THE UNIVERSITY OF BRITISH COLUMBIA

Opportunity Assessment of British Columbia's Agricultural Greenhouse Gas Reductions and Carbon Sinks

Report 1: BC Agriculture GHG Emission Profile Analysis

Opportunity Assessment of British Columbia's Agricultural Greenhouse Gas Reductions and Carbon Sinks

This report summarizes the findings of three separately published detailed reports:

- Report 1: BC Agriculture GHG Emission Profile Analysis
- Report 2: Multi-Criteria Framework for GHG Emissions and Co-benefits
- Report 3: Agroecosystem Models for GHG Emissions and Co-benefits

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UBC Sustainable Agricultural Landscapes Lab

The Sustainable Agricultural Landscapes Lab contributes to understanding the ecology of and management for an agricultural system that meets current needs without compromising the needs of future generations. A major focus is to evaluate the multiple environmental impacts and ecological interactions for various management options, and to provide a better understanding across a diversity of agroecosystems and social and economic contexts.

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Disclaimer

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Cover photograph

A manual chamber for measuring soil greenhouse gas emissions set up in a corn field in Delta, B.C.
Photo credit: Paula Porto, UBC Sustainable Agricultural Landscapes Lab.

Executive Summary

This is the first of three reports prepared by the Sustainable Agricultural Landscapes laboratory at the University of British Columbia as part of the project *Opportunity Assessment of Agricultural GHG Reductions and Carbon Sinks*. The overarching objective of this report is to summarize the emission profile of the BC agricultural sector, identifying key sources of greenhouse gas (GHG) emissions and carbon sinks. This work is intended to support the development of agricultural beneficial management practices (BMPs) that can help meet GHG reduction targets. The specific objectives of this report are to:

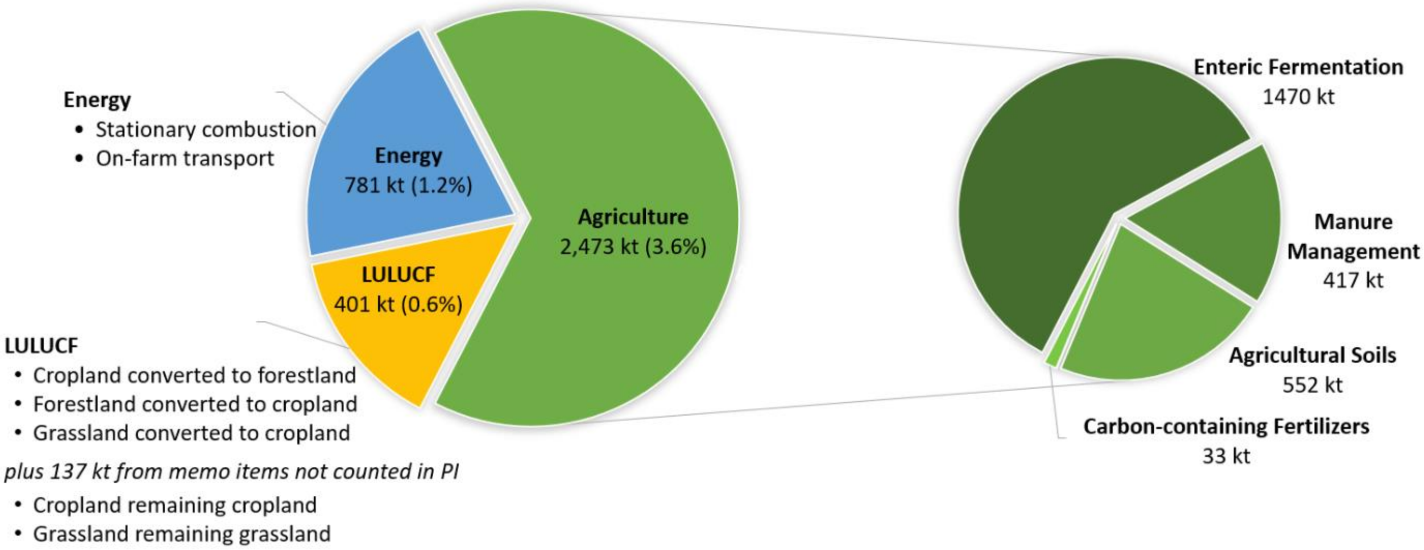
- provide a background on international, national, and provincial emission reporting
- compile available inventory, activity, and emission factor data from ECCC sources
- analyze BC's agricultural GHG profile at the disaggregated subsector level
- evaluate uncertainty in emission data by aggregated categories
- compare emission data and methodologies from different data sources

The BC Ministry of Environment and Climate Change Strategy – Climate Action Secretariat has prepared and published an annual Provincial Inventory (PI) reporting provincial GHG emissions since 2009. The BC PI is based on GHG emission data for BC from Canada's National Inventory Report (NIR), which is generated by Environment and Climate Change Canada (ECCC) and submitted each year to the United Nations Framework Convention on Climate Change (UNFCCC). The NIR and BC PI report emission estimates in a common reporting format (CRF) for five sectors: (1) Energy, (2) Industrial Processes and Product Use (IPPU), (3) Agriculture, (4) Land Use, Land-Use Change, and Forestry (LULUCF), and (5) Waste. Within the 'Agriculture' sector, emissions are reported from five aggregated emission categories. In addition to reporting by CRF sector, the NIR and BC PI also report agricultural emission estimates by economic sector, which effectively include emissions reported in the 'Agriculture' sector, plus on-farm fuel use counted in the 'Energy' and 'IPPU' sectors.

However, both of these approaches report emissions at an aggregated level, whereby agricultural sub-sectors are grouped to sum net emissions. This makes it challenging to identify the largest emission sources and sinks at a resolution that is useful for effective policy and program development aimed at agricultural emission reductions. Additionally, current reporting approaches do not count changes in agricultural practices that could potentially sequester large amounts of carbon dioxide (CO2) in agricultural soils and woody vegetation. We worked with

ECCC to compile disaggregated emission data associated with agricultural activities in BC. Our assessments included over 80 disaggregated emission subcategories (data line items), compared to the 12 aggregated data line items reporting emissions related to agricultural activities in BC.

The percent contribution of agricultural emissions from each CRF sector to BC's total emissions in 2018 are shown in the figure below. Using the disaggregated data, we analyzed BC's agricultural GHG emission profile by subcategory, and evaluated uncertainty. In collaboration with ECCC, we assessed the methods used to develop these emission estimates for Canada's NIR and which are reported in BC's PI. Finally, we made preliminary comparisons of emission data and methodologies from different sources.



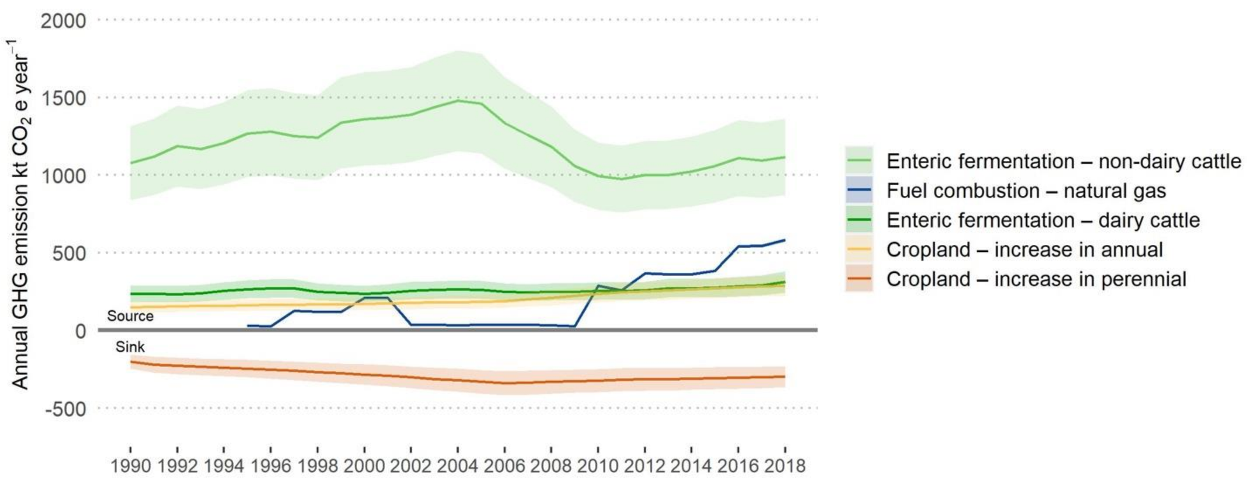
Combining agricultural emissions from the 'Agriculture', 'Energy', 'Industrial Processes and Product Use' (IPPU), and 'Land-Use, Land-use Change, and Forestry' (LULUCF) sectors results in a total of 3,655 kt CO2e or 5.4% counted in BC's 67,924 kt CO2e emissions in 2018. An additional 137 kt CO2e from cropland and grassland management are reported in the provincial inventory as memo items but not counted in the provincial total.

Following international reporting methodology for "level" and "trend" assessments, we ranked disaggregated source and sink subcategories by how strongly they contributed to total agricultural emissions, or by the extent to which their historical trend differed from the total trend. We also performed a simple percent change analysis. We presented these results based on consideration of agricultural emissions from one, three, or all four CRF sectors.

Level assessment

When the analysis is performed with only emissions from the 'Agriculture' sector, five subcategories produce 77% of total emissions. The first and second largest subcategories are enteric fermentation from non-dairy cattle and dairy cattle, respectively, which together comprise 58% of total emissions from 'Agriculture'. The next three top contributing subcategories are i) manure management: solid storage and drylot, ii) synthetic fertilizers, and iii) organic fertilizers, together comprising 19% of the total.

When agricultural emissions across the 'Agriculture', 'Energy', 'IPPU', and 'LULUCF' sectors are included, five subcategories produce 54.5% of agricultural emissions. The two subcategories of enteric fermentation (non-dairy cattle and dairy cattle) remain in the top three, but the natural gas stationary fuel combustion subcategory from 'Energy' (e.g., for heating greenhouses) contributes 12.2% as the second-largest emission source overall. The next two subcategories are in the 'LULUCF' sector and are due to changes in crop type: either to perennial or to annual production. To illustrate the level of confidence in the distribution of emissions over time, we applied the uncertainty associated with emission estimates from the 2018 NIR calculations. The figure below shows emissions subcategories with associated uncertainty for the top five key subcategories. Notably, following these are three subcategories (comprising 13.6% together) related to emissions from deforestation attributed to agriculture.



GHG emissions in the top five key subcategories from the Agriculture, Energy and Land-Use, Land-use Change, and Forestry (LULUCF) sectors. Shaded areas indicate the relative uncertainty calculated from 2018 and propagated for all years.

Percent change assessment

We assessed the long- and short-term changes in emissions. In the most recent 3-year span between 2015 and 2018, all aggregated categories increased emissions, and overall, between 2007 and 2018, BC's agricultural emissions changed by +17.0%. Specifically, from 2015 to 2018, agricultural 'Energy' emissions (from on-farm fuel use) increased by 10.4%, enteric fermentation (all subcategories) emissions increased by 6.9%, and emissions from agricultural soils increased by 12.7%.

Recommendations

Given the unique and diverse agricultural production types, soils, and climates in BC, we identified data and method updates that could lead to more accurate emission estimates for BC (26 in total). Some key management options or production types that are important in BC are not reflected in the inventory, such as cover crops, aquaculture, or in many subcategories, perennial fruit production. It is clear that developing better BC-specific emission factors and activity data with higher spatial resolution would help improve the accuracy of emissions. Based on these identified areas for future work we provide two major recommendations:

1. Develop a "bottom-up" GHG emissions accounting approach

Given that provincial and national emission reporting is based largely on activity data acquired through a "top-down" national census, an alternative approach would be necessary to develop a robust incentive and reporting system that is adaptable to local data as it becomes available. A "bottom-up" inventory would not only allow for a greater understanding of major emission sources and sinks, it is also required to accurately account for changes in emissions when a BMP is implemented. To count many of the potential agricultural BMPs in emission reduction strategies, a system for tracking their activity data and quantification of their emission reductions needs to be developed in alignment with international reporting requirements. Options for collecting these data, for example through the Environmental Farm Plan or the Agricultural Land Use Inventory (ALUI), need to be investigated, developed, and tested.

2. Improve the resolution and incorporation of spatially-explicit data

Given the diversity of soil types, climates, and production systems in BC, and the strong influence these factors play in GHG emissions, incorporating improved spatially-explicit data into accounting efforts is important for increasing accuracy and enabling certain BMPs to be included in provincial estimates. The resolution of the current national-level estimates based on Landsat satellite imagery is too low to effectively detect many fine feature changes in the landscape that have been shown to have sizable impacts on the emissions profile, such as afforestation and deforestation on agricultural lands. ALUI data collection could be expanded and improved to incorporate higher-resolution imagery to address this need. More extensive ALUI data would not only improve emissions related to land use land cover change but also improve the quantification of soil carbon emissions and sinks. To effectively account for changes in soil carbon, developing a baseline of the current status of provincial soils is essential. Accurate soil carbon maps, and higher resolution land use, and land use/land cover change data could also be used to prioritize regions across the province for BMP investment that will maximize GHG benefits.

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AAFC	Agriculture and Agri-Food Canada
ALUI	Agricultural Land Use Inventory
BC	British Columbia
BMP	Beneficial management practice
CAS	British Columbia Ministry of Environment and Climate Change Strategy – Climate Action Secretariat
COA	Census of Agriculture
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalents
CH4	Methane
CRF	Common reporting format
ECCC	Environment and Climate Change Canada
ECCS	British Columbia Ministry of Environment and Climate Change Strategy
ecodistrict	A geographical unit used for land-based emissions calculations
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land use, land-use change, and forestry
AFF	British Columbia Ministry of Agriculture, Food, and Fisheries
AFF-CAT	British Columbia Ministry of Agriculture, Food, and Fisheries – Climate Action Team
N	Nitrogen
NI	National GHG Inventory
NIR	National Inventory Report
N2O	Nitrous oxide
PI	Provincial Inventory
PIR	Provincial Inventory Report
PRP	Pasture range and paddock
UBC	University of British Columbia
SLC	Soil Landscapes of Canada
SOC	Soil organic carbon
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

Effective GHG mitigation planning for BC agriculture largely depends on an accurate understanding of emission sources and sinks in the province and how they have changed over time. This requires not only a comprehensive, disaggregated emissions dataset for BC agriculture, but also accurate and appropriate methods to collect and develop these estimates. Accuracy in GHG emissions data depends on a) the quality of emission factors of agricultural activities and b) the quality of data on agricultural activities. Work is needed to compare emissions data and methodology across data sources and over time to identify discrepancies and uncertainty in GHG emission profiles at the provincial scale. This entails a thorough analysis of the provincial components of the National GHG Inventory (NI) that uses Intergovernmental Panel on Climate Change (IPCC) standards to meet United Nations Framework Convention on Climate Change (UNFCCC) agreements. This will provide a clearer understanding of next steps to improve coverage and accuracy in GHG emissions data for BC agriculture. A provincial disaggregated dataset also enables the identification of key agricultural subsectors and helps in the development of beneficial management practices (BMPs) that would be the most effective at providing GHG benefits (either emission reductions or carbon sinks).

In previous work, AFF conducted a review of the methods used for emission estimates related to agriculture in BC for the 2006 National Inventory (NI) (published May 2008). This work was undertaken in 2008 when there was not yet a Provincial Inventory (PI) in BC. This review focused on four emissions categories, which included three emissions categories attributed to the 'Agriculture' sector in the 2006 NI: 1. Agricultural soils, 2. Manure management, and 3. Enteric fermentation, and an emissions category attributed to Land Use Land-Use Change and Forestry (LULUCF): 4. Deforestation attributable to agriculture (i.e., forestland converted to cropland).

In the 2008 review, methodology and data gaps were identified (Forbes and Droppo 2008, Rogstrand 2008, Schmidt 2008, Zabek et al. 2008) and reported to the Greenhouse Gas Division of Environment Canada as areas for improvements for NI estimates for BC agriculture. At the initiation of the analysis described in this report, the AFF Climate Action Team (AFF-CAT) indicated that it is unclear as to which of these recommendations have / have not been addressed and incorporated into current versions of the NI. We have worked with Environment and Climate Change Canada (ECCC) to determine the status of the primary recommendations relevant to the

'Agriculture' sector categories presented in the work from 2008. These are included (with an indication of their status) in **Section 5. Areas for improvement of inventory data.**

More recently, AFF performed a literature review (Hall 2017) to better understand GHG inventory methodologies used to report emissions for the agricultural sector in the NI, and to develop a methodology to measure and report GHG reductions in the agricultural sector in BC. The overall goal of the project was to allow AFF to report emission reductions from efforts focused on the implementation of BMPs for enhanced nutrient management, specifically focusing on nitrogen (N). An outcome of this project was an Excel-based tool which can calculate emission reductions (kg N2O year-1, reported as kg CO2e year-1) per unit of N fertilizer (kg N year-1) reduction, using data collected through the BC EFP BMP program. AFF, however, has recognized that enhanced nutrient management to reduce N fertilizer applications and, subsequently, N2O emissions, represents only a small portion of emissions reduction potential related to the agricultural sector in BC.

Building on this, further work was completed by AFF to assess BMPs supported through the Environmental Farm Plan (EFP) program for multiple criteria, including GHG emission reductions (Powell 2018). In this assessment, criteria for BMP evaluation included climate change mitigation, adaptation, and environmental co-benefits: biodiversity, erosion, air quality, integrated pest management, nutrient management planning, riparian, and water quality. This project provided a general guide to which BMPs are most suitable for being implemented or implemented with some modifications, but the guide has limited potential for helping decision-makers identify BMPs that meet provincial-level goals, such as meeting GHG reduction targets. Additionally, outcomes were exclusively qualitative, which makes assessing differences and benefits among options challenging.

