REGIONAL GREENHOUSE GAS EMISSIONS FROM CULTIVATION OF CANOLA FOR USE AS BIOFUEL
CANOLA CULTIVATION IN CANADA

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The European Commission

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EXECUTIVE SUMMARY

The developments in the European biodiesel and hydrogenated vegetable oil (HVO) markets are determined to a large extent by the Renewable Energy Directive (RED II). In November 2016, the European Commission published its ‘Clean Energy for all Europeans’ initiative. As part of this package, the Commission adopted a legislative proposal for a recast of the Renewable Energy Directive. In the context of the co-decision procedure, a final compromise text among the EU institutions was agreed in June 2018. In December 2018, the revised renewable energy directive 2018/2001/EU[1] entered into force.

The RED II has set new overall biofuels targets for the EU and has also defined sustainability requirements. Biofuels without proof of sustainability are not eligible to be counted towards biofuels quota fulfillments and thus are of very limited commercial interest. Inter alia, biofuels must achieve a minimum of 50% greenhouse gas (GHG) emissions savings compared to the fossil reference for plants starting operation before 2015. Installations starting operation after 5 October 2015 but before January 2021, must achieve a GHG saving of at least 60%. Plants starting production after January 2021 but before January 2026 must meet a 65% reduction.

The easiest way to prove compliance with the GHG criteria is the use of the GHG default values from the REDII. The default value for rapeseed biodiesel (which can also be used for canola) provides only a 47% GHG savings (50.1 g CO_2e/MJ) compared to the fossil reference (94 g CO_2e/MJ). The GHG default values from the RED were also split into so-called disaggregated default values for cultivation of rapeseed (32 g CO_2e/MJ), processing (16.3 g CO_2e/MJ) and transport and distribution (1.8 g CO_2e/MJ).

Annex VI of the Directive states that an alternative to using the conservative default values or calculating actual GHG values for each farmer, the REDII allows the use of “estimates of emissions from cultivation (…) derived from the use of averages”.

This study seeks to report estimates for the GHG emissions arising from cultivation of the biofuel feedstock canola in Canada at a similar size as or more fine-grained than the NUTS (Nomenclature of territorial units for statistics) 2 areas within the EU. It identifies regions similar to the NUTS 2 regions in the EU and calculates estimates of emissions from the cultivation of canola as biofuel feedstocks in accordance with the guidance given by the REDII methodology. In total nine so-called reconciliation units (RU) were identified.

The summary table below presents the different total emissions from cultivation of canola in the different Canadian NUTS 2 regions. The GHG emissions range from 473 to 873 kg CO_2eq/dry-ton canola. Assuming a conversion factor of 0.0600 kg dry feedstock/MJ fatty acid methyl ester (FAME) biodiesel and an allocation factor of 0.6330 between the canola oil and the canola meal then the cultivation emissions range from 18 to 33 g CO_2eq/MJ Canola FAME. All values, except for RU 22, are lower than the default value of 32 g CO_2eq/MJ Canola FAME.

[1] European Commission. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

Table 1 GHG Emissions from Cultivation of Canola

Single emissions ($kg\ CO_2eq$/dry-tonne)						Total emissions	
Region	Seeding	Fertilizer production[2]	N_2O field emissions[3]	Pesticide production	Field operations	(kg CO_2eq/dry-tonne)	g CO_2eq/MJ FAME
RU 22	2.2	270.3	533.8	7.5	59.3	873.1	33
RU 23	1.9	255.2	317.5	6.5	51.6	632.7	24
RU 24	2.0	250.0	265.1	6.6	51.6	575.2	22
RU 28	1.9	250.2	199.3	6.3	42.5	500.2	19
RU 29	2.0	255.6	165.3	6.6	43.2	472.7	18
RU 30	2.2	263.0	187.7	7.4	42.9	503.2	19
RU 34	2.2	278.5	288.0	7.3	49.4	625.2	24
RU 35	2.0	233.4	206.8	6.6	44.6	493.4	19
RU 37	2.2	279.1	378.4	7.5	56.1	723.3	27

[2] Includes neutralization of N fertilizer acidification effects, and fertilizer transportation.
[3] Includes direct and indirect emissions.

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1. INTRODUCTION

Canada is a leading producer of canola in the world. Most of the production is exported, either as seed, oil or meal. The European Union is an important outlet for Canada's canola. Large volumes of canola oil are used for biodiesel production. Around 99% of the Canadian canola production takes place in the three Prairie Provinces Manitoba, Saskatchewan and Alberta (see Figure 1 and Table 2).

The developments in the European biodiesel and hydrogenated vegetable oil (HVO) markets are determined to a large extent by the Renewable Energy Directive (RED II). In November 2016, the European Commission published its 'Clean Energy for all Europeans' initiative. As part of this package, the Commission adopted a legislative proposal for a recast of the Renewable Energy Directive. In the context of the co-decision procedure, a final compromise text among the EU institutions was agreed in June 2018. In December 2018, the revised renewable energy directive 2018/2001/EU[4] entered into force.

The RED II has set new overall biofuels targets for the EU and has also defined sustainability requirements. Biofuels without proof of sustainability are not eligible to be counted towards biofuels quota fulfillments and thus are of very limited commercial interest. Inter alia, biofuels must achieve a minimum of 50% greenhouse gas (GHG) emissions savings compared to the fossil reference for plants starting operation before 2015. Installations starting operation after 5 October 2015 but before January 2021, must achieve a GHG saving of at least 60%. Plants starting production after January 2021 but before January 2026 must meet a 65% reduction.

The easiest way to prove compliance with the GHG criteria is the use of the GHG default values from the REDII. The default value for rapeseed biodiesel (which can also be used for canola) provides only a 47% GHG savings (50.1 g CO_2e/MJ) compared to the fossil reference (94 g CO_2e/MJ). The GHG default values from the RED were also split into so-called disaggregated default values for cultivation of rapeseed (32 g CO_2e/MJ), processing (16.3 g CO_2e/MJ) and transport and distribution (1.8 g CO_2e/MJ).

Annex VI of the Directive states that an alternative to using the conservative default values or calculating actual GHG values for each farmer, the REDII allows the use of "estimates of emissions from cultivation (…) derived from the use of averages".

Article 31 of the Directive (Calculation of the greenhouse gas impact of biofuels, bioliquids and biomass *fuels) further states:*

> *2. Member States may submit to the Commission reports including information on the typical greenhouse gas emissions from the cultivation of agricultural raw materials of the areas on their territory classified as level 2 in the nomenclature of territorial units for statistics (NUTS) or as a more disaggregated NUTS level in accordance with Regulation (EC) No 1059/2003 of the European Parliament and of the Council. Those reports shall be accompanied by a description of the method and data sources used to calculate the level of* emissions. *That method shall take into account soil characteristics, climate and expected raw material yields.*
>
> *3. In the case of territories outside the Union, reports equivalent to those referred to in paragraph 2 and drawn up by competent bodies may be submitted to the Commission.*

[4] European Commission. (2018) (n 1)

Canada specific values for the cultivation of canola were approved by the Europe Commission on December 18, 2017[5]. The decision by the European Commission is valid for 5 years and thus expires in December 2022.

Following the requirements laid out in the Directive and set by the European Commission, this report calculates new aggregated GHG emissions and GHG emission savings from cultivation of canola feedstocks in Canada on a regional level similar or finer grained to the NUTS 2 level in the EU.

In a first step, the respective regions needed to be defined for calculating averages for a similar level as the NUTS 2 level within the EU. Chapter 2 of this report describes the derivation of regions in compliance with the NUTS 2 requirements. The methodology for the GHG calculation has been deduced from the requirements formulated by the Commission in the REDII and the Commission Implementing Regulation 2022/996[6] . Chapters 3 and 4 describe the methodology applied as well as the data input and data sources used for the GHG emission calculation. Chapter 5 includes methodology and data input for calculating the nitrous oxide emissions. Chapter 6 entails the results of the GHG calculation as well as main impact factors.

[5] Commission Implementing Decision (EU) 2017/2379. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017D2379&from=SV

[6] EC (2022). Commission Implementing Regulation (EU) 2022/996. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R0996&from=EN

2. DERIVATION OF NUTS 2 EQUIVALENT REGIONS IN CANADA

2.1 USING AVERAGE GHG VALUES FOR AGRICULTURAL AREAS

As noted in the previous chapter, Article 31 of the RED II allows typical GHG emission values at the NUTS 2 level to be submitted to the Commission by Member States and that territories outside of Union can present similar reports to the Commission.

The following chapter describes the application of the NUTS 2 concept as required by the REDII within Canada. Based on the NUTS 2 concept (as described in chapter 2.2), a similar level has been identified and transposed in Canada (chapter 2.3).

2.2 NUTS CONCEPT

The Nomenclature of Territorial Units for Statistics (NUTS) is an EU-developed geocode standard for subdividing the economic territory of Member States into territorial units for statistical purposes.[7] The NUTS classification is hierarchical. It subdivides each Member State into NUTS level 1 territorial units, each of which is subdivided into NUTS level 2 territorial units, these in turn being subdivided into NUTS level 3 territorial units.

There are two requirements for the identification of territorial units:

1. **Administration**: There shall be an existing administrative unit, i.e., a geographical area with an administrative authority that has the power to take administrative or policy decisions for that area within the legal and institutional framework of the Member State.
2. **Population**: In order to establish the relevant NUTS level in which a given class of administrative units (NUTS 1, 2 or 3) in a Member State is to be classified, the average size of this class of administrative units in the Member State shall lie within the following population thresholds:

   NUTS 1: 3 million to 7 million
   NUTS 2: 800,000 to 3 million
   NUTS 3: 150,000 to 800,000

If for a given level of NUTS (1, 2 or 3) no administrative units of a suitable scale exist in a Member State, this NUTS level shall be constituted by aggregating an appropriate number of existing smaller contiguous administrative units. This aggregation shall take into consideration such relevant criteria as geographical, socio-economic, historical, cultural or environmental circumstances.

The NUTS 2 level is the relevant level for calculating average GHG emission values for agricultural production. Therefore, the general rule for a region outside the EU for which average GHG emission values are calculated would be that it must lie within an administrative unit and the population of this administrative unit would need to be between 800,000 and 3 million people.

[7] EC (2003): Regulation (EC) No 1059/2003 of the European Parliament and of the Council of 26 May 2003 on the establishment of a common classification of territorial units for statistics (NUTS). Brussels. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32003R1059&from=EN

2.3 TRANSPOSITION OF NUTS CONCEPT TO CANADA

Although the NUTS concept is specifically developed for the EU, according to REDII the concept can be transposed to 3rd countries such as Canada to calculate average GHG values. The European Commission states "… within the EU, the averages should be for NUTS 2 areas or for a more fine-grained level. A similar level would logically also be appropriate outside the EU." To define regions in Canada according to this "similar level" the above-mentioned criteria on administration and population has been used.

99% of the canola production takes place in the three Prairie Provinces of Alberta, Saskatchewan and Manitoba. These three main provinces of canola production will be further considered within the study. Figure 1 shows the canola growing regions of Canada.

Figure 1 Canola Production in Canada[8]

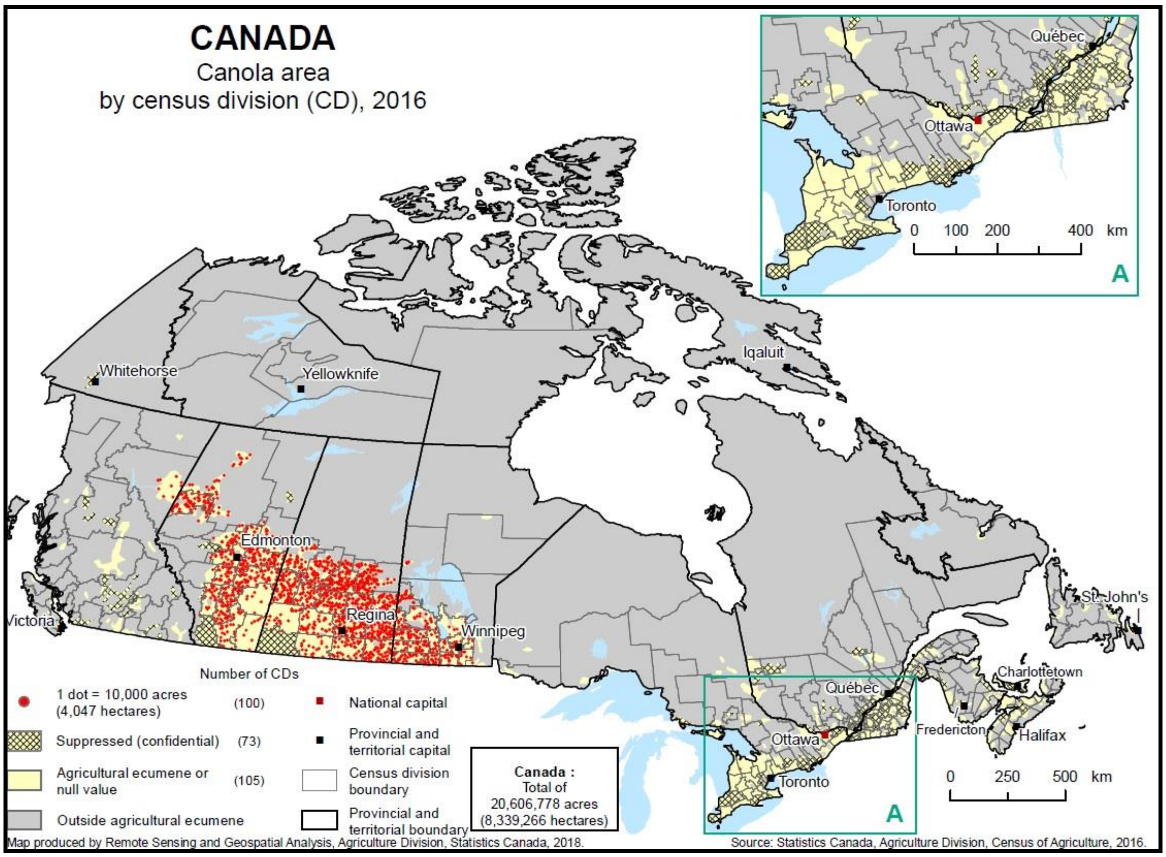


Table 2 provides an overview on the harvested areas of canola from 2018 – 2020 in Canada. The three Prairie Provinces produce over 99% of the canola produced in Canada each year.

