodology review, lowering emissions can be accomplished by reducing net energy requirement, increases in digestibility or rations, or decreased time in inefficient stages of production. Increases in variables like cattle weight, growth rate, activity, milk production, and wintering practices increase net energy requirements and emissions for the specific state of production. However, further research needs to be conducted to quantify the effect of the changing variables across production stages and changing emissions between sources.

While not as big a source as enteric fermentation, manure management is still a significant source of greenhouse gas emissions. Both CH_4 and N_2O are emitted during the management process and require separate estimates. Once again using cattle as an example, the emission factor for CH_4 is estimated as a function of daily volatile solids excreted (VS_t), maximum CH_4 production potential for manure (B_{0T}), a conversion factor for each animal waste management system used (AWMS) (MCF_{ij}), and the fraction of each type of AWMS used within the climate region for a defined animal population ($AWMS_{Tij}$) (ECCC, 2021a). The subscript i indicates the AWMS used and j the climate region.

$$EF_{(MM)T} = VS_T * 365 * B_{0T} * 0.67kg/m^3 * \sum_{ij} MCF_{ij} * AWMS_{TIJ} \quad (10)$$

If B_{0t} is assumed to be constant for each animal population, and based on the IPCC default values, the emission factor is dependent on the VS_T and the AWMS used. While VS_T provides the total amount of manure excreted, the MCF for each AWMS determines the emissions for the specified quantity, more precisely, it determines the share of B_{0T} emitted (ECCC, 2021a). Liquid storage systems have a higher MCF factor, ranging from 0.13 to 0.20 compared with 0.01 to 0.2 for dry storage, and thus emits more CH_4, given a similar VS_T (ECCC, 2021a). The following model is used for cattle to estimate the value of daily volatile solids excreted (equation 11).

$$VS = \left[GE * \left(1 - \frac{DE\%}{100}\right) + (UE * GE)\right] * \left(\frac{1-ASH}{18.45\ MJ}\right) \quad (11)$$

The gross energy requirement first estimated in the enteric fermentation model is carried over and used in the manure management estimate. The digestibility of the rations is also incorporated into the model. It follows a similar pattern in which an increased in $DE\%$, all else equal, lowers total volatile solids and decreases the emission factor. The model also includes urinary energy (UE) and the ash fraction of manure, i.e., the fraction of manure that is non-organic (ASH) (ECCC, 2021a). This equation can be modified to estimate VS for swine by substituting GE with dry matter intake (DMI) multiplied by 18.45.

Compared with other cattle subcategories, the emission factor for dairy is significantly higher than for non-dairy cattle (ECCC, 2021k, 2021j, 2021l). It can be observed that gross energy requirements for dairy are well above that of non-dairy cattle, given energy requirements for increased milk production, which alone would result in higher VS production (ECCC, 2021l). The average *MCF* for dairy cattle is also significantly higher than non-dairy cattle, given the difference in AWMS used (ECCC, 2021j). Dairy, for example, has 64 per cent of total manures managed in liquid storage compared to 5.3 per cent for non-dairy. A combination of higher VS production and average *MCF* has resulted in dairy cattle having an implied emission factor 9.47 times larger than non-dairy cattle (ECCC, 2021j).

N_2O emissions from manure management are comprised of both direct emissions and indirect emissions (i.e., volatilization and indirect emissions from leaching and runoff) (ECCC, 2021a). Direct N_2O emissions are estimated using equation 12; the equation can be broken into two sections. First is the activity data, estimated kg nitrogen in each type of AWMS in each province, and a corresponding emission factor for each type of AWMS (ECCC, 2021a).

$$N_2O_{(mm)} = \sum_i \sum_{AWMS}\left(N_{i,T} * N_{i,AWMS} * N_{EX,T}\right) * EF_{AWMS} * \frac{44}{28} \tag{12}$$

Within the equations $N_{i,T}$ is the provincial population of livestock category T, $N_{i,AWMS}$ is the percentage of manure help in each type of AWMS, $N_{EX,T}$ is the nitrogen excretion rate for the animal population, and EF_{AWMS} is the emission factor for each AWMS. The fraction $\frac{44}{28}$ is used to convert N_2O-N to N_2O emissions. The methodologies used for estimating $N_{EX,T}$ differs between cattle types, with dairy cattle using a Tier 2 methodology while non-dairy using a Tier 1 methodology (ECCC, 2021a); see Hatfield et al. (2006) for methodological description.

