Regional greenhouse gas emissions from cultivation of canola for use as biofuel or bioliquid

Canola cultivation in Canada

Report from 2016

Report for the *(Canadian Government party)*

Executive Summary

The EU Directive on the promotion of the use of energy from renewable sources (Directive 2009/28/EC, known as the Renewable Energy Directive or RED)[1] requires that by 2020, 20% of the European Community's gross final consumption of energy should come from renewable sources, and 10% of each Member State's transport energy consumption should be from renewable sources. It is anticipated that biofuels and bioliquids will play a key role in meeting both the overall Community level target and the transport sector target for the deployment of renewable energy.

Annex V of the RED contains carbon defaults (GHG emissions) for a number of biofuel feedstocks. These defaults consist of three different components: cultivation, biofuel conversion and transport and distribution. Article 19 of the RED sets out how GHG emissions savings for biofuels and bioliquids are to be calculated, with specific requirements on the estimation of GHG emissions from the cultivation of agricultural crops for biofuels specified in Annex V C (6).

The EU RED total default value for cultivation, biofuel conversion and transport/distribution of rapeseed-biodiesel amounts to 52 g CO_2eq/MJ, which results in a GHG emission saving of 38%.

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 2 areas within the EU.[2] 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 RED methodology. In total eight so-called reconciliation units were identified.

Lowest emissions occurred in the Subhumid Prairies (RU 29) and the Semiarid Prairies (RU 30) of Saskatchewan, while canola production in the reconciliation units of Manitoba resulted in highest emissions. The greatest emissions from crop cultivation arose from N_2O from soil, the production of fertilizers and from fuel used to power machinery during cultivation and harvest.

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 428.0 to 865.7 kg CO_2eq/dry-ton canola. Assuming a conversion factor of 0.0655 kg dry feedstock/MJ DAME biodiesel and an allocation factor of 0.5860 between the canola oil and the canola meal then the cultivation emissions range from 16 to 33 kg CO_2eq/MJ Canola FAME.

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[1] EC (2009a): Directive 2009/28/EC on the promotion of the use of energy from renewable sources. Brussels. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN

[2] EC (2010a): Communication 2010/C160/02 from the Commission on the practical implementation of the EU biofuels and bioliquids sustainability scheme and on counting rules for biofuels. Brussels. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2010:160:0008:0016:EN:PDF

Table 1: Emission of GHG from cultivation of canola

	Single emissions (kg CO_2eq/dry-ton)					Total emissions	
Region	Seeding	Fertilizer production	N_2O field emissions	Pesticide production	Field operations	(kg CO_2eq/dry-ton)	Kg CO_2eq/MJ FAME
RU 23	2.4	262.5	523.5	4.2	73.1	865.7	33
RU 24	2.2	266.5	510.6	3.7	64.9	847.9	33
RU 28	2.5	212.8	499.5	3.8	71.4	790.0	30
RU 29	2.5	203.1	319.4	3.6	63.4	592.0	23
RU 30	2.2	190.2	206.5	2.8	55.1	456.8	18
RU 34	2.2	170.4	421.2	3.3	57.7	654.8	25
RU 35	1.9	154.2	338.4	2.6	54.9	552.0	21
RU 37	2.1	166.6	198.2	2.8	58.3	428.0	16

Table of Contents

Abbreviations

AAFC	Agriculture and AgriFood Canada
a.i.	active ingredient
C	Carbon
CaO	Calcium oxide
CANB	Canadian Agricultural Nitrogen Budget
CCC	Canola Council of Canada
CS	Carbon Stock
CTS	Crop-and-Tillage System
EC	European Commission
EF	Emission Factor
ESN	Environmentally Smart Nitrogen (Polymer-Coated Urea)
EU	European Union
FQD	Fuel Quality Directive
g	Gram
g/m^2	gram per square meter
g CO_2eq/MJ	gram CO_2-equivalents per Megajoule
GHG	Greenhouse Gas
ha	Hectare
IPCC	Intergovernmental Panel On Climate Change
IT	Intensive Tillage, herein referred to as conventional tillage
JRC	Joint Research Centre
K_2O	Potassium oxide
kg	Kilogram
kg/ha	kilogram per hectare
kg/ha/yr	kilogram per hectare per year
kg CO_2eq/dry-t	kilogram CO_2-equivalents per dry ton
kWh	Kilowatt-hour
LCA	Life Cycle Assessment
l	Litre
l/ha	Litre per hectare
l/t/yr	Litre per ton per year
l/dry-t/yr	Litre per dry-ton per year
LPG	Liquid Petroleum Gas
LUC	Land Use Change
LULUCF	Land Use, Land-Use Change and Forestry
MJ	Megajoule
mill.	Million
N	Nitrogen
NT	No tillage, herein referred to as zero tillage
NUTS	Nomenclature of Units for Territorial Statistics
N_2O	Nitrous oxide
P_2O_5	Phosphate
PRDX	Maximum Potential Production (Century Model Parameter)

RED	Renewable Energy Directive
RU	Reconciliation Unit
S	Sulfur
SLC	Soil Landscape of Canada
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
t	Tonne (referring to 1,000 kg)
UAN	Urea Ammonium Nitrate
UNFCCC	United Nations Framework Convention On Climate Change

1 Introduction

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

The developments in the European biodiesel market are determined to a large extent by the Renewable Energy Directive (RED).[3] On 23 April 2009, the European Commission adopted a Directive on the promotion of the use of energy from renewable sources (Directive 2009/28/EC). In September 2015 it was amended by the Directive (EU) 2015/1513.[4] The RED has set an overall biofuels target 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 35% greenhouse gas (GHG) emissions savings compared to the fossil reference. This will rise to 50% with effect from 1 January 2018. Installations starting operation after 5 October 2015, must achieve a GHG saving of at least 60%.

The easiest way to prove compliance with the GHG criteria is the use of the GHG default values from the RED. The default value for rapeseed biodiesel (which can also be used for canola) is only 38% GHG savings (52 g CO_2e MJ^{-1}) compared to the fossil reference (83.8 g CO_2e MJ^{-1}). The GHG default values from the RED were also split into so-called disaggregated default values for cultivation of rapeseed (29 g CO_2e MJ^{-1}), processing (22 g CO_2e MJ^{-1}) and transport and distribution (1 g CO_2e MJ^{-1}).

As an alternative to using the conservative default values or calculating actual GHG values for each farmer, the RED allows the use of „estimates of emissions from cultivation (…) derived from the use of averages". Those averages shall be calculated for smaller geographical areas than those used in the calculation of the default values". "Within the EU, the averages should be for NUTS 2 areas or for a more fine-grained level". According to the Communication 2010/C/160/02 for countries outside the EU a similar level as the NUTS 2 level would be appropriate for calculating averages.

Following these requirements and specification set by the European Commission, this project aimed to calculate 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 RED and the Communication. Chapter 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.

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3 EC (2009a) l.c.

4 EC (2015b): Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesl fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources. Brussels. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L1513&from=EN

2 Derivation of NUTS 2 equivalent regions in Canada

2.1 Using average GHG values for agricultural areas

As an alternative to the conservative default values, the RED provides the alternative to use average GHG emission values for agricultural production. It states that „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". According to the Communication 2010/C/160/02 the default values were (with one exception) calculated for a global level. It further highlights that for countries outside the EU a similar level as the NUTS 2 level applied In the EU would be appropriate for calculating averages. [5]

The following chapter describes the application of the NUTS 2 concept as required by the RED 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 a EU-developed geocode standard for subdividing the economic territory of Member States into territorial units for statistical purposes.[6] 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.

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[5] EC (2010a) l.c.

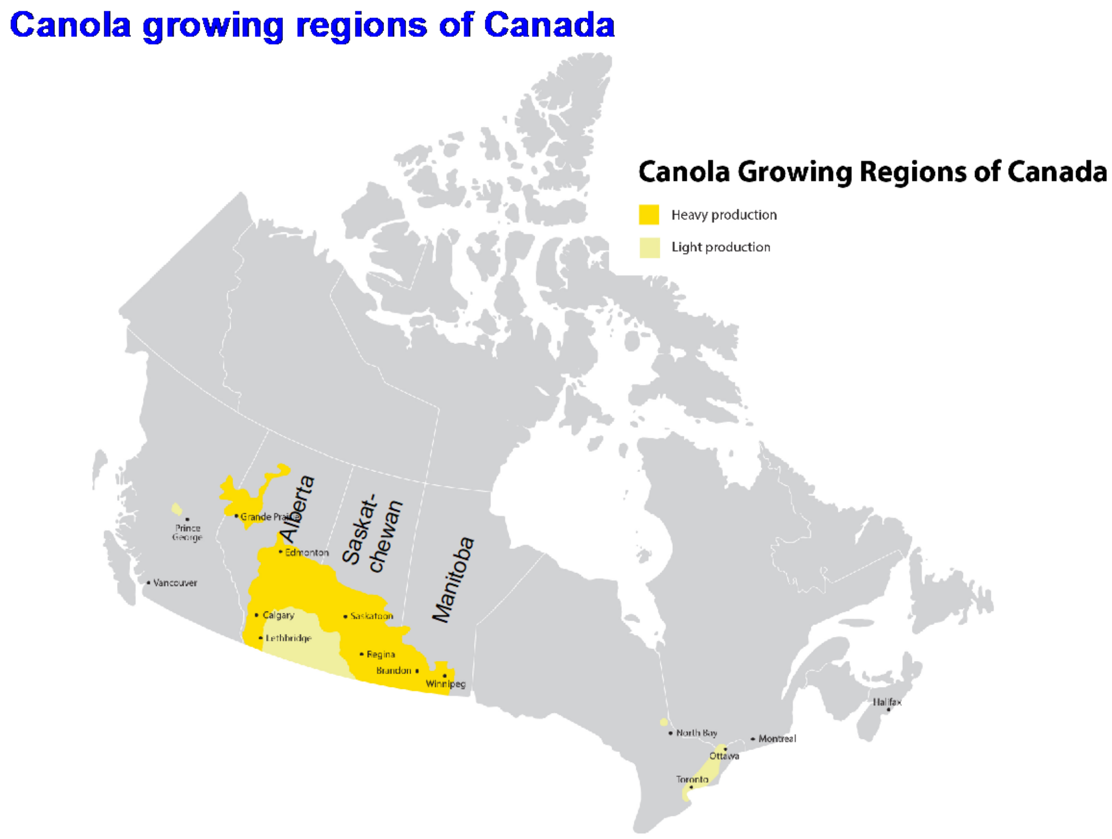
[6] EC (2003): Regulation (EC) No 1059/2003 of the European Parliament and of the Council of 26 May 2003 on the establishment of a common classification of territorial units for statistics (NUTS). Brussels. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32003R1059&from=EN