[8] Statistic Canada. Canola Area by Census Division 2016. https://www150.statcan.gc.ca/n1/en/pub/95-634-x/2017001/article/54904/pdf/m-c-074-eng.pdf?st=AFRYI-Np

Table 2 Harvested Area of Canola 2015 – 2020[9]

Year	Total Canada	Prairie Provinces			Total Prairie Provinces in 1,000 of hectares (and percentage on total canola area)
		Manitoba	Saskatchewan	Alberta	
	1,000 ha				
2015	8,364.4	1,290.9	4,492.0	2,519.2	8,302.1 (99.3%)
2016	8,263.3	1,254.5	4,522.4	2,422.0	8,198.9 (99.2%)
2017	9,273.1	1,276.8	5,131.4	2,788.3	9,196.5 (99.2%)
2018	9,119.7	1,367.5	4,955.0	2,703.0	9,025.5 (99.0%)
2019	8,471.3	1,298.5	4,756.3	2,355.6	8,410.4 (99.3%)
2020	8,325.4	1,374.6	4,579.6	2,313.5	8,267.7 (99.3%)

For this study, based on the criteria for administration and population, nine areas that are similar to the NUTS 2 level have been derived within these three Provinces. As each of the nine areas lie within one of the three Provinces and as the provinces are administrative units, the criterion of administration is fulfilled.

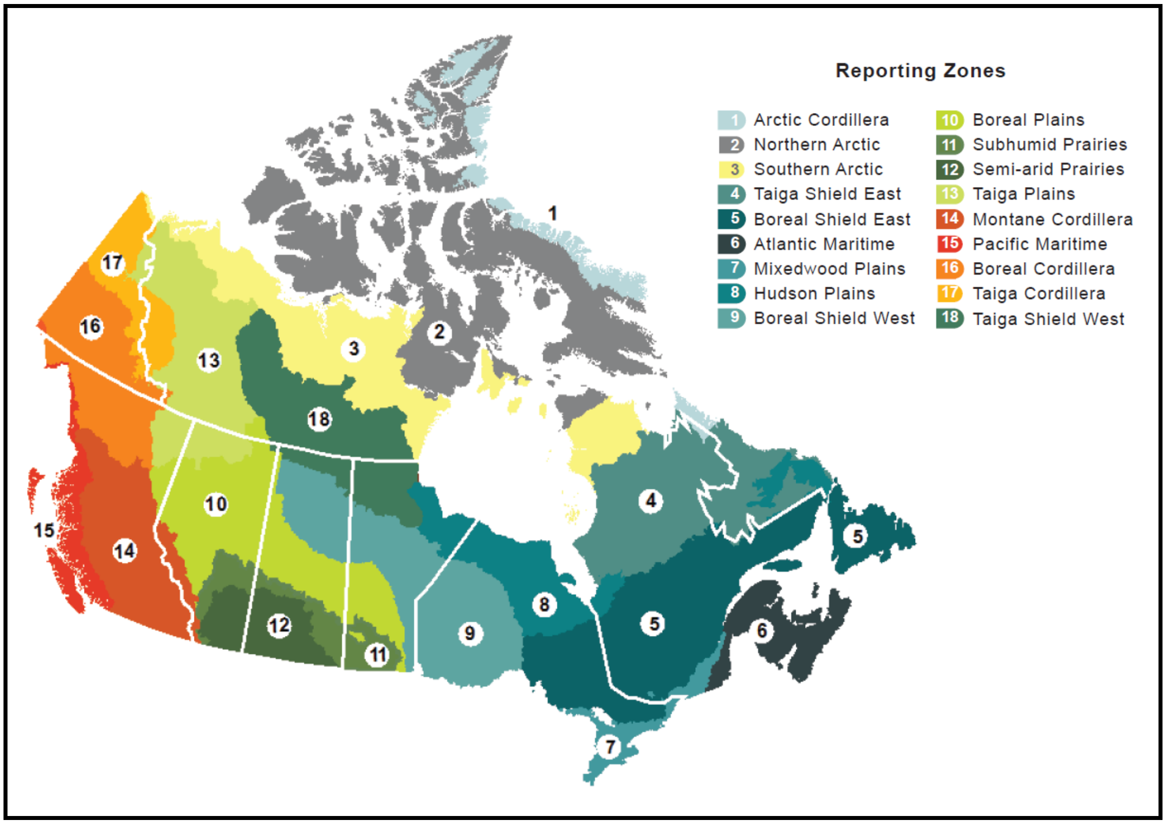
In addition, the Provinces of Saskatchewan and Manitoba with a population of about 1 million each would also fulfill the criterion on population themselves as these figures lay within the range for NUTS 2 areas of 800,000 to 3 million people. However, these Provinces comprise different climates and soil types and therefore are not adequate to calculate greenhouse gas emissions related to canola cultivation. Therefore, they are, in all three cases, split into a more fine-grained level by applying two additional steps:

1. **Overlying with Ecozone Maps**

   Ecozones are areas of the earth's surface representative of large and very generalized units characterized by interactive and adjusting abiotic and biotic factors. Canada comprises 18 ecozones, inter alia the Boreal Plain or the Prairies (see Figure 2). In their current boundaries they were developed for UNFCCC reporting purposes.

[9] Statistics Canada. Table 32-10-0359-01 Estimated areas, yield, production, average farm price and total farm value of principal field crops, in metric and imperial units. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210035901

Figure 2 Ecozones in Canada[10]

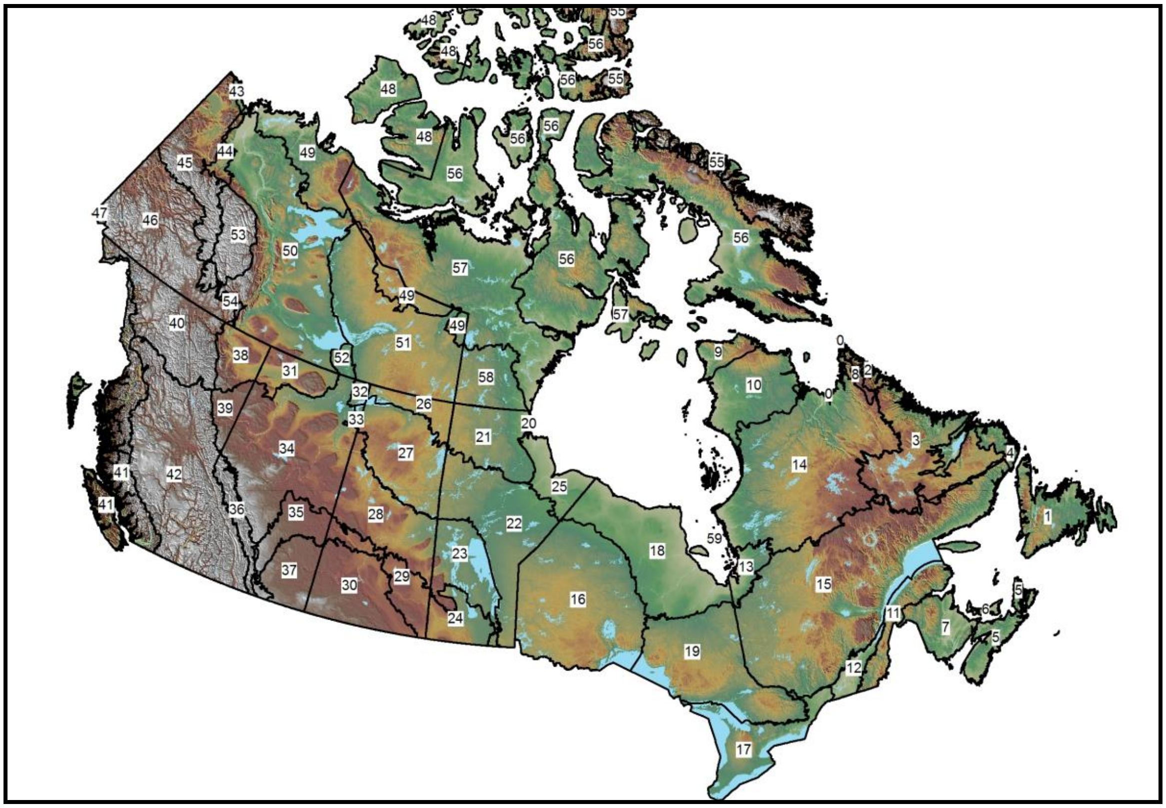


2. Overlying with the Agriculture and AgriFood Canada (AAFC) Reconciliation Units (RUs)

A Reconciliation Unit (RU) is the smallest spatial unit at which activity data from the different sources (Such as AAFC, Canadian Government and Canadian Forest Service) can be harmonized (see Figure 3). RUs are AAFC Reporting Zones subdivided by provincial boundaries. A RU is therefore within a single Province.

[10] Government of Canada (2022): National Inventory Report 1990 – 2022. Greenhouse Gas Sources and Sinks in Canada. Part 1. Environment and Climate Change Canada https://publications.gc.ca/collections/collection_2022/eccc/En81-4-2020-1-eng.pdf

Figure 3 Reconciliation Units (RUs) for Canada[11]



GHG values have been produced only for those RUs with significant areas in canola cultivation.

By applying these two steps and using the RUs and the detailed data available for them, the administrative and population requirements from the NUTS 2 concept in the EU is fulfilled. The data used is representative of canola production conditions in the respective regions. In addition, within the regions there are similar climatic and soil conditions and similar production systems and products. The NUTS 2 requirements are therefore more than met. The fulfillment of the administration and population requirements is summarized in Table 3. The population data is by Census division and each Census division has been applied to an RU. Some Census Divisions overlap two RUs but the population is assigned to just one of the RUs but since all RUs are far below the 3 million population limit this simplification has no impact on the qualification.

[11] AAFC (2001): Opportunities for Reduced Non-Renewable Energy Use in Canadian Prairie Agriculture Production Systems. Ottawa. http://www5.agr.gc.ca/resources/prod/doc/pol/pub/reductopp/pdf/reductopp_e.pdf

Table 3 The Derivation of Reconciliation Units and the Fulfillment of NUTS 2 requirements[12]

Province	Administrative Unit	Population	Ecozone	RU	Population	NUTS2 or smaller fulfilled
Manitoba	Yes	1.4 Million	Boreal Shield West	22	37,000	**Yes**
			Boreal Plain	23	57,390	**Yes**
			Subhumid Prairies	24	1,235,000	**Yes**
Saskatchewan	Yes	1.2 Million	Boreal Plain	28	175,000	**Yes**
			Subhumid Prairies	29	122,000	**Yes**
			Semiarid Prairies	30	842,000	**Yes**
Alberta	Yes	4.4 Million	Boreal Plain	34	471,000	**Yes**
			Subhumid Prairies	35	1,884,000	**Yes**
			Semiarid Prairies	37	1,670,000	**Yes**

[12] Statistics Canada (2022): Population Projections for Canada, Provinces and Territories. https://www150.statcan.gc.ca/n1/pub/91-520-x/91-520-x2022001-eng.htm

3. METHODOLOGY

3.1 CULTIVATION OF CANOLA FOR BIOFUEL PRODUCTION

The methodology for this study was based on the text of the REDII[13], according to which the GHG emissions from the production and use of transport fuels, biofuels and other bioliquids shall be calculated as:

$E = e_{ec} + e_l + e_p + e_{td} + e_u – e_{sca} – e_{CCS} – e_{CCr}$ Equation (1)

Where:

E	Total GHG emissions from supply and use of the fuel (in g CO_{2eq}/MJ)
e_{ec}	GHG emissions from the extraction or cultivation of raw materials
e_l	Annualized (over 20 years) GHG emissions from carbon stock change due to land use change
e_p	GHG emissions from processing
e_{td}	GHG emissions from transport and distribution
e_u	GHG emissions from the fuel in use (shall be taken to be zero)
e_{sca}	GHG emissions savings from soil carbon accumulation via improved agricultural management
e_{ccs}	GHG emissions savings from carbon capture and geological storage
e_{ccr}	GHG emissions savings from carbon capture and replacement

In this study, only the GHG emissions of cultivating the raw materials e_{ec} are included.

Whenever possible, the input data used represents Canada at NUTS 2 level. Regarding the methodology set out in the REDII and further specified in the “Note on The Conducting and Verifying Actual Calculations of GHG Emission Savings”, the following requirements were considered in the calculation of GHG emissions:

Estimates of emissions from cultivation may be derived from the use of averages calculated for smaller geographical areas than those used in the calculation of the default values, as an alternative to using actual values.

Emissions from the extraction or cultivation of raw materials, e_{ec}, shall include emissions from the extraction or cultivation process itself; from the collection of raw materials; from waste and leakages; and from the production of chemicals or products used in extraction or cultivation.

N_2O emissions are calculated according to the European Commission’s Commission Implementing Regulation (EU) 2022/996.[14] Chapter 5 provides an overview on the calculation method for N_2O emissions.

Emissions from irrigation were integrated in the chapter on field operations and nitrous oxide emissions.

Data on the use of lime for agricultural soils is not collected in the Census of Agriculture. The total quantity of limestone applied in the 2022 National Inventory report was 382,000 tonnes on 47 million hectares. The average rate is very low (8 kg/ha) and there is no information on use by RU or even by Province. There are large regions of the 9 RUs that are considered in

[13] European Commission (2018/2001) (n 1), Annex V, C.
[14] European Commission (2022). (n 6)

this work that have alkaline soils (pH>7)[15]. It has been assumed that no lime is added to the canola production area.

GHG emissions of agricultural feedstocks shall be expressed in kg CO_2eq per dry-ton feedstock.[16]

Emissions from the manufacture of machinery and equipment shall not be taken into account. [Annex V, Part C, Point 1].

The greenhouse gases to be taken into account are CO_2, N_2O and CH_4, and for calculation in terms of CO_2 equivalences those gases shall be valued as follows CO_2: 1; CH_4: 25 and N_2O: 298. [Annex V, Part C, Point 4].

Wastes, agricultural crop residues, including straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerine (glycerine that is not refined), shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials. [Annex V, Part C, Point 18].

[15] Geography of acid soils in the Prairie provinces. https://www.grainews.ca/columns/les-henry-geography-of-acid-soils-in-the-prairie-provinces/

[16] European Commission (2018/2001) (n 1), Annex V, C. Point 2.