The equation used for estimation indirect N_2O emission from manure volatilization is shown in equation 13. Equation 13 follows a similar structure to that of 12. The activity data in this estimate differs as it is the amount of manure nitrogen that volatilizes as NH_3 and NO_x for each AWMS (ECCC, 2021a). The activity data is estimated with the inclusion of the $Frac_{GasMS(T,AWMS)}$ variable, the fraction of manure that volatilizes as NH_3 and NO_x for a specific AWMS and population. The emission factor for the atmospheric disposition of nitrogen, EF_4, is included within the equation and assigned a value of 0.01kg N_2O-N per kg (NH_3-N+NO_x-N volatilized).

$$N_2O_{(mm)} = \sum_i \sum_{AWMS}\left(N_{i,T} * N_{i,AWMS} * N_{EX,T} * Frac_{GasMS(T,AWMS)}\right) * EF_4 * \frac{44}{28} \quad (13)$$

The final indirect emission estimate from manure management is only applied to the dairy and the swine industry and accounts for N_2O emissions from leaching and runoff (ECCC, 2021a). Limited coverage of livestock categories is a result of limited data available. The equation used to estimate N_2O emissions from runoff and leaching again follows a similar equation of 12 and 13. The activity data estimates the total nitrogen runoff and leaching for each population and AWMS. Within equation 14, $Frac_{LeachMS(T,AWMS)}$ is the fraction of manure N losses for a given livestock population and AWMS, and the emission factor EF_5 is assigned a value of 0.0075 kg N_2O-N per (kg N leaching/runoff) (ECCC, 2021a).

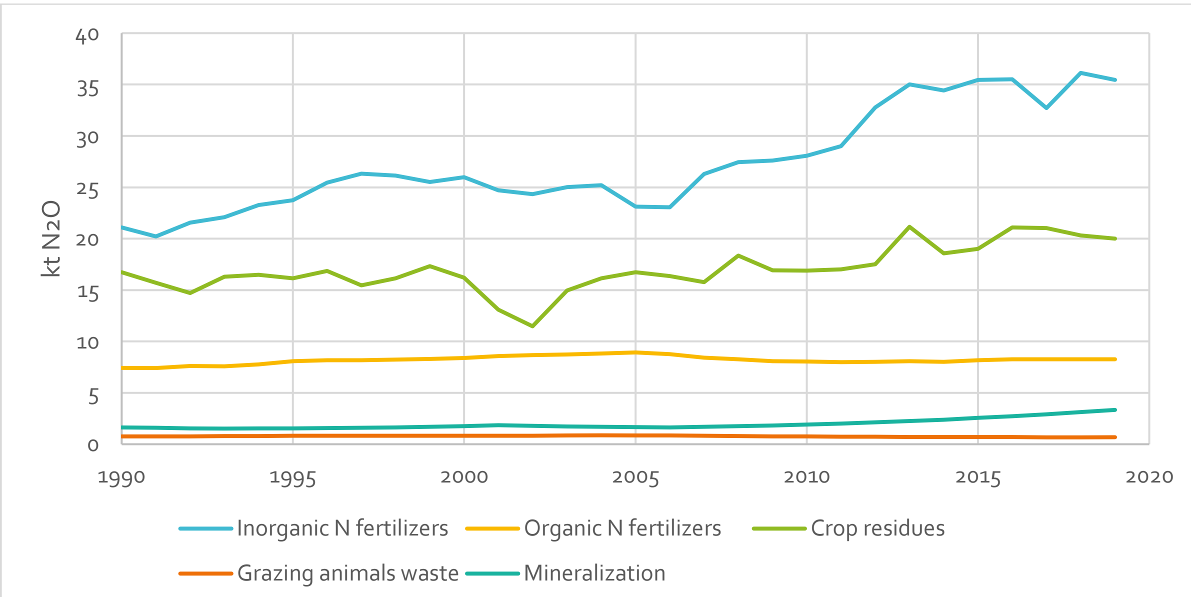
$$N_2O_{(mm)} = \sum_i \sum_{AWMS}\left(N_{i,T} * N_{i,AWMS} * N_{EX,T} * Frac_{LeachMS(T,AWMS)}\right) * EF_5 * \frac{44}{28} \quad (14)$$

