Australia's National
Science Agency

Greenhouse gas emissions from the cultivation of canola oilseed in Australia

Prepared to meet the requirements of the European Commission Directive 2018/2001/EU of the European Parliament and of the Council (REDII) on the promotion of the use of energy from renewable sources (recast)

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Executive summary

Australia is a major supplier of canola[1] into the European Union biodiesel market, with over 1.8 million tonnes exported annually to European countries. The European Commission's Renewable Energy Directive (RED II) sets a mandated target of 50-65% greenhouse gas (GHG) savings, compared to fossil fuels and depending on the age of the biofuel production plant, for biofuels entering the EU transportation fuel market.

Currently, an international total default value of 47% savings in GHG emissions applies to canola, relative to emissions from the use of fossil diesel. This means there is a need to independently verify emissions associated with Australian canola production to maintain access to this market, and to meet this need Australia has prepared an equivalent "Country Report" to those produced by EU Member states. This "Australian Country Report" has been prepared by the Australian Government Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia's national research agency, to document the GHG emissions associated with the cultivation of canola (to the farm gate), for submission to the European Commission (EC). This resource will enable biofuel producers to ascertain if they can source canola from Australia and still meet the revised GHG savings target, in a similar way to how the EU Country Reports are now widely being used.

Assessment of GHG emissions was undertaken at the State level as these regions within Australia are the most similar to NUTS2 regions in Europe. GHG emissions by State ranged from 0.441 to 0.873 tonne CO_2-eq /tonne canola seed (dry matter). At a national level, GHG emissions associated with canola cultivation were found to be 0.460 tonne CO_2-eq/tonne canola seed (dry matter).

The greatest contribution to GHG emissions (national average) came from the manufacture of fertiliser, with 50% of the total emissions, followed by CO_2 from fuel use (14%). N_2O from crop residues and direct N_2O emissions in response to chemical fertiliser application accounted for about 13% and 6%, respectively, but these fractions varied significantly between states. Variation in GHG emissions between the States was largely driven by climate variables such as rainfall and evapotranspiration. High-rainfall and irrigated systems, although having higher crop yields, had higher emission intensities, largely associated with greater nitrogen inputs and higher relative N_2O emission factors.

This report and the emissions calculations have been reviewed by two independent organisations: University of Melbourne (Australia) and SGS Germany GmbH (Germany). The final report incorporates the review feedback as an Appendix. The European Commission has also reviewed the report (following the independent reviews) and the authors have updated it based on feedback received (see version history).

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[1] Canola is the term used in Australia for oilseed rape.

Glossary of abbreviations

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
a.i.	Active ingredient
CH_4	Methane
CO_2	Carbon dioxide
CO_2-eq	Term for describing the different greenhouse gases as a common unit relative to the global warming potential of CO_2
DM	Dry matter
EC	European Commission
EF	Emissions factor
EU	European Union
FAME	Fatty acid methyl ester
FY	Financial year, from 1 July to 30 June for Australian sources. E.g. FY2016 is FY2015/16.
GHG	Greenhouse gas
GWP_{100}	Relative measure of how much heat is trapped by a greenhouse gas compared to CO_2 over a 100-year time interval
IPCC	Inter-Governmental Panel on Climate Change
N	Nitrogen
N_2O	Nitrous oxide
NAAR	Net acid addition rate
NUTS2	Nomenclature of Territorial Units for Statistics Level 2
P	Phosphorus
pH	Measure of soil acidity
REDI	Renewable Energy Directive 2009/28/EC plus amendments (version 5 October 2015)
REDII	Renewable Energy Directive 2018/2001/EU plus amendments (version 21 December 2018) and supplemented by regulation 2019/807/EU
UNFCCC	United Nations Framework Convention on Climate Change

Part I Country report

1 Introduction

The European Commission's (EC) Renewable Energy Directive (REDII) 2018/2001/EU sets a mandated target of at least 32% for the overall share of energy from renewable sources in the Union's gross final consumption of energy in 2030. Each European Union (EU) country has committed to an Integrated National Energy and Climate Plan so that the overall pooled target reaches 32%.

These plans include sectoral targets for electricity, heating and cooling, and transport. The REDII requires that each country has at least 14% of their transport fuels originating from renewable sources by 2030, with a limitation that "*the share of biofuels and bioliquids, as well as of biomass fuels consumed in transport, where produced from food and feed crops, shall be no more than one percentage point higher than the share of such fuels in the final consumption of energy in the road and rail transport sectors in 2020 in that Member State, with a maximum of 7 % of final consumption of energy in the road and rail transport sectors in that Member State*". In the amended REDI (Directive 2015/1513/EU) the cap on biofuels produced from food and feed crops was also 7%.

Currently, greenhouse gas (GHG) emissions savings for biofuels consumed in the transport sector need to be a minimum of 50% compared to fossil fuels, for fuel delivered at the bowser from biofuel plants in operation before 2015. For plants in operation after 2015, the reduction target is 60%, and for plants starting operation from 2021, the reduction target is 65%.

These targets need to be met also for biodiesel produced from Australian canola[2]. This will enable Australia to continue to export canola to the EU for biodiesel production. Currently, a globally applicable total default value of 47% savings in greenhouse gas emissions (REDII) applies to canola biodiesel relative to emissions from the use of fossil diesel, which is below the required reduction targets.

To detail emissions associated with Australian canola cultivation specifically, a first "Country Report" was submitted to the EC in 2016 (Eady, 2017). The current study provides an update to that report, using data for the most recent five years of cultivation (2015/16 to 2019/20).

Reporting for EU member states is done at the Nomenclature of Territorial Units for Statistics Level 2 (NUTS2). A NUTS2 region is an existing administrative unit (or is a collection of contiguous administrative units), whose population lies between 800,000 and 3 million people. The vast majority of these "NUTS2 GHG values" are lower than the disaggregated default value for cultivation and are today being used by most producers to demonstrate the level of GHG savings.