4. DATA FOR CALCULATIONS

Data were collated on the factors used in the REDII: Information specific for the NUTS 2 equivalent regions in Canada was used. The following sections outline the data used for: area and crop yields; seed rates; crop residue returns to soil; fertilizer and pesticide applications; and fuel consumption during cultivation.

The data in this report has been derived from primary and secondary data sources. Important sources of input data include Statistics Canada and crop insurance systems. The most recent data sources have been used. Yields are based on 2018-2020 average data.

Further regional data has been obtained from AAFC on N_2O emission factors.[17] This data is IPCC Tier 2 type data that is also used to generate the Canadian National Inventory Report submitted annually to the UNFCCC and is therefore peer reviewed.

4.1 CULTIVATED AREAS AND YIELDS AT THE NUTS 2 LEVEL

Only regions where canola is cultivated over a significant area are considered in the study. Thus, nine NUTS 2 equivalent regions have been identified in Canada, which are important for canola production.

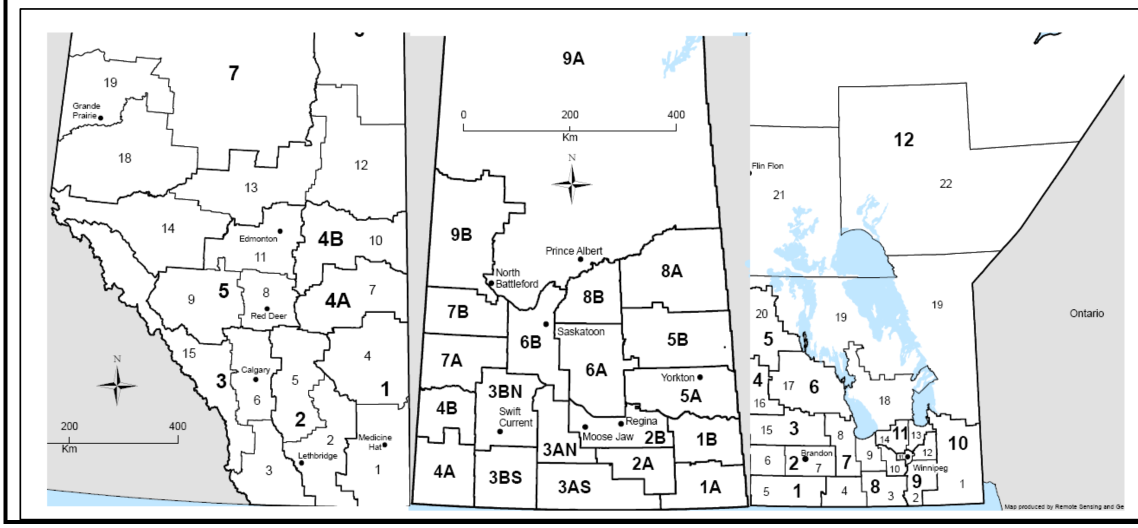
Data on cultivated area as well as canola yield was provided by Statistics Canada for 2018-2020[18]. Data was available for so-called small area data regions. In Manitoba there are 12 small area data regions, in Saskatchewan there are 20, and in Alberta there are 8 regions. The small area data regions are the same as Census Agricultural Regions (CAR), although there is a different numbering system. In the following figure (Figure 4) the Census Agricultural regions for the three provinces are shown.

[17] AAFC, (2022): Personnel communications, D. Worth, August 11, 2022. Ottawa.

[18] Statistics Canada. Estimated areas, yield and production of principal field crops by Small Area Data Regions, in metric and imperial units. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210000201

Figure 4 Census Agricultural Regions[19]

The Agricultural Census Regions in Manitoba, Saskatchewan and Alberta



From the figure it is apparent that there are more Census Agricultural Regions than reconciliation units. Therefore, CAR's data were aggregated on an RU basis. Area and yield data for the CAR is available on an annual basis.[20] In this report, estimates are based on average yields reported for 2018-2020. For the final greenhouse gas emission values in kg CO_2eq per ton canola, the dry matter yield was used. The standardized moisture content of canola in Canada lies between 7 and 9%[21]. In parallel to the Canadian Grain Commission, a historical 8.5% moisture basis was used to convert from moist tonnes to dry tonnes. The results are shown in Table 4.

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[19] Statistics Canada (2022): 2016 census agricultural regions and census divisions. Manitoba. https://www150.statcan.gc.ca/pub/95-630-x/2017000/pdf/Prov46_CARCD-eng.pdf, Statistics Canada (2022) 2016 census agricultural regions and census divisions. Saskatchewan. https://www150.statcan.gc.ca/pub/95-630-x/2017000/pdf/Prov47_CARCD-eng.pdf, Statistics Canada (2022): 2016 census agricultural regions and census divisions. Alberta. https://www150.statcan.gc.ca/pub/95-630-x/2017000/pdf/Prov48_CARCD-eng.pdf

[20] Statistics Canada (2022). Statistics Canada. Table 32-10-0002-01 Estimated areas, yield and production of principal field crops by Small Area Data Regions, in metric and imperial units https://doi.org/10.25318/3210000201-eng

[21] Canadian Grain Commission (2022): Western Canadian canola – Scientific analysis of harvest and export quality. https://www.grainscanada.gc.ca/en/grain-research/export-quality/oilseeds/canola/2020/02-summary.html

Table 4 Cultivated Area and Yields of Canola in Canada 2018 – 2020

	Manitoba			Saskatchewan			Alberta		
	RU 22	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
Cultivated area (ha)	15,922	255,424	1,075,554	1,028,714	2,036,675	1,691,311	896,240	1,122,941	455,292
Production, tonnes	33,155	611,070	2,544,342	2,531,100	4,787,980	3,547,586	1,920,505	2,642,795	945,304
Moist yield canola (t/ha/yr)	2.08	2.39	2.37	2.46	2.35	2.10	2.14	2.35	2.08
Dry yield canola (dry-t/ha/yr)	1.91	2.19	2.16	2.25	2.15	1.92	1.96	2.15	1.90

4.2 SEED RATE

In 2011, the Canola Council of Canada initiated a Western Canada Canola Production Survey[22]. The primary purpose of the survey was to identify and analyze all of the production factors that might possibly impact yield and the profitability of growing canola in western Canada. The survey was sent to approximately 1,000 producers and over 900 useful surveys were received. The survey recipients were targeted to ensure that they represented all of the Canadian production and that each single region was represented based on its canola production area.

It has been possible to analyze the data from the survey and report much of the information by RU. This collation and reporting of the data have been performed by AAFC (Smith et al, 2012). Due to confidentiality reasons, it was not possible to report the data from RU 22 due to the small sample size. A seed rate of 5.4 to 5.6 kg/ha was found by the survey. That is still the most recent survey.

The Saskatchewan Crop Planning Guide 2021[23] recommends a seeding rate of 5 lb/acre (5.6 kg/ha) and the Manitoba CROPPLAN Production Cost, Marketing and Management Calculator [24] recommends a seeding rate of 5 lb/acre (5.6 kg/ha). The Saskatchewan value is the same as it was in 2016 but the Manitoba value has increased by 10%. A conservative value of 5.6 kg seed/ha has been used for all RUs. That is at the high end of the 2011 range and is the recommended value in the two Provincial Government crop planning guides.

The emission factor for canola seed is the standard value reported in Commission Implementing Regulation (EU) 2022/996[25]. It is 0.7565kg CO_2eq/kg seed.

[22] Canola Council of Canada, CCC (2011): Survey of Canola farmers. Winnipeg
[23] Saskatchewan Agriculture. 2021. Crop Planning Guide 2021. https://publications.saskatchewan.ca/api/v1/products/111426/formats/125043/download
[24] Manitoba Agriculture. 2021. CROPPLAN Production Cost, Marketing and Management Calculator. https://www.gov.mb.ca/agriculture/farm-management/production-economics/pubs/calculator-cropplan.xls
[25] European Commission 2022 (n 6)

Table 5 Canola Seed Rates (kg/ha) in Canada

	Manitoba			Saskatchewan			Alberta		
	RU 22	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
Seed (kg/ha)	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6

4.3 Fertilizer Application

Actual data on fertilizer application rates of fertilizer applied was obtained for Manitoba (2018 only) and Saskatchewan (2018-2020) from their crop insurance programs. Fertilizer application rates from Stratus Surveys for 2016, 2017, and 2019 were also obtained to supplement the crop insurance data.

4.3.1 Fertilizer Application Rates

The fertilizer rates are all reported on a per area basis by the reporter. This is how the values are entered into the calculator developed for this project, but the rates must be tied to the yield as the GHG emissions are reported per tonne of canola produced. The information from each of the three sources is discussed below.

4.3.1.1 Manitoba

The Manitoba Crop Insurance Corporation[26] stopped collecting and reporting fertilizer application rates in 2018, the first year of the time period used for this study. The data for the 2016 to 2018 period is shown below.

[26] Manitoba Agricultural Services Corporation. 2021. Manitoba Management Plus Program. http://www.mmpp.com/mmpp.nsf/mmpp_index.html

Table 6 Manitoba Crop Insurance Fertilizer Application Rates

RU	2016	2017	2018	2016-2018
Nitrogen	Kg/ha			Average kg/t (moist)
22	129.6	134.4	136.8	56.4
23	126.7	130.3	135.5	47.8
24	122.3	126.0	130.4	48.2
Phosphorus				
22	44.8	44.7	49.4	19.7
23	42.2	43.1	45.2	15.9
24	40.0	41.2	42.7	15.8
Potassium				
22	12.0	16.9	13.5	5.8
23	13.9	13.7	16.0	5.3
24	8.5	8.7	10.3	3.5
Sulphur				
22	16.4	17.8	15.0	6.8
23	22.1	23.0	23.8	8.4
24	20.3	20.5	21.1	7.9

4.3.1.2 Saskatchewan

The Saskatchewan crop insurance data[27] for canola for the three-year period 2018-2020 is shown in the following table.

Table 7 Saskatchewan Crop Insurance 2018-2020 Fertilizer Application Rates

RU	Application rate	2018-2020
Nitrogen	kg/ha	Average kg/t (moist)
28	134.1	51.0
29	126.2	48.5
30	118.2	50.3
Phosphorus		
28	39.3	14.9
29	39.5	15.2
30	35.5	15.1
Potassium		
28	10.4	3.9
29	8.7	3.3
30	4.7	2.0
Sulphur		
28	26.7	10.1
29	23.4	9.0
30	19.5	8.3

[27] Saskatchewan Crop Insurance Corporation. 2021. Personal Communication, Donna Hack. June 8, 2021.

4.3.1.3 Stratus

Stratus Ag Research[28] undertook surveys of producers of canola in the three Prairie provinces in 2016 (400 respondents), 2017 (660 respondents), and 2019 (508 respondents). The responses were sorted by province and ecozone (RU). There were no responses for RU 22. The average of those three years is summarized in the following table.

Table 8 Stratus Fertilizer Application Data – Imperial Units

RU	N	P_2O_5	K_2O	S	Yield
	Pounds/acre				Bushels/acre
23	138.3	39.1	22.9	26.9	45.63
24	126.9	42.0	22.0	20.7	46.24
28	118.1	32.7	15.5	27.0	46.18
29	121.6	37.6	17.9	24.9	46.29
30	108.9	40.7	17.5	23.7	42.43
34	125.7	36.5	23.6	27.4	44.36
35	120.1	36.5	23.6	27.4	52.15
37	118.9	38.5	23.2	24.2	44.66

The Stratus application rates are all higher than the crop insurance rates but the yields are also higher and they are higher than the StatsCan yields. The same data in metric units is shown in the following table.

Table 9 Stratus Fertilizer Application Data - Metric

RU	N	P_2O_5	K_2O	S	Yield
	kg/t canola (moist)				T (moist)/ha
23	60.6	17.1	10.0	11.8	2.56
24	54.9	18.2	9.5	8.9	2.59
28	51.1	14.1	6.7	11.7	2.59
29	52.5	16.3	7.7	10.7	2.59
30	51.3	19.2	8.2	11.2	2.38
34	56.7	16.5	10.6	12.4	2.49
35	46.0	14.0	9.0	10.5	2.92
37	53.2	17.2	10.4	10.8	2.50

4.3.2 Fertilizer Rate Summary

The following table compares the rate data from the three sources and the value selected for the modelling. The rate per unit area is then shown (the value used in the calculations) based on the yields in each RU from Statistics Canada.

[28] Stratus Ag Research has undertaken annual surveys of selected crops and areas for Fertilizer Canada. The results have not been published in the public domain.

Table 10 Nitrogen Fertilizer Application Rates

RU	Crop Insurance	Stratus	For Modelling	
	Kg/tonne			Kg/ha
22	56.4	-	56.4	112.8
23	47.8	60.6	54.2	129.5
24	48.2	54.9	51.5	122.0
28	51.0	51.1	51.0	125.5
29	48.4	52.5	50.4	118.5
30	50.3	51.3	50.8	107.7
34	-	56.7	56.7	123.0
35	-	46.0	46.0	108.6
37	-	53.2	53.2	112.3

For Saskatchewan and Manitoba, the average of the two information sources are used. The Stratus values are used for Alberta since that is the only data source available.

The available Phosphorus data is shown in the following table. The values are relatively close and an average value is used where multiple values are available.

Table 11 Phosphorus Fertilizer Application Rates

RU	Crop Insurance	Stratus	For Modelling	
	Kg/tonne			Kg/ha
22	19.7	-	19.7	40.2
23	15.9	17.1	16.5	39.9
24	15.8	18.2	17.0	40.2
28	14.9	14.2	14.5	35.7
29	15.2	16.3	15.5	36.8
30	15.1	19.2	17.1	36.1
34	-	16.5	16.5	35.4
35	-	14.0	14.0	33.2
37	-	17.2	17.2	36.3

The potassium fertilizer data is shown in the following table. The Stratus values are significantly higher than the values from the two crop insurance programs. Potassium fertilizer has the lowest carbon intensity of the three major fertilizers and the absolute magnitude of the differences is small. The average value has been used where available and an average of those values has been used for the other RUs.