2.3 Transposition of NUTS concept to Canada

Although the NUTS concept is specifically developed for the EU, according to RED 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."7 To define regions in Canada according to this "similar level" the above-mentioned criteria on administration and population has been used.

99.9% of the canola production takes place in the three Prairie Provinces 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. Table 2 provides an overview on the harvested areas of canola from 2009 – 2014 in Canada.

Figure 1: Canola production in Canada[8]



[8] Canola Council of Canada (2015): Canola growing region map. http://www.canolacouncil.org/media/image-gallery/canola-growing-region-map/

Table 2: Harvested area of canola 2009 – 2014 in thousands of acres[9]

Year	**Total Canada**	Prairie provinces			Total prairie provinces in 1,000 of acres (and percentage on total canola area)
		Manitoba	Saskatchewan	Alberta	
2009	**16,101.7**	3,200.0	7,850.0	4,900.0	15,950.0 (99.1%)
2010	**16,945.9**	3,110.0	8,125.0	5,500.0	16,735.0 (98.8%)
2011	**18,753.8**	2,720.0	9,850.0	5,970.0	18,540.0 (98.9%)
2012	**21,743.8**	3,550.0	11,400.0	6,550.0	21,500.0 (98.9%)
2013	**20,160.10**	3,175.00	10,600.00	6,180.00	19,955.0 (99.0%)
2014	**20,618.10**	3,075.00	10,650.00	6,725.00	20,450.0 (99.2%)

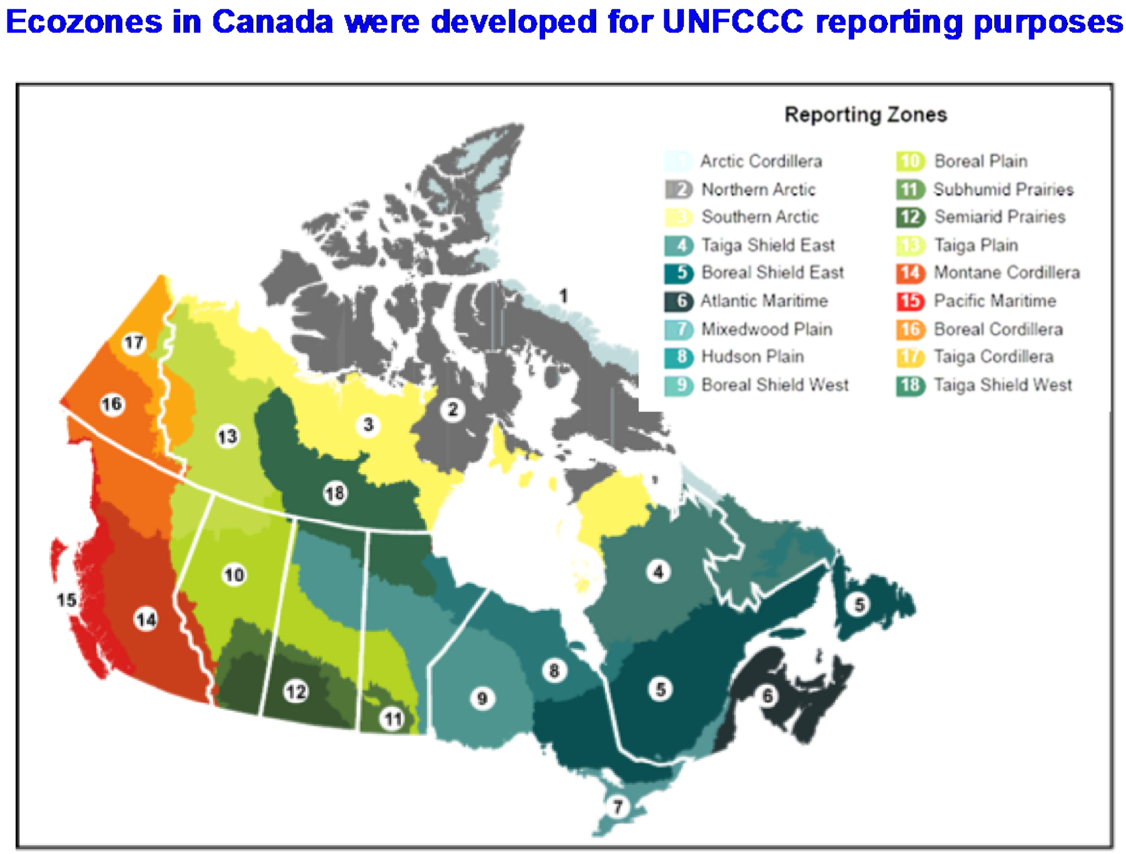
For this study, based on the criteria for administration and population, eight areas that are similar to the NUTS 2 level have been derived within these three Provinces. As each of the eight areas lie within one of the three Provinces and as the provinces are administrative units, the criterion of administration 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 (2015j): Harvested areas canola, CANISM table 001-0017, http://www5.statcan.gc.ca/cansim/a47

Figure 2: Ecozones in Canada[10]

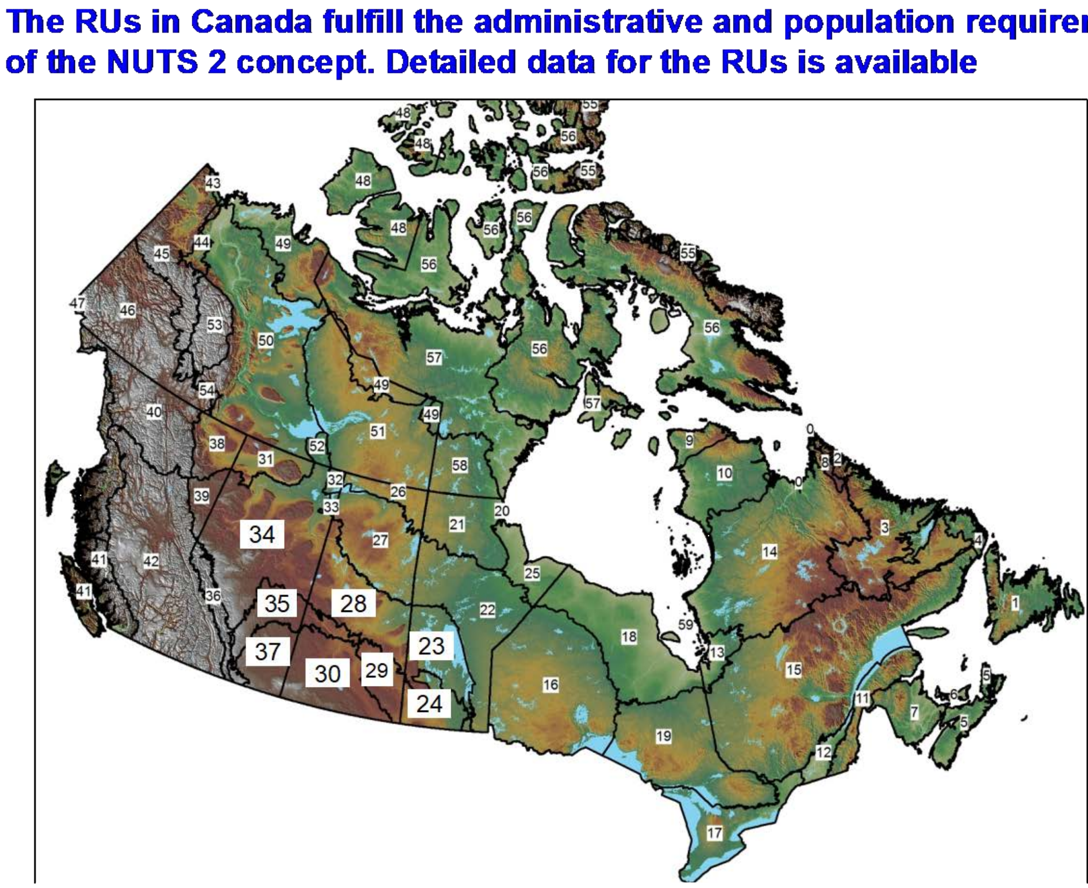


2. **Overlying with the Agriculture and AgriFood Canada (AAFC) Reconciliation Units (RUs)**

   A 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 (2012): National Inventory Report 1990 – 2010. Greenhouse Gas Sources and Sinks in Canada. Part 1. Environment and Climate Chane Canada http://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_submissions/application/zip/can-2012-nir-11apr.zip

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



For RU 22, RU 27 and RU 36 no GHG values have been produced, as only limited canola production takes place in these regions.