The implied emission factor dairy N_2O emissions have decreased by 27.6 per cent since 1990, decreasing from 1.27 to 0.92 (ECCC, 2021k). This is likely a result of changes in the AWMS used. In 1990, liquid waste management systems accounted for 17.35 of the total AWMS systems, which has since increased to 63.78 per cent in 2019 (ECCC, 2021j). While emissions are still higher than non-dairy cattle, this is likely due to different feed, with dairy consuming more digestible feed and having larger energy requirements (ECCC, 2021l). From 1990 to 2019, the emissions gap between the two livestock categories decreased from 108 to 31 per cent (ECCC, 2021k, 2021j, 2021l). Growth in emission from non-dairy cattle appears to be primarily driven by changes in the average live weight and resulting increase in nitrogen excretion and not changes in AWMS used(ECCC, 2021l, 2021k).Given the methodology just discussed, there are many options for measurable decreases in emissions originating from animal production. Notably, decreasing the gross energy requirements for cattle may be an area where emission reduction could take place and provide flexibility to producers, given the number of variables that can be manipulated within the GE estimate. Before providing recommendations, further research needs to be conducted, as these effects have only been viewed in isolation.

Direct Soil Emissions

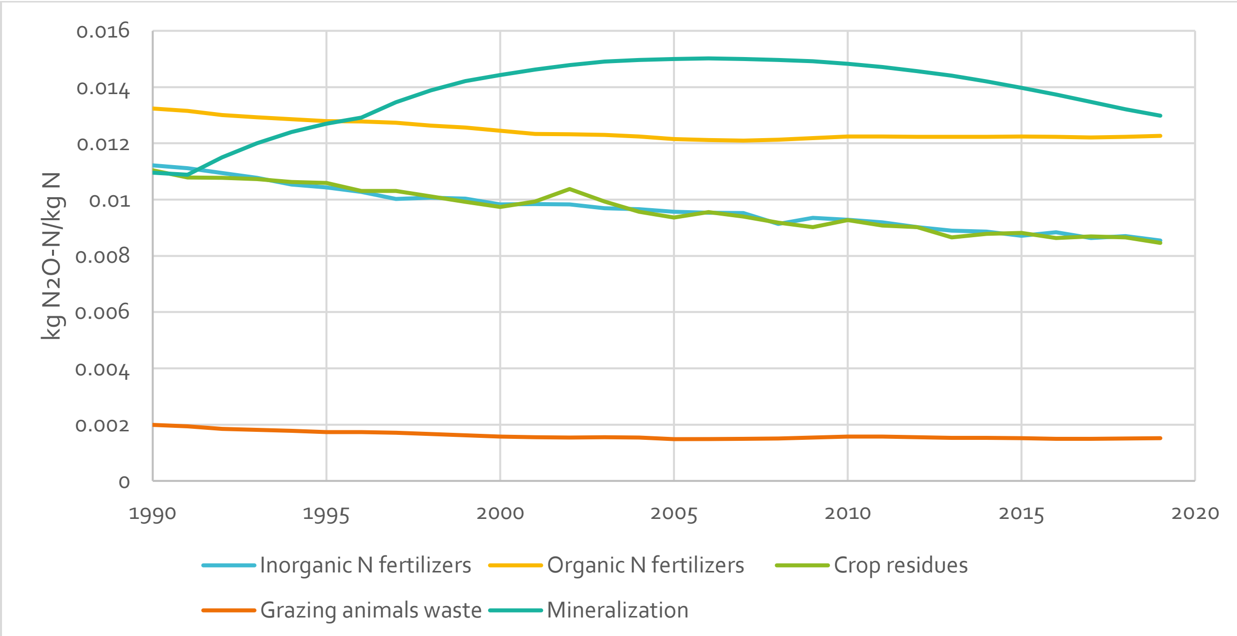
Direct soil emissions make up 34 per cent of Canada's agriculture GHG emissions in 2019 (ECCC, 2021b). Canada's only proposed emission reduction target related to agriculture is focused on "fertilizer-based" emissions. While little detail has been made available about the proposed reductions, the government's concern appears to be around the increase in inorganic nitrogen fertilizer use, which has increased by 120 per cent since 1990 resulting in an emission increase of 68 per cent from 1990 to 2019 (ECCC, 2021m). Inorganic fertilizer-based emissions have also grown as a share of direct soil emissions, increasing from 44 per cent in 1990 to 52 per cent in 2019 (ECCC, 2021m). Given the current methodology, if the emission reduction target were to be set, there would be significant pressure to reduce activity, as options to reduce the emission factors are limited.