There is provision in REDII for non-EU countries to submit similar country reports. This "Australian Country Report" has been prepared by the Australian Government Commonwealth Scientific and Industrial Research Organisation (CSIRO) to document the GHG emissions associated with the

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[2] Canola is the term used in Australia for oilseed rape.

cultivation of canola (to the farm gate), for submission to the EC, to enable importers to ascertain if they can source canola from Australia and still meet the revised GHG savings target.

Canola is an important crop in Australia as it provides benefits as a break crop for cereals in terms of weed and disease control (Angus *et al.* 2015) and is a high value crop that makes a significant contribution to farm profitability. Canola is a winter oilseed (April to November growing season) and is grown throughout the cropping regions in New South Wales, Victoria, South Australian and Western Australia (Figure 1), with a small quantity grown in southern Queensland and in Tasmania.

Canola yields are relatively low (generally well below 2.5 tonne/ha; Figure 2) compared to canola from other countries (Agriculture and Horticulture Development Board 2013; Ahlgren *et al.* 2011; Elsgaard 2010), as most Australian canola is grown under low rainfall dryland conditions. Canola is normally grown in rotation with cereal and legume crops. In some parts of Australia, a pasture phase of two to three years may be used in cropping rotations. The normal crop cycle for canola is 12 months with a pre-planting fallow period following the harvest of the previous winter crop in the rotation. Large areas of cultivation in Australia are untaken with no or low tillage practices to conserve moisture and reduce soil erosion. Weed control during the pre-crop fallow is achieved with herbicide application and by crop residue management to kill weed seeds.

Australian canola is not grown on soils with high organic matter content, known as histosols (where there is 40 centimetres or more of organic soil material in the upper 80 centimetres, and the soil has an organic carbon content of 12-18%). The average soil carbon content in the top 30 cm of soil for cropping regions in each State range from 0.8% for Western Australia to 3% for Tasmania (Terrestrial Ecosystem Research Network 2016).

Total exports of canola from Australia averaged 2.3 million tonne over the period 2017 to 2021 (Australian Bureau of Statistics 2021a). Australia is a major supplier of canola into the EU biodiesel market, with on average 1.8 million tonne exported annually to European countries during this period (Table 1).

Table 1. Average annual canola exports from Australia to Europe for 2012-2015 (as in preceding canola country report) and 2017 to 2021.

State	Average Canola exports to Europe 2012-2015 (tonne)	Average Canola exports to Europe 2017-2021 (tonne)
New South Wales (NSW)	260,051	193,471
Victoria (Vic)	282,117	330,225
Queensland (Qld)	0	0
South Australia (SA)	259,210	236,233
Western Australia (WA)	900,102	1,073,397
Tasmania (Tas)	0	0
Total	1,701,480	1,833,326

Source: (Eady 2017; Australian Bureau of Statistics 2021a).

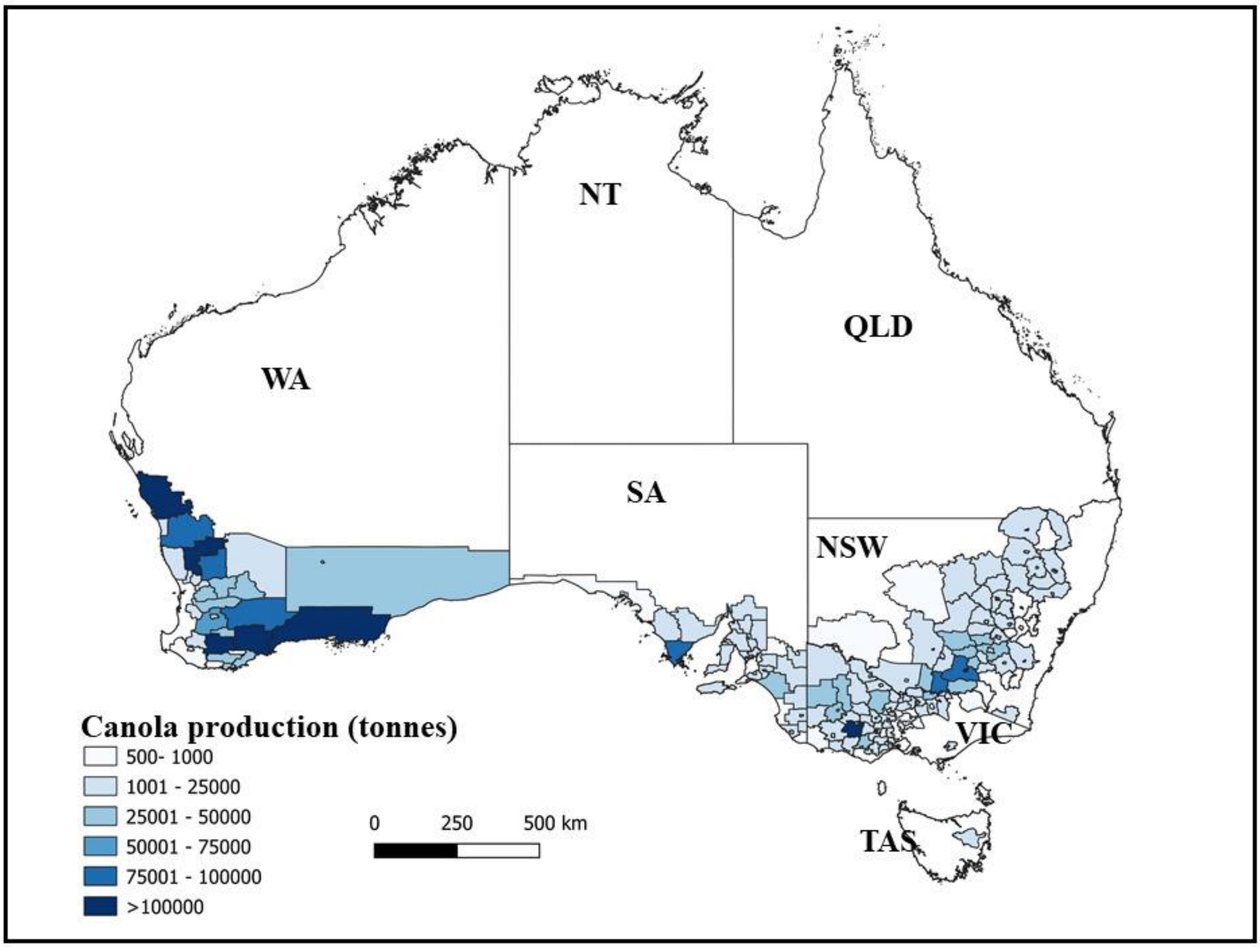


Figure 1. Average canola production quantities (FY 2015/16-2019/20) by statistical area (SA2). Note that for some larger SA2 the production only takes place in a fraction of the area typically along the border of the higher production regions. Source: Australian Bureau of Statistics, 2021b; 2021c.