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 even on a more fine-grained level and more representative for 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.

[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	Adminis-trative unit	Population*	Ecozone	RU	Population*	NUTS 2 or smaller fulfilled
Manitoba	**yes**	**1.3 mill.**	**Boreal Plain**	23	56,690	yes
			Subhumid Prairies	24	1,104,740	yes
Saskatchewan	**yes**	**1.1 mill.**	**Boreal Plain**	28	167,324	yes
			Subhumid Prairies	29	123,237	yes
			Semiarid Prairies	30	729,951	yes
Alberta	**yes**	**3.9 mill.**	**Boreal Plain**	34	452,960	yes
			Subhumid Prairies	35	1,573,799	yes
			Semiarid Prairies	37	1,712,562	yes

*** Total province population numbers can be higher than sum of RU population numbers due to the fact that not all RUs of the provinces are canola production areas**

12 (S&T)[2] Consultants Inc. (2012): LCI Data for Canadian Canola Production, Winnipeg. Statistics Canada (2015i): Annual population estimates, http://www.statcan.gc.ca/daily-quotidien/130926/t130926a002-eng.htm (Last visit: 01/04/2015)

3 Methodology

3.1 Cultivation of canola for biofuel production

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

$E = e_{ec} + e_{l} + e_{p} + e_{td} + e_{u} – e_{sca} – e_{CCS} – e_{CCr} - e_{ee}$ 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
e_{ee}	GHG emissions savings from excess electricity from cogeneration

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 RED 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. [Annex V, Part C, Point 6].
- 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 shall be calculated according to the European Commission's Communication on practical implementation of the EU biofuels and bioliquids sustainability scheme and on counting rules for biofuels.[14] Chapter 5 provides an overview on the calculation method for N_2O emissions according to the EC communication.
- Emissions from irrigation were integrated in the chapter field operations.
- The production of canola in Canada takes place on alkaline soils and thus the need for soil pH adjustment through the addition of lime is avoided.
- GHG emissions of agricultural feedstocks shall be expressed in kg CO_2eq per dry-ton feedstock [EC Note][15]

[13] EC (2009a) l.c., Annex V, C.
[14] EC (2010a) l.c.
[15] EC (2015a) l.c.

- 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: 23 and N_2O: 296. [Annex V, Part C, Point 5]
- 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]

In the study three different aggregated GHG emission values of canola cultivation for eight identified Canadian RUs were calculated.

4 Input data for canola cultivation for biofuel production

Data were collated on the factors used in the RED: 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 2012-2014 average data. Some of the data is available at latest for 2011 from a survey initiated by the Canola Council of Canada (CCC). The CCC initiated the survey to gather data on canola production practices in Western Canada. The project was funded by AAFC. The survey was undertaken by Blacksheep Strategy and the data was analyzed by AAFC. [16] 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. The regional data that was found relevant to the calculation of GHG emissions was extracted from the survey by AAFC.

Further regional data has been obtained from AAFC on N_2O emission rates.[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, eight NUTS 2 equivalent regions have been identified in Canada, which are important for canola production. Due to confidentiality reasons it was not possible to report the data from RUs 22 and RU 39 due to the small sample size. Respondents from RU 22 were included with RU23 and RU 39 was merged with RU 34.

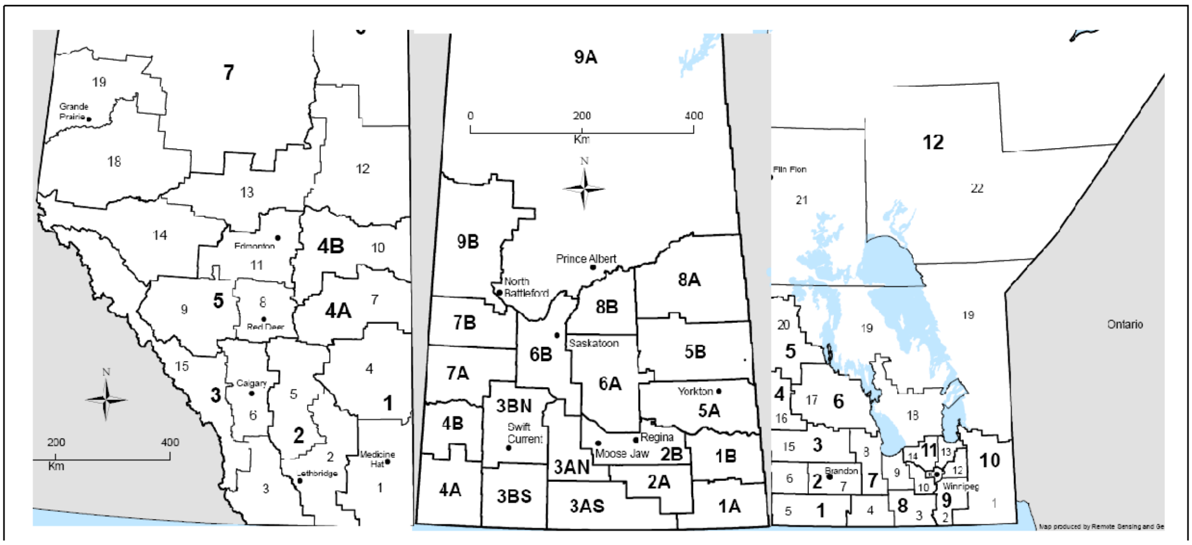
Data on cultivated area as well as canola yield was provided by Statistics Canada for 2012-2014. Data was available for so-called small area data regions. In Manitoba there are 12 small area data regions, in Saskatchewan there are 20, and in Alberta there are 8 regions. The small area data regions are the same as Census Agricultural Regions (CAR), although there is a different numbering system. In the following figure the Census Agricultural regions for the three provinces are shown.

[16] Smith, E., Barbieri, J. (2012): Summary of Inputs and Production Practices used by Canola Growers in 2011. Agriculture and AgriFood Canada. Lethbridge Research Centre. and AAFC, personnel communications, D. Worth. Ottawa.

[17] AAFC, (2014): Personnel communications, D. Worth, Oct. 29, 2014. Ottawa.

Figure 4: Census Agricultural Regions[18]

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 RU basis. CAR's data have not been split into more than one RU. Area and yield data for the CAR is available on an annual basis.[19] In this report, estimates are based on average yields reported for 2012-2014. 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%[20]. In parallel to the Canola Grain Commission, a historical 8.5% moisture basis was used in order to permit annual and regional deviations.

Table 4: Cultivated area (ha) and yields of canola in Canada 2012 – 2014.

	Manitoba		Saskatchewan			Alberta		
	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
Cultivated area (ha/yr)	482000	758000	2353000	1268000	730000	815000	1207400	548000
Moist Yield canola (t/ha/yr)	1.83	1.97	1.75	1.73	1.93	2.00	2.26	2.19
Dry yield canola (dry-ton/ha/yr)	1.67	1.80	1.60	1.58	1.77	1.83	2.07	2.00

18 Statistics Canada (2015c): 2011 census agricultural regions and census divisions. Manitoba. http://www.statcan.gc.ca/sites/default/files/map1mn-eng.pdf, Statistics Canada (2015d): 2011 census agricultural regions and census divisions. Saskatchewan. http://www.statcan.gc.ca/sites/default/files/map1sk-eng.pdf, Statistics Canada (2015e): 2011 census agricultural regions and census divisions. Alberta. http://www.statcan.gc.ca/sites/default/files/map1al-eng.pdf

19 Statistics Canada (2015f). Estimated areas, yield and production of principal field crops by Small Area Data Regions, in metric and imperial units, annually. http://www5.statcan.gc.ca/cansim/a03?lang=eng&id=0010071&pattern=0010071&searchTypeByValue=1&p2=35

20 Canadian Grain Commission (2011 – 2014): Western Canadian canola – Scientific analysis of harvest and export quality. https://www.grainscanada.gc.ca/canola/hqcm-mqrc-eng.htm

4.2 Seed rate

A seed rate of 5.38 to 5.6 kg/ha was assumed for canola production based on the CCC survey from 2011. The survey of canola farmers was performed by the Canada Canola Council in 2011.[21]

Table 5: Canola seed rates (kg/ha/yr) in Canada 2011[22]

	Manitoba		Saskatchewan			Alberta		
	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
Seed (kg/ha/yr)	5.49	5.49	5.49	5.49	5.38	5.60	5.49	5.60

4.3 Fertilizer application

Average annual applications of the following fertilizers were collected:

- Nitrogen (N) fertilizer input (kg N per ha and yr).
- Phosphorus (P) fertilizers input (kg P_2O_5 per ha and yr).
- Potassium (K) fertilizer input (kg K_2O per ha and yr).
- Sulfur (S) input (kg S per ha and yr).