Figure 12: Direct Source N_2O Emissions by Nitrogen Source from 1990-2019



Source: Environment and Climate Change Canada. (2021m, April 12). Table 3.D Sectoral Background Data for Agriculture: Direct and indirect N2O emissions from agricultural soils. National Inventory Submissions 2021: CRF Tables. Gatineau: Government of Canada. Retrieved from https://unfccc.int/sites/default/files/resource/can-2021-crf-12apr21.zip

Figure 13: Direct Source Implied Emission Factors from 1990-2019



Source: Environment and Climate Change Canada. (2021m, April 12). Table 3.D Sectoral Background Data for Agriculture: Direct and indirect N2O emissions from agricultural soils. National Inventory Submissions 2021: CRF Tables. Gatineau: Government of Canada. Retrieved from https://unfccc.int/sites/default/files/resource/can-2021-crf-12apr21.zip

To begin estimating direct soil emissions, a base emission factor is first estimated. The estimate is made at the eco-district level before being aggregated together for provincial and national totals (ECCC, 2021a). Eco-districts are part of Canada's ecological framework and comprise areas with similar biophysical conditions and climate; although the size of the eco-district varies depending on its characteristics, it does have a minimum size of approximately 100,000 ha (1000 km^2) (Agriculture and Agri-Food Canada, 2013). The base emission factor, EF_{BASE}, is dependent on the climate and topography present within the eco-district (ECCC, 2021a).

$$EF_{BASE} = EF_{CT,\frac{P}{PE}=1} * F_{TOPO} + EF_{CT} * (1 - F_{TOPO}) \quad (15)$$

Within equation 15, EF_{CT} is the emission factor for the eco-district given a specific $\frac{P}{PE}$ ratio. $\frac{P}{PE}$ is the ratio between long-term precipitation, P, and potential long-term evaporation, PE, from

May to October within the eco-district (ECCC, 2021a). The F_{TOPO} variable represents the fraction of the landscape where the soil is likely to be intermittently saturated, such as low-lying areas and depressions in the terrain, and these areas are assumed to have a $\frac{P}{PE}$ equal to one which has a value of 0.017 kg N_2O-N/kg N/Year (ECCC, 2021a). The EF_{CT} ranges considerably between across Canada with the lowest average measures found to be 0.0016 kg N_2O-N kg $N^{-1}yr^{-1}$ in the brown soil regions of the Canadian prairies to 0.012 kg N_2O-N kg $N^{-1}yr^{-1}$ as an average emission factor in Ontario and Quebec (ECCC, 2021a). The emission factors within the eastern provinces also have to be further modified to account for winter and spring thaw. The adjustment is made by multiplying the emission factor within those provinces by 1.4 (ECCC, 2021a).