Overall, no project thus far has undertaken the formative task of establishing a comprehensive emission profile for agriculture in BC or developed a detailed assessment of the approach for establishing emission profiles for BC's agricultural subcategories.

1.1. Report objectives and approach

This is the first of three reports prepared by the Sustainable Agricultural Landscapes laboratory at the University of British Columbia as part of the project *Opportunity Assessment of Agricultural Greenhouse Gas Reductions and Carbon Sinks*. The overarching objective of this report was to summarize the emissions profile of the BC agricultural sector, identifying key sources of GHG emissions and sinks. This work was intended to support the long-term project development of strategic BMP programming to meet GHG reduction targets. The specific objectives of this work were to:

- Provide a general background on international and provincial emissions reporting
- Compile available inventory, activity and emission factor data from ECCC sources
- Analyze GHG profiles by subsector
- Evaluate uncertainty in emission data by subsector and activity
- Compare emission data and methodologies from different data sources

Building on this work, we explain how data from this report has informed the assessment of BMPs for GHG reductions in the province in our report, *Multi-criteria Framework for GHG Emissions and Co-benefits*, and can be incorporated into province-wide modelling in our report, *Agroecosystem Models for GHG Emissions and Co-benefits*.

2. GHG emissions reporting

2.1 International reporting requirements

UNFCCC is an international treaty that was adopted in 1992 and came into effect in 1994 (United Nations Framework Convention on Climate Change n.d.). It is the parent treaty of both the 1997 Kyoto Protocol and the 2015 Paris Agreement. The overall goal of all agreements under the UNFCCC is to prevent anthropogenic impacts on the global climate. UNFCCC's reporting guidelines require that Parties submit an annual inventory (by April 15) of all anthropogenic GHG emissions (sources and removals) for all years from the base year to two years before the inventory is submitted. This is referred to as the National Inventory (NI) and is prepared by each country. The NI contains two parts:

1. Common reporting format (CRF) tables – standardized, quantitative data tables
2. National Inventory Report (NIR) – a transparent and detailed description of inventory methodologies. Specifically, this report outlines references, sources of information, data sources, institutional arrangements for how the inventory is prepared (i.e., quality control procedures), and a description of any recalculations or changes from the previous inventory.

The UNFCCC's reporting guidelines require GHG emission estimates to be reported using five sectors: (1) Energy, (2) Industrial Processes and Product Use (IPPU), (3) Agriculture, (4) LULUCF, and (5) Waste (UNFCCC, 2014). These are referred to as 'CRF sectors'. The 'Agriculture' sector (CRF Sector 3) accounts for GHG emissions from the production of crops and livestock but does not include emissions from on-farm energy use, on-farm use of lube oil and grease, or CO2 emissions and removals from agricultural lands; these emissions are instead reported in 'Energy' (CRF Sector 1), 'IPPU' (CRF Sector 2), and 'LULUCF' (CRF Sector 4), respectively.

Beyond this, the UNFCCC's reporting guidelines provide only a high-level structure for reporting emissions (UNFCCC, 2014). This includes an overview followed by descriptions of the category, methodological issues, uncertainties and time-series consistency category-specific quality assurance and quality control (QA/QC), and verification, and if applicable category-specific recalculations. Within this high-level structure provided by the UNFCCC reporting guidelines, national GHG inventories are then developed and reported according to methodologies outlined by IPCC.

The IPCC is the United Nations international body for reviewing climate change science and is composed of three Working Groups and a Task Force on National Greenhouse Gas Inventories. This Task Force develops the methodologies for estimating and reporting national-level GHG emissions and removals (Intergovernmental Panel on Climate Change [IPCC] n.d.). The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019) are the most recent IPCC guidelines.

2.2 Canada's national GHG inventory

Nationally, Environment and Climate Change Canada (ECCC) is responsible for preparing and submitting the NI each year to UNFCCC. The NI consists of CRF data tables and the NIR; sections of the NIR that are relevant to the 'Agriculture' sector (Sector 3) are summarized in **Table 1**. ECCC uses the five IPCC sectors (as listed previously) in the NIR for Canada and has also adopted the suggested aggregation level of analysis for the 'Agriculture' sector as outlined by IPCC (2006) these categories are summarized in **Table 2**. Our report is based on the most recent NIR at the time of our project, which was published in April 2020 and reports emissions for the period 1990 – 2018 and was compiled using the 2006 IPCC Guidelines (Environment and Climate Change Canada [ECCC] 2020a).

Table 1. *NIR report sections relevant to the 'Agriculture' sector (IPCC Sector 3).*

NIR Report	Section	Section Description	Relevance to the Agriculture Sector
Part 1	Chapter 5	*Agriculture (CRF Sector 3)*	For each category: category description, methodological issues, uncertainties and time-series consistency, quality assurance and quality control (QA/QC) and verification, recalculations, and planned improvements
Part 2	Annex 1	*Key Categories*	List of IPCC categories and the inventory categories included in them (Table A1-1)
	Annex 2	*Uncertainty*	Summary of uncertainty estimates by inventory category (Table A2-1)
	Annex 3.4	*Methodology for the Agriculture Sector*	Description of methodologies and data sources by category and subcategory
	Annex 6.4	*Agriculture*	Compilation of emission factors used in calculations for the 'Agriculture' sector (Tables A6.4-1 to Table A6.4-29)
Part 3	n/a	n/a	Summary tables of GHG emissions at the national level and by province, sector, and gas. Aggregated category descriptions across all sectors in Table A9-1.

Table 2. *IPCC proposed categories and corresponding categories used in Canada's National Inventory (NI).*

IPCC Proposed Level of Aggregation (Vol. 1 Ch. 4 IPCC 2006)	**2020 NI Category Title** (ECCC 2020b)
Enteric Fermentation (CH_4)	Enteric Fermentation
Manure Management (CH_4, N_2O)	Manure Management – CH_4
	Manure Management – N_2O
Indirect N_2O Emissions from Manure Management	Manure Management – Indirect N_2O
Direct N_2O Emissions from Managed Soils	Agricultural Soils – Direct N_2O
Indirect N_2O Emissions from Managed Soils	Agricultural Soils – Indirect N_2O
Biomass Burning	Field Burning of Agricultural Residues
Liming	Liming, Urea Application, and Other Carbon-Containing Fertilizers
Urea Application	

Importantly, in addition to reporting emissions by IPCC sectors outlined by UNFCCC, Canada's NI also reports emissions by economic sector. Economic sectors are defined by ECCC, and reporting emissions by economic sector allows for an evaluation of emission profiles that is more useful for high-level policy decisions (ECCC 2020a). In Canada's 2020 NI, the economic agricultural sector includes all emissions in the IPCC 'Agriculture' sector, plus on-farm fuel use. On-farm fuel use includes emissions from on-farm transportation and stationary combustion (Energy, IPCC Sector 1) and on-farm use of lube oils and greases (IPPU) (IPCC Sector 4). Notably, on-farm fuel use does not include on-farm electricity consumption. Electricity consumption is allocated to the power generation plants because all emissions are allocated to their source (Frank Neitzert, personal communication, January 29, 2021).

2.3 BC's provincial GHG inventory

The BC Ministry of Environment and Climate Change Strategy – Climate Action Secretariat (ECCS – CAS) has prepared and published an annual Provincial Inventory (PI) since 2009 with the same two-year data delay as the NI. The most recent report at the time of this project was published in April 2020 and reports 1990-2018 emissions data. The PI consists of three parts: (1) PI data tables (British Columbia Ministry of Environment and Climate Change Strategy [ECCS] 2020a), (2) methodology book (ECCS 2020b), and (3) method changes and exceptions table (ECCS 2020c). A Provincial Inventory Report (PIR) is no longer developed but was published in the years 2009, 2010, 2012, and 2014 (Government of British Columbia n.d.).

The BC PI is based on GHG emissions data (i.e., 'line items') for BC from Canada's NI. However, if higher resolution BC-specific data are available and are more accurate than the data used to compile the NI, then ECCS-CAS can substitute these local data in the PI (ECCS 2020b). According to the methodology book, there were no such replacements in the 2020 PI. However, some data are recategorized from the NI for the PI, and two divergences relevant to our report are:

1. Canada's NI only reports 'LULUCF' sector data at the national level, not at the provincial level. However, ECCC shares these data with ECCS-CAS such that the PI reports these data at the provincial level.
2. In Canada's NI, LULUCF emissions and removals are not counted towards the national total (ECCC, 2020b). In contrast, the BC PI does count some LULUCF line items towards the provincial total. Specifically, emissions from land conversions (afforestation and deforestation) are counted towards the provincial total, but all other LULUCF line items (i.e. 'land remaining' / unconverted lands) are reported as memo items in the BC PI and not counted in the provincial total (ECCS 2020b).

Similar to the NI, the PI also groups emissions using two approaches: by IPCC sector and by economic sector). The economic agriculture sector includes all emissions in the IPCC 'Agriculture' sector, plus on-farm fuel use. On-farm fuel use includes emissions from on-farm transportation and stationary combustion ('Energy', Sector 1) and on-farm use of lube oils and greases ('IPPU', Sector 4).

However, neither the CRF sector nor economic sector approach captures CO2 emissions from and removals by agricultural lands, which are reported in IPCC Sector 4 (LULUCF). Therefore, to meet AFF's objectives for a comprehensive emissions profile for agriculture in BC, we have included all emissions reported in the IPCC 'Agriculture' sector (AG), plus agricultural emissions reported in the IPCC 'Energy' (EN), 'IPPU' (IP), and 'LULUCF' (LU) sectors. We used three levels of agricultural emissions data in this analysis: 1. AG, 2. AG + EN + IP, and 3.AG + EN + IP + LU. Note that the second data inclusion level (AG + EN +IP) is simply the agriculture economic sector, as reported in the BC PI and in Canada's NI. However, on-farm electricity consumption is not included in the BC PI, nor in this report, because these emissions are attributed to their source, i.e. power plants. Emission categories included in our approach are summarized in **Table 3**.

Unless otherwise stated, all emissions are reported in kilotonnes of CO2 equivalents (kt CO2e). Analyses in this project are focused on data published in 2020, which reports emissions for the period 1990-2018. Select years used in this analysis are 2018 (the most recent inventory year), 1990 (the 'base' year for UNFCCC), and 2007 – the reference year for GHG reduction targets in BC (*Climate Change Accountability Act* 2007).

Table 3. *Emission categories related to BC agriculture included in this project.*

BC PI Agriculture Sector	BC PI Economic Agriculture Sector	CRF Sector	Category
Included	**Included**	**Agriculture – CRF Sector 3 [AG]**	
			All categories
Not included	Included	**Energy – CRF Sector 1 [EN]**	
			Transport – Agriculture
			Stationary Combustion – Agriculture
Not included	Included	**IPPU – CRF Sector 2 [IP]**	
			Non-energy products from fuels and solvent use – Agriculture
Not included	Not included	**LULUCF – CRF Sector 4 [LU]**	
			See Table 8 for list of categories and subcategories included.

3. Inventory data

3.1. Activity data

Much of the activity data used for calculating emissions reported in Canada's NI originates from Statistics Canada. The majority of these data are further manipulated by AAFC or ECCC, for example to: area-weight values at the ecodistrict level, resolve problems in the data such as for 'headquarter reporting', work around suppressed data, or to more accurately model the distribution of animal populations throughout the year. It is clear that the methods described in the NIR do not provide a level of detail to enable calculations without more information and substantial support from ECCC and AAFC, and coordination with Statistics Canada. A summary of the location of and access to activity data for calculating emissions data following NIR methodology is in **Table 4**. All of these data require coordination with ECCC to use appropriately. Based on this, and from conversations with the AFF team, the emphasis in this project has been on gathering activity data that is useful to the multi-criteria framework and BMP analysis (see our report, *Multi-criteria Framework for GHG Emissions and Co-benefits*).

In addition, we have met with several AFF branches and industry groups. These meetings were primarily to 1. scope for data that is robust and adequate to refine estimates of emissions for BC agriculture, and 2. gather data on current adoption, or adoptability, of BMPs for GHG reduction in BC agriculture.

Many steps are required during the data reallocation process prior to use in calculating emission estimates for the inventory. Statistics Canada data must first be reallocated from Statistics Canada census area boundaries to the geographical units used for inventory calculations (ecodistricts). There are 1,027 ecodistricts in Canada which are characterized by distinct topography and climate. However, the area boundaries used by Statistics Canada (i.e., census consolidated subdivisions) do not align with Soil Landscapes of Canada (SLC) ecodistrict boundaries; the former are political / cultural boundaries while the latter are environmental. Statistics Canada data is reallocated to ecodistricts by AAFC (Corey Flemming, personal communication, Nov. 25, 2020) prior to use by ECCC. The reallocation is termed an 'area weighted polygon interpolation procedure' and uses an 'AAFC SLC interpolated table'. It is unclear how this reallocation would compare to a completely spatially-explicit approach. AAFC also performs other data adjustments, such as using Earth Observation (EO)-based AAFC land-use mapping of cropland area to resolve issues associated with farm headquarters reporting; the result of this is an EO-adjusted interpolated Census of Agriculture dataset. In our preliminary work on areas (4) and (5), we have overlaid census subdivision and ecodistrict boundary files in GIS software to develop ratio tables which describe a percent allocation of each subdivision to each ecodistrict; this work is discussed further in Section 5 of this report. While our ratio tables are a reasonable approximate for an exploratory analysis like this, it is not congruent with NIR methodology, and more complicated reallocations will require additional datasets.

Table 4. *Sources of activity data for emission categories and subcategories in the 'Agriculture' sector.*

Category – Subcategory	Activity Data	Activity Data Source
Enteric Fermentation		
Cattle		
Dairy cattle		

Non-dairy cattle		Statistics Canada: Livestock survey; see NIR Part 2 Table A3.4–1
Non-Cattle		
Swine		Statistics Canada: Livestock survey; see NIR Part 2 Table A3.4–1
Sheep & Lambs		
Buffalo		Statistics Canada: Census of Agriculture; see NIR Part 2 Table A3.4–1
Llamas & Alpacas		
Deer & Elk	Population by ecodistrict	
Goats		
Horses		
Mules & Asses		Statistics Canada: Census of Agriculture & personal communications; see NIR Part 2 Table A3.4–1
Wild Boar		Statistics Canada: Census of Agriculture; see NIR Part 2 Table A3.4–1

Manure Management		
CH4		
Dairy Cattle		
Non-Dairy Cattle		
Swine		
Sheep & Lambs		
Buffalo		
Llamas & Alpacas		
Deer & Elk		
Goats		
Horses		
Mules & Asses		
Wild Boar	Population by ecodistrict	Same as enteric fermentation
Poultry		
Rabbit		
Fox		
Mink		
N2O – Direct		
Liquid Systems		
Solid Storage & Drylot		
Composting		
Other		
N2O – Indirect		
Ammonia Volatilization		

	N Leaching		

Agricultural Soils			
Direct			
	Inorganic N fertilizer	1. area of specified field crops by ecodistrict 2. recommended N per crop type, by soil classification by ecodistrict	1. Statistics Canada (area under field crops) 2. ECCC (list of field crops, recommended N by crop type)
	Organic N fertilizers	Animal populations by ecodistrict; Human population by ecodistrct	Statistics Canada; Requires further methods refinement from ECCC
	Crop residue decomposition	Area under field crops by ecodistrict	Statistics Canada, allocated to SLC polygons
		Average yield of field crops by ecodistrict	Statistics Canada, allocated to SLC polygons
	Mineralization/immobilization with loss/gain of soil organic matter (SOM)	Annual loss of SOC reported in LULUCF by ecodistrict	ECCC
	Tillage	Fraction of cropland in reduced- or no-till by each ecodistrict	Statistics Canada; Requires further methods refinement from ECCC
	Irrigation	Fraction of irrigated cropland by ecodistrict	Statistics Canada; Requires further methods refinement from ECCC
	Manure deposited by grazing animals on pasture range and paddock (PRP)	Animal population by ecodistrict	Statistics Canada; Requires further methods refinement from ECCC
	Cultivation of organic soils	Constant over time	ECCC
	Summerfallow	Based on inorganic N fertilizer, organic N fertilizer, and crop residue data	See other categories
Indirect			
	Atmospheric deposition	Based on inorganic N fertilizer, organic N fertilizer, and PRP data	See other categories
	Nitrogen leaching and run-off	Based on inorganic N fertilizer, organic N fertilizer, PRP, and crop residue data	See other categories

Crop Residue Burning		
CH_4	Area under, and average yield, of specified field crops by ecodistrict	Statistics Canada; Requires further methods refinement from ECCC
N_2O		

Limestone, Urea, & UAN		
Dolomite, limestone, urea	Lime and dolomite used for agricultural purposes	Natural Resources Canada – published data for 1990 to 2006, unpublished data for more recent years (available on request). Also requires consultation with Canadian Fertilizer Institute for methods refinement.

3.2. Emission factors

An emission factor (EF) is a value that associates a quantity of GHGs released to the atmosphere with an activity associated with the release of a given GHG. An EF is expressed as the weight of a specific GHG per unit of activity (e.g., hectare or head of cattle) that produces the GHG. Depending on the emission subcategory, EFs are either Tier 1 IPCC default values or more specifically derived Tier 2 factors (i.e., specific to a manure management system, animal category, ecodistrict, etc.). There are no Tier 3 emissions calculations reported in Canada's NIR for the 'Agriculture' sector. Published EFs for AG are summarized in Appendix 6.4 of Canada's 2020 NIR (ECCC 2020c). However, EFs for several subcategories within the 'agricultural soils' category of AG are calculated on an ecodistrict basis and these values are not published.

Table 5 summarizes the published location (if applicable) and status of our access to unpublished EFs for calculating emissions for AG emissions in BC.