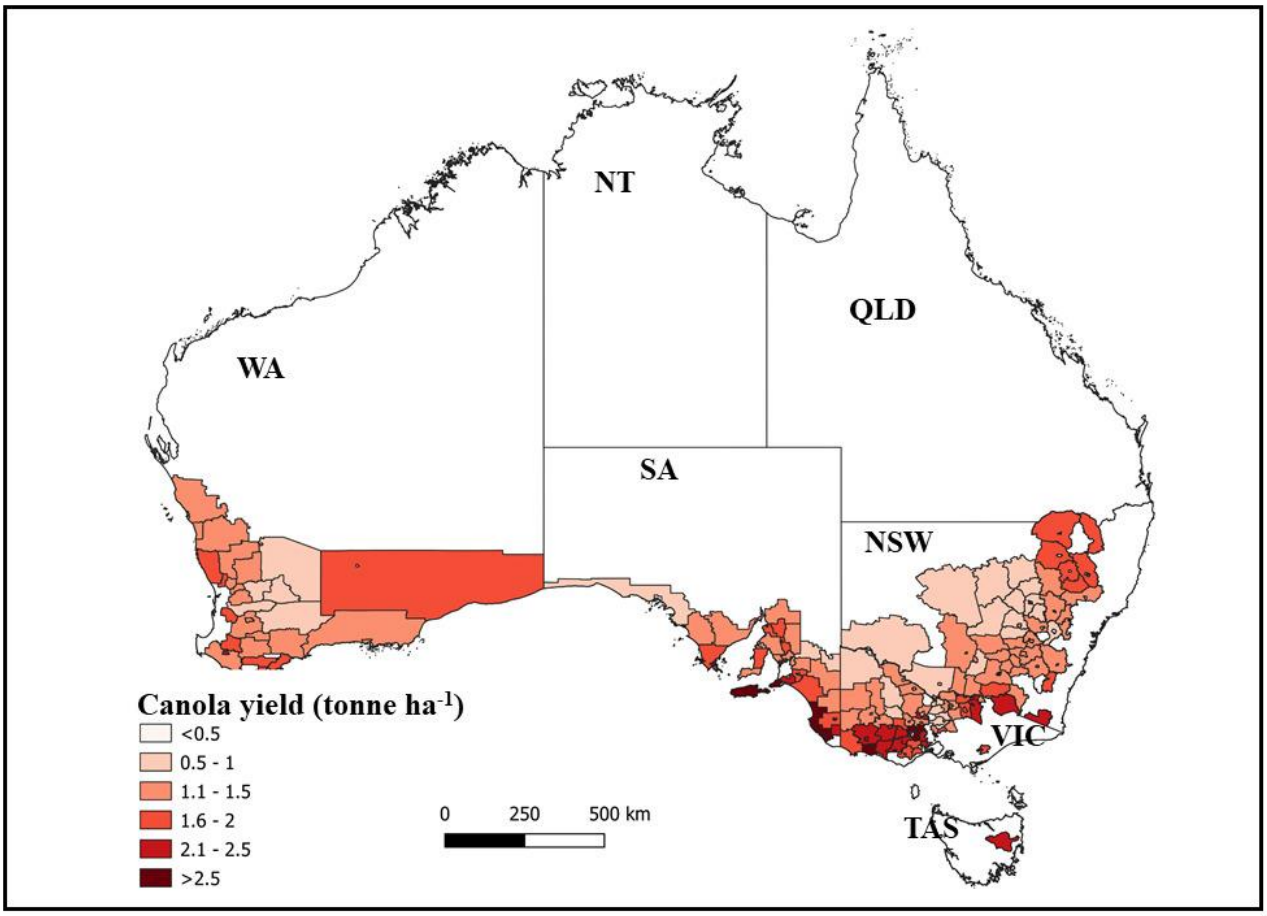


Figure 2. Average canola yield (FY 2015/16-2019/20) by statistical area (SA2). Note that for some larger SA2 the production only takes place in a fraction of the area. The yield shown is not achieved over the entire area of the SA2 only for those areas that are actually producing . Source: Australian Bureau of Statistics, 2021b; 2021c.

2 Methodology

2.1 “NUTS2 equivalent” regions in Australia

The REDII (Annex V.C.5) allows the use of “estimates of emissions from cultivation … derived from the use of averages” for a region, as alternative to conservative default values or actual GHG values at a farm level. To make available these alternative GHG values, the RED required European Member States to report to the EC typical GHG emission values for cultivation of agricultural raw material at a regional level (REDII, Article 31 Paragraph 2). The REDII (Article 31 Paragraph 3) also states that “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”. This means that an equivalent of level 2 in the nomenclature of territorial units for statistics (NUTS2) needs to be defined for such a territory, in this case Australia. The definition of a NUTS2 region in Europe is:

> *In the NUTS (Nomenclature of Territorial Units for Statistics) classification the NUTS2 class is applied to basic regions for the application of regional policies (Eurostat 2011). Population thresholds for NUTS2 are a minimum of 800,000 and maximum of 3 million, however, this is not a strict description and some NUTS2 regions fall out of this range (across all NUTS2 in the EU in 2007, the minimum population was 27,000 and maximum was 11.63 million).*

In Australia the closest statistical regions to the description of NUTS2 region are States (Table 2). Each State has its own constitution, which divides its government into the same divisions of legislature, executive, and judiciary as the federal government (Australian Government 2015). Therefore, States meet the criteria of being distinct administrative units where regional policies are applied and have been used in this report to define the area in which canola is produced. In the States where the population exceeds 3 million, this is largely due to the concentration of population in the State capitals, with 65% of the New South Wales population living in Sydney, 77% of the Victorian population living in Melbourne, and 49% of the Queensland population living in Brisbane (Australian Bureau of Statistics 2021d, 2022). A similar situation exists for crops grown in some NUTS2 regions in Europe; in Germany the NUTS2 region “Berlin" and in France the NUTS2 region "Ile-de-France" have populations in excess of 3 million due to large urban centres.