To account for differences in climate between eco-districts, Rochette et al. (2008) fit a linear model (see equation 16) using estimated emission factors from the Canadian prairies and adjusted emission factors for Ontario and Quebec.

$$EF_{CT} = 0.022\frac{P}{PE} - 0.0048 \quad (16)$$

The activity data used to estimate direct emissions is measured in kilograms of nitrogen applied. However, given differences in nitrogen types, each source is estimated separately. Emissions estimates for organic and inorganic fertilizer, incorporated crop residual, and mineralization associated with the loss of organic matter follow a similar equation (ECCC, 2021a). Within equation 17, N_2O emissions for each nitrogen source is equal to the sum of the product of nitrogen applied within the eco-district, N_i, the eco-districts base emission factor, and the weighted average of the eco-districts soil texture, $RF_{TEXTURE,i}$, and then multiplied by 44/28 to convert N_2O-N to N_2O.

$$N_2O = \sum_i \left(N_i * EF_{Base,i} * RF_{TEXTURE,i}\right) * \frac{44}{28} \quad (17)$$

It is important to note that soil texture does not directly affect N_2O emissions; however, it is included in the equation as it correlates closely with several factors that do (ECCC, 2021a). Additionally, the variable is only applied in Eastern Canada's eco-districts, where emissions correlating with changing soil texture can be observed. Within Eastern Canada, fine soil textures are correlated with increased N_2O emissions and assigned a value of 1.2. Coarse soils correlated with decreased emissions relative to medium textures and were assigned a value of 0.8. Medium textures are assigned a value of 1, which is the same as all Western Canadian soils (ECCC, 2021a). The average soil texture for the eco-district is then estimated by multiplying the fraction of each soil texture in an eco-district its assigned value, 0.8, 1.0, or 1.2 (ECCC, 2021a).

Activity data is also required to be estimated for each nitrogen source. While a full description of the methodologies used to estimate each source can be found in annex 3.4 of the national inventory report, this section focuses only on the estimate for inorganic fertilizer application and modification from the base emission factor. The first step for estimating nitrogen application is to estimate a recommended fertilizer application rate (ECCC, 2021a). Production data within each eco-district is then multiplied by a recommended fertilizer application rate. The methodology assumes that all manure produced within an eco-district is applied to fields within that eco-district as organic fertilizer and that organic fertilizer is preferred to inorganic fertilizer. The next step is to then subtract total available nitrogen from manure from the recommended application rate to get total N fertilizer potentially applied within the eco-district, N_{APPLDi}. To better reflect actual fertilizer application practices, use within the eco-district, N_{APPLDi} is adjusted using provincial fertilizer sales data.

$$N_{Fert,i} = N_{Appld,i} * \left[\frac{N_{Sales,p}}{\sum_i^n N_{Appld,i}}\right] \quad (18)$$

Equation 18 is used to adjust the potential fertilizer application rate to the application rate used in the emission estimate for each eco-district, $N_{Fert,i}$ (ECCC, 2021a). Within the equation $N_{Sales,p}$ is the quantity on nitrogen fertilizer sold within the province and $\sum_{i}^{n} N_{Appld,i}$ is the total potential fertilizer application within the province. The model does not differentiate between types of inorganic fertilizer, like stabilized nitrogen or fertilizers with inhibitors to reduce emissions, which are accounted for at farm level and in specific quantification protocols.

Once base emissions are estimated, further steps can be taken to account for different production practices, including the adoption of no-till, irrigation, or summer fallow. For example, expanding the model to account for no-till or reduced till within the province can be seen in equation 19 (ECCC, 2021a).

$$N_2O_{Till} = \sum_i \left[\left(N_{Fert,i} + N_{Man-Crops,i} + N_{RES,i}\right) * \left(EF_{Base,i} * FRAC_{RT-NT,i} * (F_{Till} - 1)\right)\right] * \frac{44}{28}$$

(19)

Within equation 19, N_2O_{Till} is the total emissions generated from the adoption of the practice (ECCC, 2021a). $N_{Fert,i}$, $N_{Man-Crops,i}$, and $N_{RES,i}$ is the activity data for measured for added nitrogen within the eco-district and includes inorganic fertilizer, organic fertilizer, and incorporated crop residual. The base emission factor is modified by a ratio factor, which indicates the impact of no-till within the region production and the fraction of the eco-district under no-till practices. The effects of no-till on N_20 emissions vary depending on the province in which the production occurred. In Prairie Canada, F_{Till} decreases the base emission factor and has a value of 0.8, while in Eastern Canada F_{Till} has a value of 1.1 (ECCC, 2021a).