Table 5. *Status of emission factors (EFs) for emission categories in the 'Agriculture' sector.*

Category – Subcategory	Tier	Emission Factor Data [reported in NIR Part 2 (ECCC 2020c)]
Enteric Fermentation		
Cattle		
Dairy cattle	2	Appendix 6, Table A6.4-2
Non-dairy cattle	2	
Non-Cattle		
Swine	1	Appendix 6, Table A6.4-2

Sheep & Lambs	1	
Buffalo	1	
Llamas & Alpacas	1	
Deer & Elk	1	
Goats	1	
Horses	1	
Mules & Asses		
Wild Boar	1	

Manure Management		
CH4		
Dairy Cattle	2	Appendix 6, Table A6.4-6
Non-Dairy Cattle	2	
Swine	2	Appendix 6, Table A6.4-7
Sheep & Lambs	2	Appendix 6, Table A6.4-8
Buffalo	2	
Llamas & Alpacas	2	
Deer & Elk	1	
Goats	2	
Horses	2	
Mules & Asses	1	
Wild Boar	2	
Poultry	2	
Rabbit	1	
Fox	1	
Mink	1	
N2O - Direct		
Liquid Systems	1/2*	Appendix 6, Tables A6.4-9, A6.4-10, A6.4-11, A6.4-12 * Tier 1 for 'beef', and Tier 2 for 'dairy', 'swine', and 'other animals'
Solid Storage & Drylot	1/2*	
Composting	1/2*	
Other	1/2*	
N2O - Indirect		
Ammonia Volatilization	1/2*	Appendix 6, Tables A6.4-13, A6.4-15, A6.4-16, A6.4-27 * Tier 1 for 'beef' and 'other animals', and Tier 2 for 'dairy' and 'swine'
N Leaching	1/2*	

Agricultural Soils		
Direct		
Inorganic N fertilizer	2	Weighted average emission factor for each ecodistrict. Unpublished; Calculated by ECCC.
Organic N fertilizers	2	
Crop residue decomposition	2	

	Mineralization/immobilization with loss/gain of soil organic matter (SOM)	2	
	Tillage	2	
	Irrigation	2	
	Manure deposited by grazing animals	2	
	Cultivation of organic soils	1	Appendix 6, Table A6.4-24
	Summerfallow	2	Based on inorganic N fertilizer, organic N fertilizer, and crop residue data
Indirect			
	Atmospheric deposition	1	Appendix 6, Table A6.4-27
	Nitrogen leaching and run-off	1	
Crop Residue Burning			
	CH4	1	Appendix 6, Table A6.4-28
	N2O	1	
Limestone, Urea, & UAN			
	Dolomite, limestone, urea	1	Appendix 6, Table A6.4-29

3.3. Uncertainty in emission estimates

We assessed the uncertainty associated with the aggregated emission categories related to BC agriculture from the AG, IP, EN, and LU sectors. We used the error propagation methods from Canada's NIR Part 2 (using **Equation 1** and **Equation 2** shown below) to combine uncertainties (ECCC 2020c). These are Equations 3.1 and 3.2 from Volume 1 (Chapter 3) of the 2019 IPCC Guidelines for National GHG Inventories; methods are described in more detail in the example worksheet provided in Table 3.2[1] (IPCC 2019). **Equation 1** (IPCC Equation 3.1) is used for combining uncertainties when multiplying (or dividing) quantities, while **Equation 2** (IPCC Equation 3.2) is used for combining uncertainties when adding or subtracting quantities (IPCC 2019).

Equation 1:

$$\boldsymbol{U_{total} = \sqrt{U_1^2 + U_2^2 + \cdots + U_n^2}}$$

[1] We found a discrepancy in the IPCC guidelines for these methods, where the Table 3.2, column L equation does not align with the description for column L calculations provided on the page 3.26, preceding Table 3.2. We performed the calculations according to the description provided on page 3.26 (IPCC 2019) as this description matched the example calculations provided in Table 3.2.

Equation 2:

$$U_{total} = \frac{\sqrt{(U_1 \times x_1)^2 + (U_2 \times x_2)^2 + \cdots + (U_n \times x_n)^2}}{|x_1 + x_2 + \cdots + x_n|}$$

Where *Utotal* is the combined uncertainty of either the product or sum of the quantities (half the 95 percent confidence interval divided by the total) and expressed as a percentage; *xi* are the (positive or negative) quantities to be combined; and *Ui* are the percentage uncertainties associated with each of the quantities.

We extracted the national-level uncertainties associated with the activity data and emission factors used to calculate emission estimates, as well as the combined uncertainty (for activity data and emission factors) from Table A2-2 in the NIR (ECCC 2020c p. 16) for the primary emission categories within AG, EN, IP, and LU. These are provided in **Table 6**. The combined uncertainty is calculated in Canada's NI using **Equation 1**. The following preliminary data processing / assumptions, and observations, were made when extracting these national-level uncertainties from Canada's NIR:

1. When we replicated these simple error propagation calculations for combined uncertainty, our values did not always align with those reported in the NIR. For example: as shown in **Table 6** below, N_2O emissions from 'Agricultural soils – indirect' has 7.9% uncertainty in activity data and 75% uncertainty in the emission factor. According to the IPCC worksheet, the combined uncertainty of this category should be calculated as $\sqrt{7.9^2 + 75^2} = 75.4\%$, however, NIR reported 100% for the combined uncertainty. For such discrepancies, we used the value given in the NIR.
2. Agricultural categories of the energy sector (on-farm transportation and stationary combustion) are not specified in Table A2-2 of the 2020 NIR. For these subcategories we used the uncertainties reported for *Fuel Combustion Off-Road* and *Fuel Combustion Other Sectors*, respectively.

To estimate uncertainty associated with provincial-level agricultural emissions for BC, we combined these national-level uncertainties with provincial-level emissions data (received from ECCC) at the primary category level, using the IPCC worksheet format. The following data processing assumptions were made before the national-level uncertainties were used in the IPCC worksheet for BC emissions:

1. If the uncertainties of an emissions category are reported in the NIR as GHG-specific, but the corresponding emissions category in the BC PI is not GHG-specific, then emissions from all gases were summed and their uncertainties were combined using **Equation 2** for error propagation.

   Example: As shown, uncertainties associated with emissions from off-road fuel combustion are specified by type of GHG. However, in the BC inventory, emissions from on-farm transportation fuel combustion is not GHG-specific. In this case, we used **Equation 2** to combine the uncertainties (1.1%, 11%, and 71%) into one combined uncertainty:

   $$U_{total} = \frac{\sqrt{(1.1\% \times 34238)^2 + (11\% \times 529)^2 + (71\% \times 470)^2}}{|34238 + 529 + 470|} = 1\%$$

   The combined uncertainties for 'crop residue burning', 'stationary combustion', 'cropland remaining cropland', 'grassland remaining grassland', and 'forestland converted to cropland' were also calculated this way, using values from **Table 6.**

2. The uncertainties reported in the NIR for the subcategories *Limestone*, *Urea Application,* and *Other Carbon-Containing Fertiliz*ers (**Table 6**) were combined for the primary emissions category *Carbon-Containing Fertilizers* (**Table 7**):

   $$U_{total} = \frac{\sqrt{(58\% \times 180)^2 + (52\% \times 2177)^2 + (52\% \times 249)^2}}{|180 + 2177 + 249|} = 43.9\%$$

Uncertainties associated with BC agricultural emissions in 2018 are included in **Table 7**. There is no uncertainty reported in the NIR for the 'grassland converted to cropland' subcategory, but it is included in **Table 7** for completeness. The total uncertainty by sector is a summation of uncertainties from all the categories within the sector, combined using **Equation 2**. For example, the uncertainty in all agricultural emissions from the LULUCF sector (12.7%; **Table 7**), was calculated by entering annual emission and combined uncertainties on all agricultural subcategories in

Table 7 (blue) into error propagation using **Equation 2**:

$$U_{LULUCF} = \frac{\sqrt{(23\% \times 135)^2 + (64\% \times 0)^2 + (15\% \times 403)^2 + (100\% \times -2)^2}}{|135 + 0 + 403 + \ -2|} = 12.7\%$$

The same principle applies to the total uncertainty in the BC PI, which is the summation of uncertainties from each sector related to agricultural activities. This uncertainty calculation process was then repeated for the annual emission data of each year from 1990 to 2018.

Table 6*. Agricultural emission categories and associated uncertainty in Canada's National Inventory Report (from Table A2-2, ECCC 2020c).*

Sector	IPCC category name	GHG	2018 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	National combined uncertainty	Annual contribution to sector variance by category in 2018	Annual contribution to national variance by category
			kt CO2e	%	%	%	%	%
AG	Agriculture—Enteric Fermentation	CH4	24,142	-	-	22	0.8	0.06
AG	Agriculture—Manure Management	CH4	3,846	-	-	32	0.0	0.00
AG	Agriculture—Manure Management Direct Emissions	N2O	3,369	1	44	51	0.1	0.01
AG	Agriculture—Manure Management Indirect Emissions	CH4	703	1	100	100	0.0	0.00
AG	Agriculture—Direct Agriculture Soils	N2O	20,439	8	27	34	1.4	0.11
AG	Agriculture—Indirect Agriculture Soils	N2O	4,229	8	75	100	0.5	0.04
AG	Agriculture—Field Burning of Agricultural Residues	CH4	37	50	40	64	0.0	0.00
AG	Agriculture—Field Burning of Agricultural Residues	N2O	12	50	48	69	0.0	0.00
AG	Agriculture—Limestone CaCO3	CO2	180	30	50	58	0.0	0.00
AG	Agriculture—Urea Application	CO2	2,177	15	50	52	0.0	0.00
AG	Agriculture—Other Carbon-Containing Fertilizers	CO2	249	15	50	52	0.0	0.00
EN	Fuel Combustion—Off-Road	CO2	34,238	1	0	1	0.0	0.0

EN	Fuel Combustion—Off-Road	CH4	529	1	11	11	0.0	0.0
EN	Fuel Combustion—Off-Road	N2O	470	2	71	71	0.0	0.0
EN	Fuel Combustion—Other Sectors	CO2	77,549	2	2	2	0.0	0.0
EN	Fuel Combustion—Other Sectors	CH4	3,196	6	15	15	0.0	0.0
EN	Fuel Combustion—Other Sectors	N2O	930	5	32	32	0.0	0.0
IP	IPPU—Non-Energy Products from Fuels and Solvent Use	N2O	11,545	-	20	20	4	0.0
LU	LULUCF—Land Converted to Forest Land	CO2	(334)	-	100	100	0.0	0.0
LU	LULUCF—Grasslands	CH4	1	-	64	64	0.0	0.0
LU	LULUCF—Grasslands	N2O	-	-	69	69	0.0	0.0
LU	LULUCF—Cropland	CO2	10,287	-	23	23	1.3	0.0
LU	LULUCF—Cropland	N2O	12	-	40	40	0.0	0.0
LU	LULUCF—Conversion of Forest Land	CO2	10,765	-	15	15	0.6	0.0
LU	LULUCF—Conversion of Forest Land	CH4	185	-	21	21	0.0	0.0
LU	LULUCF—Conversion of Forest Land	N2O	96	-	20	20	0.0	0.0

Table 7. *Sectoral total uncertainty and BC total uncertainty in agricultural related GHG emission inventory in 2018.*

Sector	Category	GHG	2018 annual emission	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty	Contribution to Sector variance by subcategory in 2018	Contribution to BC variance by subategory in 2018
			kt CO2e	%	%	%	%	%
AG	Enteric Fermentation	CH4	1470.3	-	-	22	1.7	0.7
AG	Manure Management - CH4	CH4	182.3	-	-	32	0.1	0.0
AG	Manure Management - Direct N2O	N2O	194.9	1	44	51	0.2	0.1
AG	Manure Management - Indirect N2O	N2O	40.2	1	100	100	0.0	0.0
AG	Agricultural Soils - Direct	N2O	439.1	8	27	34	0.4	0.2
AG	Agricultural Soils - Indirect	N2O	113.1	8	75	100	0.2	0.1
AG	Crop Residue Burning	CH4/ N2O	0.0	NA	NA	51	0.0	0.0
AG	Carbon-Containing Fertilizers	CO2	33.2	NA	NA	44	0.0	0.0
EN	On-Farm Transportation	CH4/ N2O / CO2	187.4	NA	NA	1	0.0	0.0
EN	Stationary Combustion	CH4/ N2O / CO2	593.8	NA	NA	2	0.0	0.0
IP	Non-Energy Products from Fuels and Solvent Use	CO2	0.0	-	20	20	0.0	0.0
LU	Cropland remaining Cropland	NS	135.0	NA	NA	23	0.3	0.0
LU	Grassland remaining Grassland	NS	0.0	NA	NA	64	0.0	0.0
LU	Forest Land converted to Cropland	NS	403.0	NA	NA	15	1.3	0.0
LU	Grassland converted to Cropland	NS	2.0*	n/a	n/a	n/a	n/a	n/a
LU	Cropland converted to Forest Land	NS	-2.0	-	100	100	0.0	0.0
AG	Sector Total	NS	2473.1			% Uncertainty in sector inventory SQRT(SUM(J))		15.9%
EN	Sector Total	NS	781.2					1.6%
IP	Non-Energy Products from Fuels and Solvent Use	NS	0.0					0.0%
LU	Sector Total	NS	536.0					12.7%
Total	n/a	NS	3792.3			**% Uncertainty in BC inventory SQRT(SUM(K))**		11%

* Emissions from 'Grassland converted to Cropland' are not counted in the total for LU emissions in the uncertainty propagation calculations because no uncertainty is reported for this category in Canada's 2020 NIR. This line item is only included for completeness.

4. GHG profile analysis

4.1. Emissions data related to BC agriculture

Disaggregated emissions data was provided from various contacts at ECCC. Descriptions of the inventory subcategories that are relevant to and included in this analysis are provided in **Table 8**. Some LU subcategories do not report emissions for certain inventory years; for simplification, we have replaced any of these unreported emissions with 'zero'.

Emissions from the EN – stationary combustion are disaggregated into the fuel subcategories provided in the disaggregated data: natural gas, propane, heavy fuel oil, kerosene & stove oil, light fuel oil. We have not disaggregated emissions from EN – transportation. In the EN transportation subcategory, more than 98% and 95% (in 1990 and 2018, respectively) of emissions in this subcategory come from non-renewable diesel fuel oil use in engines over 19 kW (25hp). In 1990, Tier 1-3 engines comprised 100% of emissions in this group (diesel engines over 19 kW (25hp)). This is reduced to 60% in 2018, where the other 40% comes from Tier 4 diesel engines (which appear in 2012 at ~7%). Emission totals from AG, EN, IP, and LU are graphed in **Figure 1**. Overall, AG emissions are consistently at least twice the agricultural emissions from LU and EN combined. Agricultural missions from IP followed a consistent downward trend from a peak of 23.1 kt CO2e in 1995 to 0 kt CO2e in 2018. Agricultural emissions from LU and EN have varied in their magnitude and relative proportions from 1990 to 2018. While agricultural emissions in LU were more than twice those from EN in 1990, this trend is reversed for the most recent inventory year in 2018. Notably, EN emissions are substantially reduced for the years 2002 – 2009, corresponding to a substantial drop in emissions reported for stationary combustion (specifically natural gas). This is possibly due to an error in the activity data used to calculate these emissions and is detailed further in **Table 15**. AG emissions peaked in 2004 prior to a brief decline through 2011; **Figure 3** shows these trends are largely due to fluctuations in the 'enteric fermentation' category, which is presumably tied to impacts of bovine spongiform encephalopathy (BSE) on cattle populations during this time period.

Analyses and trends of subcategories within sectors are presented and discussed in the following sections. All acquired emissions data were compiled in MS Excel and submitted to AFF-CAT.