Where possible an average value for 2012-2014 has been used. In Manitoba and Saskatchewan, fertilizer application rates for synthetic N fertilizers, S fertilizers, K_2O fertilizers and P_2O_5 fertilizers for 2012-2014 are available through the Manitoba and Saskatchewan crop insurance programs. Both of these programs have very high participations. In both cases the data is spatially available so that it can be allocated to a specific RU. In Alberta fertilization rate data on synthetic N fertilizers, S fertilizers, K_2O fertilizers and P_2O_5 fertilizers is not available for the period after 2011. Therefore, the data collected by the Canola Council Canada survey 2011 were adapted and included in the calculation.[23]

Table 6: Fertilizer application rates (kg/ha/yr) in Canada

	Manitoba		Saskatchewan			Alberta		
	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
Synthetic N-fertilizer (kg N/ha/yr)	116.7	123.0	96.2	83.7	91.0	88.9	94.5	96.6
Manure (kg N/ha/yr)	0.0	9.7	27.4	1.7	1.8	3.4	8.3	8.0
K_2O-fertilizer (kg K_2O/ha/yr)	7.3	7.0	4.4	2.1	1.5	9.0	9.2	3.8
P_2O_5-fertilizer (kg P_2O_5/ha/yr)	36.4	39.3	28.5	25.8	27.8	29.1	24.6	28.0
S-fertilizer (kg S/ha/yr)	19.4	19.7	19.0	14.7	13.8	17.6	19.2	12.9

Manitoba Agricultural Services Corporation (MASC) requires producers insured by them to supply their yield and management information. Via the Manitoba Management Plus Program

[21] Canola Council of Canada, CCC (2011): Survey of Canola farmers. Winnipeg.
[22] CCC (2011) l.c.
[23] CCC (2011) l.c.

(MMPP) anonymized production and management data of producers can be generated. The database allows access to the yield and fertilizer application rates by crop and is sortable by municipality and risk areas.[24]

The Saskatchewan Crop Insurance Corporation (SCIC) has a Saskatchewan Management Plus Program (SMP) similar to Manitoba's' that is designed to give producers actual crop production information to help make more informed farm management decisions and help SCIC maintain, develop and enhance Crop Insurance programs. From the Seeded Acreage Report and Production Declaration form, SCIC collects information including crop and variety, land use (summerfallow, stubble, irrigated), seeding date, chemicals/fertilizers applied, average grade produced and yields. The SMP database can be queried by risk zone to produce yield and fertilizer application rates, which for this work were allocated to the three RU's of interest. [25]

In Alberta, the data collected by the Canola Council Canada survey 2011 were adapted and included in the calculation.[26] As shown in the following table, the fertilization rates in 2011 were higher than in the previous three year average between 2008 and 2010. Therefore, the application of 2011 survey data is a conservative approach.

Table 7: Alberta Fertilization Data (kg/t canola)[27]

Nutrient	**RU 34**		**RU 35**		**RU 37**	
	2008-2010	**2011**	**2008-2010**	**2011**	**2008-2010**	**2011**
N	40.58	44.44	43.4	41.83	34.53	44.41
P	12.67	14.53	10.73	10.90	10.63	12.78
K	7.02	4.49	6.19	4.08	1.00	1.73
S	9.37	8.79	7.10	8.49	5.38	5.91

Nitrogen application via manure was included in the 2011 CCC survey by asking for any stock breeding (beef, hog, dairy or poultry) and the relevant amount of manure applied on the fields. The AAFC Holos tool provided the typical N contents of manure.[28]

Emission factors are based on regional factors from GHGenius and Ecoinvent.

[24] Manitoba Agricultural Services Corporation (2015): Manitoba Management Plus Program. http://www.mmpp.com/mmpp.nsf/mmpp_browser_fertilizer.html

[25] Crop Insurance Corporation (2015): Personnel communications, D. Hack, March 16, 2015. Melville.

[26] CCC (2011) l.c.

[27] Alberta Agriculture and Rural Development (2014): AgriProfit$ Benchmark Analysis. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ10237

[28] Little, S., Lindeman, J., Maclean, K. Janzen, H. Holos (2009): A tool to estimate and reduce greenhouse gases from farms. Ottawa. ftp://ftp.agr.gc.ca/pub/outgoing/HOLOS/Holos_V1.1.2/Holosv1.1.2.zip

Table 8: Emission factors used for the different fertilizers (except Nitrogen)

Input	Emission factors	Unit	Source
Sulfur	0.158	kg CO_2eq/kg S	GHGenius 4.03a, 2014
Ammonium thio-sulfate	0.154	kg CO_2eq/kg S	GHGenius 4.03a, 2014
K_2O	0.362	kg CO_2eq/kg K_2O	GHGenius 4.03a, 2014
P as P_2O_5	1.34	kg CO_2eq/kg P_2O_5	Ecoinvent 3.1, 2014

Within Canada also S-fertilizers are applied in form of pure Sulfur, ammonium sulfate, ammonium thio-sulfate and fertilizer blend. Highest S inputs occurred in RU 24 and lowest S inputs in RU 37. Sulfur is a waste product in western Canada from refineries, gas plants and oil sands plants. To include a more regionalized emission factor, the emission factor of 0.158 kg CO_2eq/kg S from GHGenius 4.03a, 2014 has been used.

4.4 Different Nitrogen fertilizer types

Typical mineral N-fertilizers for canola production in Canada were anhydrous ammonia, urea (liquid), ESN (polymer-coated urea), urea ammonium nitrate (UAN), ammonium nitrate, ammonium sulfate and fertilizer blend.

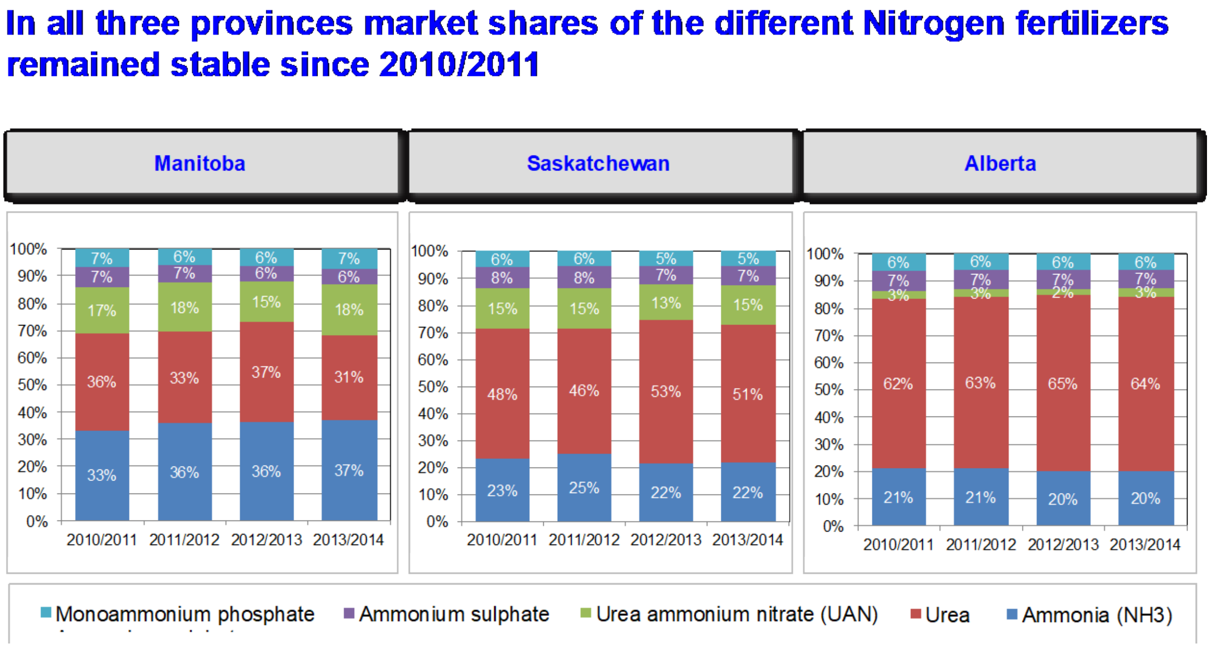
Table 9: N-application by fertilizer type (kg N/ha/yr)

	Manitoba		Saskatchewan			Alberta		
Fertilizer type	**RU 23**	**RU 24**	**RU 28**	**RU 29**	**RU 30**	**RU 34**	**RU 35**	**RU 37**
Anhydrous ammonia	48.8	50.7	40.1	19.2	7.2	20.6	14.8	12.2
Urea	33.8	28.3	22.9	28.7	45.2	39.4	51.3	56.4
ESN	0.6	0.4	1.3	2.7	4.3	1.1	5.9	7.0
UAN (liquid)	19.6	22.4	3.6	9.8	11.4	2.2	0.0	2.1
Ammonium nitrate	0.0	2.1	2.2	3.3	0.7	1.1	1.3	1.5
Ammonium sulfate	7.1	7.0	5.0	4.3	3.2	6.1	6.1	5.3
Fertilizer blend	6.7	12.2	21.2	15.7	19.0	18.3	15.0	12.2
Ammonium thio-sulfate	0.5	0.5	0.2	0.3	0.3	0.1	0	0
Total mineral N fertilizer (without Ammonium thio-sulfate)	**116.7**	**123.0**	**96.2**	**83.7**	**91.0**	**88.9**	**94.5**	**96.6**

The type of Nitrogen fertilizers applied is not specified in the crop insurance programs and therefore not available for all three provinces for the calculation period 2012-2014. Therefore, the shares of Nitrogen fertilizers applied, as referred to in the 2011 Canola Survey, have been used.