Of particular interest to Alberta, the methodology used to estimate irrigation assumes land under irrigation has a $\frac{P}{PE}$ ratio equal to 1, which results in irrigated land potentially emitting up to 10 times more N_2O than non-irrigated land in the same area (ECCC, 2021a). The model used to estimate the effects of irrigation can be found in Equation 20, where N_2O_{IRRI} is emission from irrigation and $FRAC_{IRRI,i}$ is the fraction of land within the eco-district under irrigation (ECCC, 2021a).

$$N_2O_{IRRI} = \sum_i [(N_{Fert,i} + N_{Man-Crops,i} + N_{RES,i}) * (0.017 - EF_{Base,i}) * FRAC_{IRRI,i}] * \frac{44}{28} \quad (20)$$

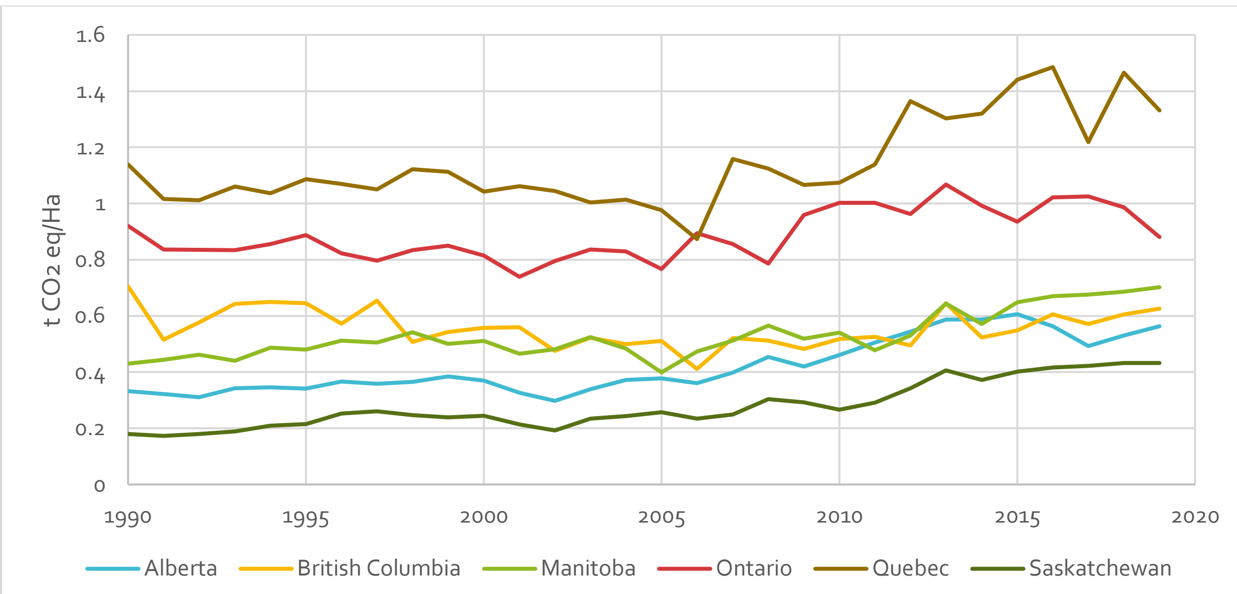
Under the IPCC methodology, dung deposited of fields contributes to emissions from agricultural soils and is accounted for separately from manure applied as organic fertilizer (ECCC, 2021a). Under the CES measurements, these emissions are reallocated from crop production to animal production (ECCC, 2021c). The model used to estimate these emissions can be found in equation 21.

$$N_2O_{PRP} = \sum_{T,i} (N_{T,i} * N_{EX,T} * N_{PTP,T} * EF_{PRP,T}) * \frac{44}{28} \quad (21)$$

Within the equation, $N_{T,i}$ is the population of livestock group T in eco-district i, $N_{EX,T}$ is the nitrogen excretion rate a specific livestock group, $N_{PTP,T}$ is the fraction of manure deposited on a pasture range or paddock, and $EF_{PRP,T}$ is the emission factor for manure within the eco-district (ECCC, 2021a). The last direct emission source for agricultural soils comes from the cultivation of organic soils. The methodology follows a Tier 1 estimate in which the area cultivated is multiplied by the default emission factor, which has a value of 8.0 kg N_2O-N/ha/year (ECCC, 2021a).