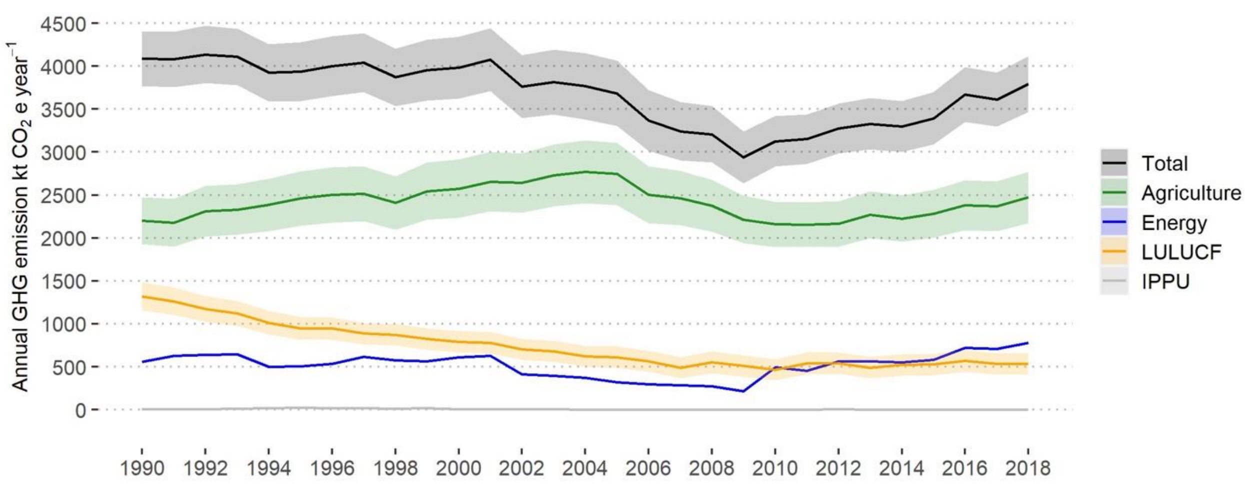

Figure 1. *Trends in overall GHG emissions related to agriculture in BC from four sectors: 'Agriculture', 'LULUCF', 'Energy', and 'IPPU', from 1990 to 2018 (data acquired from ECCC). Shaded areas indicate the relative uncertainty calculated from 2018 and propagated for all years.*

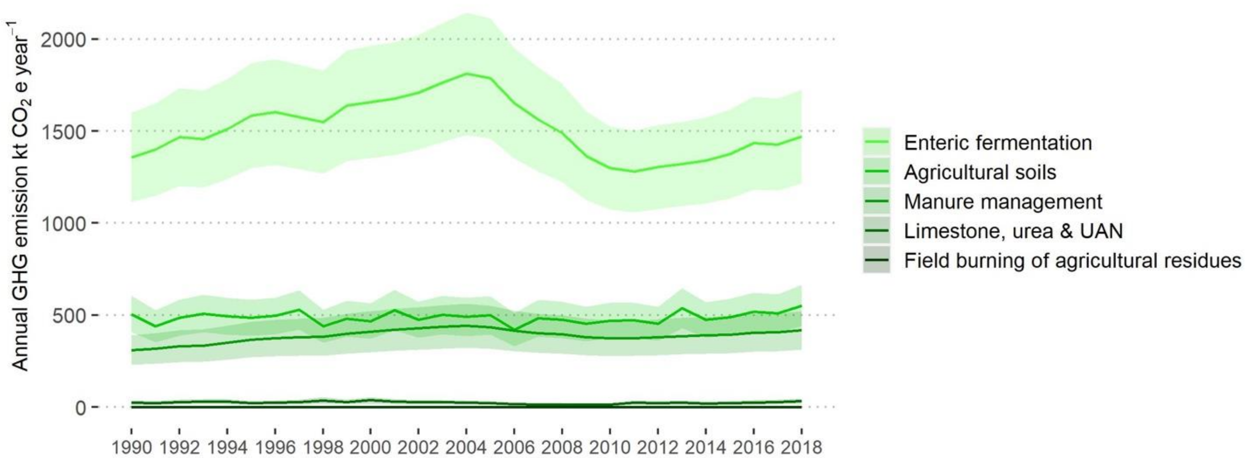

Figure 2. *Trends in GHG emissions in the four primary emission categories in the BC 'Agriculture' sector. Shaded areas indicate the relative uncertainty calculated from 2018 and propagated for all years.*

__Table 8.__ Descriptions of GHG emission subcategories included in this analysis.

Sector	Category	Subcategory	Description	Reference
AG	Enteric Fermentation	Dairy Cattle	CH4 emissions from enteric fermentation from dairy cattle (only includes dairy cows, all replacements, steers, and bulls are included in Non-Dairy Cattle)	NIR 2020, Part 2 p. 72 & 226
AG	Enteric Fermentation	Non-Dairy Cattle	CH4 emissions from enteric fermentation from non-dairy cattle (includes beef cattle and dairy cattle replacements)	NIR 2020 Part 2, p. 72 & 226
AG	Enteric Fermentation	Sheep & Lambs	CH4 emissions from enteric fermentation from sheep & lambs	NIR 2020 Part 2, p. 72
AG	Enteric Fermentation	Swine	CH4 emissions from enteric fermentation from swine	NIR 2020 Part 2, p. 72
AG	Enteric Fermentation	Buffalo	CH4 emissions from enteric fermentation from buffalo	NIR 2020 Part 2, p. 72
AG	Enteric Fermentation	Horses	CH4 emissions from enteric fermentation from horses	NIR 2020 Part 2, p. 72
AG	Enteric Fermentation	Other	CH4 emissions from enteric fermentation from: llamas & alpacas, deer & elk, goats, wild boar, and mules & asses	NIR 2020 Part 2, p. 72; also disaggregated data provided by ECCC confirmed which subcategories are included
AG	Manure Management - CH4	Dairy Cattle	CH4 emissions from manure management from dairy cattle (only includes dairy cows and dairy heifers, all other replacements, bulls, and steers are included in Non-Dairy Cattle)	NIR 2020, Part 2 p. 72 & 226
AG	Manure Management - CH4	Non-Dairy Cattle	CH4 emissions from manure management from non-dairy cattle (also includes some dairy replacements, and dairy steers and bulls)	NIR 2020, Part 2 p. 72 & 226
AG	Manure Management - CH4	Swine	CH4 emissions from manure management from swine	NIR 2020 Part 2, p. 72
AG	Manure Management - CH4	Poultry	CH4 emissions from manure management from poultry	NIR 2020 Part 2, p. 72
AG	Manure Management - CH4	Horses	CH4 emissions from manure management from horses	NIR 2020 Part 2, p. 72
AG	Manure Management - CH4	Other	CH4 emissions from manure management from: sheep & lambs, buffalo, llamas & alpacas, deer & elk, goats, rabbit, fox, mink, wild boars, and mules & asses	NIR 2020 Part 2, p. 72; also disaggregated data provided by ECCC confirmed which subcategories are included
AG	Manure Management - Direct N2O	Liquid Systems	Direct N2O emissions from animal manures handled in liquid systems	Disaggregated data provided by ECCC confirmed which subcategories are included

AG	Manure Management - Direct N2O	Solid Storage & Drylot	Direct N2O emissions from animal manures handled in solid storage and drylot systems	Disaggregated data provided by ECCC confirmed which subcategories are included
AG	Manure Management - Direct N2O	Composting	Direct N2O emissions from animal manures handled in composting systems (not including anaerobic digesters)	Disaggregated data provided by ECCC confirmed which subcategories are included
AG	Manure Management - Direct N2O	Other	Direct N2O emissions from animal manures handled in systems other than liquid, solid storage & drylyot, and composting; excludes anaerobic treatment lagoons and daily spread, which are not typically used in Canada; excludes emissions from urine and dung deposited on pasture, range, and paddock (which are included in Agricultural Soils)	2020 NIR Part 2, p. 88, 98; disaggregated data provided by ECCC confirmed which subcategories are included
AG	Manure Management - Indirect N2O	Ammonia Volatilization	N2O emissions from volatilization of N as NH3 and NOx from manure management systems, and subsequent re-deposition; excludes emissions from urine and dung deposited on pasture, range, and paddock	2020 NIR Part 2, p. 98, 99
AG	Manure Management - Indirect N2O	N Leaching	N2O emissions from leaching and runoff of N from manure management systems; leaching and runoff are only estimated for dairy and swine sectors	2020 NIR Part 2, p. 98
AG	Agricultural Soils - Direct	Synthetic (inorganic) Fertilizer	N2O emissions from inorganic fertilizer application	2020 NIR Part 2, p. 106
AG	Agricultural Soils - Direct	Organic Fertilizers	N2O emissions from application of biosolids and manure from waste management systems	2020 NIR Part 2, p. 103
AG	Agricultural Soils - Direct	Pasture Range Paddock	N2O emissions from animal wastes deposited on pasture, range, and paddock by grazing animals	2020 NIR Part 2, p. 108
AG	Agricultural Soils - Direct	Crop Residues	N2O emissions from crop residue decomposition; crops include wheat, barley, corn/maize, oats, rye, mixed grains, flax seed, canola, buckwheat, mustard seed, sunflower seed, canary seeds, fodder corn, sugar beets, tame hay, dry peas, soybean, dry white beans, coloured beans, chickpeas and lentils	2020 NIR Part 2, p. 109, 110

AG	Agricultural Soils - Direct	Mineralization of soil organic carbon (SOC)	N2O emissions from organic matter mineralization, due to changes in land management practices (1. mixture of cropland type, 2. tillage, 3. area of summerfallow), as estimated in the LULUCF Cropland remaining Cropland category	2020 NIR Part 2, p. 110
AG	Agricultural Soils - Direct	Histosols	N2O emissions from cultivation of organic soils (histosols) for annual crop production	2020 NIR Part 2, p. 110
AG	Agricultural Soils - Direct	Summerfallow	N2O emissions from cropland in summerfallow	2020 NIR Part 2, p. 111
AG	Agricultural Soils - Direct	Tillage	N2O emissions from adoption of no-till and reduced tillage; for areas with chernozemic soils in BC, a reduced EF is used for adoption of reduced- or no-till	2020 NIR Part 2, p. 111; also Corey Flemming (personal communication, April 13, 2021)
AG	Agricultural Soils - Direct	Irrigation	N2O emissions from irrigated conditions	2020 NIR Part 2, p. 112
AG	Agricultural Soils - Indirect	Atmospheric Deposition	N2O emissions from N volatilization as NH3 and NOx from application of inorganic and organic N fertilizers to cropland, and urine and dung to pasture, range, and paddock, and subsequent re-deposition.	2020 NIR Part 2, p. 113
AG	Agricultural Soils - Indirect	Leaching & Runoff	N2O emissions from leaching and runoff of inorganic and organic N fertilizers, and crop residue N from agricultural soils	2020 NIR Part 2, p. 114
AG	Crop Residue Burning	Crop Residue Burning	CH4 and N2O emissions from field burning of agricultural residues; includes spring wheat, winter wheat, oats, barley, mixed grains, flaxseed, and canola	2020 NIR Part 2, p. 117
AG	Carbon-Containing Fertilizers	Carbon-Containing Fertilizers	CO2 emissions from application of lime, urea, or urea-based N fertilizer (i.e. urea ammonium nitrate (UAN))	2020 NIR Part 2, p. 119, 120
EN	Stationary Combustion	Agriculture	CO2, CH4, and N2O emissions from on-farm stationary combustion (i.e. on-site machinery operations and space heating), including natural gas, propane, heavy fuel oil, kerosene & stove oil, light fuel oil; does not include emissions from fisheries	2020 NIR Part 2, p. 29; disaggregated data provided by ECCC confirmed which fuels are included and which gases are produced
EN	Transportation	Agriculture	CO2, CH4, and N2O emissions from on-farm transportation	2020 NIR Part 3, p. 10; disaggregated data from ECCC confirmed which gases are produced
IP	Non-Energy Products from	Agriculture	CO2 emissions from the use of lubricant oils and greases	2020 NIR Part 3,

	Fuels and Solvent Use			p. 12; disaggregated data from ECCC confirmed which gases are produced
LU	Cropland remaining cropland	Change in Area of Summer fallow - decrease	CO2 emissions from cropland in summer fallow	2020 NIR Part 2, p. 140
LU	Cropland remaining cropland	Change in Area of Summer fallow - increase	CO2 emissions from cropland in summer fallow	2020 NIR Part 2, p. 140
LU	Cropland remaining cropland	Change in Mixture of Cropland Type - increase in annual	CO2 emissions from cropland in annual production	2020 NIR Part 2, p. 140
LU	Cropland remaining cropland	Change in Mixture of Cropland Type - increase in perennial	CO2 emissions from cropland in perennial production	2020 NIR Part 2, p. 140
LU	Cropland remaining cropland	Change in Tillage Practices - Conventional to Reduced	CO2 emissions from change in tillage practices	2020 NIR Part 2, p. 140
LU	Cropland remaining cropland	Change in Tillage Practices - Conventional to Zero-till	CO2 emissions from change in tillage practices	2020 NIR Part 2, p. 140
LU	Cropland remaining cropland	Change in Tillage Practices - Reduced to Conventional	CO2 emissions from change in tillage practices	2020 NIR Part 2, p. 140
LU	Cropland remaining cropland	Change in Tillage Practices - Reduced to Zero-till	CO2 emissions from change in tillage practices	2020 NIR Part 2, p. 140
LU	Cropland remaining cropland	Change in Tillage Practices - Zero-till to Conventional	CO2 emissions from change in tillage practices	2020 NIR Part 2, p. 140
LU	Cropland remaining cropland	Change in Tillage Practices - Zero-till to Reduced	CO2 emissions from change in tillage practices	2020 NIR Part 2, p. 140
LU	Cropland remaining cropland	Cultivation of Organic Soils	CO2 emissions from cultivation of organic soils (histosols) for annual crop production	

LU	Cropland remaining cropland	Perennial Woody Crops	CO2 emissions and removals from woody biomass on croplands, including from trees and shrubs on agricultural land, as well as vineyards, fruit orchards, and Christmas trees; remote sensing used to determine trees and shrubs and Census of Agriculture (COA) used to estimate area of vineyards, fruit orchards, and Christmas trees	2020 NIR Part 2, p. 150
LU	Cropland remaining cropland	Residual Emissions - Forestland converted to cropland	Net residual CO2 emissions from the conversion of forestland to cropland more than 20 years prior to the reporting year, including emissions from dead organic matter	2020 NIR Part 1, p. 158; confirmed CO2 source from ECCC disaggregated data
LU	Cropland remaining cropland	Residual Emissions - Grassland converted to cropland	Residual CO2 emissions from the conversion of grassland to cropland more than 20 prior to the reporting year	NA – zero in BC
LU	Forestland converted to cropland	Residual Emissions	Residual CO2 emissions from the conversion of forestland to cropland over the past 20 years (inclusive of the inventory year), including emissions from dead organic matter, but not soil organic C (NIR assumes that in Western Canada, deforested lands remain under permanent pasture for at least 20 years, so there is no net soil C loss from deforestation) (McConkey et al., 2014)	2020 NIR Part 1, p. 162, 163; confirmed CO2 source from ECCC disaggregated data
LU	Forestland converted to cropland	Immediate Emissions – Logging, Uprooting and Burning	Immediate CO2, CH4, and N2O emissions from the conversion of forestland to cropland, including logging, uprooting, and burning; emissions from biomass and dead organic matter	2020 NIR Part 1, p. 162, 163; confirmed CO2 source from ECCC disaggregated data
LU	Cropland converted to forestland	Annual Processes	CO2 emissions and removals from conversion of cropland to forestland (reported as 'afforestation' in the PI), including changes in carbon stored in biomass, dead organic matter, and soil	Confirmed CO2 source from ECCC disaggregated data
LU	Grassland remaining grassland	Prescribed Burning – Conventional Harvest	Grassland is unimproved pasture or grassland only used for grazing domestic livestock, and only occurs where the land would not naturally regrow into forest. ECCC assumes no change in grassland management practices since 1990, so this subcategory reports emissions from prescribed burns on grassland; emissions include CH4, CO, NOx, and N2O.	2020 NIR Part 1, p. 145, 164

LU	Grassland remaining grassland	Wildfires	Same as 'Prescribed burning – Conventional Harvest' for natural wildfires	Same as for 'Prescribed Burning – Conventional Harvest'
LU	Grassland converted to cropland	Change in Area of Summerfallow, Change in Mixture of Cropland Type, and Change in Tillage Practices	Same as for the ten corresponding subcategories in 'Cropland remaining cropland'	Same as for the ten corresponding subcategories in 'Cropland remaining cropland'
LU	Grassland converted to cropland	Residual Emissions	Residual CO2 and N2O emissions from the conversion of grassland to cropland over the past 20 years (inclusive of the inventory year); emissions from the soil and dead organic matter pools	Confirmed CO2 source from ECCC disaggregated data

4.2. Key categories identified using level and trend assessments

As recommended in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006), it is good practice to identify *key categories* of GHG sources and sinks through a systematic and objective assessment. *Key categories* are those that substantially influence the total GHG inventory, either in terms of the absolute total (identified through level assessment) or the trend (identified in the trend assessment) of emissions and removals. The goal is to help governing bodies prioritize areas to focus efforts for improving estimates. Approach 1 outlined by IPCC (and used by ECCC for the NIR) is to assess the relationship between the level and trend of each category's GHG estimates and the overall total and trend of emission estimates. The two methods under Approach 1 to identify *key categories* to prioritize are: 1. level assessment and 2. trend assessment; these are calculated as the percent contribution of each emission category to overall emission levels and trends, respectively.

The level assessment identifies *key categories* based on their contribution to the absolute total of emissions and removals and identifies the largest contributing categories that make up 95 of the absolute value of the total emissions and removals. However, some categories may be too small to be identified by the level assessment, so the trend assessment is used to identify categories with trends that are substantially different than the trend of the overall emissions (IPCC 2006), and which are therefore also *key categories* within the inventory.

This methodology was developed for national-level inventories, but it is useful here given the scale and scope of the emission profile in this project. ECCC summarizes three IPCC requirements for defining source and sink categories prior to a key category analysis. To adopt this methodology, these source / sink requirements have been modified for this provincial-level assessment. These are summarized in **Table 1**. GHG emission subcategories used in the level and the trend assessments are described in **Table 6**. All LULUCF emission estimates are disaggregated into source and sinks for the level and trend assessments, as recommended by IPCC.

Table 9. *Modifications of IPCC guidelines for defining source and sink categories for key category assessment.*

Requirement	Description	Modification
1.Report in CO2 equivalents	"IPCC categories should be used with emissions expressed in CO2 equivalent units according to standard global warming potentials (GWPs)." [ECCC, 2020b, p.1]	No modification.
2. Group by individual gases	"A category should be identified for each gas emitted or removed, since the methods, emission factors, and related uncertainties differ for each gas." [ECC, 2020b, p.1]	Estimates for Energy emissions are aggregated for 'stationary combustion' and 'transportation' subcategories and are not reported as individual gases.
3. Group by common emission factor	"Categories that use the same emission factors based on common assumptions should be aggregated before analysis." [ECCC, 2020b, p.1]	Estimates for Energy emissions are aggregated for 'stationary combustion' and 'transportation' subcategories, regardless of emission factors.