The nitrogen fertilizer sold in each province is available from Statistics Canada 2015[29] and it can be compared year to year and to the results from the 2011 Canola Survey. The following figures show the development of the most important fertilizer types in the three Canadian provinces.

Figure 5: Market share of different types of Nitrogen fertilizer sold in the three different Provinces 2010 till 2014[30]



As shown in the figure, the application of different types of N fertilizers were quite stable in each province since 2011. Therefore, it can be assumed that the share of different N fertilizer types remained stable between 2011 and the calculation period 2012-2014.

The emission factors for producing and transporting synthetic fertilizers were mainly taken from regionalized data bases like Ecoinvent[31] and GHGenius[32]. The emission factors from Ecoinvent derived from the latest version 3.1, 2014 of Ecoinvent. For GHGenius also the latest version, GHGenius 4.03a has been used to derive the GHG emissions.

Regional information for Canada is available for ammonia production and potash mining. In 2007 an NRCan report benchmarked the performance of the Canadian ammonia industry from 2000 till 2002. The emission factor includes the energy consumption for ammonia production; however, as it does not include further processing for the end products of ammonia fertilizer, it can only be used for anhydrous ammonia and ammonium sulfate production. The adapted emission factor for anhydrous ammonia and ammonium sulphate accounts 2.87 kg CO_2eq/kg N (GHGenius 4.03, 2014, NRCan report 2007).

For urea, the emission factor of 2.91 kg CO_2eq/kg N from Ecoinvent has been used. It is assumed that the fertilizer blend is mainly based on urea or ammonia for blend. ESN

[29] Statistics Canada (2015g): Fertilizer shipments to Canadian agriculture and export markets, by product type and fertilizer year, cumulative data, annual (metric tonnes). Table 001-0068 http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=0010068&paSer=&pattern=&stByVal=1&p1=1&p2=31&tabMode=dataTable&csid=

[30] Alberta Agriculture and Rural Development (2014): AgriProfit$ Benchmark Analysis. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ10237

[31] Ecoinvent is a database providing of consistent and transparent life cycle inventory (LCI) data (http://ecoinvent.org/).

[32] GHGenius is a model for lifecycle assessment of transportation fuels (www.ghgenius.ca)

(Environmentally Smart Nitrogen) is a urea fertilizer coated with a polymer. Therefore, the same emission factor as for urea is applied. Further emission factors from Ecoinvent, that had been used, are that for ammonium nitrate (8.36 kg CO_2eq/kg N) and for urea ammonium nitrate (UAN liquid, 5.44 kg CO_2eq/kg N).

4.5 Crop residue returns

Emissions arising from crop residues are also included in line with the methodology of the RED. The crop residue data for canola is based on Janzen et al. 2003.[33] The amount of nitrogen in the residue was calculated per ton of seed.

Table 10: Canola crop residues and respective N concentrations

	Canola	Above Ground Biomass	Below Ground Biomass
Relative dry matter (DM) allocation (%)	0.26	0.60	0.15
N concentration in g N/kg	35	8	10
kg N in residue/t seed		16.8	5.3

The total crop residue nitrogen is 22.1 kg N/t of seed produced at 9% oilseed moisture. Based on the seed rates, the k N input per hectare and year from crop residue return has been calculated for each RU.

Table 11: Crop residue returns (kg N/ha/yr) in Canada

	Manitoba		Saskatchewan			Alberta		
	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
N from crop residues (kg N/ha/yr)	40.4	43.5	38.7	38.2	42.7	44.2	49.9	48.4

4.6 Pesticides

Latest available data on pesticides comes from the 2011 CCC survey. The 2011 survey asked for the number of field applications of individual pesticides by brand and if the application rate was the recommended rate, higher or lower. The majority of respondents replied that the products were applied at the recommended rate and that on average more growers used less than the recommended rate than more. Most of the lower rates of application were for second or third applications of herbicide or a second application of insecticide or fungicide. The survey data did not collect the actual rate information, so “higher” and “lower” rates are not defined. It was found reasonable to assume that, on average, all pesticides were applied at their recommended rates.

For “other pesticides” the recommended application rate was averaged over all of the other pesticides used, this category represents only 2% of herbicides and fungicides and 14% of

[33] Janzen HH, Beauchemin KA, Bruinsma Y, Campbell CA, Desjardins RL, Ellert BH, Smith EG. (2003): The fate of nitrogen in agroecosystems: an illustration using Canadian estimates. Berlin. http://www.springerlink.com/content/qg1uq482l4650624/

insecticides. The recommended application rate was the rate reported in the Alberta Crop Protection Guide. [34]

About 14 different plant protection products are applied within Canada. Typical active ingredients (a.i.) are Clethodim, Glyphosate, Glufosinate-ammonium, Imazamox and Imazethapyr, Tepraloxydim, Deltamethrin, Chlorpyrifos, Cychalothrin-lambda, Cyprodinil and Fudioxonil, Pyraclostrobin, Boscalid, Prothioconazole, Iprodione and Proiconazole. In total highest pesticide applications took place in RU 23 with 0.85 kg/ha/yr active ingredients, lowest pesticide applications took place in RU 30 with 0.57 kg/ha/yr.

Table 12: Pesticides application rates (kg active ingredient./ha/yr) in Canada 2011

	Manitoba		**Saskatchewan**			**Alberta**		
	RU 23	**RU 24**	**RU 28**	**RU 29**	**RU 30**	**RU 34**	**RU 35**	**RU 37**
Pesticides (kg a.i./ha/yr)	0.8	0.8	0.7	0.6	0.6	0.7	0.6	0.7

For Glyphosate the emission factor of 9.79 kg CO_2eq/kg Glyphosate from Ecoinvent 3.1, 2014 has been used. As for all other plant protection products no specific emission factors were available the emission factor for other pesticides of 8.04 kg CO_2eq/kg active ingredient (Ecoinvent 3.1, 2014) was used.

4.7 Field operations

The latest available data on fuel consumption is from 2011. The direct energy use was calculated based on the field operations reported in the 2011 CCC survey and energy use factors for the various different types of equipment that is used. It was combined with fuel consumption based on the tillage type and the latest available data on canola yield.

Diesel fuel use was based on number of field operations and assumptions on fuel consumption. In-field operations, tillage or pre-seeding activities, seeding and crop activities were included. The annual consumption accounted for between 12.5 l/t/yr in RU 37 and 18.0 l/t/yr in RU 23 (for moist canola). Electricity and natural gas are linked to irrigation, storage and aeration. In 2012 - 2014 electricity consumption and natural gas consumption was highest in RU 37. The main reason is the high yields in this RU. Lowest electricity and natural gas consumption occurred in RU 23, RU 28, RU 34 and RU 35. All consumption figures have been adapted by the dry matter content of canola.

Very little land is irrigated in western Canada. The Canola survey undertaken in 2011 found that between 0 and 2% of land in the different RUs was irrigated. This is in line the 2011 Census of Agriculture which reports that 1.3 % of western Canadian (Alberta, Manitoba, Saskatchewan) land was irrigated, with the majority of that being in southern Alberta and outside of the normal growing area for canola.[35]

[34] Alberta Agriculture and Rural Development (2011): Crop Protection. Edmonton. https://www.agric.gov.ab.ca/app08/showpublications?ttype=CP

[35] Statistics Canada (2011a): Census of Agriculture, irrigation in the year prior to the census, Table 004-0210, http://www5.statcan.gc.ca/cansim/a47

Statistics Canada (2015a): Estimated areas, yield, production and average farm price of principal field crops, in metric units, annual. CANSIM, Harvested area, Table 001-0010, Ottawa. http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=10010

Table 13: Energy consumption in canola production (per dry-ton canola and year) – adapted to dry matter content

	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

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.

The diesel consumption for the different tillage types was calculated based on data about the tillage types used in each RU in 2011, the number of passes for different machineries of the different tillage types and the fuel consumption by the machinery. The survey provided the distribution of tillage categories by RU.

Table 14: Share of the tillage systems within each RU (%)[36]

	RU 23	**RU 24**	**RU 28**	**RU 29**	**RU 30**	**RU 34**	**RU 35**	**RU 37**
Conventional tillage	36.4	26.3	12.5	5.5	2.6	9.1	9.1	10.0
Minimum/ Reduced tillage	54.6	47.5	44.4	23.4	11.4	26.0	31.2	26.7
Direct Seed	3.6	9.4	20.8	17.2	17.5	26.6	14.3	20.0
Zero tillage	5.5	16.9	20.8	53.7	67.5	37.0	45.5	41.1
Mix	0.0	0.0	1.4	0.0	0.9	1.3	0.0	2.2

The equipment for the different tillage practices include harrow, light duty or field cultivator, deep tillage cultivator, disc type implement, plow, fall spray and spray burn-off.

[36] Smith, E., Barbieri, J. (2012) l.c.