Table 2. Population statistics for Australian States at the end of June 2015 (Eady 2017) and at the end of June 2021 (Australian Bureau of Statistics, 2021d; 2022)

State	Population June 2015 (million)	Population June 2021 (million)
New South Wales	7.62	8.19
Victoria	5.94	6.65
Queensland	4.78	5.22
South Australia	1.70	1.77
Western Australia	2.59	2.68

Tasmania	0.52	0.54

2.2 System Boundary for the GHG calculations

The REDII (Article 31 Paragraph 2) specifies that the GHG cultivation emissions estimated at a regional level shall take into account soil characteristics, climate and expected raw material yields. The directive also specifies that "emissions from the extraction or cultivation […] shall include emissions from the extraction or cultivation process itself; from the collection, drying and storage of raw materials; from waste and leakages; and from the production of chemicals or products used in extraction or cultivation. Capture of CO_2 in the cultivation of raw materials shall be excluded." (Annex V.C.5). For this study GHG emissions were estimated from cradle-to-farm gate for canola production (on both a wet and dry matter basis) covering the inputs of seed, fertiliser, lime, diesel for farm operations, and pesticides for crop protection. In broad-acre dryland cropping systems in Australia, there is no electricity associated with cultivation or on-farm storage of canola grain. For irrigated systems water pumping is powered by diesel engines.

Emissions associated with the manufacture of machinery and equipment were excluded as per REDII (Annex V.C.1) and crop residue co-products, such as hay, were given a zero allocation of GHG emissions. Inputs required for weed control during the pre-planting fallow period were included, with the crop cycle commencing immediately post-harvest of the preceding crop in the rotation (usually a cereal or legume) and finishing with harvest of the canola crop, generally a 12-month period.

2.3 Sourcing of data to calculate GHG emissions for regions

REDII (Annex V.C.5) states that "Estimates of emissions from agriculture biomass cultivation may be derived from the regional averages." The approach taken in the preparation of this report was to use official statistics from the Australian Bureau of Statistics (for yield, fertiliser types and area irrigated), published surveys, where more detailed information was required (for crop residue management, tillage practices, control traffic farming practices, dual-purpose canola cropping, moisture and protein content of grain), and published tools based on empirical relationships for estimation of inputs (such as N-fertiliser, lime, fuel use and seeding rates). An overview of inputs and data sources can be found in Table 3.

Table 3. Sources of data for canola yield, farm inputs and management practices that are material for greenhouse gas emissions.

Input	Data source
Yield	Australian Bureau of Statistics (2017; 2018; 2019; 2020; 2021b) for dryland production from 2015/16 to 2019/20 and State Department of Agriculture sources (Department of Primary Industries 2012) for irrigated production.

Fertiliser type	State level statistics for fertiliser use in broad-acre cropping (Australian Bureau of Statistics 2018)
Fertiliser quantity	Generic Yield and N Calculator (Baldock 2012) crosschecked with various State Government Agriculture Department publications on fertiliser requirements.
Place of fertiliser manufacture	Fertiliser industry data (Stephen Annells, Fertilizer Australia, pers. comm.) and Centre for International Development (Center for International Development 2019)
Lime quantity	Based on Net Acid Addition Rate of canola production (Baldock *et al.* 2009).
Area irrigated	Customised data from Australian Bureau of Statistics (supplied by Peter Meadows, Australian Bureau of Statistics) for area of canola irrigated from 2015/16 to 2019/20.
Area dual purpose cropping	Dual Purpose Canola Impact Case Study (CSIRO, 2021).
Crop residue management	National data for broad-acre cropping land in Australia (Commonwealth of Australia, 2021).
Tillage practices	National survey data for broad-acre cropping land in Australia (Australian Bureau of Statistics 2018).
Moisture and protein content of grain	New South Wales Department of Primary Industries Oils Research Laboratory, an accredited National Association of Testing Authorities facility (http://www.nata.com.au/nata/; Jamie Ayton, NSW DPI, pers.comm. Email 9/2/2022)
Pesticide quantity	Various State Government Agriculture Department publications on pest control in canola (see Section 3.4).
Fuel use	Australian-based fuel calculator adjusted based on review of Controlled Traffic Farming impact on fuel use (see Section 3.5).
Seeding rates	Seed calculator (Bucat and Seymour, 2019) based on seed specifications provided by Department of Agriculture and Food (Mark Seymour, Department of Agriculture and Food, WA, pers. comm.)
Climate data for rainfall and evapotranspiration	Climate data (rainfall, temperature, evaporation) was sourced from the SILO climate database (Queensland Government 2022).

A consistent approach was applied across each of the States. Where possible, data sources and methods applied are publicly available for verification. The results are representative for the 5-year period from 2015/16 to 2019/20 and are expressed in tonne of CO_2-eq per tonne of canola seed on dry matter basis and per MJ FAME (fatty acid methyl ester).

2.4 Scope of GHG emissions and emissions factors

The GHG emissions in scope for the study were CO_2, CH_4 and N_2O, with a 100 year Global Warming Potential of CO_2:1; CH_4:25 and N_2O:298, as specified in the REDII (Annex V.C.4).