Level assessment

The level assessment is performed by first calculating the percent contribution of each emissions category for the most recent inventory year using

Equation 3. Next, categories are sorted by their percent contribution to the overall emissions in descending order of magnitude, and the top categories that comprise 95% of the total emissions are identified as *key categories.*

Equation 3:

$$L_{x,t} = \frac{|E_{x,t}|}{\sum_y |E_{y,t}|}$$

Where:

$L_{x,t}$	=	level assessment for source or sink *x* in latest inventory year (year *t*) *[reported in columns 6,7,8 in* **Table 10***]*
$\lvert E_{x,t} \rvert$	=	the absolute value of emission or removal estimate of source or sink category *x* in year *t* *[absolute value of column 5 in* **Table 10***]*
$\sum_y \lvert E_{y,t} \rvert$	=	Total contribution, which is the sum of the absolute values of emissions and removals in year t calculated using the aggregation level chosen by the country for key category analysis; because both emissions and removals are entered with a positive sign, the total contribution/level can be larger than a country's total emissions less removals *[sum of the absolute values in column 5 in* **Table 10***]*

Trend assessment

The trend assessment identifies *key categories* that may not be identified in the level assessment but are important due to their contribution to the overall emissions trend. This analysis identifies categories "whose trend is different from the trend of the total inventory, regardless of whether [the] category trend is increasing or decreasing, or is a sink or a source. Categories whose trend diverges most from the total trend [are] identified as *key*, when this difference is weighted by the level of emissions or removals of the category in the base year." (IPCC 2006 p. 416). The trend assessment treats increasing and decreasing trends the same, however, governing bodies may not want to invest resources into better estimates of *key categories* with decreasing trends, but this is case-by-case, and depends on why emissions are changing. Typically, the trend assessment would be performed using the base inventory year

(1990) and the current inventory year (2018). However, as per AFF's request, we have performed the trend assessment using 2007 as the base inventory year, in place of 1990.

Each category's trend assessment is calculated according to Equation 4. After calculating the trend assessment for a given category using this equation, then each category's contribution to the trend is then calculated by dividing the trend assessment (**Tx,t**) for a given category by the sum of the calculated trend assessments for all categories. This calculated value is referred to as a category's contribution to the trend. The categories are then sorted in descending order of magnitude based on this value (contribution to the trend). A cumulative contribution is calculated for the top categories (sum of category's contribution to the trend) and *key categories* are identified as those that, when summed together, add up to 95% of the cumulative contribution.

Equation 4:

$$T_{x,t} = L_{x,0} * \left| \left[\frac{(E_{x,t} - E_{x,0})}{|E_{x,0}|} \right] - \left[\frac{\left(\sum_y E_{y,t} - \sum_y E_{y,0}\right)}{|\sum_y E_{y,0}|} \right] \right|$$

Where:

$T_{x,t}$	=	trend assessment of source or sink category *x* in year *t* as compared to the base year (year 0) *[column 7 in* **Table 11**, **Table 12**, *and* **Table 13***]*
$L_{x,0}$	=	the level assessment for source or sink category *x* in year 0 (derived from Equation A1-1) *[columns 6, 7, 8 in* **Table 10***]*
$E_{x,t}$ and $E_{x,0}$	=	real values of estimates of source or sink category *x* in years *t* and 0, respectively *[columns 5 and 6 in in* **Table 11**, **Table 12**, *and* **Table 13***]*
$\sum_y E_{y,t}$ and $\sum_y E_{y,0}$	=	Total inventory estimates in years *t* and 0, respectively *[sum of columns 5 and 6 in in* **Table 11**, **Table 12**, *and* **Table 13***]*

In cases where the base year emissions are zero for a given category, **Equation 4** is re-arranged to avoid zero in the denominator (IPCC 2006):

Equation 5:

$$T_{x,t} = \left| \frac{E_{x,t}}{\sum_y |E_{y,0}|} \right|$$

IPCC recommends that these assessments are performed separately for at least two levels of data: with and without LULUCF sector data. For our analysis, we implemented three levels of data inclusion: 1. AG only, 2. AG + EN + IP, and 3.AG + EN + IP + LU. The assessments are performed at the subcategory level within AG, IP, and LU, as data at this level of detail were acquired for these sectors; data at the subcategory level was also used for EN – 'stationary combustion'. However, data at a higher aggregation level was used for EN – 'transportation' as this category is cannot be disaggregated meaningfully with the data that was provided (as described in **Section 4.1. Emissions data related to BC agriculture**).

4.2.1. Level assessment results

The level assessment of emission subcategories related to agriculture in BC identified 22 to 24 *key* emission subcategories, depending on the level of data inclusion, as discussed in the previous section; results are presented in **Table 10**. When the analysis is performed with only emissions form AG, five subcategories produce 77.0% of emissions. The first and second largest subcategories are enteric fermentation from non-dairy cattle and dairy cattle, respectively, which together comprise 58% of emissions from AG. The next three top contributing subcategories are i) manure management: solid storage and drylot, ii) synthetic fertilizers, and iii) organic fertilizers, together comprising 19% of the total.

When agricultural emissions across AG, EN, IP, and LU sectors are included, five subcategories produce 54.3% of agricultural emissions. The two subcategories of enteric fermentation (non-dairy cattle and dairy cattle) remain in the top three, but emissions from on-farm use of natural gas in 'stationary combustion' (primarily natural gas for heating greenhouses) contributes 12.2% as the second largest source overall. The next two key subcategories are from LU and are attributed to changes in crop type: to perennial or to annual crops. We applied the uncertainty calculated for 2018 to illustrate our confidence in the distribution of emissions over time in the top five key subcategories (). Notably, following these top five subcategories are three subcategories (total 13.5%) related to emissions from deforestation attributed to agriculture.

Table 10. *Key categories determined from level assessment of 2018 emission estimates, with consideration of emissions from AG, EN, IP, and LU. Subcategories are ranked in order of their contribution to the 2018 level assessment, largest to smallest, to the three combined sectors. Percent contribution of each subcategory is reported here. Within each of the three level assessments (i.e. AG, AG+EN+IP, AG+EN+IP+LU), cumulative total indicates the sum of the level assessment for subcategories up to and including a given row.*

	Category	Subcategory	Gas	2018 emissions (kt CO2e)	2018 Level Assessment (%)			Cumulative Total (%)		
					AG	AG + EN + IP	AG + EN + IP + LU	AG	AG + EN + IP	AG + EN + IP + LU
AG	Enteric Fermentation	Non-Dairy Cattle	CH4	1118	45.2	34.3%	23.4 %	45.2%	34.3%	23.4%
EN	Stationary Combustion	Natural Gas	NA	582	NA	17.9%	12.2 %	NA	52.2%	35.5%
AG	Enteric Fermentation	Dairy Cattle	CH4	312	12.6 %	9.6%	6.5%	57.8%	61.8%	42.0%
LU	Cropland remaining cropland	Change in Mixture of Cropland Type - increase in perennial	CO2	-297	NA	NA	6.2%	NA	NA	48.3%
LU	Cropland remaining cropland	Change in Mixture of Cropland Type - increase in annual	CO2	289	NA	NA	6.0%	NA	NA	54.3%
LU	Cropland remaining cropland	Residual Emissions - Forestland converted to cropland	NA	246	NA	NA	5.1%	NA	NA	59.4%
LU	Forestland converted to cropland	Residual Emissions	NA	208	NA	NA	4.3%	NA	NA	63.8%
LU	Forestland converted to cropland	Immediate Emissions	NA	195	NA	NA	4.1%	NA	NA	67.8%
EN	Transportation	Agriculture	NA	187	NA	5.8%	3.9%	NA	67.6%	71.8%
AG	Manure Management - Direct N2O	Solid Storage & Drylot	N2O	175	7.1%	5.4%	3.7%	64.9%	72.9%	75.4%
AG	Agricultural Soils - Direct	Synthetic Fertilizer	N2O	172	6.9%	5.3%	3.6%	71.8%	78.2%	79.0%
AG	Agricultural Soils - Direct	Organic Fertilizers	N2O	128	5.2%	3.9%	2.7%	77.0%	82.1%	81.7%
AG	Manure Management - CH4	Dairy Cattle	CH4	100	4.0%	3.1%	2.1%	81.0%	85.2%	83.8%
LU	Cropland remaining cropland	Change in Area of Summerfallow - decrease	CO2	-94	NA	NA	2.0%	NA	NA	85.7%

LU	Cropland remaining cropland	Perennial Woody Crops	CO2	-81	NA	NA	1.7%	NA	NA	87.4%
AG	Agricultural Soils - Direct	Crop Residues	N2O	72	2.9%	2.2%	1.5%	83.9%	87.4%	88.9%
AG	Agricultural Soils - Indirect	Leaching & Runoff	N2O	64	2.6%	2.0%	1.3%	86.5%	89.4%	90.3%
AG	Manure Management - CH4	Non-Dairy Cattle	CH4	52	2.1%	1.6%	1.1%	88.6%	91.0%	91.4%
LU	Cropland remaining cropland	Cultivation of Organic Soils	CO2	52	NA	NA	1.1%	NA	NA	92.4%
AG	Agricultural Soils - Indirect	Atmospheric Deposition	N2O	49	2.0%	1.5%	1.0%	90.6%	92.5%	93.5%
LU	Cropland remaining cropland	Change in Area of Summerfallow - increase	CO2	42	NA	NA	0.9%	NA	NA	94.3%
AG	Agricultural Soils – Direct N2O	Irrigation	N2O	41	1.6%	1.2%	0.8%	92.2%	93.7%	95.2%
AG	Manure Management - Indirect N2O	Ammonia Volatilization	N2O	40	1.6%	1.2%	0.8%	93.8%	95.0%	-
AG	Limestone, Urea & UAN	Limestone, Urea & UAN	CO2	33	1.3%	1.0%	0.7%	95.2%	-	-

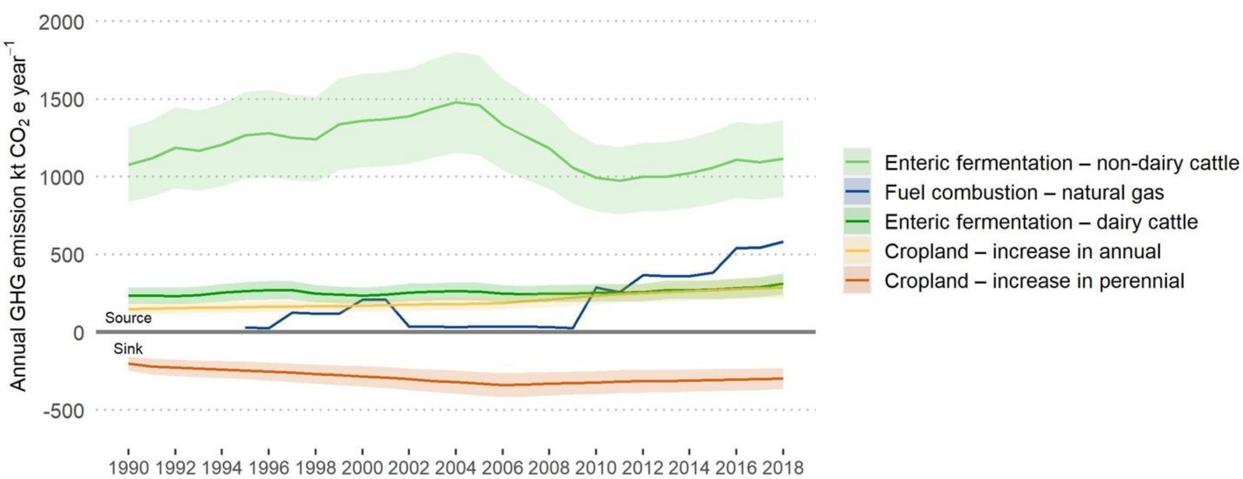

Figure 3. *Trends in GHG emissions in the top five key subcategories identified by level assessment of agricultural subcategories from the Agriculture, LULUCF, and Energy sectors. Shaded areas indicate the relative uncertainty calculated from 2018 and propagated for all years.*

4.2.2. Trend assessment results

The trend assessment is used to identify key categories which substantially influence the GHG inventory in terms of the trend in emissions and removals. The trend assessment identified 14, 12, and 21 key subcategories when AG (

Table 11), AG, EN and IP (**Table 12**) or AG, EN, IP, and LU (**Table 13**) were considered in the trend assessment, respectively. The top five key subcategories in the AG trend assessment account for 75.3% of the cumulative total. The top two key subcategories, 'enteric fermentation – non-dairy cattle' and 'enteric fermentation – dairy cattle' subcategories, comprise 55.1% of the cumulative total in the AG trend assessment, and also ranked highly in the corresponding level assessment. The next three top key subcategories identified are 'agricultural soils – synthetic fertilizer', 'manure management – CH4 – dairy cattle', and 'limestone, urea, and UAN'.

The AG, EN, and IP trend assessment (**Table 11**) identified similar top five *key subcategories* as those identified in the corresponding level assessment; these make up 87.1% of the trend assessment cumulative total. Notably, three of these *key subcategories,* 'enteric fermentation – non-dairy cattle', 'transportation – agriculture', and 'manure management – direct N2O – solid storage & drylot', are identified here due to a decreasing trend.

In the AG, EN, IP, and LU trend assessment (**Table 12**) the top five *key subcategories* comprise 73.3% of the cumulative total in this trend assessment and are similar to those subcategories identified in the corresponding level assessment (**Table 10**). These are 'stationary combustion – agriculture', 'enteric fermentation – non-dairy cattle', forestland converted to cropland – residual emissions', 'transportation – agriculture', and 'cropland remaining cropland – residual emissions – forestland converted to cropland'. These are graphed in **Figure 4**.

Table 11. *Key subcategories determined from trend assessment of 2018 emission estimates from AG, relative to a 2007 base year. Subcategories are ranked in order of their contribution to trend, largest to smallest. Cumulative total is the sum of the 'contribution to trend' for subcategories up to and including a given row. Key subcategories are those top categories that comprise 95% of the cumulative totals.*

Sector	**Category**	**Subcategory**	**Gas**	**GHG emission estimates** (kt CO2e)		**Trend Assessment** (%)	**Contribution to Trend** (%)	**Cumulative Total** (%)
				Base Year 2007	**Current Year** 2018			
AG	Enteric Fermentation	Non-Dairy Cattle	CH4	1256.9	1118.4	5.8	37.6	37.6
AG	Enteric Fermentation	Dairy Cattle	CH4	244.8	312.3	2.7	17.5	55.1
AG	Agricultural Soils - Direct	Synthetic Fertilizer	N2O	136	171.5	1.4	9.2	64.3
AG	Manure Management - CH4	Dairy Cattle	CH4	76	99.9	1.0	6.2	70.6
AG	Limestone, Urea & UAN	Limestone, Urea & UAN	CO2	15.6	33.2	0.7	4.6	75.2
AG	Agricultural Soils - Direct	Organic Fertilizers	N2O	110	127.8	0.7	4.6	79.8
AG	Agricultural Soils - Direct	Crop Residues	N2O	61.1	72.3	0.4	2.9	82.7
AG	Manure Management - Direct N2O	Solid Storage & Drylot	N2O	183.4	174.8	0.4	2.4	85.1
AG	Enteric Fermentation	Horses	CH4	23.3	15	0.3	2.2	87.3
AG	Enteric Fermentation	Buffalo	CH4	16.5	8.9	0.3	2.0	89.3
AG	Agricultural Soils - Indirect	Leaching & Runoff	N2O	57.7	64	0.2	1.6	90.9
AG	Manure Management - CH4	Swine	CH4	14.7	9.5	0.2	1.4	92.3
AG	Agricultural Soils - Direct	Summerfallow	N2O	5.3	0.2	0.2	1.3	93.6
AG	Agricultural Soils - Direct	Mineralization of SOC	N2O	9	12.8	0.2	1.0	94.6

Table 12. *Key subcategories determined from trend assessment, with consideration of emissions from AG, EN, and IP, and using 2007 as the Base Year. Subcategories are ranked in order of their contribution to trend for the combined sectors, largest to smallest. Cumulative total is the sum of the 'contribution to trend' for subcategories up to and including a given row. Key subcategories are those top categories that comprise 95% of the cumulative total.*

Sector	**Category**	**Subcategory**	**Gas**	**GHG emission estimates** (kt CO_2e)		**Trend Assessment** (%)	**Contribution to Trend** (%)	**Cumulative Total** (%)
				Base Year 2007	**Current Year** 2018			
EN	Stationary Combustion	Natural Gas	n/a	38	582	19.5	44.7	44.7
AG	Enteric Fermentation	Non-Dairy Cattle	CH_4	1257	1118	13.4	30.6	75.4
EN	Transportation	Agriculture	n/a	223	187	2.7	6.3	81.7
AG	Manure Management - Direct N_2O	Solid Storage & Drylot	N_2O	183	175	1.5	3.5	85.2
AG	Enteric Fermentation	Dairy Cattle	CH_4	245	312	0.8	1.9	87.1
AG	Limestone, Urea & UAN	Limestone, Urea & UAN	CO_2	16	33	0.5	1.2	88.3
AG	Enteric Fermentation	Horses	CH_4	11	0	0.5	1.1	89.4
AG	Manure Management - CH_4	Non-Dairy Cattle	CH_4	23	15	0.5	1.0	90.4
AG	Agricultural Soils - Direct	Synthetic Fertilizer	N_2O	54	52	0.4	1.0	91.4
AG	Enteric Fermentation	Buffalo	CH_4	136	172	0.4	0.9	92.3
AG	Manure Management - CH_4	Dairy Cattle	CH_4	16.5	8.9	0.4	0.9	93.2
AG	Agricultural Soils - Indirect	Atmospheric Deposition	N_2O	76	100	0.4	0.8	94.0

† n/a indicates an aggregated subcategory with more than one GHG

Table 13. *Key subcategories determined from trend assessment, with consideration of emissions from AG, EN, IP, and LU and using 2007 as the Base Year. Subcategories are ranked in order of their contribution to trend for the combined sectors. Cumulative total is the sum of the 'contribution to trend' for subcategories up to and including a given row. Key subcategories are those top categories that comprise 95% of the cumulative total.*