Table 12　Potassium Fertilizer Application Rates

RU	Crop Insurance	Stratus	For Modelling	
	Kg/tonne			Kg/ha
22	5.8	-	6.0	12.3
23	5.3	10.0	7.6	18.4
24	3.5	9.5	6.6	15.6
28	4.0	6.7	5.3	13.0
29	3.3	7.7	5.5	13.0
30	2.0	8.3	5.2	11.0
34	-	10.6	6.0	12.9
35	-	9.0	6.0	14.2
37	-	10.4	6.0	12.7

The sulphur data is shown in the following table. The Stratus values are higher than the crop insurance values but not by a significant amount. The average value has been used where available and an average of those values has been used for the other RUs. The average difference between the two sources is 1 kg/tonne. This difference has been added to the RU 22 value and subtracted from the Alberta RUs.

Table 13　Sulphur Fertilizer Application Rates

RU	Crop Insurance	Stratus	For Modelling	
	Kg/tonne			Kg/ha
22	6.8	-	7.8	15.9
23	8.4	11.8	10.1	24.4
24	7.9	8.9	8.4	19.9
28	10.13	11.7	10.9	26.8
29	8.99	10.7	9.9	23.5
30	8.29	11.2	9.7	20.5
34	-	12.4	11.4	24.4
35	-	10.5	9.5	22.5
37	-	10.8	10.8	22.8

The values used for the calculations are shown in the following table.

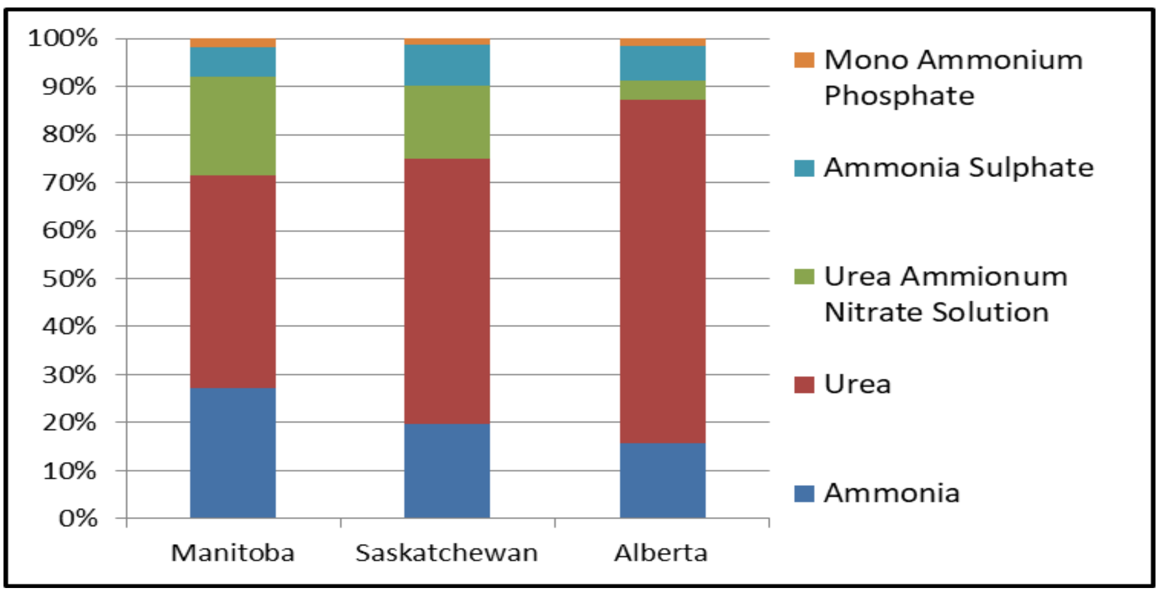
Table 14 Fertilizer Application Rates (kg/ha) in Canada

	Manitoba			Saskatchewan			Alberta		
	RU 22	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
Synthetic N-fertilizer (kg N/ha/yr)	112.8	129.5	122.0	125.5	118.5	107.7	123.0	108.6	112.3
K_2O-fertilizer (kg K_2O/ha/yr)	12.3	18.4	15.6	13.0	13.0	11.0	12.9	14.2	12.7
P_2O_5-fertilizer (kg P_2O_5/ha/yr)	40.2	39.9	40.2	35.7	36.8	36.1	35.4	33.2	36.3
S-fertilizer (kg S/ha/yr)	15.9	24.4	19.9	26.8	23.5	20.5	24.4	22.5	22.8

4.4 Different Nitrogen Fertilizer Types

Statistics Canada does report fertilizer shipments to the provinces on the basis of the type of fertilizer[29]. This information is reported by crop year (July 1 to June 30), with the assumption that fertilizer shipped during the fertilizer year will be applied in the second calendar year. The three-year average for July 2017 to June 2020, representing the calendar years 2018, 2019 and 2020 is shown in the following figure.

Figure 5 Nitrogen Fertilizer Sales by Type – 2017/2020



Source: Statistics Canada. Table 32-10-0038-01

[29] Statistics Canada. Table 32-10-0038-01 Fertilizer shipments to Canadian agriculture and export markets, by product type and fertilizer year, cumulative data (x 1,000). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210003801

There was also information available from the Stratus 2019 survey at the RU level for Alberta, Saskatchewan and Manitoba. This information was used for the Ammonia, Urea, UAN and Ammonium Nitrate rates. The information for RU 22 was the Statistics Canada information. The values used for canola production are shown in the following table. The difference between the provincial average and the Stratus canola data was small but it did result in a small increase in the average fertilizer manufacturing emissions.

Table 15 Nitrogen Fertilizer Type for Canola

RU	Ammonia	Urea	UAN	AN/CAN	AS	MAP	DAP
	Fraction						
22	0.272	0.444	0.204	0.000	0.063	0.018	0.000
23	0.613	0.306	0.000	0.000	0.063	0.018	0.000
23	0.422	0.368	0.130	0.011	0.053	0.015	0.000
28	0.384	0.441	0.096	0.000	0.068	0.011	0.000
29	0.184	0.597	0.122	0.015	0.070	0.012	0.000
30	0.104	0.658	0.127	0.023	0.076	0.013	0.000
34	0.399	0.491	0.031	0.000	0.064	0.015	0.000
35	0.200	0.670	0.040	0.010	0.065	0.015	0.000
37	0.067	0.824	0.022	0.000	0.071	0.016	0.000

4.5 MANURE

There is no information on manure application rates in Canada. Statistics Canada reports on the area that receives manure (Statistics Canada 2023).

Table 16 Manured Area

	Manitoba	Saskatchewan	Alberta
	Hectares		
Solid Manure	135,129	260,565	449,658
Liquid Manure	85,038	32,730	93,370
Total Area	220,167	293,295	543,028

A report from Agriculture and Agrifood Canada[30] reported on the type of land that the manure was applied to. Overall, they reported that across Canada, land receiving solid manure was used for growing perennial forages (45%), cereals (27%), corn (14%), and oilseeds (9%) in 2011. Land receiving liquid manure was used for growing perennial forages (39%), corn (32%), oilseeds (14%), and cereals (14%). Oilseeds includes canola, soybeans, mustard and sunflower and flax. They did provide a breakdown by province. The oilseed percentage by Province is shown in the following table.

[30] Agriculture and AgriFood Canada. 2016. Canadian Manure Management Practices on Cropland from the Farm Environmental Management Survey (FEMS) 2011. 2016. https://publications.gc.ca/collections/collection_2016/aac-aafc/A59-38-2016-eng.pdf

Table 17 Percent of Manured Area in Oilseeds

	Manitoba	Saskatchewan	Alberta
		Percent	
Solid Manure	11.8	12.4	12.7
Liquid Manure	33.6	34.7	35.7
Total Area	45.4	47.1	48.4

The area of the various oilseeds in the three provinces is shown in the following table.

Table 18 Oilseed Crop Area

	Manitoba	Saskatchewan	Alberta
		Hectares	
Canola area	1,346,900	4,756,700	2,474,473
Flax area	21,467	284,167	36,800
Soybean area	594,767	86,947	0
Mustard area	1,350	113,300	41,333
Sunflower Area	30,033	2,800	1,450
Total Area	1,994,517	5,243,914	2,554,056
Canola area as Percentage of oilseed area	68%	91%	97%

The following table shows the calculated area of canola that has manure applied and the percentage of the total canola area.

Table 19 Fraction of Canola Area with Manure

	Manitoba	Saskatchewan	Alberta
		Percent	
Canola area	1,346,900	4,756,700	2,474,473
Canola area manured	30,063	39,610	87,622
Percent manured	2.23%	0.83%	3.54%

There is no information on the quantity of manure that is applied. The AAFC report on manure management reported that only 2.9% of solid manure on the prairies is tested for nutrient and 37.2 % of the liquid manure is tested.

The 2019 Stratus survey indicated that 99% of canola growers applied synthetic nitrogen fertilizer. Thus, it is likely that manure application rates were less than the total N required.

Discussions with agronomists at Agriculture and Agrifood Canada, the University of Manitoba and commercial crop advisors[31] indicate that the maximum manure application rate is 75% of

[31] Devon Worth, Physical Scientist, AAFC. Dr. Curtis Rempel, Vice President Crop Production & Innovation, Canola Council of Canada and Adjunct Professor, Department of Food and Human Nutritional Sciences, Faculty of Agriculture and Food Sciences, University of Manitoba. Dr. Mario Tenuta. Canada Research Chair in Applied Soil Ecology Department of Soil Science, University of Manitoba.

the total N that is applied for the crop. Some land will receive less as P is the limiting factor. All crops receive at least 25% of the N fertilizer as synthetic fertilizer. The amount of manure N applied for each RU is calculated based on the total N reported as applied by synthetic fertilizer times 0.75 times the fraction of canola that receives manure in the province. The rates calculated are shown in the following table.

Table 20 Estimated Manure N Applied

RU	Kg N as manure/ha
22	1.86
23	2.14
24	2.01
28	0.78
29	0.74
30	0.67
34	3.27
35	2.88
37	2.98

4.6 FERTILIZER EMISSION FACTORS

There are Canada specific emission factors for the fertilizers used in Canada. For this work the emission factors that have been used are the standard values specified by the Commission where they are available.

There are no standard values for Mono Ammonium Phosphate (MAP) as an N source and no value for S other than as ammonia sulphate as N.

For the MAP we have used the same value per kg of N as is used per kg of P_2O_5 as we don't know how the value for the P_2O_5 was partitioned, to arrive at the standard values.

Three other commercial sulphur products were included in the Stratus data. One is a Potassium Magnesium Sulphate product. It will have a very low GHG emission profile likely similar to potash, the second product is an elemental sulphur product which will also have a low GHG emission profile since elemental sulphur is essentially a waste product from the oil and gas sector in Canada; the third product is Monoammonium Phosphate with Ammonium Sulphate and Sulphur. The sulphur in this product is an average of AS and elemental sulphur.

The emissions for sulphur that are not accounted for by the ammonium sulphate application will be calculated based on the assumption that each of the three other sulphur products are used in equal volumes. Elemental sulphur will be zero rated, the potassium magnesium sulphate product will have the same emissions as potash, and the third product will have half of the emissions of ammonium sulphate since it is a blend of AS and elemental sulphur. This results in an emission factor for the other S of 0.55 kg CO_2eq/kg of S.

4.6.1 CO_2 Emissions from Urea Applications

Urea and UAN fertilizers will release CO_2 when they are applied to the soil. This CO_2 is not included in the standard emission factors for the production of these products. The IPCC emission factor for these emissions for urea is 0.20 tonnes C/tonne of urea. Since urea contains 0.46 tonnes of N per tonne of urea, the emission factor can be expressed as 0.435

tonnes of C per tonne of N. To arrive at the tonnes of CO_2 this must be multiplied by 44/12 to arrive at 1.59 tonnes of CO_2/tonne of N in urea.

UAN fertilizer contains 30% urea, so the CO_2 emission factor is 0.688 tonnes of CO_2/tonne of N in UAN. (0.06 tonnes C/tonne of UAN, 32% N in UAN, 60/0.32*44/12=688 g CO_2/tonne of N).

These values have been added to the emission factor for urea and UAN production in the calculation. These emissions are now included in the fertilizer production emissions.

4.7 Fertilizer Transportation

Fertilizers are produced in the canola production regions. There are nine nitrogen manufacturing facilities, one in Manitoba, one in Saskatchewan, and seven in Alberta. There are nine potash manufacturing facilities in Saskatchewan, and there is one phosphorus facility in Alberta.

There is no detailed data on the fertilizer transportation distances to the farms available. Estimates have been made based on the location of the facilities in each Province. These are shown in the following table. These are one way distance estimates based on the location of the nitrogen fertilizer plants in relation to the location of the RUs.

Table 21 Fertilizer Transportation Estimates

RU	Estimated Distance, km
22	280
23	200
24	100
28	350
29	250
30	150
34	200
35	200
37	200

The fertilizer transport emission factor has been calculated using the Standard Value for Truck (40 tonne) for liquids and pellets (Diesel), and the emission factor for diesel fuel of 95.1 g CO2/MJ. This is slightly more conservative than the factors for dry products. The emission factors are shown in the following table. The transportation emission factors include the emissions from an empty return and thus they are applied to the one-way distance.

Table 22 Transport Emission Factor

Parameter	Emission Factor	g CO_2 eq/t-km
Fuel Efficiency	0.87 MJ/tonne-km	
CO_2	95.1 g/MJ	82.737
CH_4	0.0040 g/t-km	0.100
N_2O	0.0016 g/t-km	0.477
Total		83.314

The mass of all of the fertilizers and the pesticides has been used to calculate the transportation emissions. The mass of the N fertilizers has been calculated based on the N content.

The transportation emissions are the sum of the mass transported, the distance transported and the transport emission factor.

4.8 Crop Residue Nitrogen Returns

Emissions arising from crop residues are also included in line with the methodology of the REDII[32]. The crop residue data for canola is based on the approach used in the implementing regulations.[33] This is a variation of the IPCC methodology as the IPCC does not provide the necessary parameters for rapeseed (canola). The amount of nitrogen in the residue was calculated per tonne of seed.

Table 23 Canola Crop Residues and Respective N Concentrations

	Canola Seed	Above Ground Biomass	Below Ground Biomass
Relative dry matter (DM) allocation	1.0	1.5	0.19
N concentration in g N/kg		11	17
kg N in residue/dry t seed		16.5	3.2
kg N in residue/moist t seed		15.1	2.9

The total crop residue nitrogen is 18.1 kg N/t of moist seed produced at 8.5% oilseed moisture. Based on the yields, the N input per hectare and year from crop residue return has been calculated for each RU.