GHG emissions factors (EF) for production of farm inputs such as fertiliser, lime, pesticides, and transport were derived from ecoinvent 3.8 (Wernette et al. 2016), an international peer-reviewed life cycle assessment (LCA) database having a global geographic scope, and also used in the definition of some of the input data to assess default emissions (EC, 2019). The EF assumed for fertiliser included a transport component appropriate for imported and domestically sourced fertiliser in Australia. The EF for diesel combustion in farm machinery and for pumping irrigation water were sourced from (Commonwealth of Australia, 2021a). All the EF sourced from ecoinvent 3.8 are presented in Appendix A.

No relevant waste and leakages were identified, other than those included as emission sources (e.g. burning of residues, leaching of nitrogen).

On-farm emissions for direct and indirect N_2O from the use of nitrogen fertilisers were derived (see Section 3.7) using the Intergovernmental Panel on Climate Change (IPCC) tier-2 approach for Australia (Commonwealth of Australia, 2021), the official approved method for Australia's reporting requirements for the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement. Emissions related to management of crop residues were calculated using the IPCC tier-1 dry-climate EF (IPCC, 2019). Australia's national reporting still uses the old tier-1 EF for this emission source (Commonwealth of Australia, 2021) but, as shown in Section 3.7, the rainfed cropping zone meets all the criteria for the lower dry-climate tier-1 EF for nitrogen in crop residue. The Australian government are currently investigating this method improvement.

Table 4. Summary of cultivation inputs with associated greenhouse gas emissions factor and source.

Product input or activity	Data source	Emissions factor (EF)
Seed (kg)	Seed input was 3.6 kg of canola seed per ha, with emission factor adopted from EC 2019 (see Section 3.2).	0.7565 kg CO_2-eq/kg seed
Urea (kg)	ecoinvent 3.8, corrected for sequestration credit and excluding infrastructure processes in line with EC (2019) urea production, CN (China; 11.73%) urea production, RoW (Rest of World; 88.27%)	EF (CN) = 2.871 kg CO2-eq/kg EF (RoW) = 1.929 kg CO2-eq/kg Urea EF (weighted by source) = 2.040 kg CO2-eq/kg
Mono ammonium phosphate (MAP) (kg)	ecoinvent 3.8, corrected for sequestration credit and excluding infrastructure processes in line with EC (2019) monoammonium phosphate production, CN (China; 11.73%) monoammonium phosphate production, RoW (Rest of World; 88.27%)	EF (CN) = 1.134 kg CO_2-eq/kg EF (RoW) = 0.789 kg CO_2-eq/kg MAP EF (weighted by source) = 0.830 kg CO_2-eq/kg
Urea ammonium nitrate (UAN) (kg)	ecoinvent 3.8, corrected for sequestration credit and excluding infrastructure processes in line with EC (2019) urea ammonium nitrate production, CN (China; 11.73%) urea ammonium nitrate production, RoW (Rest of World; 88.27%)	EF (CN) = 2.534 kg CO_2-eq/kg EF (RoW) = 1.624 kg CO_2-eq/kg UAN EF (weighted by source) = 1.731 kg CO_2-eq/kg

Lime (kg)	ecoinvent 3.8: limestone production, crushed, for mill RoW market for transport, freight, lorry>32 metric ton, EURO4	EF (RoW) = 0.0028273 kg CO_2- eq/kg EF = 0.092966 kg CO_2- eq/tonne.km
Herbicide, insecticide and fungicide (kg of active ingredient)	ecoinvent 3.8: market for glyphosate GLO Glyphosate made up the bulk of pesticide use and has a higher EF than generic pesticide inventory in ecoinvent 3.8. Hence, this more conservative value was used to cover all pesticides.	EF = 11.43 kg CO_2-eq/kg active ingredient
Fertiliser transport – sea (tonne.km)	ecoinvent 3.8: transport, freight, sea, bulk carrier for dry goods	EF = 0.006527 kg CO_2- eq/tonne.km
Fertiliser transport – rail (tonne.km)	ecoinvent 3.8: market for transport, freight train RoW	EF = 0.048783 kg CO_2- eq/tonne.km
Fertiliser transport – road (tonne.km)	ecoinvent 3.8: market for transport, freight, lorry>32 metric ton, EURO4	EF = 0.092966 kg CO_2- eq/tonne.km
Diesel (l)	Australian National Greenhouse Accounts (Commonwealth of Australia 2021a)	EF diesel = 3.38 kg CO_2-eq/l
Direct N_2O from N fertiliser (Gg)	Australian National Inventory Report (Commonwealth of Australia 2021)	EF = 0.0005 (Gg N2O-N/Gg N applied) for <600mm rainfall EF = 0.0085 (Gg N2O-N/Gg N applied) for >600mm rainfall and irrigated crop
N_2O from crop residues (Gg)	IPCC 2019	EF = 0.005 (Gg N_2O-N/Gg N) IPCC dry climate tier-1 emission factor
Indirect N_2O from leaching (N fertiliser + crop residue) (Gg)	Australian National Inventory Report (Commonwealth of Australia 2021)	FracLEACH = 0.24 (Gg N/Gg applied) IPCC default fraction of N lost through leaching EF = 0.011 (Gg N2O-N/Gg N) FracWET by State (see 3.7)
Indirect N_2O from atmospheric deposition (Gg)	Australian National Inventory Report (Commonwealth of Australia, 2021)	FracGASF = 0.11 (Gg N/Gg applied) EF as for direct N_2O
Burning of residues (Gg of each element)	Australian National Inventory Report (Commonwealth of Australia, 2021)	EF (Gg element /Gg burnt) = (CH_4=0.0035; N_2O=0.0076)

3 Input data and calculation model

3.1 Cultivated areas and yields

Data sourced from the Australian Bureau of Statistics (2022) were used to estimate a 5-year average yield (2015/16 to 2019/20) for canola grown in each State under dryland systems (Table 5). Yields were converted to a dry matter basis using grain testing data on moisture content from each State over the same period, supplied by the New South Wales Department of Primary Industries Oils Research Laboratory, an accredited National Association of Testing Authorities facility (http://www.nata.com.au/nata/).