Sector	**Category**	**Subcategory**	**Gas**	**GHG emission estimates** (kt CO2e)		**Trend Assessment** (%)	**Contribution to Trend** (%)	**Cumulative Total** (%)
				Base Year 2007	**Current Year** 2018			
EN	Stationary Combustion	Natural Gas	n/a	38	582	12.6	34.2	34.2
AG	Enteric Fermentation	Non-Dairy Cattle	CH4	1257	1118	8.2	22.4	56.6
LU	Forestland converted to cropland	Residual Emissions	n/a	291	208	3.1	8.4	65.0
EN	Transportation	Agriculture	n/a	223	187	1.7	4.6	69.6
LU	Cropland remaining cropland	Residual Emissions - Forestland converted to cropland	n/a	260	246	1.4	3.7	73.3
LU	Cropland remaining cropland	Change in Mixture of Cropland Type - increase in annual	CO2	201	289	1.3	3.4	76.8
AG	Manure Management - Direct N2O	Solid Storage & Drylot	N2O	183	175	0.9	2.5	79.3
LU	Forestland converted to cropland	Immediate Emissions	n/a	138	195	0.8	2.1	81.4
AG	Enteric Fermentation	Dairy Cattle	CH4	245	312	0.6	1.7	83.1
LU	Cropland remaining cropland	Change in Area of Summerfallow - decrease	CO2	-85	-94	0.5	1.5	84.6
LU	Cropland remaining cropland	Change in Area of Summerfallow - increase	CO2	-72	-81	0.5	1.3	85.9
LU	Cropland remaining cropland	Perennial Woody Crops	CO2	54	42	0.5	1.3	87.3

LU	Cropland remaining cropland	Change in Mixture of Cropland Type - increase in perennial	CO2	-335	-297	0.4	1.2	88.5
AG	Limestone, Urea & UAN	Limestone, Urea & UAN	CO2	16	33	0.4	1.0	89.4
AG	Agricultural Soils - Direct	Synthetic Fertilizer	N2O	11	0	0.3	0.8	90.2
AG	Enteric Fermentation	Horses	CH4	136	172	0.3	0.8	91.0
AG	Manure Management - CH4	Non-Dairy Cattle	CH4	23	15	0.3	0.8	91.8
AG	Manure Management - CH4	Dairy Cattle	CH4	76	100	0.3	0.7	92.5
AG	Enteric Fermentation	Buffalo	CH4	54	52	0.3	0.7	93.2
AG	Cropland remaining cropland	Cultivation of Organic Soils	CO2	17	9	0.2	0.7	93.9
AG	Agricultural Soils - Indirect	Atmospheric Deposition	N2O	52	52	0.2	0.6	94.4

† n/a indicates an aggregated subcategory with more than one GHG

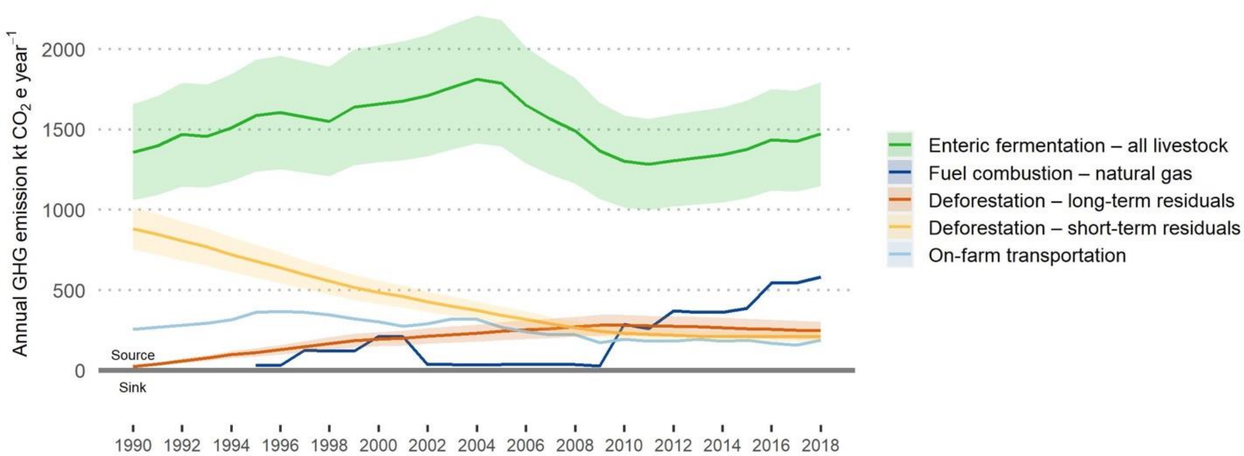

Figure 4. *Trends in GHG emissions in the top five key subcategories identified by trend assessment of agricultural subcategories from the Agriculture, Energy, IPPU, and LULUCF*

sectors. Shaded areas indicate the relative uncertainty calculated from 2018 and propagated for all years.

4.3. Short-term trends: Percent change

Given that BC no longer publishes a PIR, the most recent BC PIR was published in 2014. This 2014 PIR does not use key category assessments but instead reports both short-term (i.e., 1- and 3-year) percent changes in emissions, as well as long-term percent change (i.e., from the reference year (2007) used for emission estimate targets in BC). In contrast to the NIR *key category* assessment – a useful tool for identifying areas to prioritize for refining estimates – the provincial-level percent-change assessment illustrates more recent trends and allows for comparisons to a designated reference year (i.e., 2007).

In BC, provincially legislated targets require that BC's GHG emissions must be reduced by 40, 60, and 80% below 2007 levels by 2030, 2040, and 2050, respectively (*Climate Change Accountability Act* 2007). Emission reduction targets for individual sectors were set by the BC Minister of Environment and Climate Change in March 2021. These targets are expressed as a range of five percentage points and apply to four BC sectors. Legislated reduction targets have been set at 27 to 32% for transportation, 38 to 43% for industry, 33 to 38% for oil and gas, and 59 to 64% for buildings and communities sectors (ECCS 2021). Agricultural emissions are categorized under several of these sectors (Ken Porter, personal communication, June 3, 2021) and could contribute to meeting their emission reductions targets. Agricultural emissions are categorized as follows: On-farm transportation emissions are in the transportation sector; On-farm stationary combustion and crop and livestock production are in the industry sector; and Emission from deforestation (forestland converted to cropland) are in the buildings and communities sector. Emissions from cropland management related to storage and release of CO2 from soil organic matter and woody biomass are not counted in the provincial inventory (reported as memo items), and therefore would not currently be associated with emission reduction targets.

The 2018 emission estimates and short-term trends are summarized in **Table 14**. Total agricultural emissions from AG, EN, IP, and LU have changed by +17.0% from 2007. This is fueled by +174.6% change in EN (on-farm transport and stationary combustion), and specifically stationary combustion (+857.7%). Overall, the agricultural emissions from LU have increased by 9.8% from 2007, but recent trends have been more moderate (+1.9% from 2015).

Overall GHG emissions solely from AG have changed by +0.3% from the 2007 to 2018 (**Table 14**;**Figure 1**). The short-term trend from 2015 to 2018 has been an increase of 8.3%. Enteric fermentation (largest category in AG) decreased (-5.9%) from 2007 to 2018, with decreases in non-dairy cattle enteric fermentation (-11.0%), but with increases from dairy cattle (+27.6%). In the short term (2015 to 2018), enteric fermentation emissions from non-dairy and dairy cattle subcategories have increased by 5.7% and 13.3%, respectively. No aggregated category in AG has a decreasing trend since 2015 through 2018.

***Table 14**. Emissions from 'Agriculture', 'LULUCF', 'Energy', and 'IPPU' sectors in BC related to agriculture – 2018 emission estimates and recent trends.*

Sector – Category – Subcategory	**2018 emissions** (kt CO2e)	**3-year trend**	**1-year trend**	**2007-2018**
All Sectors – Total	3792.3	+11.8	+5.0	+17.0
Agriculture - Total	2473.1	+8.3	+4.3	+0.3
Enteric Fermentation - Total	1470.3	+6.9	+3.1	-5.9
Dairy Cattle	312.3	+13.3	+7.7	+27.6
Non-Dairy Cattle	1118.4	+5.7	+2.0	-11.0
Horses	15	-6.8	0.0	-35.6
Sheep & Lambs	9.3	-5.1	-3.1	-17.0
Swine	3.4	+6.2	0.0	-27.7
Buffalo	8.9	-8.2	0.0	-46.1
Other [llamas & alpacas, deer & elk, goats, wild boars, mules & asses]	3	-3.2	0.0	-45.5
Manure Management Total	417.4	+5.7	+2.6	+3.8
Manure Management - CH4 Total	182.3	+9.2	+4.5	+10.3
Dairy Cattle	99.9	+13.3	+7.7	+31.4
Non-Dairy Cattle	52.2	+6.3	+2.0	-3.3
Poultry	16.7	+1.8	0.0	+9.9
Swine	9.5	+9.2	-1.0	-35.4
Horses	2.2	-4.3	0.0	-35.3
Other [buffalo, llamas & alpacas, deer & elk, goats, sheep & lamb, rabbit, fox, mink, wild boars]	1.8	-21.7	-10.0	-10.0
Manure Management - Direct N2O – Total	194.9	+3.1	+1.1	-0.8
Liquid Systems	14.2	+10.9	+6.8	+31.5
Solid Storage & Drylot	174.8	+2.3	+0.6	-4.7
Composting	0	0	0	0
Other	5.9	+9.3	+3.5	+156.5
Manure Management – Indirect N2O – Total	40.2	+3.6	+1.3	-0.2
Ammonia Volatilization	40	+3.6	+1.3	-0.5
N Leaching	0.2	0.0	0.0	+100.0
Agricultural Soils – Total	552.2	+12.7	+8.3	+14.1

Agricultural Soils – Direct – Total	439.1	+13.4	+8.5	+16.5
Synthetic Fertilizer	171.5	+22.6	+21.7	+26.1
Organic Fertilizers	127.8	+6.8	+4.4	+16.2
Pasture Range Paddock	4.4	+4.8	0.0	-10.2
Crop Residues	72.3	+15.3	-1.5	+18.3
Mineralization of SOC	12.8	+11.3	+0.8	+42.2
Histosols	10.6	0.0	0.0	0.0
Summerfallow	0.2	-91.3	-81.8	-96.2
Tillage	-1	-25.0	-11.1	-66.7
Irrigation	40.5	+8.9	+0.7	-0.5
Agricultural Soils – Indirect – Total	113.1	+10.1	+7.4	+5.6
Atmospheric Deposition	49.1	+7.4	+6.0	-0.6
Leaching & Runoff	64	+12.3	+8.5	+10.9
Field Burning of Agricultural Residues	0	0	0	0
Limestone, Urea & UAN	33.2	+43.1	+16.5	+112.8
LULUCF – Total	538	+1.9	+0.7	+9.8
Cropland remaining cropland – Total	135	-1.5	-0.7	+117.7
Change in Area of Summerfallow - Decrease in SF	-94	-3.3	-1.1	-10.6
Change in Area of Summerfallow - Increase in SF	42	-8.7	-2.3	-22.2
Change in Mixture of Cropland Type - Increase in Annual	289	+6.6	+1.8	+43.8
Change in Mixture of Cropland Type - Increase in Perennial	-297	+3.6	+1.3	+11.3
Change in Tillage Practices - Conventional to Reduced	-3	+25.0	0.0	0.0
Change in Tillage Practices - Conventional to Zero-till	-14	-7.7	-7.7	-55.6
Change in Tillage Practices - Reduced to Conventional	0	0	0	0
Change in Tillage Practices - Reduced to Zero-till	-5	-66.7	-25.0	-400.0
Change in Tillage Practices - Zero-till to Conventional	0	0	0	0
Change in Tillage Practices - Zero-till to Reduced	0	0	0	0
Cultivation of Organic Soils	52	0.0	0.0	0.0
Perennial Woody Crops	-81	-11.0	-2.5	-12.5
Residual Emissions - Forestland converted to cropland	246	-5.4	-1.6	-5.4
Residual Emissions - Grassland converted to cropland	0	0	0	0
Forestland converted to cropland – Total	403	+2.8	+1.3	-6.1
Residual Emissions	208	-1.0	-1.0	-28.5
Immediate Emissions from Forest Conversion - Logging, Uprooting and Burn	195	+7.1	+3.7	+41.3
Cropland converted to forestland – Total	-2	+50.0	0.0	+71.4
Grassland converted to cropland – Total	2	-33.3	0.0	-66.7
Grassland remaining grassland – Total	0	0	0	0
Prescribed Burning - Conventional harvest	0	0	0	0
Wildfires	0	0	0	0
Energy – Total	781.2	+34.6	+10.4	+174.6
Transportation	187.4	+0.5	+20.1	-15.8
Stationary Combustion	593.8	+50.8	+7.7	+857.7

IPPU – Total	0	-1.0	0	+1.0
Non-Energy Products from Fuels and Solvent Use	0	-1.0	0	+1.0

5. Areas for improvement of inventory data

The reviews of emission estimates for BC agriculture by AFF working groups in 2008 identified several areas of improvement (Forbes and Droppo 2008, Rogstrand 2008, Schmidt 2008, Zabek et al. 2008). The key suggestions from these past reviews, in addition to further gaps identified by our team in our current review, and possible actions and level of priority for future investigation are summarized in **Table 15**. We have performed some preliminary work to explore areas 1, 4, 5, 16, and 20, and this work is discussed in **Section 5.1. Comparison of data and methodologies from different sources**.

Table 15. *Summary of primary areas for future work identified in provincial inventory data related to agricultural emissions; P = priority level, 2008 = indicates if the issue was reported in recommendations made in the 2008 review of methodologies by AFF. The areas for future work with an asterisk (*) next to the priority level have been started with an exploratory analysis in the following section of this report.*

Area for future work	2008	Details	Impact	Relevant Actions	P
Multiple AG categories					
(1) Discrepancy in livestock populations between data sources	No	Different values given from Statistics Canada census data and ALUI inventories.	Livestock populations are used for emission estimates in three categories: agricultural soils, manure management, and enteric fermentation.	See **Section 5.1.3. Sensitivity analysis of enteric fermentation emissions from cattle,** outlining a simple sensitivity analysis of enteric fermentation emission estimates using an estimated potential variation in both activity and emission factor input data.	M*

Area for future work	2008	Details	Impact	Relevant Actions	P
(2) Percentage distribution of Animal Waste Management Systems not accurate to BC	Yes	The national average used for the percentage of manure applied to PRP for dairy and non-dairy cattle subcategories does not align with the expert opinion reported in Marinier et al. (2004) for BC.	Primarily, the expert opinion (Marinier et al., 2004) highlights that BC has a much more extensive cattle industry (i.e., more manure deposited on PRP), such that calculations would over-estimate the amount of manure going into waste management systems and then land-applied, and under-estimate manure deposited on PRP.	Resolved: This has been updated. As of 10 years ago, national averages are no longer used (personal communication, Corey Flemming, April 13, 2021).	L
Agricultural Soils					
(3) Fertilizer sales from BC Peace River Region allocated to Alberta	Yes	Canadian Fertilizer Institute fertilizer sales data for BC Peace River region are included with Alberta sales data (Schmidt, 2008).	Estimates for all other regions would be 77% of actual values, due to provincial-level reallocation process (Schmidt, 2008).	Resolved: N sales for North BC have been removed from Alberta and added to BC (Yang et al., 2007).	n/a
(4) Exclusion of important BC crop categories	Yes	NIR does not include the crop category for tree fruit, berry, grapes, nuts, or for vegetables.	Estimates of N fertilizers are inaccurately assigned to eco-districts.	(a.) In this report: comparison of GIS maps of NIR-calculated fertilizer allocations by ecodistrict from Hall (2017) with our GIS maps developed from Statistics Canada activity data on excluded crop categories and reported fertilizer use (discussed in **Section 5.1.2. N fertilizer allocations to ecodistricts by data sources).** (b.) Conduct / incorporate regional surveys of nutrient management practices for use in refining future NI / PI.	H*
(5) Inaccurate N fertilizer allocations	Yes	NIR assumption that zero N fertilizer is applied in ecodistricts where manure N production meets or exceeds recommended crop N application. Fertilizer N application inaccurately becomes zero in regions with high manure production.	Compounded by data gap (4), because N requirements of excluded crop categories would increase total recommended N.		