Table 24 Crop Residue Returns

	Manitoba			Saskatchewan			Alberta		
	RU 23	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
N from crop residues (kg N/ha)	37.6	43.2	42.7	44.4	42.4	37.9	38.7	42.5	37.5

Crop residue burning is not regularly monitored in Canada. The last survey was undertaken in 2006 and only 1% of the canola residue was burned in Manitoba and Saskatchewan and none in Alberta[34]. The quantity of crop residue that was burned had decreased over time. It has been assumed that no canola crop residue was burned in the 2018 to 2020 period.

[32] European Commission (2018) (n 1)
[33] European Commission (2022) (n 6)
[34] National Inventory Report 1990–2020: Greenhouse Gas Sources and Sinks in Canada. Part 2. https://publications.gc.ca/collections/collection_2022/eccc/En81-4-2020-2-eng.pdf

4.9 NEUTRALIZATION OF ACIDITY FROM NITROGEN FERTILIZERS

The soils of Western Canada are alkaline and lime is not added to the soils. The Commission Implementation Regulation[35] includes a non-IPCC category of theoretical lime addition for counter the acidification potential of nitrogen fertilizers.

The emission factors are 0.783 kg CO_2/kg of N fertilizer and 0.806 kg CO_2/kg N for urea. These emissions as calculated are shown in the following table.

Table 25 CO_2 Emissions from Neutralization of Acidity

	Manitoba			Saskatchewan			Alberta		
	RU 23	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
CO_2 emission from N fertilizer neutralization per moist tonne	43.0	42.8	40.8	40.5	40.2	41.0	45.6	36.8	43.4

4.10 PESTICIDES

There is no canola specific pesticide rate data reported in Canada. The 2011 Canola Council survey reported on the number of applications of individual products and whether the rate applied was at, above or below the recommended values. From this data the pesticide application rate was estimated to be 0.68 kg ai/ha.

Alberta Environment and Parks has been collecting pesticide sales data on a regular basis since 1993. For 2018, Alberta Environment and Parks undertook its sixth provincial scale review of pesticide sales[36], using the same data collection and reporting process as was implemented in previous years. This is the latest report available. Alberta categorizes pesticide sales by active ingredient, chemical group, sector of use and geographic distribution in the Province. The findings are shown in the following table.

[35] European Commission (2022) (n 6)

[36] Overview of 2018 pesticide sales in Alberta. https://open.alberta.ca/dataset/fc2a6bbb-a070-444c-8616-97fad2d08ae4/resource/4a6d2fbb-6904-4b09-a312-81aa810ca25a/download/aep-overview-2018-pesticide-sales-alberta-2020-07.pdf

Table 26 Alberta Pesticide Sales

Type of Use	2003	2008	2013	2018	2018
	kg ai	kg ai	kg ai	kg ai	%
Herbicides, PGR's	7,158,660	10,257,303	13,200,340	13,759,642	82.2
Insecticides, Acaracides, Repellents	433,176	236,169	200,572	319,087	1.9
Fungicides	319,465	388,560	807,883	963,399	5.8
Vertebrate Control Products and Vertebrate Repellents	1,713	12,458	11,334	13,065	0.1
Adjuvants and Surfactants	1,350,160	1,580,104	1,010,265	1,684,881	10.1
Other	1,314	1,501	678	4,564	0.0
Total	9,264,488	12,476,096	15,231,072	13,744,639	100

Herbicides dominate the pesticide usage with 82.2% of all pesticides sold in 2018 being in that category. Adjuvants and surfactants are carriers for the active ingredient and include products such as paraffin mineral oils, esters and methylated canola oil.

Agricultural pesticides accounted for 95.8% of the total provincial pesticide sales in 2018.

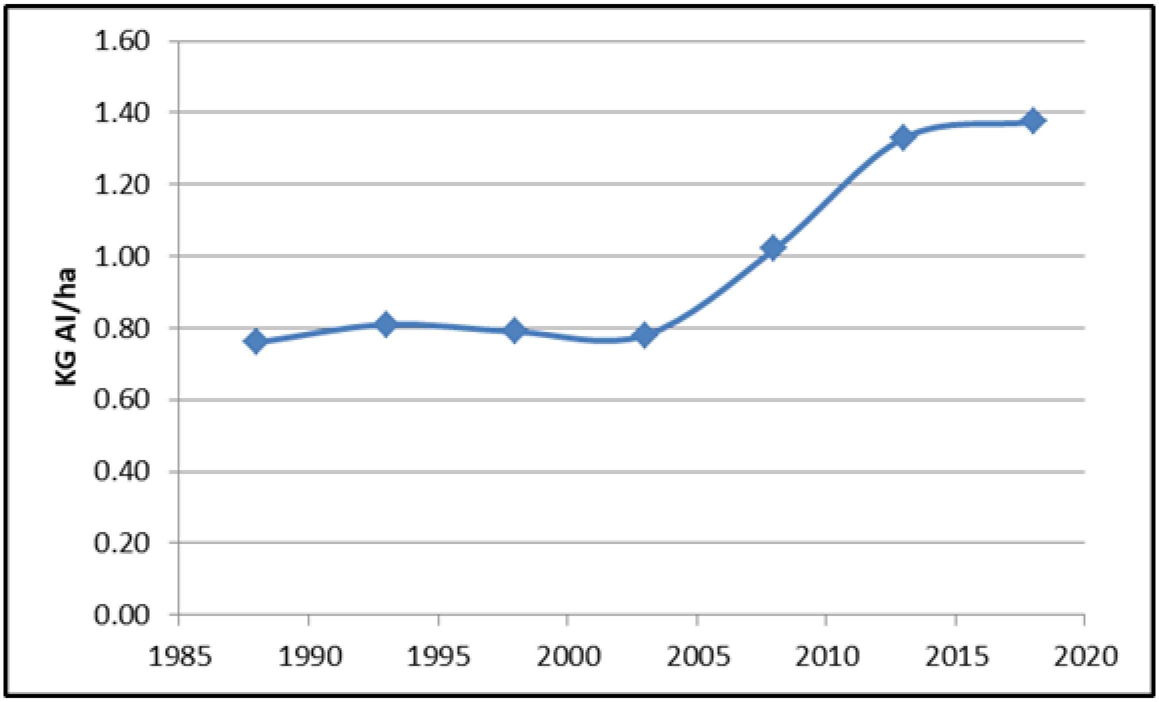
The top eighteen product groups account for 95% of pesticide sales to agriculture. The top 15 active ingredients are shown in the following table.

Table 27 Alberta Pesticide Sales Active Ingredients

Active Ingredient	Usage	2018 Sales (kg ai)
Glyphosate	Herbicide	8,289,611
Glufosinate	Herbicide	950,679
MCPA	Herbicide	925,350
Surfactant Blend	Adjuvant	754,758
2,4-D	Herbicide	641,052
Petroleum Hydrocarbon Blend	Adjuvant	397,956
Bromoxynil	Herbicide	367,728
Bentazon	Herbicide	264,765
Fluroxypyr	Herbicide	261,166
Triallate	Herbicide	222,547
Diquat	Herbicide	173,706
Ethalfluralin	Herbicide	171,059
Polyoxyalkylated alkyl phosphate ester	Adjuvant	140,892
Paraffin Base Petroleum Oil	Adjuvant	139,836
Total		13,701,105

The average application rate in Alberta in 2018 was 1.37 kg AI/ha this excludes the adjuvants use. Alberta does note that some crops such as potatoes and sugar beets have much higher pesticide application rates than cereals and oilseeds.

Figure 6 **Alberta Pesticide Application Rates**



From the Alberta data on pesticide sales, it is known that rates increased for a period of time possibly due to the increase adoption of herbicide tolerant varieties of canola seeds. For this modelling we have used a rate of 1.37 kg ai/ha for canola for the period 2018 to 2020. This should be a conservative value as Alberta notes that some crops have higher application rates than grains and oilseeds.

Table 28 **Pesticides Application Rates**

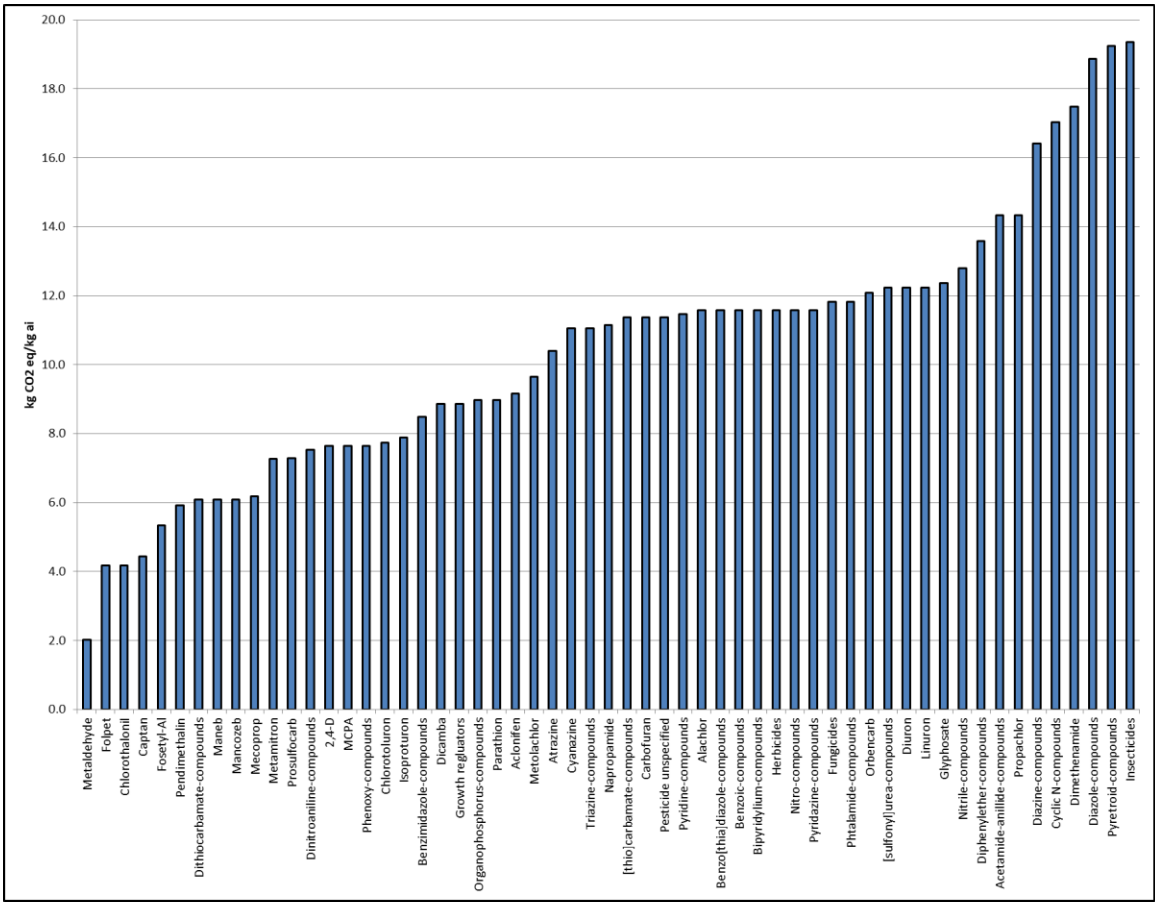
	Manitoba			Saskatchewan			Alberta		
	RU 22	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
Pesticides (kg ai./ha)	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37

The EU Implementing Regulation states that the emission factor for pesticides is included in Annex IX but there is no value reported there.

Dominique Maxime of CIRAIG (personal communication; 2016) developed GHG emissions for the pesticides in the Ecoinvent database assuming that the products were manufactured in North America.

The GHG emissions calculated by Maxime are shown in the following figure. The average value is 10.4 kg CO_2eq/kg ai. That value has been used here.

Figure 7 GHG Emissions Pesticide Products



4.11 FIELD OPERATIONS

Detailed, recent information on the energy use of farm implements for the production of most grains and oilseeds in Canada is not available. The 2011 canola survey reported information on the field practices, equipment used, number of passes, etc. but did not ask for the fuel use.

The CCC survey did not directly ask how much energy was used on the field but it did ask about the number of field operations that were undertaken. From this information the field energy use was calculated. The field operations can be grouped into three categories, tillage or pre-seeding activities, seeding, and in crop (including harvesting) activities. This survey did not include any production in RU 22.

Table 29 Energy Consumption in Canola Production

	Manitoba		Saskatchewan			Alberta		
	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
Diesel consumption (l/dry-t/yr)	19.7	17.4	18.5	16.3	13.8	14.8	14.1	13.6
Electricity consumption (kWh/dry-t/yr)	2.7	3.0	2.7	3.0	4.1	2.7	2.7	7.7
Natural gas consumption (MJ/dry-t/yr)	0.0	0.4	0.0	0.3	1.7	0.0	0.0	5.3

This information is now a decade old and there have been changes in tillage practices. It is provided for comparison only and it was not used in the calculations.

4.11.1 Cultivation

Several years ago, Agriculture and Agri-Food Canada developed the Prairie Crop Energy Model (PCEM)[37]. This model estimates the energy use for each soil zone in each Prairie Province for each type of cultivation (no till, reduced till, and conventional). The fuel consumption includes activities during seeding, crop protection and harvest operations. The fuel consumption parameters for the three tillage types are shown below.

Table 30 Diesel Fuel by Tillage Type

RU	Conventional Tillage	Reduce Tillage	No Tillage
	Litres Diesel/ha		
22	37.3	32.1	25.2
23	37.1	31.9	25.0
24	36.9	31.7	24.7
28	34.4	29.9	25.5
29	34.4	29.9	25.5
30	33.6	28.9	23.1
34	35.8	30.8	24.4
35	33.5	29.3	25.4
37	31.7	28.3	22.2

The fraction of each tillage type for each RU for the three-year period is shown in the following table. This information was supplied by Agriculture and Agri-Food Canada[38]. This source provided the information by RU. The information is used to develop the National Inventory Report and uses an extrapolation of the data from the Agricultural Census (collected every five years). There are other sources (Statistics Canada)[39], that provide

[37] Nagy, C.N., 1999. Energy coefficients for agriculture inputs in Western Canada. CSALE Working Paper Series #2, Saskatoon, SK: Centre for the Studies in Agriculture Law and the Environment.
[38] AAFC (2022) (n 16)
[39] Statistics Canada, 2022. Tillage and seeding practices, Census of Agriculture, 2021. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210036701

information at the Provincial level or at the Census Agricultural Region but only every five years.