Differences in emissions intensities can be observed across provinces with per hectare emissions ranging between 0.432 t CO_2eq/Ha in Saskatchewan to 1.33 t CO2eq/Ha in Quebec (see Figure 13). Differences in these emissions can be partially attributed to differences in the $\frac{P}{PE}$ ratios between provinces. For example, average annual rain fall within the prairie provinces ranges (between 409 mm to 454 mm) is significantly lower than Ontario (684 mm), and Quebec (761 mm) (Prairie Climate Centre, 2019). Differences also arise from provincial crop mix and management practices. Alberta and Saskatchewan have the lowest emission intensities in Canada; however, there are noticeable differences between the two provinces. While the environment (Prairie Climate Centre, 2019), crop mix (Statistics Canada, n.d.-a), and production practices are similar (Statistics Canada, 2018a, 2018b), Alberta does have significantly more land under irrigation, with 472,549 ha compared with 56,116 ha in Saskatchewan(Statistics Canada, 2018b). Given the methodology and fraction of land under irrigation, this leads to higher emissions on a per hectare basis.

Figure 14: Average Emissions from Crop Production per Hectare of Crop Land



Source: Statistics Canada. (n.d.-a). Table 32-10-0359-01 Estimated areas, yield, production, average farm price and total farm value of principal field crops, in metric and imperial units. doi: https://doi.org/10.25318/3210035901-eng;

While the current methodology is effective at estimating emissions over large areas, the use of the methodology to identify and develop policy options to reduce soil-based emissions is limited. This limitation is caused by the limited number of variables affected by production decisions, while many emission factor variables are outside of the farmer's control; for example both variables used in the estimation of the base emission factor, $\frac{P}{PE}$, and F_{TOPO}, are outside the control of the farmer. With the current methodology, production decisions do affect the quantity of fertilizer, but the type of fertilizer use does not have a specific emission factor. Some farm level emission estimates, such of in the case of 4R nitrogen stewardship quantification protocol used in Alberta's TIER program, provides carbon offset credits if specific types of nitrogen fertilizer are used when accompanied with additional soil testing (Government of Alberta, 2015).

Options to reduce emissions will likely have to focus on reducing activity given the methodology noted here. There could be a shift to crop with lower nitrogen requirements, however this shift would be difficult within the western provinces as the average crop mix within Alberta, Saskatchewan, and Manitoba already has relatively low average nitrogen requirements when compared with other regions. An effective but somewhat unrealistic option to reduce agricultural soil emissions could be to move production from the Maritimes, Quebec, and Ontario to the Western Provinces given the significant differences in the emission factors for the regions.

Promoting the adoption of reduced till or no-till practices will also have limited effects in western provinces, particularly in Alberta, as the adoption rate is already high at 88.41 per cent (Statistics Canada, n.d.-b); at 100 per cent adoption N_2O emissions will only decrease by 2.3 per cent given emission factors. Within Eastern Canada, the adoption of no-till has a direct negative effect on N_2O emissions but will likely increase soil texture over time (Castellini et al., 2019); the corresponding net effect on emissions will be dependent of the rate of soil texture change and frequency of updating the $RF_{TEXTURE,i}$ variable.

Irrigation practices provide an interesting opportunity to reduce emissions; however, emissions have to be estimated at the farm level to do so. All irrigated land is currently assigned a $\frac{P}{PE}$ ratio of 1, yet if farm level estimates were considered an adjusted ratio could be estimated in which water usage is added to the precipitation value. This methodology could then be further developed to incentivize water conservation and emission reductions. A potential issue with the current methodology around irrigation is that it may be inflating the emission values within the region. If irrigation is applied to low lying ground, the effect of irrigation would be zero as both $\frac{P}{PE}$ values are equal to 1. However, by estimating emissions using $F_{TOPO,i}$ and $FRAC_{IRRI,i}$, identifying areas in which both occur can not be accounted for.