Area for future work	2008	Details	Impact	Relevant Actions	P
(6) Equation A3.4-21 (reconciling recommended fertilizer application with fertilizer sales) is incorrect in the NIR	No	If the incorrect equation is used, then the reconciliation process would scale the final estimate of total fertilizer N applied, on an ecodistrict basis, in the wrong direction.	Fertilizer applications in BC would be scaled by roughly ~20 in the wrong direction.	Resolved: ECCC has confirmed this is a typo and not the actual equation used.	n/a
(7) Fertilizer sales reported by Statistics Canada potentially include sales to forestry	No	This is suggested as a possible reason why sales exceed recommended application rates in BC Yang et al. (2007).	The reconciliation process described in the line above would be carried out with inaccurate fertilizer sales data.	Resolved: ECCC has confirmed that the Stats Canada questionnaire for fertilizer sales does differentiate between sales to agriculture versus other sectors.	n/a
(8) Only annual crop categories used to calculate residue burning emissions	No	In BC, crop residue burning is/has been common in perennial systems (i.e., tree fruits and berries), but is not accounted for.	Emissions subcategory 'crop residue burning' is zero for BC for all inventory years.	Gather activity data and emission factors for residue burning in perennial crops.	L
(9) Only annual crop categories used to calculate crop residue decomposition emissions	Yes	Emissions from residue decomposition from perennial crops are not accounted for nor are emissions from forestry residues used as mulches in fruit production accounted for.	Likely under-estimating emissions from crop residue decomposition.	Develop/incorporate research on perennial crop residue biomass and mulches and associated emission factors.	L
(10) Base N2O emission factor is developed from Ontario, Quebec, and Prairie province data	Yes	This emission factor is used to calculated N2O emissions per kg N applied to agricultural soils.	Given BC's diverse climate, geography and types of production, N2O emissions could be over- or under-estimated.	Compare local BC data to modelled emission factors used in the NIR.	L
(11) Unclear how N2O emissions from tillage are accounted for in BC	Yes	According to Rochette et al. (2008) BC uses a ratio factor for tillage of 1.0 (i.e., RFtill = 1), meaning the contribution of tillage to N2O emissions is not accounted for.	Despite Rftil = 1, the tillage subcategory of direct N2O emissions from agricultural soils still reports changes in N2O, indicating the use of an Rftill other than 1.	Update: The soil N2O emission factor (EF) applies to tillage on Chernozemic soils, and the net impact in BC is a reduced EF for these soils. For all other soils, the EF is not adjusted for tillage (personal communication, Corey Flemming, April 13,	L

Area for future work	2008	Details	Impact	Relevant Actions	P
				2021). These EFs will be updated in the future based on Liang et al. (2020).	
(12) Over-winter emissions (besides spring thaw) are not accounted for	Yes	The NIR accounts for increased emissions from spring snowmelt / thaw, but does not account for soil emissions during the winter months	Likely under-estimating winter emissions from saturated and high nutrient content soils in the Fraser Valley.	Develop and incorporate research on winter N2O emissions from saturated, high-N soils.	L
(13) Texture not accounted for in N2O emissions from BC soils	Yes	The impact of soil texture on N2O emissions is accounted for in Quebec, Ontario, and Atlantic provinces', but not BC or Prairie provinces' estimates. (RF_texture = 1 for all ecodistricts in BC).	Unknown; could be over- or under-estimating N2O emissions from N applications.	Incorporate soil texture data into NIR estimates for N2O emissions from agricultural soils in BC.	L
(14) N application recommendations by crop are based on application rates by crop by soil great group	Yes	N application rates for different crops are calculated by multiplying N application rates per crop per soil great group, by the weighted proportion of soils in each ecodistrict, to give an ecodistrict-specific N application rate per crop. This does not account for variability in N application rates by different regions in BC.	Unknown; could be over- or under-estimating N2O emissions from N applications.	Conduct / incorporate regional surveys of nutrient management practices (fertilizer and manure applications) to validate / correct NIR assumptions.	L
Enteric Fermentation					
(15) Inaccurate mature / average body weight of milking herd in BC	Yes	From the 2008 review, there was more in average body weight of milking herd between provinces than would be expected.	In the 2008 review, BC dairy cows had 21% higher emission factor than Quebec dairy cows (larger than expected). Update: No alternative datasets have been identified; however, some changes have been implemented: beef cattle weights are scaled across the time series based on trends in beef carcass weights, and for dairy cattle, Lactanet	Overall, these updates result in small changes, and more accurate average body weights would result in more accurate emissions estimates.	L

Area for future work	2008	Details	Impact	Relevant Actions	P
			(https://lactanet.ca/en/home/) data is used to revise several parameters based on herd size and milk productivity (personal communication, Corey Flemming, April 13, 2021).		
(16) Dairy replacements and bulls reported under 'non-dairy' category	Yes	For enteric fermentation, Dairy cattle only includes dairy cows, dairy replacements are grouped with Non-Dairy. (For manure management and PRP (Ag. soils), Dairy Cattle includes dairy cows and dairy heifers.)	This causes error in the use of the data. This inflates GHG's associated with beef production, while decreasing GHGs associated with milk production – potentially distorting the GHGs / unit of product.	Request dairy replacements and bulls separately for BC, so that BC data can be more accurate.	M
(17) Digestible Energy (DE) values from non-BC sources	Yes	Values for DE from US National Research Council were previously used.	Update: for dairy cattle, all DE values are calculated based on measured feed data from Lactanet; for beef cattle, the DE values from Boadi et al. (2004) are still used, contingent on any data updates (personal communication, Corey Flemming, April 13, 2021).	If there are known sources of local data for DE values for beef cattle, these can very easily be supplied to ECCC to be incorporated in their estimates.	L
Manure Management					
(18) Liquid dairy manure management categories need to be more detailed	Yes	The 2008 MAL review suggested: liquid slurry (1) with and (2) without natural crust cover, (3) uncovered anaerobic lagoon, (4) pit storage below animal confinements >1 month.	Unknown; impacts CH4 and N2O emissions from manure management.	Liquid systems are now accounted for in the dairy sector, including sub-types of liquid storage systems (i.e., tanks, earthen basins), as well as crusts and covers (personal communication, Corey Flemming, April 13, 2021).	L*
(19) Methane conversion factors for liquid dairy manure are not BC-specific	Yes	Liquid dairy manure is the largest manure category in BC, but not accurately represented in past inventories.	Unknown; impacts CH4 and N2O emissions from manure management.	This has been updated with more specific methane conversion factor values; see notes in line above regarding specific liquid storage system sub-types.	L*
Other - Agriculture (not included in NIR or PIR)					
(20) Aquaculture N2O emissions not accounted for	No	Aquaculture N2O emissions come from N (fertilizers, excreta, and uneaten feed) in the fish farm water.	These emissions are not currently accounted for in the NIR or BC PIR. N2O emissions roughly estimated at 65 kt CO2e year-1 for BC salmon aquaculture; see **Section 5.1.4. Estimates of**	Develop and incorporate aquaculture emissions data into NIR; incorporate into the PIR in the meantime.	M

Area for future work	2008	Details	Impact	Relevant Actions	P
			N2O emissions from aquaculture in BC for calculation details.		
(21) Emissions from fishing vessels not accounted for in BC PI	No	Fuel use by commercial fishing vessels is included in fuel combustion (CRF Sector 1), but not reported for in a way that is attributable to the agricultural sector.	Increased and more accurate emissions attributed to the agricultural and fisheries (food) sector in BC.	Request emissions from fuel use by commercial fishing vessels to be reported separately to include with agriculture and fisheries emissions in future PI	M
(22) Include N2O emissions from applying (municipal) compost to agricultural land	No	Currently emissions from compost applications are not included in the NI or PI.	N2O emissions from agricultural soils are under-estimated.	ECCC is currently working to develop activity data to implement this change (see NIR Part 1 p. 193).	L
(23) Cover crops use is not considered in NIR	No	Emission reductions (N2O emissions) due to cover crop use is not accounted for.	Emissions are likely over-estimated if cover crops are widely adopted.	Develop and incorporate cover crop activity and emission factor data into NIR; incorporate into a bottom-up PI	M
LULUCF					
(24) Recommendations related to LULUCF – deforestation and afforestation	See Zabek et al. (2008) for recommendations related to LULUCF deforestation and afforestation estimates related to BC.				L
(25) Cover crops use is not considered in NIR	No	Emission reductions (CO2 sequestration) due to cover crop use is not accounted for.	Emissions are likely over-estimated if cover crops are widely adopted.	Develop and incorporate cover crop activity and emission factor data into NIR; incorporate into a bottom-up PI.	M
Energy					
(26) Inaccurate fuel consumption activity data used to calculate on-farm stationary combustion emissions for some inventory years.	No	Average annual emissions reported in the stationary combustion disaggregated data we received from ECCC for 1995 to 2001, 2002 to 2009, and 2010 to 2018 are 285, 70, and 422 kt CO2e, respectively.	Emissions are likely under-reported for the on-farm stationary combustion subcategory for the years 2002 to 2009.	We have identified this issue to ECCC (personal communication, Frank and Kristine), and they are working with Stats Canada to investigate further.	L

5.1. Comparison of data and methodologies from different sources

Performing assessments (e.g., sensitivity analyses) or calculating / refining emission estimates depend on acquiring detailed input data from ECCC, in addition to other required datasets (i.e., accurate and adequate provincial-level activity data). Our project team has focused on identifying alternative sources of activity data and has not explored alternative sources or calculations for emission factors. One of the clear limitations for producing accurate emission profiles is the spatial limitations and accuracy of using Statistics Canada data as the base for activity data. We have explored potential alternatives for accessing / developing current activity data at the provincial level by contacting and/or meeting with various AFF branches as well as industry representatives.

We have spoken with individuals from the AFF Business Risk Management Branch who could provide additional data for the use of fertilizer for farms enrolled in their programs. Specifically, they track the dollar value of fertilizer (amount spent) which may be useful for further refinement of fertilizer assumptions. The main limitation is that this data represents only a fraction of all farms in BC.

Our conversation with the Geospatial team lead from the AFF Strengthening Farming branch identified the value of the provincial Agricultural Land Use Inventories (ALUI) as potential sources for activity data. The ALUI data could potentially provide greater precision for a number of different sub-categories of agricultural activity data. The limitations of these data sets are that they are not collected province-wide and the frequency of acquisition is limited. In some regions such as the lower mainland or the Okanagan the ALUIs are collected using dashboard surveys and in some select cases have been completed more than once. In other regions, such as the northern part of the province, data for the ALUIs are being collected using high resolution satellite imagery and have not been acquired for more than one time point. The AFF Extension and Support Services Branch has demonstrated how these data sets can be integrated to provide provincial scale activity data for the purpose of tracking air emissions (Sawychy et al. 2014).

Comparisons between the ECCC data and these locally-produced datasets could illustrate the potential limitations of the current NI and PI methods but also the value of increasing the frequency and spatial extent of the ALUI data collection. It is clear that these datasets would impact a number of sub-categories and potentially address some of the issues identified in **Table 15**.

To better understand what the implications of a few of the issues we identified as areas of future work (**Table 15**), we have performed some preliminary method comparisons. These comparisons were prioritized based on: consultation with AFF, relative importance, and our capability to do them within our time and resource constraints of this project. Our preliminary analyses were focused on three areas of future work: N fertilizer allocation (**Table 15**; areas 4 and 5), livestock population sources and enteric fermentation estimates (**Table 15**; areas 1 and 16), and aquaculture emissions (**Table 15**; area 20).

5.1.2. N fertilizer allocations to ecodistricts by data sources

Currently the NI assumes that zero N fertilizer is applied in ecodistricts where manure N production meets or exceeds recommended crop N application. Thus fertilizer N application inaccurately becomes zero in these regions with high manure production yet despite known (and documented) N fertilizer applications. For example, the NI reports no N fertilizer applications in ecodistricts in the lower Fraser Valley due to high manure N production in these ecodistricts.

To illustrate this issue, we used figures developed from data previously shared from ECCC to AFF for a methodology review project by AFF (Hall 2017). Specifically, Hall (2017) used input data from the in the 2014 NI for estimated application of N from fertilizer and manure by ecodistrict in BC. Maps were generated from this data to show the allocation of applied fertilizer and manure N (kg ha-1) by ecodistrict (Hall 2017). For reference, these maps are included in this report in **Figure A - 1** and **Figure A - 2**.

These figures clearly show that in ecodistricts where manure N production meets or exceeds total recommended crop N applications, fertilizer N applications are zero. To better understand the potential impacts of this inaccuracy, we used two Census of Agriculture datasets to compare alternative approaches for allocating fertilizers: 1. Expenditures on fertilizer and lime in 2005 (Statistics Canada n.d.) and 2. Hectares of commercial fertilizer applied in 2015 (Statistics Canada n.d.). These data were downloaded at the highest level of resolution (census consolidated subdivision). To match NI methodology as close as possible, we overlaid the census consolidated subdivision boundaries on ecodistrict boundaries, and then reallocated census activity data to ecodistricts. This is performed by developing ratio tables in GIS software, which describe the percent overlap between a census consolidated subdivision and a given ‘agriculturally-active’ ecodistrict (we used a list of agriculturally-active ecodistricts (as described in the NIR) from Hall (2017)).

The maps we generated from Statistics Canada data on expenditures on fertilizer and lime by ecodistrict in 2005, and hectares of commercial fertilizer application in 2015 by ecodistrict are provided in **Figure A - 3** and **Figure A - 4**. As presumed, these data on fertilizer applications by ecodistrict do not align with those provided by ECCC for Hall (2017), as illustrated in **Figure A - 1** and **Figure A - 2**. Specifically, **Figure A - 3** and **Figure A - 4** show substantial applications of, and expenditures on, N fertilizers in ecodistricts in the Fraser Valley, whereas fertilizer applications reported in the NI for these ecodistricts (**Figure A - 4**) are zero, due to high manure N production in these ecodistricts (**Figure A - 3**).

We also assessed the potential impact that the omission of the tree fruit, berry and grape crop categories (**Table 15**; area 4) from the 'agricultural soils' category would be. For example, the 2012 Fraser Valley Soil Nutrient Study (Sullivan and Poon 2012) reported that manure application to blueberry fields is uncommon, and instead N fertilizer application rates ranged from 45 to 185 kg N ha-1 for the 30 fields sampled. Yet as noted previously, these N fertilizer applications in these ecodistricts are not currently captured in the NI.

We acquired and reallocated hectares (ha) of crop production data for these crop categories (tree fruits, berries, and grapes) (Statistics Canada n.d.) to ecodistricts using the same reallocation procedures in GIS as described previously. The area under each crop category within an ecodistrict (ha) was multiplied by provincial recommended N application rates by category (120, 100, and 35 kg N ha-1 for tree fruit, berries, and grapes, respectively, as summarized by Yang et al., (2007)) to estimate the total recommended N application for each of these crop categories in each ecodistrict. Recommended N applications were then summed for all crop categories in an ecodistrict to determine a total recommended N application for each ecodistrict before they were mapped using GIS (**Figure A - 5**).

This map (**Figure A - 5**) shows that for just one ecodistrict in the Fraser Valley, these crop categories represent over 1.2 million kg of recommended applied N that are not being properly accounted for in the NI estimates. When summed for the province (all ecodistricts), our estimates indicate that these categories account for 2,301,522 kg recommended N (~3 % of the total fertilizer N applications reported in the NI for BC in 2018). If these crop categories were included in NI estimates, they would increase total recommended N application in ecodistricts they are grown in and would better reflect the actual distribution of applied (fertilizer) N across ecodistricts in BC.

Although the total amount of fertilizer used for the NI or the PI would not necessarily change based on these reallocations, given the other areas of work we identified related specifically to the estimation of N_2O (**Table 15**; area 10-14) it is likely that total emissions will. We have yet to evaluate the magnitude or even the direction of this impact on emission profiles. It is however, clear that this mis-allocation of fertilizer precludes using any BMP development for the tree fruit, berry and grape sectors in emission reductions accounting

5.1.3. Sensitivity analysis of enteric fermentation emissions from cattle

In our analysis we identified several areas of future work related to the enteric fermentation subcategory, the largest source of emissions for BC agriculture, that should be explored further. We assessed the impact of classifying dairy replacements and bulls with ‘non-dairy’ cattle for enteric fermentation emissions, instead of with ‘dairy’ cattle (**Table 15**; areas 4 and 16). To do this we averaged the June 1 and July 1, 2018 cattle population numbers from Statistics Canada livestock survey data and combined these with average emission factors for cattle from NIR Part 2 Table A3.4-7 (ECCC, 2020c). When comparing the total emission estimates from our calculations with those reported in the 2018 NI, we found that this change did not result in large differences. The NI reported emission of 1,430.7 kt CO_2e, and with the reclassification we calculated a slightly lower value of 1,419.2 kt CO_2e (**Table 16**). These differences can be attributed to the EFs published in Annex 6 of NIR Part 2 which are national “implied” EFs (i.e., final emissions divided by sum of population), and the actual EFs used for calculations are at a much more disaggregated level than what is publicly available (for 38 different cattle production subcategories) (personal communication, Corey Flemming, January 11, 2021). By properly categorizing dairy replacements and bulls with ‘dairy’ cattle rather than with ‘non-dairy’ cattle, there are changes in the subcategory which they are attributed to. The dairy cattle emissions are roughly 100 kt CO_2e higher (~ 33% %) and ~ 110 kt CO_2e (~10 %) lower for non-dairy cattle, compared to what is reported in the disaggregated emissions provided by ECCC.

We also explored the potential emission impacts of inaccurate livestock population or EF data (**Table 15**; area 1). We did this by comparing emission estimates calculated from variations in both activity (population) and emission factor (EF) data. We chose to vary the numbers in range that would be plausible given that the uncertainty for the EF obtained from the NI is 22%, and the uncertainty associated with the population numbers is unknown. Results of this preliminary assessment are shown in **Table 16**. If one of these factors is changed by 5%, the total for enteric emissions also changes by 5% and results in 1.9 % change in agriculture emissions (including AG, EN, IP, and LU). Similarly, if each of these factors changed by 5%, total enteric fermentation emissions from cattle would change by 10.3%. However, if both of these factors changed by 10% or 15%, total enteric fermentation emissions from cattle would change by 21.0% or 32.3%, respectively. Notably this 32.3% change in this emission source would translate to a roughly 12.1% change in total agriculture emissions (including AG, EN, IP, and LU). Given the sizable changes in the total emissions from variations in population and EF data, our analysis confirms the need for further work in this area to reduce uncertainties.

Table 16. *Calculated enteric fermentation emission estimates for dairy and non-dairy cattle to assess potential impacts from areas for future work (**Table 15**; areas 1 and 16).*

Cattle type	**Emission estimates**						
	2018 data from National Inventory	**Data from our calculations with re-categorization**	**+5% populatio n**	**+5% EF**	**+5% EF & populatio n**	**+10% EF & populatio n**	**+15% EF & populatio n**
	kt CO2e yr-1						
Dairy	312.3	412.0	432.6	432.6	454.3	498.5	544.9
Non-dairy	1,118.4	1,007.1	1,057.5	1,057.5	1,110.4	1,218.6	1,331.9
Cattle total	1,430.7	1,419.2	1,490.1	1,490.1	1,564.6	1,717.2	1,876.8
Change in total enteric fermentation emissions			5.0%	5.0%	10.3%	21.0%	32.3%
Change in total agriculture emissions			1.9%	1.9%	3.8%	7.9%	12.1%

5.1.4. Estimates of N2O emissions from aquaculture in BC

Emissions from aquaculture are not reported in the NI or PI (**Table 15**; area 20). In 2018, BC aquaculture produced 87,010 tonnes of salmon in aquaculture production (Statistics Canada, 2020). The primary emissions associated with aquaculture are energy use and N2O emissions from the water (MacLeod et al., 2019). Based on an estimated emission factor of ~0.75 kg CO2e kg live weight-1 (MacLeod et al., 2019) for the N2O emissions only, salmon aquaculture in BC emits roughly 65 kt CO2e year-1. While we have not estimated an uncertainty around these emissions and there are also likely sizable emissions from the transport of aquaculture products and on-site energy use, this emission estimate represents a minor component of the current total at only 1.7% (including AG, EN, IP, and LU).