Canola is generally grown as a dryland crop in Australia with the exception of some production areas in the Murrumbidgee irrigation region in New South Wales and in the south-eastern region of South Australia, and in Tasmania. The area of irrigation for this study was drawn from Australian Bureau of Statistics data from 2015/16 to 2019/20. As irrigation area for canola is not reported separately in a published dataset, customised data was prepared for this project by the Australian Bureau of Statistics (Peter Meadows, Australian Bureau of Statistics, pers. comm.). The area of irrigation for New South Wales was 1.56% of total area of canola planted and for South Australia was 1.27% of total area of canola planted, and for Tasmania was 39.5% of the area planted. In the other States the area irrigated was < 1% and not considered material. The yield for irrigation systems in New South Wales was based on State Department of Agriculture sources (Department of Primary Industries 2009, 2012), as there was no separate reporting by the Australian Bureau of Statistics for irrigated canola yield. For South Australia the same yield has been adopted for irrigated canola. Due to the small area of canola cultivation in Tasmania (average 1050 ha from 2015/16 to 2019/20) and the relatively high proportion of irrigation, canola production in Tasmania was assumed to be 100% irrigated and Australian Bureau of Statistics data was used to estimate yield. The average GHG emissions for New South Wales and South Australia were calculated as a weighted average based on the respective areas planted in each system. Yields under irrigation are set to 2.67 tonne/ha for New South Wales and South Australia.

Since the period 2010/11-2014/15, canola cultivation has increasingly adopted the so-called “dual purpose” approach. Crops grown using this approach are first grazed during early vegetative stages before being allowed to recover and harvested for grain (CSIRO 2021). Dual purpose canola in Australia occupies about 200,000 ha (New South Wales, 150,000 ha; Victoria, 32,000 ha; South Australia, 12,000 ha; Western Australia, 2,000 ha) (CSIRO, 2021)

Table 5. Average production statistics for Australian canola seed for the five-year period from 2015/16 to 2019/20 with yield adjusted to a dry matter basis. Sources for area, production, yield: Australian Bureau of Statistics (2017; 2018; 2019; 2020; 2021b). Source for dry matter and protein: Jamie Ayton, NSW DPI, pers.comm.

State	Area planted (ha)	Production (tonne harvested)	Yield (tonne harvested/ha)	Dry Matter (%)	Yield (tonne DM/ha)	Whole seed Protein (%)
New South Wales (dryland, single purpose)	432307	510458	1.18	94.4	1.11	23.9
New South Wales (dryland, dual purpose)	147662	174355	1.18	94.4	1.11	23.9
New South Wales (irrigated)	9185	24524	2.67[b]	94.4	2.52	23.9
Victoria (dryland, single purpose)	360847	569473	1.58	94.5	1.49	22.0
Victoria (dryland, dual purpose)	32000	50501	1.58	94.5	1.49	22.0
Queensland	945	873	0.92	94.4[a]	0.87	23.9[a]
South Australia (dryland, single purpose)	170912	260103	1.52	94.3	1.44	21.3
South Australia (dryland, dual purpose)	11848	18031	1.52	94.3	1.44	21.3
South Australia (irrigated)	2346	5826	2.67[b]	94.3	2.52	21.3.
Western Australia (dryland, single purpose)	1248253	1510091	1.21	93.8	1.13	20.3
Western Australia (dryland, dual purpose)	2000	2420	1.21	93.8	1.13	20.3
Tasmania (irrigated, single purpose)	1050	2558	2.44	94.5[a]	2.30	22.0[a]

[a] As there was no testing done for Queensland and Tasmanian grain, the value of the nearest State was assumed.

[b] Yield for irrigated canola was derived from gross margin documents (Department of Primary Industries 2009, 2012)

3.2 Seeding rate

Typical seeding rates (kg/ha) for canola were estimated from the equation below, using a seed calculator (Bucat and Seymour, 2019) based on a seed number of 250 000 per kg, germination rate of 90%, field establishment of 50%, and target plant density of 40 plants/m^2 (Mark Seymour, Department of Agriculture and Food, WA, pers. comm.).

> Seeding rate (kg/ha) = ((Target plant density (plants/m2) x 10,000)/(Germination rate x Establishment rate))/Seeds per kg

These are typical seed parameters for open pollinated canola seed retained by farmers for planting the next season's crop in an average rainfall season. Farmers' saved seed is the predominant seed source (84% in Western Australia and 77% in south eastern Australia) (Zhang *et al.* 2016). These figures for quantity of seed are consistent with data provided by relevant State

Departments of Agriculture, as listed in the same source documents used for pesticides (Table 10) and for large size open pollinated seed under reasonable establishment conditions (Bucat and Seymour 2017). The emissions associated with seed inputs were calculated using the default emission factor (EC 2019; see Table 4). The quantity of seed input is set at 3.6 kg/ha across all States.

3.3 Fertiliser inputs for canola

The macro nutrients that were identified as important for canola production in Australia are nitrogen (N), phosphorus (P) and sulphur (S) (McCaffery *et al.* 2009). However, there are no canola specific data on fertiliser use available from the Australian Bureau of Statistics, so the approach taken was to use the available statistics for broad-acre cropping to identify the major types of fertilisers used and the amount of fertiliser was estimated based on crop demand for N and P. Where required, S is assumed to be supplied with soil conditioners such as gypsum.

3.3.1 Quantity of nitrogen and phosphorus fertilisers applied

In the absence of canola specific data on fertiliser use from the Australian Bureau of Statistics, N fertiliser inputs were calculated using the equations developed for canola in the Generic Yield and Nitrogen Calculator (Baldock 2012). This approach gives a consistent method across all regions for estimating N inputs, and the results were well aligned with some of the available regional estimates for N fertiliser use for canola (as per the source documents as listed in Table 10). The equations used in the N Calculator were adjusted so that they calculated the overall N requirement to grow the harvested grain plus loss of N from leaching, volatilisation, denitrification, stubble removal and burning. A copy of the Generic Yield and Nitrogen Calculator can be obtained from the author at maartje.sevenster@csiro.au. Data for the N content of grain from each State was sourced from the New South Wales Department of Primary Industries Oils Research Laboratory, an accredited National Association of Testing Authorities facility (http://www.nata.com.au/nata/).