Table 31 Tillage Fraction by RU

RU	Conventional Tillage	Reduced Tillage	No Tillage
22	0.444	0.366	0.190
23	0.451	0.382	0.167
24	0.415	0.382	0.203
28	0.124	0.323	0.553
29	0.083	0.230	0.687
30	0.032	0.119	0.849
34	0.155	0.239	0.606
35	0.099	0.174	0.727
37	0.090	0.119	0.791

The calculated diesel fuel consumption is shown in the following table. These values are all higher than the energy use that was calculated from the 2011 survey and using these values will be more conservative.

Table 32 Direct Energy Use

RU	Province	PCEM
		L Diesel Fuel/ha
22	MB	33.1
23	MB	33.1
24	MB	32.4
28	SK	28.0
29	SK	27.2
30	SK	24.1
34	AB	27.7
35	AB	26.9
37	AB	23.8

4.11.2 Irrigation

The irrigated area by crop is no longer available at the national level. The total area by province is available. The total area of field crops irrigated has been increasing slowly up until the 2020 time period with most of the growth accounted for by Alberta as shown in the following table (Table 38-10-0241-01)[40].

[40] Statistics Canada. Total area that received irrigation by crop type. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810024101

Table 33 Field Crop Irrigated Area

	2010	2012	2014	2016	2018	2020
	hectares					
Atlantic provinces	680	-	850	1,200	1,323	-
Quebec	2,810	2,940	2,680	4,040	3,644	-
Ontario	9,820	16,050	6,040	15,330	21,899	8,503
Manitoba	11,820	20,420	18,840	29,770	31,058	18,238
Saskatchewan	26,230	19,800	24,590	23,050	32,817	30,828
Alberta	263,110	280,570	293,140	309,430	307,434	281,699
British Columbia	14,400	4,760	4,200	3,700	3,524	2,060
Canada	328,870	346,530	350,340	386,520	401,699	345,581

We have assumed that the proportion of field crops within a region or province is constant and so we have used that ratio to adjust the RU level data for irrigated area to field crop irrigated area in the RU. The 2018 data from the above table is used. The calculated irrigated area in the following table is slightly lower than the area in Table 33 which is expected since there is some agricultural activity in other RUs in Canada that are not large enough to be included in our criteria.

The RUs with canola production and the estimated percentage of the crop area in each RU that is irrigated is shown in the following table.

Table 34 Irrigated Area by RU

RU	Province	Irrigated Area, ha	% of crop area irrigated
22	MB	9	0.0%
23	MB	229	0.0%
24	MB	29,532	0.8%
28	SK	123	0.0%
29	SK	2,376	0.0%
30	SK	20,550	0.2%
34	AB	4,908	0.2%
35	AB	43,060	1.4%
37	AB	255,191	8.2%

The percentage of crop area that is irrigated in the canola producing RUs is very small and it is likely that the percentage of canola area irrigated is even smaller as it is more likely that irrigated land will be devoted to high return crops such as corn. It is therefore assumed that none of the canola area is irrigated for the purposes of calculating energy use, with the exception of RUs 24, 35, and 37.

In Alberta, the irrigated area by crop is available (Alberta Agriculture, 2020)[41]. There are 5,765 ha of irrigated canola in RU 35 (0.6%) and 42,500 ha (7%) in RU 37 These values are used in the GHG emission calculations.

[41] Alberta Agriculture. 2020. Alberta irrigation information 2020. https://open.alberta.ca/dataset/c0ca47b0-231d-4560-a631-fc11a148244e/resource/8e300417-d8eb-43e1-a574-284f0253e577/download/af-alberta-irrigation-information-2020.pdf

The type of energy used for irrigation is reported for all districts in Alberta. The average for all districts for the 2018 to 2020 period is shown in the following table. Electricity use is higher and natural gas energy use is slightly lower than the values used in the previous work.

Table 35 Irrigation Energy Use by Type

Type	Fraction
Electricity	0.59
Natural Gas	0.24
Diesel	0.021
LPG or gasoline	0.000
Gravity	0.120
Other	0.025
Total	0.996

Alberta Agriculture and Rural Development (2010)[42] undertook an assessment of the energy efficiency of a number of systems in the province. They found that electric systems required 0.19 kWh/m^3 of water supplied and natural gas systems used 0.79 kWh/m^3 (2.82 MJ/m3). It is assumed that the efficiency of the diesel, propane and other is the same as the natural gas.

In 2020 the volume of water applied was 3,500 cubic meters per hectare[43], so the energy use can be calculated per hectare of irrigated cropland. The results are shown in the following table. The energy use is slightly higher than what was used previously due to the higher rates of water used.

Table 36 Energy Use per Hectare Irrigated Cropland

Energy Source	kWh/hectare	MJ/hectare
Electricity	278	
Natural Gas	472	1,700
Diesel	41	149
Gasoline	0	0.0

The data in the above table along with the fraction of irrigated area for each crop in each RU will be used to calculate the energy use and GHG emissions due to irrigation.

4.11.3 Storage

The energy requirements for moving grain from a truck into a bin and then back into a truck depend on the rate of transfer, the height that the product is raised, and the design of the system. Typical values are in the range of 4 to 10 tonnes/kWh (Alberta Agriculture)[44]. This would add 0.50 kWh/tonne using the low end of the range and including the in and out movements from the bin.

[42] Alberta Agriculture and Rural Development. 2010. Irrigation System Energy Trial Assessment Project.
[43] Alberta Agriculture. 2020. Alberta irrigation information 2020. https://open.alberta.ca/dataset/c0ca47b0-231d-4560-a631-fc11a148244e/resource/8e300417-d8eb-43e1-a574-284f0253e577/download/af-alberta-irrigation-information-2020.pdf
[44] Alberta Agriculture and Rural Development. Screw Conveyors.

Aeration of the storage bin can consume electricity. A study of canola bins in Alberta[45] found an average of 2.33 kWh of electricity per tonne was consumed for bin aeration. We will assume that 2.5 kWh/tonne for the power consumption during aeration for a total power consumption of 3.0 kWh/tonne.

Other than the aeration none of the canola is dried.

4.12 Emission Factors

The Implementing Regulation[46] has some emission factors for liquid fuels, natural gas, and electricity but the natural gas and the electricity values are specific to the EU or to member states. The fossil fuel emission factors from the Implementing Regulation have been used.

Table 37 Emission Factor

	EU	Manitoba	Saskatchewan	Alberta
Electricity, g CO_2eq/kWh	No value for Canada	25	850	778
Natural gas, g CO_2eq//MJ (LHV)	66.0			
Diesel Fuel, g CO_2eq//MJ LHV)	95.1			
Gasoline, g CO_2eq//MJ (LHV)	93.3			
LPG, g CO_2eq//MJ LHV)	66.1			

The conversion of the fossil fuels from using MJ as the functional unit to using litres has been done using the conversion factors shown in the following table. They are all EU values.

Table 38 Fossil Fuel Conversion Factors

Fuel	Energy, MJ (LHV) /kg	Density, kg/litre
Diesel Fuel	43.1	0.832
Gasoline	43.2	0.745
LPG	46.0	0.52

Electricity production in Manitoba and Saskatchewan is owned by the provincial governments; in Alberta it is privately owned. There is limited interchange of electricity between the provincial grids. The Manitoba system is mainly hydroelectric, whereas coal and natural gas dominates the power systems of the other two provinces. GHGenius has full lifecycle emission factors for the electricity, including generation and distribution.

The electricity emission factors are from the Environment and Climate Change Canada LCA model (2023).[47]

[45] 3D Energy Ltd. 2021. Evaluating Energy Efficiency of On-Farm Grain Conditioning Systems. https://www.teamalbertacrops.com/wp-content/uploads/2021/06/Grain-Conditioning-with-Cover-June-14th21ETEL.pdf

[46] European Commission (2022) (n 6)

[47] Environment and Climate Change Canada. 2023. Clean Fuel Regulations: Specifications for Fuel LCA Model CI Calculations. Page 87. https://data-donnees.ec.gc.ca/data/regulatee/climateoutreach/carbon-intensity-calculations-for-the-clean-fuel-regulations/en/Resources/CFR-Specifications-for-Fuel-LCA-Model-CI-Calculations-v2.0.pdf

4.13 ENERGY SUMMARY

The energy requirements for each RU can now be calculated from the data presented above. This is summarized in the following table.

Table 39 Canola Energy Use

RU	Province	Diesel, L/ha	Gasoline, L/ha	Natural gas, MJ/ha	LPG L/ha	Electricity, kWh/ha
22	MB	33.1	0.0	0.0	0.0	3.0
23	MB	33.1	0.0	0.0	0.0	3.0
24	MB	32.4	0.0	13.6	0.0	5.2
28	SK	28.0	0.0	0.0	0.0	3.0
29	SK	27.2	0.0	0.0	0.0	3.0
30	SK	24.1	0.0	0.0	0.0	3.0
34	AB	27.7	0.0	0.0	0.0	3.0
35	AB	26.9	0.0	10.2	0.0	4.7
37	AB	23.8	0.0	119.0	0.0	22.5

5. NITROUS OXIDE EMISSIONS

Canada calculates the N_2O emissions from crop production using an IPCC Tier 2 methodology as required in the Implementing Regulations. Many of the emission factors were updated for the 2022 National Inventory Report[48] and those updated factors are used here. The emission factors are specific to the RU in most cases.

N_2O emissions from agricultural soils consist of direct and indirect emissions. N_2O emissions from anthropogenic nitrogen inputs occur both directly from the soils to which the nitrogen is added and indirectly. Changes in crop rotations and management practices, such as tillage and irrigation, affect direct N_2O emissions by altering the mineralization rates of organic nitrogen, nitrification and denitrification.

Indirect emissions occur through two pathways:

(1) the volatilization of nitrogen from inorganic fertilizer and manure applied to fields as NH_3 and NOx and its subsequent deposition off-site; and

(2) the leaching and runoff of inorganic fertilizer, manure, biosolids and crop residue N.

All three sources are discussed further below.

5.1 DIRECT EMISSIONS

Direct sources of N_2O from soils include the application of organic and inorganic nitrogen fertilizers, crop residue decomposition, losses of soil organic matter through mineralization, and cultivation of organic soils. In addition, Canada also reports two country-specific sources of emissions/removals: tillage practices and irrigation. Emissions/removals from these sources are estimated on the basis of nitrogen inputs from the application of organic and inorganic nitrogen fertilizers and crop residue nitrogen.

Canada has developed a Tier 2 methodology using country-specific emission factors to estimate N_2O emissions from inorganic nitrogen fertilizer application on agricultural soils, which takes into account moisture regimes, soil texture, nitrogen sources, cropping systems, and topographic conditions. Emissions of N_2O are estimated for each ecodistrict and can be scaled up to RU, provincial and national scales.

The methodology follows the approach described in Liang et al. (2020)[49], with modifications based on expert consultation with the Canadian scientific community.

The approach involves determining base emission factors "EF Base" for each of 405 ecodistricts, using long-term growing season precipitation. The EF_Base is subsequently modified to reflect site-specific practices (tillage and irrigation) and conditions. Data on long-term climate normals and topographic characteristics are used to develop an EF_Base.

$$EF\_Base_i = [EF\_CT_{i,P=PE} \times FR\_Topo_i + EF\_CT_{i,P} \times (1 - FR\_Topo_i)] \times RF\_TX_i$$

[48] Environment and Climate Change Canada (2022) (n 30)

[49] Liang, C., MacDonald, D., Thiagarajan, A., Flemming, C., Cerkowniak, D. and Desjardins, R., 2020. Developing a country specific method for estimating nitrous oxide emissions from agricultural soils in Canada. *Nutrient Cycling in Agroecosystems*, *117*(2), pp.145-167. https://doi.org/10.1007/s10705-020-10058-w

Where:

EF_Base_i	a weighted average of emission factors for ecodistrict i, taking into account moisture regimes, topographic conditions, and soil texture, kg N_2O-N kg N^{-1} yr^{-1}
$EF\_CT_{i,P}$	emission factor, estimated at actual P in ecodistrict i, kg N_2O-N kg N^{-1}
$EF\_CT_{i,P=PE}$	emission factor, estimated at *P=PE* in ecodistrict *i*, kg N_2O-N kg N^{-1}
FR_Topo_i	fraction of the area of ecodistrict *i* that is in the lower section of the toposequence
P	long-term mean precipitation from May 1 to October 31 for ecodistrict i, mm
PE	long-term mean potential evapotranspiration from May 1 to October 31 for ecodistrict i, mm
RF_TX_i	weighted soil texture ratio factor of N_2O for ecodistrict *"i"*

The EF Base values after the modifications for tillage and irrigation for each RU are shown in the following table[50].

Table 40 Modified EF Base Values

RU	Modified EF Base, unitless
22	0.0124
23	0.0071
24	0.0060
28	0.0043
29	0.0035
30	0.0044
34	0.0059
35	0.0050
37	0.0094

There is a wide range of values across the canola growing regions which reflect the different climatic conditions, soil factors, and management practices.

The EF Base values are modified for the type of nitrogen that is applied. The factors that are applied are shown in the following table.

Table 41 Soil N_2O Ratio Factors for Cropping Systems and Nitrogen Sources

Cropping System	Nitrogen Source	Ratio
Annual	Inorganic Fertilizer	1.0
Annual	Organic Fertilizer	0.84
Annual	Crop Residue	0.84

The factor for crop residue differs from the recommended value in the Liang paper (0.29) due to the insufficient Canadian data to support the lower value.

The direct emissions in each RU are calculated as shown below.

[50] AAFC (2022) (n 16).

$$\text{Direct } N_2O = (\text{EF Base*Inorganic N} + 0.84\text{*EF Base* Crop Residue N} + 0.84\text{*EF Base*Organic Fertilizer})\text{*}44/28\text{*}N_2O \text{ GWP}$$

The direct N_2O emissions (as CO_2eq) per tonne of moist canola are shown in the following table after conversion to CO_2eq.