If a 30 per cent emission reduction target is to be implemented, ensuring that reduction efforts are quantified in national emission estimates is essential. Improving scale from eco-district to farm level emissions may be an option given the improvements in resolution of publicly available remote sensing data. Additionally, tying production practices directly to the field may improve emissions estimates. Finally, the use of current weather data instead of long run averages for estimating the $\frac{P}{PE}$ may increase the accuracy of estimates as it would better account for changing weather patterns. Through the development of better methodology and ensuring the proper quantification of the emission estimates, it may be possible to make meaningful emission reductions without large production decreases, which would be a likely case if current methodologies are used.

Conclusion

For Canada to achieve its NDC commitments by 2030, it will need to reduce emissions by 287 Mt of CO_2 eq from 2019 levels (ECCC, 2021b). Given this challenge, it is almost certain that there will be significant pressure to reduce emissions within the agricultural sector. While the fastest way to reduce emissions would likely be to reduce activity (i.e., decrease nitrogen fertilizer use or head of cattle), these policies would probably come under substantial opposition as they would decrease production, at least in the short term. By focusing on emission factors, it may be possible to identify areas where emissions can be reduced while maintaining or expanding current production levels and maintaining Canada's role as a major agricultural exporter.

This report sought to answer three questions. How do agricultural emissions relate to current climate plans, how have agricultural emissions changed over time, and how are agricultural emissions measured?

Since the signing of the Paris Agreement in 2015, Canada has introduced both the PCF and the SCP. Within these plans, mitigation efforts in agriculture have primarily focused on investment in technology and nature-based climate solutions (ECCC, 2016, 2020a). The SCP proposed an emission reduction target for fertilizer-based emissions; however, that target lacks details on how it will be accomplished, or what fertilizer-based emissions include (ECCC, 2020a).

Even with minimal involvement from the federal government, agricultural emissions have remained relatively constant since 2005, increasing or decreasing by 1 Mt CO_2eq depending on the measures used (ECCC, 2021b, 2021c). Emission changes in agricultural subcategories have primarily been driven by changes in activity data, and not improvements in the emission factors themselves. At the national level, emissions from animal production have decreased by 18 per cent to 36 Mt CO_2eq since 2005 (ECCC, 2021b). Emissions from crop production have experienced significant growth since 2005, increasing by 50 per cent to 24 Mt CO_2eq (ECCC, 2021b), primarily driven by increases in inorganic nitrogen fertilizer use within the prairie provinces (ECCC, 2021m). Changes in national agricultural emissions since 2005 have been closely reflected in Alberta's agriculture-based emissions (ECCC, 2021d). Since 2005, Alberta's emissions have decreased by 1.7 Mt to 21 Mt CO_2eq. Within this figure, emissions from animal production decreased by 21.7 per cent to 11.9 Mt, while emissions from crop production increased from 4.0 Mt to 5.9 Mt CO_2eq.

Emission estimates follow a fairly straight forward approach in which activity data is multiplied by an emissions factor. The emission factor can either be based on an international benchmark, or can be specific to the province, region, or eco-district (ECCC, 2021a). While based on an international standard, improvements to the methodology with the aim of moving the estimates from regional to farm/field level and better accounting for the producers' production decisions should be made. These improvements should improve the accuracy and precision of the estimates and better enable the quantification of the producers' decisions.

As the carbon program continues forward, this report recommends two areas of further research to be undertaken before moving into the policy development stage of the program. First, the report recommends conducting a systematic quantitative literature review of emission reduction strategies for animal and crop production to better understand the effects of changing practices on emission levels. Second, the report proposes developing a field level methodology following the IPCC guidelines that can be scaled to the eco-district, provincial and national levels. By taking these steps we can better ensure that the policies proposed in the final stage of the Carbon Program are appropriate to the producer, applicable in the situation, and most importantly quantifiable.

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