Our approach assumes the residual N pools (from crop residues, mineralisation, and fixation by a prior legume crop) are in balance and that all of the fertiliser N required ends up either in the harvested product or is lost to the system.

Phosphorus (P) fertiliser is also required for crops in Australia and the amount applied for canola production is related to the yield, with 8 kg of P required for each tonne of canola seed harvested (McCaffery *et al.* 2009). This equates to 7.5 kg P/tonne of dry canola based on the dry matter reported in Table 5.

3.3.2 Dual-purpose cropping systems

Adoption of dual-purpose canola in Australia has increased steadily since it was first practiced in 2007. It now occupies almost 200,000 ha, mainly in New South Wales (Table 6). Dual-purpose canola is grazed during its early vegetative stages; livestock are then removed, and the crop is allowed to recover before it is harvested for grain. This practice creates a co-product (forage) alongside the harvested grain.

Table 6. Estimated area of dual-purpose canola production in 2021. (Source: CSIRO, 2021)

State	Area (ha)
New South Wales	150,000
Victoria	32,000
South Australia	12,000
Western Australia	2,000
Total	**196,000**

The management inputs (fertiliser, pesticides, tractor operations) for canola that is grown for grain, and for canola that is grown for dual-purpose use, are the same except that dual purpose canola requires an additional input of nitrogen fertiliser after grazing. Research to date on the agronomy for dual purpose canola has focused on management of grazing to ensure that the crop recovers for grain production (e.g., Kirkegaard et al., 2008, 2012; Sprague et al., 2015a, 2015b; Paridaen and Kirkegaard, 2015). The amount of nitrogen that should be applied after grazing has not been well researched but is thought to be in the range 35-50 kg N/ha (pers. comm. Lindsay Bell, 2022) while amounts of 50 kg N/ha have been applied to field trials in high rainfall environments (Kirkegaard et al., 2012; Sprague et al. 2015a). For the purposes of this report, we assume that all dual-purpose canola received an increased application of nitrogen at the rate of 40 kg N/ha on top of the nitrogen rate calculated (3.3.1).

The REDII (Annex V.C.17) specifies that "greenhouse gas emissions shall be divided between the fuel or its intermediate product and the co-products in proportion to their energy content (determined by lower heating value [..]". Applying this guidance to the dual-purpose canola cultivation system, the co-product was defined as the quantity of canola forage (2.9 tonne dry matter/ha) that was consumed by sheep during the grazing phase (Kirkegaard et al., 2008; Paridaen and Kirkegaard, 2015; Sprague et al., 2015a, 2015b). The Lower Heating Value (LHV) of canola was taken to be 27.0 MJ/kg DM (EC, 2019). As no published values were available for LHV of canola forage, a value for LHV for forage was estimated based on the ratio between LHV and gross energy content of the seed. Gross energy content of forage (17.4 MJ/kg DM) and seed (28.8 MJ/kg DM) were sourced from Heuze et al. (2019a, 2019b). This resulted in an estimated LHV for forage of 16.3 MJ/kg DM. On the basis of quantity of forage consumed and yield of seed, greenhouse gas emissions were allocated to the two co-products, adjusted for the relative area of canola production where grazing was undertaken. We assumed that no dual-purpose canola was irrigated; this was a conservative approach to allocation of GHG emissions to canola forage.

3.3.3 Fertiliser mix

The mix of types of N fertilisers used for canola was based on State level statistics for fertiliser use in broad-acre cropping (Australian Bureau of Statistics 2018). Animal manure and sewerage sludge are not applied to broad-acre cropping soils in Australia. The dominant types of N fertilisers used in each State are listed in Table 7. The quantity of each fertiliser used for each State was calculated by first determining how much mono ammonium phosphate was needed to deliver 8 kg P/tonne canola harvested, then the additional N required for the crop was assumed to come from urea for all States except Western Australia, where the data indicates that additional N is from a 52:48 mix of urea and urea ammonia nitrate. This gave a tailored fertiliser mix for each state as shown in Table 7.

Table 7. Main nitrogen fertiliser type used in each State for broad-acre cropping (based on Australian Bureau of Statistics 2018) and the quantity of each fertiliser used in canola production (calculated).

State	**Main type of N fertiliser**	**Quantity fertiliser applied (kg of product/tonne canola)**		
		Mono ammonium phosphate	Urea	Urea ammonium nitrate
New South Wales (dryland, single purpose)	urea, ammonium phosphates	35.3	93.6	
New South Wales (dryland, dual purpose)	urea, ammonium phosphates	35.3	167.3	
New South Wales (irrigated)	urea, ammonium phosphates	35.3	128.2	
Victoria (dryland, single purpose)	urea, ammonium phosphates	35.3	84.9	
Victoria (dryland, dual purpose)	urea, ammonium phosphates	35.3	140.0	
Queensland	urea, ammonium phosphates	35.3	90.4	
South Australia (dryland, single purpose)	urea, ammonium phosphates	35.3	81.0	
South Australia (dryland, dual purpose)	urea, ammonium phosphates	35.3	138.1	
South Australia (irrigated)	urea, ammonium phosphates	35.3	113.1	
Western Australia (dryland, single purpose)	urea, ammonium phosphates, urea ammonium nitrate	35.3	40.0	52.4
Western Australia (dryland, dual purpose)	urea, ammonium phosphates, urea ammonium nitrate	35.3	77.7	101.7
Tasmania (single purpose)	urea, ammonium phosphates	35.3	117.7	

The place of manufacture of fertiliser (31% domestic and 69% imported) was based on fertiliser industry data from 2016 to 2020 (Stephen Annells, Fertilizer Australia, pers. comm.). The source country for imported fertilisers was established using data from the Centre for International

Development for 2015 to 2019 (Center for International Development 2019), identifying countries where fertiliser imports to Australia typically originate from.