Table 42 Direct N_2O Emissions

RU	Inorganic N	Crop Residue N	Manure N	Total
	Kg CO_2eq/moist tonne canola			
22	314.6	88.1	4.4	407.0
23	180.0	50.4	2.5	232.9
24	144.9	42.6	2.0	189.5
28	102.7	30.5	0.6	133.8
29	82.6	24.9	0.4	107.9
30	105.8	31.2	0.6	137.6
34	158.6	41.9	3.5	204.0
35	108.0	35.5	2.4	146.0
37	238.1	66.8	5.3	310.1

No canola is grown in Canada on organic soils (histosols) so no emissions for organic soils are calculated.

5.2 Indirect Emissions

A fraction of the nitrogen from organic and inorganic fertilizers that are applied to agricultural fields is transported off-site through volatilization in the form of NH_3 and NOx and subsequent re-deposition or leaching and runoff. The nitrogen that is transported from the agricultural field in this manner provides additional nitrogen for subsequent nitrification and denitrification to produce N_2O.

5.2.1 Volatilization

In the Canadian National Inventory Report a country-specific method is used to estimate ammonia emissions from the application of inorganic and manure N to soils. The method for deriving ammonia emission factors from inorganic N closely follows the model used by Sheppard et al. (2010)[51] to derive specific emission factors for various ecoregions in Canada. Ammonia emission factors are derived based on the type of inorganic N fertilizer, degree of incorporation into soil, crop type and soil chemical properties.

Canadian agricultural soils range from semi-arid to humid environments. Based on the analysis presented in the most recent IPCC methodological update, Canada uses the default IPCC emission factors EF_4 of 0.014 kg N_2O-N kg^{-1} N for wet climates and 0.005 kg N_2O-N kg^{-1} N for dry climates (IPCC, 2019)[52] to provide more accurate estimates of indirect emissions for Canadian conditions than the default emission factor published in the 2006 IPCC Guidelines.

[51] Sheppard SC, Bittman S, Bruulsema TW. 2010a. Monthly ammonia emissions from fertilizers in 12 Canadian ecoregions. Canadian Journal of Soil Science, 90: 113–127. https://cdnsciencepub.com/doi/pdf/10.4141/CJSS09006

[52] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

The $FRAC_{gasf}$ depends on soil properties, pH and cation exchange and the type of fertilizer applied. One value for each province is used as that is the level that fertilizer sales by type is available. The values for EF_4, $FRAC_{gasf,}$ and the $Frac_{gasf}$ for manure for each RU are shown in the following table.

Table 43 Volatilization Emission Factors

RU	EF_4	$FRAC_{gasf}$	FRACgasf (manure)
22	0.014	0.07	0.011
23	0.005	0.07	0.011
24	0.005	0.07	0.011
28	0.005	0.06	0.012
29	0.005	0.06	0.012
30	0.005	0.06	0.012
34	0.005	0.06	0.011
35	0.005	0.06	0.011
37	0.005	0.06	0.011

The volatilization emissions are calculated by

$$N_2O\ Vol=((N\ syn*EF_4*FRAC_{Gasf})+(Nman*EF4*Frac_{gasfman}))*44/28*N_2O\ GWP$$

The indirect N_2O emissions are summarized in the following table.

Table 44 N_2O Volatilization Emissions

RU	N_2O emissions kg CO_2eq/moist tonne canola
22	24.9
23	8.9
24	8.5
28	7.2
29	7.1
30	7.2
34	8.1
35	6.5
37	7.6

5.2.2 Leaching

When organic and inorganic fertilizers, and crop residue, are added to cropland, a portion of the nitrogen from these sources is lost through leaching and runoff. The magnitude of this loss depends on a number of factors, such as application rate and method, crop type, soil texture, rainfall and landscape. This portion of lost nitrogen can further undergo transformations, such as nitrification and denitrification, and can produce N_2O emissions off-site.

As in the case of N_2O emissions from volatilization and deposition of NH3 and NOx, this source is poorly defined because no standardized method for deriving the IPCC Tier 2 emission factors is provided in the 2006 IPCC Guidelines[53].

A modified IPCC Tier 1 methodology is used to estimate indirect N_2O emissions from leaching and runoff of fertilizers, manure, and crop residue nitrogen from agricultural soils. Indirect N_2O emissions from runoff and leaching of nitrogen at the ecodistrict level are estimated using the fraction of nitrogen that is lost through leaching and runoff ($FRAC_{LEACH}$) multiplied by the amount of inorganic fertilizer nitrogen and crop residue nitrogen and by an emission factor of 0.0075 kg N_2O-N/kg N (IPCC, 2006).

The default value for $FRAC_{LEACH}$ in the Revised 1996 Guidelines is 0.3. However, $FRAC_{LEACH}$ can reach values as low as 0.05 in regions where rainfall is much lower than potential evapotranspiration (IPCC, 2006), such as in the Prairies. Accordingly, it is assumed that $FRAC_{LEACH}$ would vary among ecodistricts from a low of 0.05 to a high of 0.3. For ecodistricts with no moisture deficit during the growing season (May through October), the maximum $FRAC_{LEACH}$ value of 0.3 recommended by the 2006 IPCC Guidelines is assigned. The minimum $FRAC_{LEACH}$ value of 0.05 is assigned to ecodistricts with the greatest moisture deficit. For the remaining ecodistricts, $FRAC_{LEACH}$ is estimated by the linear extrapolation of the two end-points.

The $FRAC_{LEACH}$ value for each of the RU is shown in the following table.

Table 45 $FRAC_{LEACH}$ by RU

RU	$FRAC_{LEACH}$
22	0.22
23	0.19
24	0.18
28	0.17
29	0.15
30	0.11
34	0.19
35	0.16
37	0.11

The leaching emissions are calculated by

$$N_2O\ Leach = (N\ syn + N_{crop\ residue} + N_{man}) * EF_5 * FRAC_{Leach} * 44/28 * N_2O\ GWP$$

The N_2O emissions by leaching are shown in the following table.

[53] 2006 IPCC Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Table 46 N_2O Indirect Leaching Emissions

RU	N_2O emissions kg CO_2eq/moist tonne canola
22	56.5
23	48.8
24	44.6
28	41.4
29	36.2
30	26.9
34	51.4
35	36.8
37	28.4

6. RESULTS

Canada specific values for canola cultivation have been calculated following the methodology outline in the REDII and the Implementing Regulation. The calculations have been done at a NUTS 2 equivalent region level. These regions were outlined in section 2 of the report.

The total emissions are the sum of the components describe in the previous sections of the report. All of the emissions are calculated first on the basis of a moist tonne of canola (Table 47. The emissions are adjusted to a dry weight basis (Table 48).

Table 47 GHG Emissions per Moist Tonne of Canola

RU	Fertilizer Production	Neutralization	Pesticide Production	Seed	Direct N_2O	Indirect N_2O	Fuel Use	Total
	kg CO_2eq/moist tonne							
22	204.4	43.0	6.8	2.0	407.0	81.4	54.2	798.8
23	190.7	42.8	6.0	1.8	232.9	57.7	47.2	578.9
24	187.9	40.8	6.0	1.8	189.5	53.0	47.2	526.3
28	188.5	40.5	5.8	1.7	133.8	48.6	38.9	457.7
29	193.7	40.2	6.1	1.8	107.9	43.3	39.6	432.5
30	199.6	41.0	6.8	2.0	137.6	34.2	39.3	460.4
34	209.2	45.6	6.6	2.0	204.0	59.5	45.2	572.1
35	176.7	36.8	6.1	1.8	146.0	43.3	40.8	451.4
37	212.0	43.4	6.9	2.0	310.1	36.1	51.3	661.8

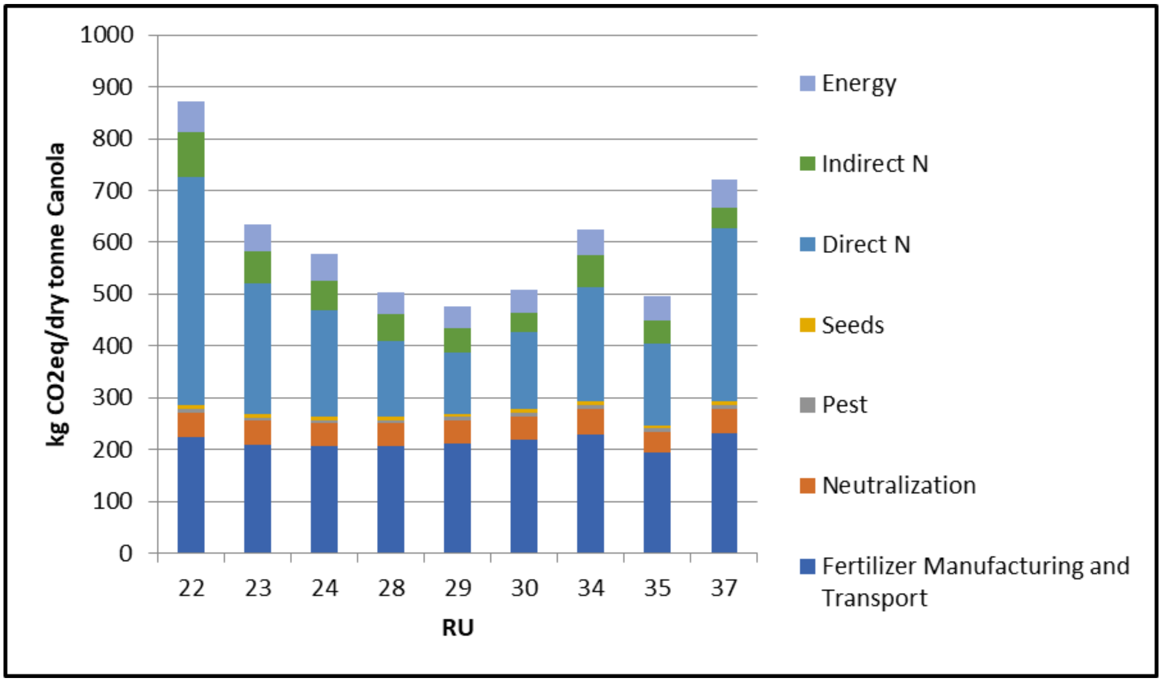
The same information on a dry weight of canola is shown in the following table.

Table 48 GHG Emissions per Dry Tonne of Canola

RU	Fertilizer Production	Neutralization	Pesticide Production	Seed	Direct N_2O	Indirect N_2O	Fuel Use	Total
	kg CO_2eq/dry tonne							
22	223.4	47.0	7.5	2.2	444.8	89.0	59.3	873.1
23	208.4	46.7	6.5	1.9	254.5	63.0	51.6	632.7
24	205.4	44.6	6.6	2.0	207.1	58.0	51.6	575.2
28	206.0	44.2	6.3	1.9	146.2	53.1	42.5	500.2
29	211.7	43.9	6.6	2.0	117.9	47.3	43.2	472.7
30	218.2	44.8	7.4	2.2	150.4	37.3	42.9	503.2
34	228.7	49.8	7.3	2.2	223.0	65.0	49.4	625.2
35	193.1	40.3	6.6	2.0	159.5	47.3	44.6	493.4
37	231.7	47.4	7.5	2.2	339.0	39.4	56.1	723.3

The emissions are dominated by the direct N_2O emissions and the fertilizer manufacturing emissions. The emissions are shown graphically in the following figure.

Figure 8 GHG Emissions



The JRC report on the calculation of defaults values[54] provided different conversion factors than were previously used in RED I and BioGrace.

Table 155 in that report shows that the oil yield is 0.42 kg oil at 9% moisture. That is 0.4615 kg oil per dry tonne. The oil has an energy content of 37 MJ/kg. Table 158 reports that 1.0246 kg of crude oil is required to produce 1 kg of refined oil and Table 159 shows that 1.00063 kg of refined oil produces one MJ of FAME. The conversion factor for converting dry tonnes of canola to MJ of FAME is 1*1000*0.4615*37/(1.0246*1.00063)=16,665 MJ FAME/dry tonne of canola. The inverse of this is 0.0600 kg/MJ FAME.

The allocation factor in the JRC work is shown in Table 157 and is 17.077 MJ of oil/(17.077+9.88) MJ of dry seed or 0.633.

The emissions per MJ of biodiesel are shown in the following table. These emissions can be compared to the default value of 32 g CO_2eq/MJ. All but one of the Canadian values are below the default value.

[54] Edwards, R., O'Connell, A., Padella, M., Giuntoli, J., Koeble, R., Bulgheroni, C., Marelli, L., Lonza, L., Definition of input data to assess GHG default emissions from biofuels in EU legislation, Version 1d - 2019, EUR 28349 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-02907-6, doi:10.2760/69179, JRC115952.

Table 49 GHG Emissions for Biodiesel

RU	g CO_2eq/MJ FAME
22	33
23	24
24	22
28	19
29	18
30	19
34	24
35	19
37	27

6.1 Comparison to Previously Approved Values

The Commission approved values for Canadian canola production in December of 2017. Those values are shown in the following table.

Table 50 2017 Implementing Decision

Region	Seeding	Fertilizer production	N_2O field emissions	Pesticide production	Field operations	(kg CO_2eq/dry-tonne)
23	2.4	262.5	523.5	4.2	73.1	865.7
24	2.2	266.5	510.6	3.7	64.9	847.9
28	2.5	212.8	499.5	3.8	71.4	790.0
29	2.5	203.1	319.4	3.6	63.4	592.0
30	2.2	190.2	206.5	2.8	55.1	456.8
34	2.2	170.4	421.2	3.3	57.7	654.8
35	1.9	154.2	338.4	2.6	54.9	552.0
37	2.1	166.6	198.2	2.8	58.3	428.0

The difference in the values for each RU and each category are shown in the following table. There was no approved value for RU 22 in 2017 so that comparison is not shown.

Table 51 Change from 2017 Implementing Decision

Region	Seeding	Fertilizer production	N_2O field emissions	Pesticide production	Field operations	(kg CO_2eq/dry-tonne)
23	-0.5	-7.3	-209.4	2.3	-21.5	-236.4
24	-0.2	-16.5	-248.3	2.9	-13.3	-275.5
28	-0.6	37.4	-301.0	2.5	-28.9	-290.6
29	-0.5	52.5	-154.8	3.0	-20.2	-120.0
30	0.0	72.8	-19.5	4.6	-12.2	45.6
34	0.0	108.1	-138.2	4.0	-8.3	-34.6
35	0.1	79.2	-135.0	4.0	-10.3	-62.0
37	0.1	112.5	173.7	4.7	-2.2	288.8

The seeding rates in the 2017 work were taken from a producer survey undertaken in 2011, the latest work relied on recommendations from Government agriculture departments. The rates in 2011 vary from 5.38 to 5.6 kg/ha. The same seeding rate and higher crop yield results in lower emissions in this work. The emission factor was the same in both reports.