Table 15: Machinery use and number of passes in tillage systems (number of passes)[37]

Type of machinery	Conventional tillage[38]	Minimum or reduced tillage[39]	Direct seed	Zero tillage	Mix
Harrow	0.48	0.4	0.17	0.08	0.17
Light duty or field cultivator	0.80	0.40	0.14	0.05	0.67
Deep tillage cultivator	0.92	0.64	0.08	0.05	0.33
Disc type implement[40]	0.16	0.08	0.03	0.0	0.0
Plow	0.01	0.0	0.0	0.0	0.0
Fall spray	0.61	0.84	0.99	1.01	0.5
Spray burn-off[41]	0.18	0.44	0.75	0.83	0.33

The equipment use by tillage category is only available for the complete sample set, as the size of some of the categories gets too small if it is done by RUs.

The fuel use for each activity (l/ha) was sourced from either recent test data for Alberta from the Agricultural Research and Extension Council of Alberta[42] or from data published by the Colorado State University.[43]

Table 16: Fuel usage by machinery (l/ha)

Type of machinery	Fuel use (l/ha) Agricultural Research and Extension Council of Alberta 2011	Colorado State University 1998
Harrow	1.4	3.73
Light duty or field cultivator	-	4.2
Deep tillage cultivator	-	10.28
Disc type implement	-	5.14
Plow	-	15.7
Spray	1.09	0.93

By multiplying the number of passes for each tillage system with the fuel consumption by machinery, the fuel consumption for the different tillage systems was calculated. The total fuel consumption for all machineries accounted for between 3.05 l/ha for zero tillage and 16.46 l/ha for conventional tillage.

Table 17: Total diesel consumption per tillage system

	Conventional tillage	Minimum or reduced tillage	Direct seed	Zero tillage	Mix
Diesel consumption	16.5	11.6	4.1	3.05	7.8

37 Smith, E., Barbieri, J. (2012) l.c.
38 Cultivation for weed control and seedbed preparation
39 30% + residue cover
40 Tandem or offset disc, discer, etc.
41 Pre-seed and pre-emergence
42 Agricultural Research and Extension Council of Alberta (2011): Energy Conservation and Energy Efficiency. Edmonton. http://www.areca.ab.ca/projects/manuals.html.
43 Colorado State University (1998): Estimating Farm Fuel Requirements. Fort Collins. http://www.ext.colostate.edu/pubs/farmmgt/05006.pdf

The fuel consumption for the different RUs was calculated by multiplying the fuel consumption of the tillage systems by the shares of tillage systems within a RU and building the sum. The total diesel fuel consumption for tillage practices lay between 4.6 l/ha in RU 30 and 12.6 l/ha in RU 23. The summarized fuel usages of tillage systems per RU are stated in the Annex. Additionally fuel use for seeding, the swathing energy, the combine and straight cut were included in the fuel consumption number.

A small fraction of the producers also apply manure to the fields. The transportation and application of the manure requires energy. The fuel consumption for manure spreading is a function of the trucking distance, application rates and the equipment used for application. The energy required to distribute and spread the manure was calculated assuming an average trucking distance of 20 km and an energy consumption rate for a medium duty truck of 6.6 MJ/t/km and a diesel energy content of 38.5 MJ/l (HHV). [44]

Furthermore, a small fraction of the canola producers irrigated their fields. Alberta Agriculture and Rural Development[45] reported that the energy use for irrigation in 2010 was supplied by 49% electricity, 31% natural gas, 15% by gravity, and the remainder diesel, liquid propane gas (LPG), or unknown. It is assumed that the efficiency of the diesel, propane and other is the same as the natural gas. According to Alberta Agriculture and Rural Development the energy efficiency of electric systems is 19.4 kWh/acre-inch of water supplied and that of natural gas systems is 80.9 kWh/acre in (291 MJ/acre-inch). [46] In 2012, Alberta Agriculture and Rural Development (2012b) also undertook an assessment of the current irrigation practices for a number of crops. For canola they found that an average of 177 mm of water was used.[47] Therefore, the energy needed to irrigate one hectare of canola accounts 164 kWh for electricity, 631 MJ for natural gas and 102 MJ for diesel fuel.

Other energy consumptions that were considered in the study are transport from field to the farmer's bin as well as electricity for storage and aeration.[48]

For diesel consumption in the RUs, regional applicable emission factors have been used. In Canada diesel is produced in one large refining center in Edmonton, Alberta and serves Western Canada with diesel fuel primarily distributed by pipeline from there. The differences in the emission factors originate from different transport distances to the different provinces. [49] The western Canadian refiners process a significant proportion of oil produced from the oil sands in combination with conventional light and heavy crude oils. The emissions for the production and combustion account 3.705 kg CO_2eq/l in Manitoba, 3.729 kg CO_2eq/l in Saskatchewan and 3.715 kg CO_2eq/l in Alberta.

The electricity production in Manitoba and Saskatchewan is owned by the Provincial Governments, in Alberta it is privately owned. There is limited interchange of the electricity between the Provincial grids. The Manitoba system is mainly hydroelectric, whereas coal dominates the power systems of the other two provinces. GHGenius has full lifecycle emission factors for the electricity, including generation and distribution. The emission factor for electricity production in Manitoba accounts 0.089 kg CO_2eq/kWh, the emission factors for Saskatchewan and Alberta are 0.863 kg CO_2eq/kWh and 0.941 kg CO_2eq/kWh respectively.

Natural gas is produced in Alberta and Saskatchewan and is distributed across Canada by pipeline. The small differences in the emission factors are caused by the different

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44 GHGenius (2012): Manual 4.01. www.ghgenius.ca

45 Alberta Agriculture and Rural Development (2011): Crop Protection. Edmonton https://www.agric.gov.ab.ca/app08/showpublications?ttype=CP

46 Alberta Agriculture and Rural Development (2010): Irrigation System Energy Trial Assessment Project. Edmonton.

47 Alberta Agriculture and Rural Development (2012) Current Irrigation Management Practices Study 2007 – 2009. Edmonton. http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13643/$FILE/cimp2report.pdf.

48 See also $(S\&T)^2$ 2012 l.c.

49 GHGenius (2012) l.c.

transportation distances involved. The emissions for the production and distribution of natural gas account 0.067 kg CO_2eq/MJ in Manitoba and 0.066 kg CO_2eq/MJ in Saskatchewan and Alberta.

4.8 Crop drying

Crop drying is not additionally included in this report. Energy consumptions for storage and aeration has been included in section 4.7 „Field operations“.

5 Nitrous oxide emissions

In addition to production emissions, mineral N-fertilizers as well as organic N-fertilizers and crop residues cause on-field N_2O-emissions after application. Other fertilizers than N-fertilizers (e.g. Sulfur) are not linked to climate-relevant on-field emissions. According to the EC Communication (2010/C1600/02) an “appropriate way to take into account N_2O emissions from soils is the IPCC methodology[50], including what are described there as both ´direct` and ´indirect` N_2O emissions.”[51]

For calculating the on-field N_2O-emissions all three IPCC Tiers can be used.[52]

In Canada, rigorously documented country-specific emission factors for direct N_2O-emissions (EF_1) and the fraction of applied organic N fertilizer materials (F_{ON}) that volatiles as NH_3, NO_x ($Frac_{LEACH}$) are provided by the Agriculture and AgriFood Canada (see table 18). Therefore, Tier 2 of the IPCC methodology was applied using a combination of country-specific and default emission factors.[53]

The application of the general rules for calculating N_2O emissions depend on the ecological characteristics of the analyzed areas. The main soil type within the eight RUs is Chernozem. Chernozem is a humus-rich mineral soil that formed on calcareous substrate. It was assumed that no canola production took place on the organic soils (i.e. histosols) that can be found rarely in the RUs. Most of the RUs comprise furthermore a cold temperate dry climate.

Table 18: Main soil and climate types of the RUs[54]

	Main soil types	Main Climate type
RU 23	Dark Grey Chernozem, Grey Luvisol	Cold temperate dry, Cold temperate moist
RU 24	Black Chernozem	Cold temperate dry
RU 28	Dark Grey Chernozem, Grey Luvisol	Cold temperate dry
RU 29	Black Chernozem	Cold temperate dry
RU 30	Brown Chernozem, Dark Brown Chernozem	Cold temperate dry
RU 34	Grey Luvisol, Dark Grey Chernozem	Cold temperate dry, Cold temperate moist
RU 35	Black Chernozem	Cold temperate dry, Cold temperate moist
RU 37	Brown Chernozem, Dark Brown Chernozem	Cold temperate dry

Further information on the classification of mineral and organic soils as well on the different soil types are published by JRC and Soils of Canada.[55] Both, the mineral soil types and the

50 The Intergovernmental Panel on Climate Change (IPCC) is the leading international organization for the assessment of climate change. In 2006 the Task Force on National Greenhouse Gas Inventories (TFI) prepared a report on IPCC Guidelines for National Greenhouse Gas Inventories for the IPCC which serve as inventory guidelines for national estimates of greenhouse gases.

51 EC (2010a) l.c.

52 EC (2010a) l.c.

53 IPCC (2006): Guidelines for National Greenhouse Gas Inventories, Vol 4, Chapter 11, p. 11.9 and p. 11.20. Hayama.

54 Soil Landscapes of Canada Working Group (2007): SLC v3.1.AAFC. (digital map and database at 1:1 million scale). Ottawa. JRC (2012): Thematic Data Layers for Commission Decision of [10 June 2010] on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC. Brussels. http://eusoils.jrc.ec.europa.eu/projects/RenewableEnergy/

cold temperate climate do influence the choice of methodology and emission factors when calculating N_2O emissions as well as carbon stock changes (e.g. c_{veg}, EF_2). Furthermore, as no cultivation on histosols took place, carbon stock calculation and N_2O emissions must not include any effects of potential soil drainage (e.g. drainage/management of organic soils F_{OS} within N_2O emission calculation).