6. Recommendations

Effective GHG mitigation programming largely depends on an accurate understanding of emission sources and sinks in the province and how they have changed over time. This requires not only a comprehensive, disaggregated emissions dataset for BC agriculture, but also accurate and appropriate methods used to collect and develop these estimates. We have identified a number of discrete areas for future work in

Table 7, however, more comprehensive next steps should include developing a provincial agricultural GHG database in order to transition to a “bottom-up” emissions accounting system, and to incorporate spatially-explicit variables in this accounting. These recommendations are discussed in the following sections.

6.1. Develop a “bottom-up” emissions accounting approach

Given that provincial- and national-level emission reporting is based largely on activity data acquired through a “top-down” national census, an alternative approach would be necessary to develop a robust incentive and reporting system that is adaptable to local data as it becomes available. A “bottom-up” inventory not only allows for a greater understanding of major emission sources and sinks, it is also required in order to account for changes in emissions (e.g., in the Provincial Inventory) when a BMP is implemented. To count many of the potential agricultural BMPs in emission reduction strategies, a system for tracking their activity data and quantification of their emission reductions needs to be aligned with international reporting requirements. Options for collecting these data, for example through the Environmental Farm Plan or the ALUI, need to be investigated, developed, and tested.

6.2. Improve the resolution and incorporation of spatially-explicit data

Given the diversity of soil types, climates, and production systems in BC, and the strong influence these factors play in GHG emissions, incorporating improved, spatially-explicit data into accounting efforts is important for increasing accuracy and enabling BMPs to be included in provincial estimates. The resolution of current national-level estimates based on Landsat satellite imagery is too low to effectively detect many fine feature changes in the landscape that have been shown to have sizable impacts on the emissions profile, such as afforestation (planting woody perennials) and deforestation on agricultural lands. ALUI data collection could be expanded and improved to incorporate higher resolution imagery to address this need. More extensive ALUI data would not only improve emissions related to land use and land cover change but would also improve the quantification of soil C emissions and sinks. To effectively account for changes in soil organic carbon (SOC), developing a baseline of the current status of provincial soils is essential. Accurate SOC maps, and higher resolution land use, and land use/land cover change data could also be used to prioritize regions across the province for BMP investment that will maximize GHG benefits.

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Appendix

Appendix A: Maps for relevant inputs in BC by ecodistrict

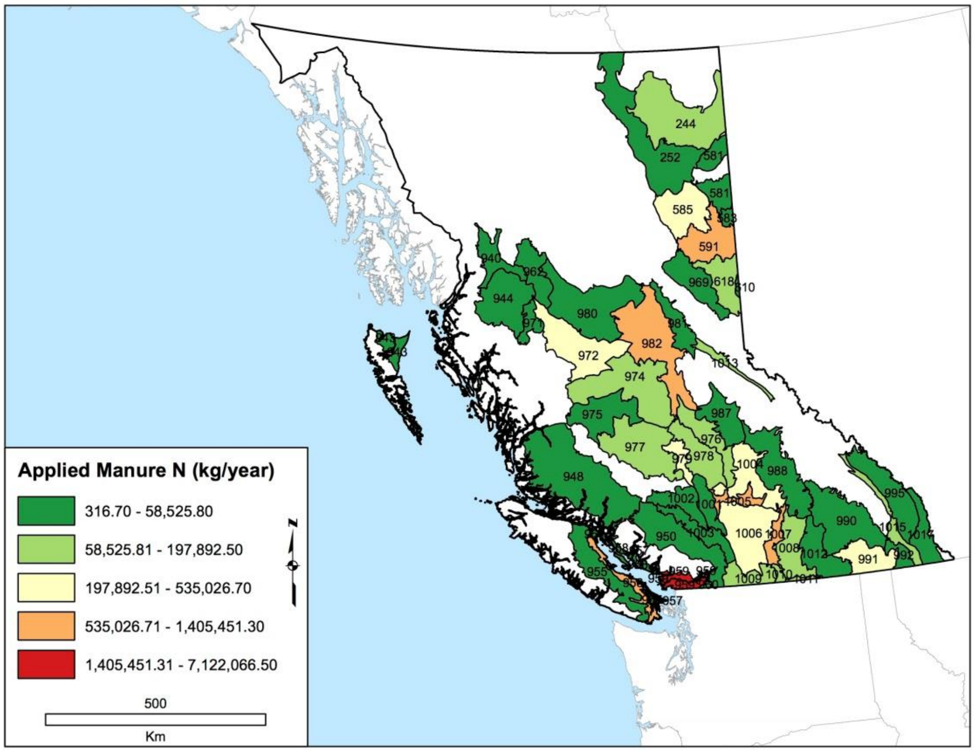


Figure A - 1. *Available nitrogen applied as manure in BC by ecodistrict (image from Hall, 2017).*

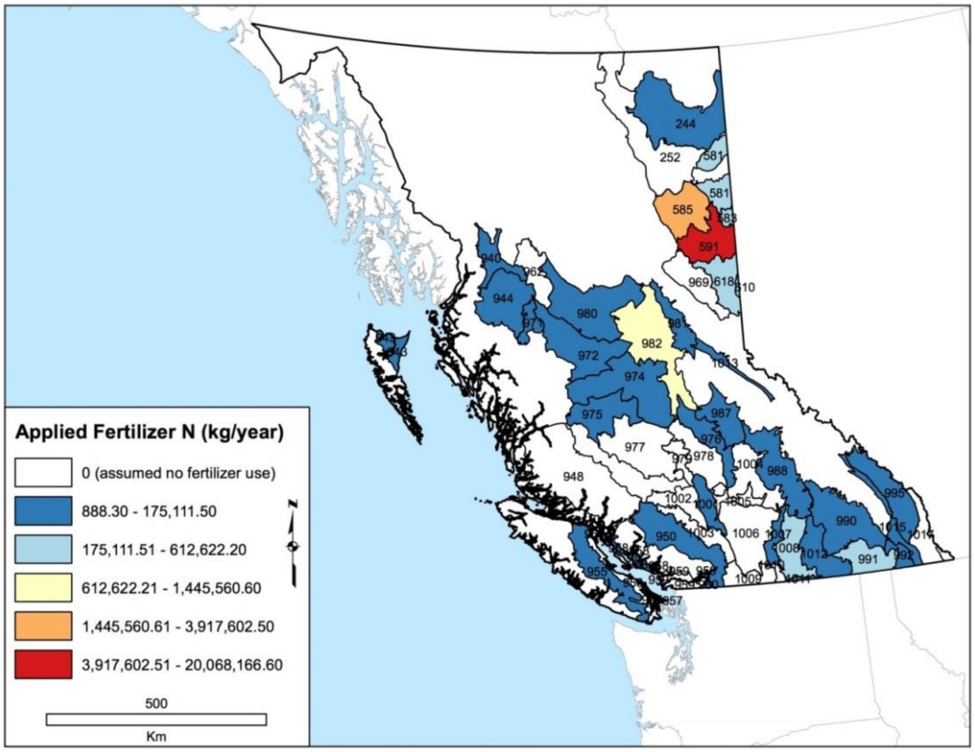
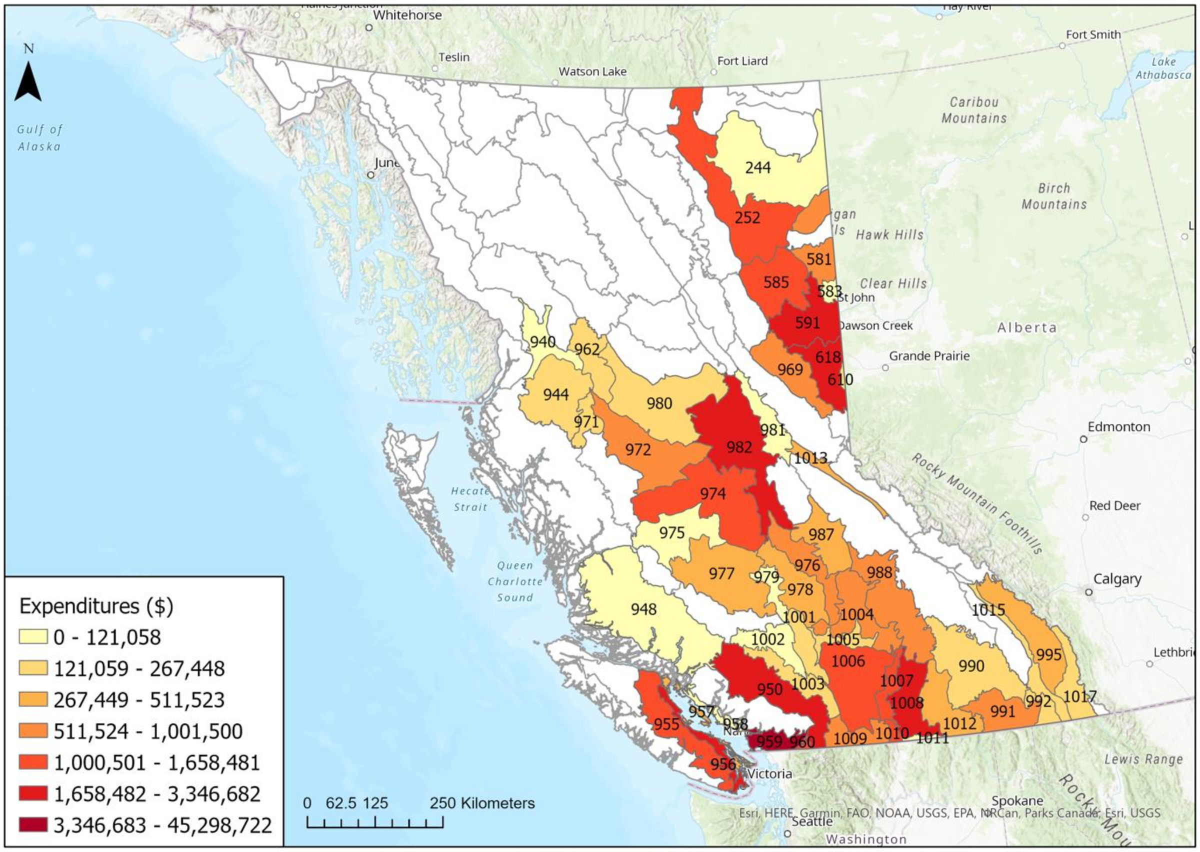


Figure A - 2. *Nitrogen applied as synthetic fertilizer in BC by ecodistrict (image from Hall, 2017).*



Credits: Statistics Canada, 2006 Census of Agriculture, Farm Data and Farm Operator Data, catalogue no. 95-629-XWE.

Figure A - 3. *Expenditures on fertilizer and lime in 2005 in BC by ecodistrict.*

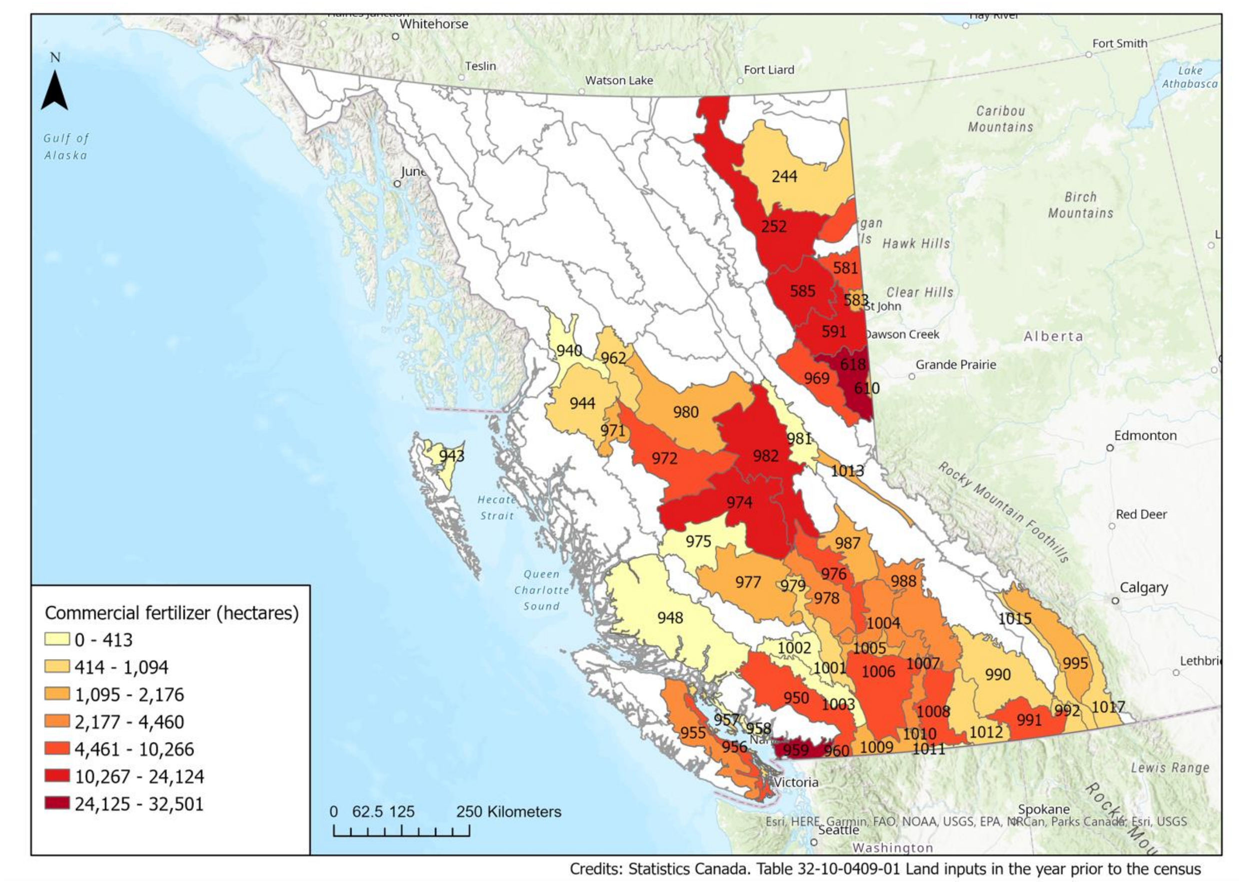


Figure A - 4. *Hectares of commercial fertilizer applied in 2015 in BC by ecodistrict.*

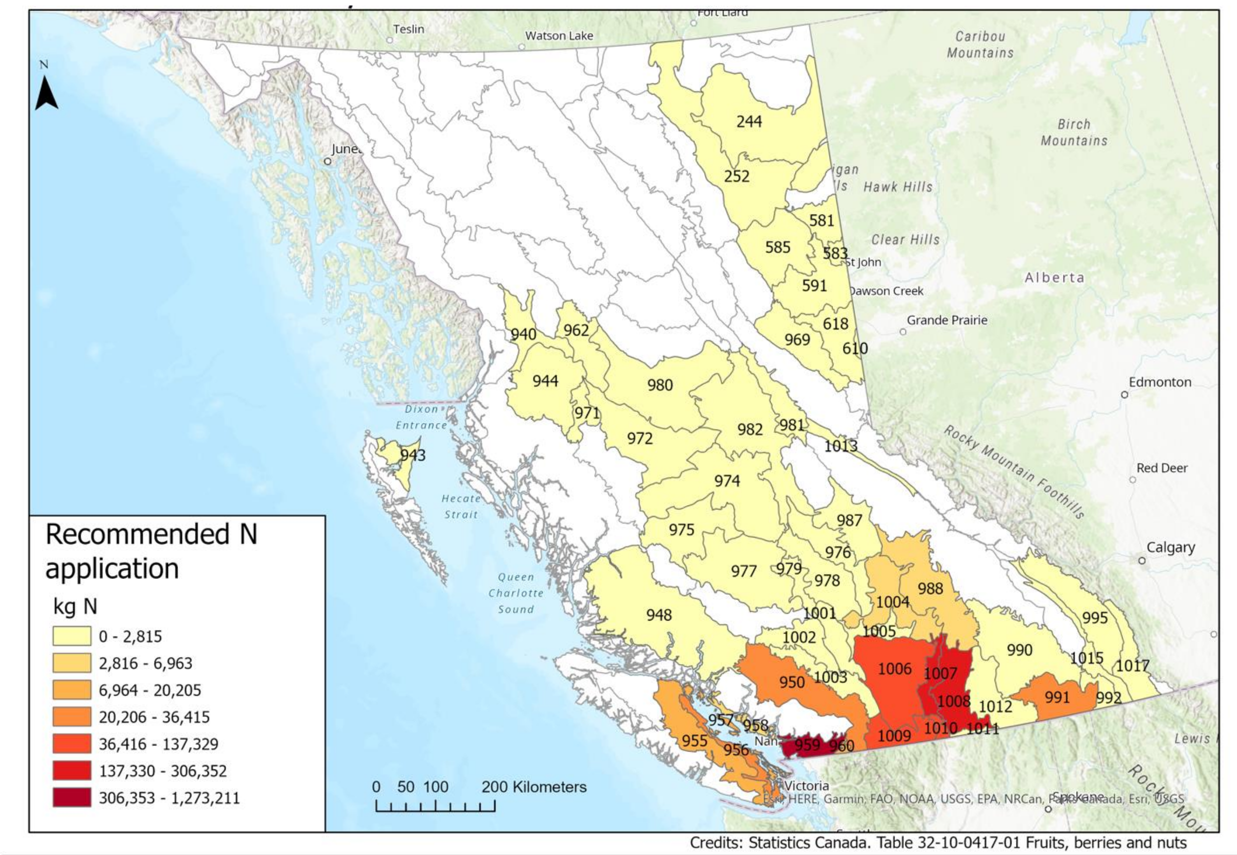


Figure A - 5. *Total recommended N application for tree fruits, grapes, and berries in 2016 in BC by ecodistrict.*