There is some variation in the fertilizer production emissions. Fertilizer applications were lower in the regions that show a reduction and there is much less variation in the fertilizer application rates between regions with the latest work. The comparison of the N rates is shown in the following table.

Table 52 Comparison of N Rates

	2017	2023
	Kg N/tonne	
23	63.8	54.2
24	62.3	54.1
28	55.0	51.6
29	48.4	51.0
30	44.2	50.4
34	44.4	51.3
35	41.8	57.4
37	44.4	46.1

Different fertilizer emission factors have been used. The 2017 work used a mixture of Canadian Values and EU Values. The comparison is shown in the following table.

Table 53 Fertilizer Emission Factors

	2017	2023
	g CO_2/kg	
Ammonia	2,870	2,832
Urea	2,910	1,935
Urea ammonium nitrate	5,400	3,381
Ammonium nitrate/calcium ammonium nitrate	8,360	4,348
Ammonium sulphate	2,870	2,724
Monoammonium phosphate		1,029
Diammonium phosphate		1,552
Sulphur	150	413
K_2O	320	1,029
P_2O_5	1340	550

There have been changes in the types of fertilizer used, with more urea and less ammonia being used. This does vary by RU which makes a simple comparison a challenge.

There have been large changes in the N_2O emissions as a result of Canada revising their Tier 2 N_2O emission factors. The primary differences are changes in EF_1 from the availability of more data and the reduction in EF_1 for crop residues. The comparison of EF_1 is shown in the following table.

Table 54 Comparison of EF_1

	2017	2023
	unitless	
23	0.0098	0.0071
24	0.0091	0.0060
28	0.0088	0.0043
29	0.0084	0.0035
30	0.0060	0.0044
34	0.0095	0.0059
35	0.0093	0.0050
37	0.0077	0.0094

These reductions in EF_1 are partly offset by the inclusion of the neutralization emissions that were not included last time. The new Canadian methodology takes a different approach to N_2O emissions in irrigated soils and that is why the factor for RU 37 has increased.

Pesticide emissions are higher due to higher application rates.

Field operation emissions are lower. These emissions are generally a function of area and as the yield increases the emissions per tonne of production decrease. There was a 15% increase in average crop yield between the two studies. A different set of emission factors was used between the two studies. The 2017 study used canola specific estimates and the new set uses a generic approach although still canola specific values. There has also been an increase in no till agriculture between the two data collection periods and that reduced the emissions.

7. VERIFICATION

SCS Global Services
GHG Verification Summary Report

Review of Regional Greenhouse Gas Emissions from Cultivation of Canola for Use as Biofuel

Prepared for:
The Canola Council of Canada

Date Completed:
October 21, 2022

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Introduction

Directive (EU) 2018/2001 of the European Parliament revised the Renewable Energy Directive (RED II). The RED II sets biofuel targets for the European Union including sustainability criteria and minimum greenhouse gas (GHG) reductions compared to a fossil fuel baseline. The RED II further outlines the methods for assigning GHG values to eligible biofuels.

Annex VI of the RED II allows estimates of emissions from cultivation derived from averages. Article 31 of the RED II allows territories outside the European Union (EU) to submit reports to the Commission quantifying typical GHG emissions from cultivation of agricultural raw materials. Those reports shall be accompanied by a description of the method and data sources used to calculate the level of emissions. That method shall take into account soil characteristics, climate and expected raw material yields. The area covered by such reports should be equivalent to level 2 in the nomenclature of territorial units for statistics (NUTS) or as a more disaggregated NUTS level in accordance with Regulation (EC) No 1059/2003 of the European Parliament and of the Council.

The European Commission has previously approved specific values for the cultivation of canola in Canada[1], which was valid for 5 years and expires in December 2022.

The Canola Council of Canada has assembled updated data and presented methodology to quantify Regional Greenhouse Gas Emissions from Canola Cultivation of Canola for Use as Biofuel[2] (the Report). The Report concludes the estimation of emissions, in CO_2 equivalents, for the cultivation of canola in each of nine specific geographic regions of Canada.

SCS Global Services has reviewed this report by assessing the following criteria:

- Compliance with the RED II Directive 2018/2001;
- Transparency of the methodology;
- Comprehensiveness and accuracy of emissions inventories;
- Appropriateness of emission factors; and
- Reproducibility of results.

Derivation of NUTS 2 Equivalent Regions in Canada

The Nomenclature of Territorial Units for Statistics (NUTS) is a device subdividing EU Member States into territorial units for statistical purposes. The NUTS classification subdivides each Member State into NUTS level 1 territorial units, each of which is subdivided into NUTS level 2 territorial units. GHG emission values for regional agricultural production are to be designated at the NUTS level 2. Reconciliation Units (RUs) are equivalent regions outside of the EU. Each RU lies within one administrative province and one

[1] Commission Implementing Decision (EU) 2017/2379. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017D2379&from=SV

[2] Regional Greenhouse Gas Emissions from Canola Cultivation of Canola for Use as Biofuel, (S&T) Squared Consultants, October 3, 2022.

ecozone. The Report identified 5 ecoregions across 3 provinces where canola is produced, resulting in 9 RUs with populations ranging from 37,000 to 1.8 million people.

The criteria for designating these regions is transparently described in the Report and is consistent with those previously approved by the Commission with the single new addition of RU 22 encompassing the Boreal Shield West ecozone of Manitoba.

Emissions Inventory

Only the GHG emission component related to the cultivating canola (e_{ec}) are included in this Report. N_2O emissions are calculated according to the European Commission's Implementing Regulation (EU) 2022/996. IPCC Tier 2 N_2O emission factors were obtained from Agriculture and Agri-Food Canada (AAFC), whose submissions are peer reviewed in conjunction with annual submissions to the UNFCCC.

Emissions from irrigation were integrated in the section on field operations and nitrous oxide emissions.

The assumption that no lime is added to canola production areas is supported by the available data described in the Report.

The calculation of CO_2 equivalents for GHGs including N_2O, and CH_4 follow Annex V, part C of the RED II.

Agricultural input data are sourced from Statistics Canada and crop insurance systems. Data on cultivated area and Canola yields are based on 2018-2020 average data. Data represent Census Agricultural Regions (CAR), which are smaller than the RUs. The aggregation of data from CARs to RUs is appropriate and consistent with RED II requirements.

Standardized moisture content of canola is consistent with data used by the Canadian Grain Commission.

Dry yield was calculated from total production and cultivated area for each of the nine RUs. Dry yields range from 1.90 to 2.25 tonnes per hectare (ha).

A seed rate of 5.6 kilograms (kg) of seed per hectare was used for all RUs. This conservative value was validated by survey results from 900 producers and found to be consistent with industry recommendations. The emission factor for canola seed is the standard value reported in the Commission Implementing Regulation (EU) 2022/996[3].

Fertilizer application rates were obtained from crop insurance programs and a survey of producers. This data was averaged to calculate application rates in kg of fertilizer per tonne of canola for nitrogen, phosphorous, potassium, and sulfur. A summary of fertilizer application rates in kg/ha is shown in Table 1.

[3] European Commission 2022 (n 6)

Table 1 Fertilizer Application Rates (kg/ha) in Canada

	Manitoba			Saskatchewan			Alberta		
	RU 22	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
Synthetic N-fertilizer (kg N/ha/yr)	112.8	129.5	122.0	125.5	118.5	107.7	123.0	108.6	112.3
K_2O-fertilizer (kg K_2O/ha/yr)	12.3	18.4	15.6	13.0	13.0	11.0	12.9	14.2	12.7
P_2O_5-fertilizer (kg P_2O_5/ha/yr)	40.2	39.9	40.2	35.7	36.8	36.1	35.4	33.2	36.3
S-fertilizer (kg S/ha/yr)	15.9	24.4	19.9	26.8	23.5	20.5	24.4	22.5	22.8

A producer survey was compared to average data from Statistics Canada to validate the types of nitrogen fertilizer used across the RUs.

The emission factors used for fertilizer are the standard, Canada specific values specified by the Commission where they are available. The determination of other emission factors for minor fertilizer components are adequately described in the Report.

Nitrogen emissions arising from crop residues are included following the methodology of the REDII[4]. The crop residue data for canola is based on the approach used in the implementing regulations.[5] Crop residue nitrogen is calculated as 18.1 kg N per tonne (wet) of canola produced. This value is applied to the yield for each RU.

CO_2 emissions from neutralization of acidity is included following the Commission Implementation Regulation[6] .

Pesticide application rate was estimated from a canola survey to determine 0.68 kg of active ingredient are applied per hectare. Pesticide sales in Alberta suggest and average application rate of 1.37 kg active ingredient per hectare for a variety of crops. This conservative estimate was applied to Canola in each of the RUs. An emission factor for the production of pesticides of 10.4 kg CO_2 equivalent per kilogram active ingredient was cited from the International Reference Center for Life Cycle Assessment and Sustainable Transition was used.

Diesel fuel used by crop tillage type was sourced for each RU from the Agriculture and Agri-Food Canada prairie Crop Energy Model and found to be more conservative than survey data of canola producers.

[4] European Commission (2018) (n 1)
[5] European Commission (2022) (n 6)
[6] European Commission (2022) (n 6)

Only three RUs are considered to have significant irrigated areas of canola. Data from Alberta Agriculture and Rural Development was used to calculate the energy used for irrigated cropland.

No energy was assigned for drying canola. However, energy was assessed for aerating and moving canola into and out of storage bins.

Emission factors for liquid fuels, natural gas, and electricity are regional values from the GHGenius LCA model. The regional values for diesel are higher for Canada than those published in the EU implementing regulation.

Canada calculates the N_2O emissions from crop production using an IPCC Tier 2 methodology as required in the Implementing Regulations. These include direct and indirect emissions from volatilization and leaching and runoff.

Conclusion

The method and approach used by the authors to calculate canola production GHG emissions is transparent and is found to follow the RED II Directive 2018/2001 methodological guidelines. The GHG emission calculations are correct, and the emission sources are comprehensive considering the scope of the Report. The emission factors are adequate, and the literature used in the report is found to be updated and relevant.

Canada specific values for canola cultivation have been calculated following the methodology outline in the REDII and the Implementing Regulation. The calculations have been done at a NUTS 2 equivalent region level. These regions have been identified as 9 specific Reconciliation Units (RU).

The total emissions are the sum of the components described above. All of the emissions are shown in Table 2 on a dry weight basis. Direct N_2O emissions are impacted primarily by inorganic fertilizer application, but also include nitrogen from crop residue.

Table 2 GHG Emissions per Dry Tonne of Canola (in kg CO2eq./dry tonne)

RU	Fertilizer Production	Neutralization	Pesticide Production	Seed	Direct N_2O	Indirect N_2O	Fuel Use	Total
	kg CO_2eq/dry tonne							
22	168.6	47.0	7.5	2.2	440.0	88.2	64.0	817.4
23	176.8	46.7	6.5	1.9	251.8	62.3	55.7	601.8
24	167.3	44.6	6.6	2.0	204.9	57.3	55.6	538.4
28	160.7	44.2	6.3	1.9	145.6	52.9	47.0	458.7
29	152.9	43.9	6.6	2.0	117.5	47.2	47.9	417.9
30	153.3	44.8	7.4	2.2	149.8	37.2	47.6	442.3
34	176.4	49.8	7.3	2.2	219.1	63.8	53.5	572.1
35	136.0	40.3	6.6	2.0	156.9	46.5	48.3	436.6
37	149.9	47.4	7.5	2.2	333.2	38.8	60.1	639.0

An exemplary conversion factor of 0.0655 kg dry feedstock per MJ of biodiesel was used to calculate the production emissions of biodiesel along with an allocation factor of 0.5860 to allocate emissions between oil and protein meal. This results in canola biodiesel emissions ranging from 17 to 31 g $CO_2eq/MJ_{biodiesel}$.

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9. APPENDICES

Standard Values from Commission Implementing Regulation (EU) 2022/996

Parameter	Value	Units
Canola Seed	756.5	g CO_2eq/kg
Ammonia	2,832	g CO_2eq/kg N
Urea	1,935	g CO_2eq/kg N
UAN	2,693	g CO_2eq/kg N
AN/CAN	4,348	g CO_2eq/kg N
Ammonium Sulphate	2,724	g CO_2eq/kg N
Mono Ammonium Phosphate	1,029	g CO_2eq/kg P_2O_5
Di Ammonium Phosphate	1,552	g CO_2eq/kg P_2O_5
Potash	413	g CO_2eq/kg K_2O

Other Standard Values

Parameter	Value	Units	Source
Pesticides	9.35	kg CO_2eq/kg ai	Ecoinvent
Elemental Sulphur	0	kg CO_2eq/kg S	Waste Product
Magnesium Sulphate	719	g CO_2eq/kg S	Calculated from Implementing Reg
Other sulphur sources	934	g CO_2eq/kg S	Half of AS
Sulphur	0.55	kg CO_2eq/kg S	Calculated Average
Manitoba			
Electricity	48	g CO_2eq/kWh	GHGenius
Diesel	3,679	g CO_2eq/litre	GHGenius
Gasoline	3,277	gCO_2eq/litre	GHGenius
Natural gas	60.48	g CO_2eq/MJ	GHGenius
LPG	1,851	g CO_2eq/litre	GHGenius
Saskatchewan			
Electricity	719	g CO_2eq/kWh	GHGenius
Diesel	3,701	g CO_2eq/litre	GHGenius
Gasoline	3,297	g CO_2eq/litre	GHGenius
Natural gas	59.00	g CO_2eq/MJ	GHGenius
LPG	1,864	g CO_2eq/litre	GHGenius
Alberta			
Electricity	855	g CO_2eq/kWh	GHGenius
Diesel	3,697	g CO_2eq/litre	GHGenius
Gasoline	3,292	g CO_2eq/litre	GHGenius
Natural gas	59.09	g CO_2eq/MJ	GHGenius
LPG	1,865	g CO_2eq/litre	GHGenius