Direct N_2O emissions occur directly on soils to which Nitrogen is added or released. They originate either from human induced N-additions or from changes in land-uses or management practices that mineralize organic N (e.g. ploughing). In Canada there are three main direct N-sources: mineral N-fertilizers, organic N-fertilizers (manure, compost) and N in crop residues (above and below ground).[56]

Therefore, the adapted IPCC formula for direct N_2O-emissions is:

$$\mathrm{N_2O\text{-}N_{Ninputs}} = (\mathrm{F_{SN}} + \mathrm{F_{ON}} + \mathrm{F_{CR}})*\mathrm{EF_1}*44/28 \qquad \text{Equation (2)}$$

Where:

F_{SN}	Nitrogen application by synthetic (=mineral) N-fertilizers
F_{ON}	Nitrogen application by organic N fertilizers
F_{CR}	Nitrogen in above and below ground crop residues
44/28	Conversion of $N_2O_{(L)}$-N emissions to N_2O-emissions for reporting
EF_1	Emission factor developed for N_2O emissions from synthetic (=mineral) fertilizers, organic N applications and crop residues under conditions i; i= 1,…n

Indirect N_2O emissions arise from leaching, runoff of NO_3-N from managed soils and atmospheric deposition. Thereby, N-fertilizers volatile as NH_3 and NO_x from managed soils and redeposit by converting into NH_4^+ and NO_3^-, which drain to soils and waters.

$$\mathrm{N_2O_{indirect}} = \left(\mathrm{N_2O}_{(L)} + \mathrm{N_2O}_{(ATD)}\right) * 44/28 \left(\frac{kg\ N_2O}{ha}\right) \qquad \text{Equation (3)}$$

Where:

$N_2O_{(L)}$	Annual amount of N_2O produced by leaching and runoff from managed soils [$kg_{N2O\text{-}N}$/yr]
$N_2O_{(ATD)}$	Annual amount of N_2O produced from atmospheric deposition of N [kg_{N2O}/yr]

N_2O from leaching, runoff from managed soils

Mineral fertilizer, organic fertilizer and crop residues are taken into account when calculating N_2O emissions from leaching and runoff.

[55] JRC: http://eusoils.jrc.ec.europa.eu/library/maps/circumpolar/download/123.pdf
Soils of Canada: http://www.soilsofcanada.ca/orders/index.php

[56] There are other N-sources like the mineralization of soil-N due to a loss of soil organic carbon stocks in mineral soils through land-use change or management practices. This must not be taken into account. Furthermore, the opposite process to mineralization, whereby inorganic N is sequestered into newly formed soil organic matter (SOM), is also not taken into account. This is because of the different dynamics of SOM decomposition and formation, and also because reduced tillage in some circumstances can increase both SOM and N_2O emission. (IPCC (2006) l.c.)

$$N_2O_{(L)} = [(F_{SN} + F_{ON} + F_{CR})] * Frac_{Leach-(H)} * EF_5$$ Equation (4)

Where:

$Frac_{LEACH-(H)i}$ Fraction of all N added to/mineralized in managed soils that is lost through leaching and runoff under different conditions i [$kg_N/kg_{Nadditions}$]

EF_5 EF for N_2O-emission from N leaching, runoff [0.01 $kg_{N2O-N}/kg_{Nleached\_runoff}$] (IPCC 2006)

N_2O from atmospheric deposition

For N_2O emissions from atmospheric deposition again organic and mineral fertilizers play a significant role.

$$N_2O_{(ATD)} = [(F_{SN} * Frac_{GASF}) + (F_{ON} * Frac_{GASM})] * EF_4$$ Equation (5)

Where:

$Frac_{GASF}$ Fraction of synthetic (= mineral) fertilizer N that volatiles as NH3, NOx [0.10 $kg_{Nvolatilized}/kg_{Napp}$] (IPCC 2006)

$Frac_{GASM}$ Fraction of applied organic N fertilizer materials (F_{ON}) that volatiles as NH3, NOx [0.2 $kg_N/kg_{Nadditions}$] (IPCC 2006)

EF_4 EF for N_2O-E from atmospheric deposition of N on soils, water surfaces [0.01 kg_{N-N2O}/ ($kg_{NH3-N+NOx-Nvola}$)] (IPCC 2006)

Changed tillage types and different irrigation conditions within Canada lead to reduced mineralization of organic N and a smaller fraction of N leached or run-off. Therefore, RU specific factors for EF_1 and $Frac_{LEACH}$ can be used. They are based on the 2011 Census of Agriculture and were provided by AAFC. As land under zero tillage systems has increased in the past years, these values are conservative.

Table 19: Adapted EF_1 and $Frac_{LEACH}$ for canola production in the different reconciliation units (kg N/kg N)[57]

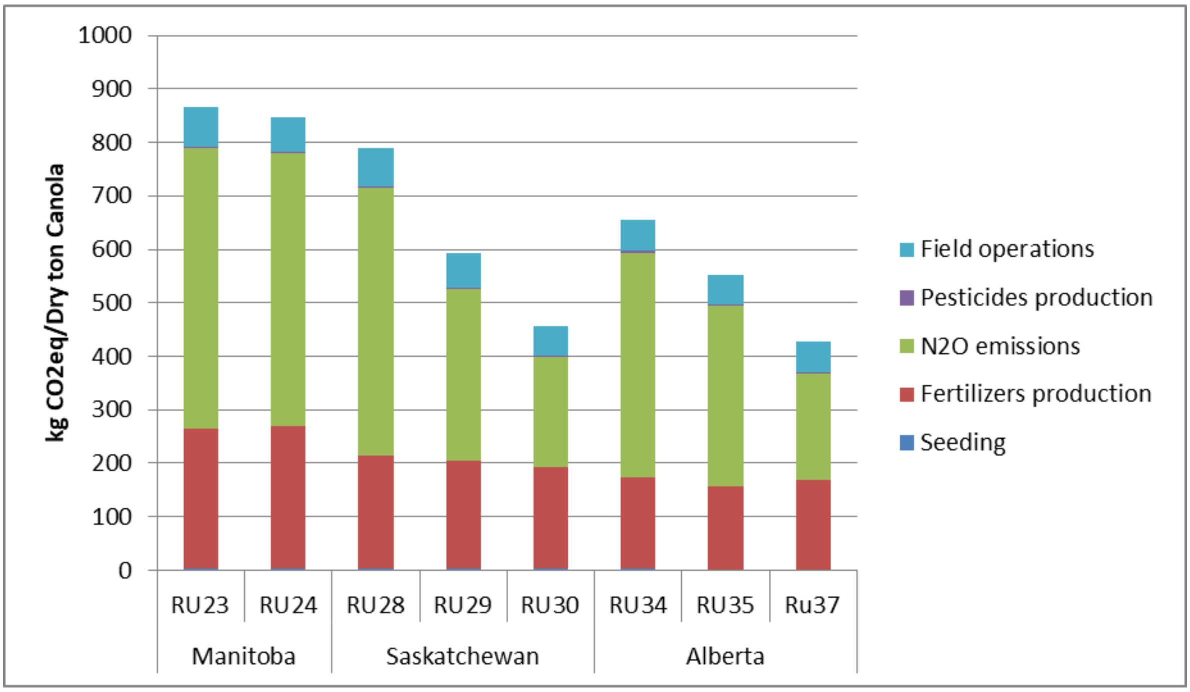
	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37
EF_{1i}	0.00978	0.00904	0.00838	0.00695	0.00426	0.00998	0.00790	0.00405
$Frac_{LEACHi}$	0.19053	0.17951	0.16979	0.14878	0.10900	0.19338	0.16271	0.10592

[57] $(S\&T)^2$ Consultants Inc. (2015): Updated LCI Data for Canadian Canola Production. Winnipeg.

6 Results

Based on the input data in Chapters 4 and 5, the emission of greenhouse gases from cultivation of canola in eight Canadian NUTS 2 equivalent regions was calculated in the units of kg CO_2eq/dry-ton canola and kg CO_2eq/MJ FAME. The total emission estimates are shown in the following figure.

Figure 6: Total GHG emissions in the RUs in kg CO_2eq/dry-ton canola



The calculations showed that major contributors to the final results were yield, the GHG emissions associated with fertilizer production and N_2O emissions.

The main emission sources of canola production in the RUs are on-field N_2O emissions from mineral and organic Nitrogen fertilizer application, production and processing of agrochemicals and diesel consumption during field operations.

Highest on-field N_2O emissions exist in RU 23 and RU 24, which are mainly caused by the low yields and high N fertilizer inputs. Lowest on-field emissions occur in RU 30 and RU 37. Reasons are high yields and low Nitrogen inputs. N-fertilizer application rates are higher in RU 37 than in RU 29. However, due to the very high yields in RU 37 N_2O emissions per ton canola have a lower impact.

Due to the high share of mineral fertilizers within RU 23 and RU 24, additionally high emissions from the production of the agrochemicals arise. These high input rates and the very low yields caused the comparatively high overall emissions.

RU 28 has comparatively low agrochemical emissions while N_2O emissions are higher. The main reason is the high input of organic manure and lower inputs of mineral N fertilizer. The same applies to RU 35, where additionally high yields lead to overall lower emissions per ton canola. The other emissions are not significantly high. Field operations lead to emissions between 54.9 kg CO_2eq/t and 73.1 kg CO_2eq/dry-ton canola. The emissions related to seed production lie between 1.9 and 2.5 kg CO_2eq/dry-ton canola.

The GHG emissions range from 428.0 to 865.7 kg CO_2eq/dry-ton canola. Assuming a conversion factor of 0.0655 kg dry feedstock/MJ DAME biodiesel and an allocation factor of

0.5860 between the canola oil and the canola meal then the cultivation emissions range from 16 to 33 kg CO_2eq/MJ Canola FAME.

Table 20: Emission of GHG from cultivation of canola

Single emissions (kg CO_2eq/dry-ton)						Total emissions	
Region	Seeding	Fertilizer production	N_2O field emissions	Pesticide production	Field operations	(kg CO_2eq/dry-ton)	Kg CO_2eq/MJ FAME
RU 23	2.4	262.5	523.5	4.2	73.1	865.7	33
RU 24	2.2	266.5	510.6	3.7	64.9	847.9	33
RU 28	2.5	212.8	499.5	3.8	71.4	790.0	30
RU 29	2.5	203.1	319.4	3.6	63.4	592.0	23
RU 30	2.2	190.2	206.5	2.8	55.1	456.8	18
RU 34	2.2	170.4	421.2	3.3	57.7	654.8	25
RU 35	1.9	154.2	338.4	2.6	54.9	552.0	21
RU 37	2.1	166.6	198.2	2.8	58.3	428.0	16

7 Verification

In order to verify and peer-review the results of the revised study, the report as well as the calculation methodology and all background information were provided to SGS Germany GmbH. The review of SGS Germany GmbH follows on the next pages.

SGS

Review of the calculation of a regional GHG emission values for the production of Canola in Canada

Date : 8 February 2016
Reference of the reviewed document:
Regional greenhouse gas emissions from cultivation of canola for use as biofuel or bioliquid - Canola cultivation in Canada, Report from 2016

Introduction

As an alternative to calculating individual Greenhouse gas (GHG) values for cultivation, the Renewable energy directive (Directive 2009/28/EC, called RED) offers the possibility to use aggregated values for particular regions.
SGS had been to review an updated version of the calculation of regional GHG emissions values for the production of canola in different geographic areas of Canada. The reviewing was performed against the following criteria:

- transparency and consistency of the methodology
- compliance with the European Directive on energy from renewable sources (directive "RED" 2009/28/EC) and related communication from the European Commission
- comprehensiveness of the emission sources in the scope (with regards to the methodology laid down in the RED directive)
- adequacy of the emissions factors
- correctness of the calculations
- relevance of the literature sources

Geographic units

Within the European Union, regional calculations of aggregated GHG emissions from cultivation can only be performed at the level of the statistical NUTS2 areas or at a finer level. Outside the Union, similar regions have to be defined in accordance to guidelines of the Communication 2010/C160/02 by the European Commission. Each so-called reconciliation unit (RUs) lies within one province (criteria of administration) and in one ecozone (as defined in Environment Canada. 2012 National Inventory Report). The maximum population of the RU is 1,71 million. Therefore the RUs are

1. smaller geographical areas than those in the calculation of the default values (requirement RED)
2. a more fine-grained level than the NUTS2 (requirement from the communication 2010/C160/02).

Furthermore, we can consider the approach more reasonable to take into account smaller geographic regions which have a certain level of homogeneity in terms of climates and soil types.

Sources of emission

In accordance with the Annex of the RED, the following sources of emissions have been found relevant at this stage of the supply chain and have been included in the calculation:

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- e_{ec} : emissions from the extraction or cultivation of raw material (including energy, fertilizers, pesticides and seeding material, and N2O emissions from the field)
- e_{sca} : emission savings through improved agricultural management (land management changes (LMC)

We found out that the relevant emissions in the scope of the methodology laid out in annex V of the RED directive have been included.
Appropriate literature sources have demonstrated that reduced frequency of summer fallow and increased frequency of no tillage and reduced tillage techniques actually promote carbon sequestration in soil and contribute to build up a carbon sink. Those LMC were found to be eligible under "improved agricultural management" as referred to in the RED directive, in line with the guidance of the European Commission in its Communication 2010/C160/02.
It has also been demonstrated that those techniques are involved in the cultivation of canola.

Methodology of quantification and sources of data
The following data sources have been used for the calculation of aggregated values:

- e_{ec} : emissions from the extraction or cultivation of raw material
    - Energy, fertilizer, pesticides,seeding material and yields have been evaluated in the different RU through a compilation of data from different sources, including:
        - survey organized by the Canola Council of Canada in 2011,
        - the Statistics Canada for 2012-2014,
        - provincial crop assurance systems.
    - The N2O emissions have been quantified based on fertilizer data and the tier 2 IPCC methodology for N2O emissions from managed soils, including updated modelisation parameters from AAFC (consistent with the 2011 Agricultural Census).
- e_{sca} : emission savings through improved agricultural management
  The emissions savings from LMC have been quantified through a modeling approach by the Agriculture and Agri-Food Canada (AAFC) as a contribution to Canada's National Inventory Report (NIR) of GHG emissions in the framework of UNFCCC. Detailed data submitted by RU were received from AAFC for the period 2007-2011, with the contribution of each LMC to carbon sequestration per year. Those figures were averaged to produce a single value of each LMC.
  Therefore method used in the verified study to determine the soil organic carbon (SOC) is not based measurements but on a modeling. This complies with Commission Decision of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC, where it is stated that. "As an alternative to using the above rule, other appropriate methods, including measurements, may be used to determine SOC. As far as such methods are not based on measurements, they shall take into account climate, soil type, land cover, land management and inputs".
  The modeling used by AAFC takes into account the relevant parameters (climate, soil type, land cover, land management and inputs) and is widely recognised by the scientific community and by the UNFCCC officials as it is used in Canada's National Inventory report on GHG emissions. We consider that figures generated by the AAFC model are appropriate to be used in this framework. Furthermore, we understand that the version of the AAFC

model used to produce this updated calculation was based on the latest available land use data, including the results of the 2011 Agricultural Census (which had not yet been included in the previous version of this work released in 2013).).

The emission factors were sourced from recognized LCA databases as Ecoinvent and GHG Genius and GHG calculation tools like Biograce.

Conclusion

The approach used by the authors and the updated GHG calculation for each region was found to be a correct evaluation of the emissions from cultivation of Canola in the relevant regions of Canada, and to be compliant with the requirements of the RED directive. The statistical data and models used have been adequately updated with the latest figure available from the relevant sources.

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Annex

Diesel fuel use

Table 21: Calculation of diesel fuel use

	RU 23	RU 24	RU 28	RU 29	RU 30	RU 34	RU 35	RU 37	Source
	l/ha								
Conventional tillage	5.99	4.33	2.06	0.91	0.43	1.50	1.50	1.65	Colorado State University 1998
Minimum / Reduced	6.32	5.50	5.14	2.71	1.32	3.01	3.61	3.09	Colorado State University 1998
Direct seed	0.15	0.39	0.86	0.71	0.72	1.09	0.59	0.82	Colorado State University 1998
Zero tillage	0.17	0.51	0.63	1.64	2.06	1.13	1.39	1.25	Colorado State University 1998
Mix	0.00	0.00	0.11	0.00	0.07	0.10	0.00	0.17	Colorado State University 1998
Seeding	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	Agricultural Research and Extension Council of Alberta 2011
Sprayer – herbicide	1.60	1.48	1.80	1.67	1.35	1.70	1.56	1.55	Agricultural Research and Extension Council of Alberta 2011
Sprayer - insecticide	0.10	0.08	0.07	0.09	0.04	0.16	0.03	0.20	Agricultural Research and Extension Council of Alberta 2011
Sprayer - fungicide	0.46	0.52	0.31	0.02	0.13	0.20	0.24	0.25	Agricultural Research and Extension Council of Alberta 2011
Swath	2.30	2.35	2.42	2.32	2.32	2.27	2.32	2.23	Agricultural Research and Extension Council of Alberta 2011
Pick-up Combine	8.66	8.85	9.12	8.76	8.76	8.57	8.76	8.39	Agricultural Research and Extension Council of Alberta 2011
Straight Combine	0.40	0.24	0.00	0.32	0.32	0.48	0.32	0.64	Agricultural Research and Extension Council of Alberta 2011
Manure Distribution Energy	0.00	0.28	0.43	0.00	0.00	0.00	0.02	0.01	(S&T)[2], CCC Survey
Total l/ha	**31.34**	**29.72**	**28.13**	**24.33**	**22.72**	**25.42**	**27.19**	**25.45**	
l/t	**17.13**	**15.09**	**16.07**	**14.06**	**11.77**	**12.71**	**12.03**	**11.62**	
	l/t								
Irrigation	0	0	0	0	0.12	0	0	0.50	Alberta Agriculture and Rural Development 2010, 2011, 2012 a
Further trucking	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	Assumption based on (S&T)[2]
Total diesel consumption (l/t)	**18.0**	**15.9**	**16.9**	**14.9**	**12.6**	**13.6**	**12.9**	**12.5**	
Total diesel consumption (l/dry-t)	**19.7**	**17.4**	**18.5**	**16.3**	**13.8**	**14.8**	**14.1**	**13.6**	Adapted to dry-matter content Canola