3.3.4 Greenhouse gas emissions associated with fertilizer production

Emissions factors assumed for the production of different fertilisers and their transport were sourced from ecoinvent 3.8 (Wernette et al., 2016). The factors were calculated without the emissions associated with so-called infrastructure processes, as per REDII (Annex V.C.1) and without the sequestration credit for use of CO_2 in urea production. In addition, the production emission factors for urea and UAN were corrected for the difference between ecoinvent and EC (2019) by applying a correction factor of 0.87 (see Appendix A). The resulting emission factors are listed in Table 4.

Three transport elements were added to imported fertilisers: rail + road transport (50:50) to port depending upon location of fertiliser production plants, sea transport from port to port distances from originating country, and road + rail transport (50:50) from port to agricultural field. For fertiliser manufactured domestically, road transport from plant to agricultural field was added (Stretch *et al.* 2014). Transport distances were estimated for each State and detailed for domestic and imported fertiliser in Table 8. Fertiliser EF factors plus the transport contribution to an overall EF for fertiliser delivered to the agricultural field are given in Table 9.

Table 8. Distance assumed for domestic and international transport of fertiliser to the agricultural field. The share of domestic manufacture is 31% (see 3.3.3). Source for import shares: (Center for International Development, 2019)

State	Transport Mode	Transport Distance Domestic Fertiliser (km)	Transport Distance for Imported Fertiliser (km) (with the percentage share imported from each country)					
			Qatar (22%)	Saudi Arabia (14%)	Indonesia/Malaysia (18%)	China (17%)	Kuwait/UAE/Oman (18%)	Russia/Other (11%)
New South Wales	Road[a]	412	206	206	206	629	226	1 333
	Ship	0	13 360	14 081	8 338	9 010	13 704	17 664
	Rail[a]	0	206	206	206	629	226	1 333
Victoria	Road	273	137	137	137	560	156	1 263
	Ship	0	12 473	13 194	7 451	10 060	12 817	16 777
	Rail	0	137	137	137	560	156	1 263
Queensland	Road	303	152	152	152	575	171	1 278
	Ship	0	12 771	14 010	6 660	7 667	13 133	17 594
	Rail	0	152	152	152	575	171	1 278
South Australia	Road	130	65	65	65	488	85	1 192
	Ship	0	11 884	12 605	6 862	10 386	12 229	16 188
	Rail	0	65	65	65	488	85	1 192
Western Australia	Road	207	104	104	104	527	123	1 230
	Ship	0	9 586	10 386	4 484	7 988	9 947	13 970
	Rail	0	104	104	104	527	123	1 230

State	Transport Mode	Transport Distance Domestic Fertiliser (km)	Transport Distance for Imported Fertiliser (km) (with the percentage share imported from each country)					
			Qatar (22%)	Saudi Arabia (14%)	Indonesia/Malaysia (18%)	China (17%)	Kuwait/UAE/Oman (18%)	Russia/Other (11%)
Tasmania	Road	135	68	68	68	491	87	1 194
	Ship	0	12 620	13 340	7 596	9 942	12 964	16 923
	Rail	0	68	68	68	491	87	1 194

[a] Includes land transport in originating country from plant to port and in Australia from port/plant to farm.

Table 9. Emission factors for fertilisers used for canola production in Australia and transport associated with domestically and internationally sourced fertiliser (kg CO_2-eq/kg fertiliser).

	Mono ammonium phosphate	Urea	Urea ammonium nitrate	Transport for domestic production	Transport for international production
New South Wales	0.83	2.04	1.73	0.038	0.138
Victoria	0.83	2.04	1.73	0.025	0.124
Queensland	0.83	2.04	1.73	0.028	0.125
South Australia	0.83	2.04	1.73	0.012	0.111
Western Australia	0.83	2.04	1.73	0.019	0.102
Tasmania	0.83	2.04	1.73	0.013	0.115

3.4 Pesticides

Annual pesticide use (quantity of active pesticide ingredient) was sourced from a series of State Department of Agriculture publications describing the frequency and type of pesticide use for canola production (Table 10). As the majority of pesticide use was glyphosate for fallow weed control, the EF adopted for all pesticides was the ecoinvent 3.8 value for glyphosate (11.43 kg CO_2-eq/kg active ingredient) rather than the emissions factor for generic pesticide (10.47 kg CO_2-eq/kg active ingredient).

A worked example, for Tasmania, of the conversion of pesticide product quantity applied to the field to quantity of active ingredient is given in Table 11. This process was followed for each of the other States using the combination of State Department of Agriculture publications relevant for each State, or from the nearest State in the case of Victoria (dryland) and South Australia (irrigated) where there were no equivalent publications. Where there are multiple publications giving pesticide application rates for canola in that State, the data were averaged across the publications.

Table 10. Quantity of pesticide active ingredient applied to canola crop from pre-planting to post-harvest.

State	Pesticide active ingredient (kg a. i./ha/year)	Source Documents
New South Wales (dryland)	4.57	Department of Primary Industries, 2012. Winter crop gross margin budgets. https://archive.dpi.nsw.gov.au/content/agriculture/gross-margin-budgets/winter-crops. Selected sheets: NSW southern zone east Canola-After-Cereal NSW Southern-west-budgets-Canola NSW North-West-canola-2012 NSW North-East-canola-2012 NSW dryland-central-east-canola-short fallow NSW dryland-central-west-canola
New South Wales (irrigated)	1.50	Department of Primary Industries, 2012. Winter crop gross margin budgets. https://archive.dpi.nsw.gov.au/content/agriculture/gross-margin-budgets/winter-crops. Selected sheets: NSW Canola Irrigated Murray Valley 2012 NSW Canola Irrigated Murrumbidgee Valley 2012 NSW Flood Irrigated Conventional OP Canola 2012
Victoria	4.90	Department of Primary Industries, 2012. Winter crop gross margin budgets. https://archive.dpi.nsw.gov.au/content/agriculture/gross-margin-budgets/winter-crops. Selected sheets: NSW southern zone east Canola-After-Cereal NSW Southern-west-budgets-Canola NSW North-West-canola-2012 NSW North-East-canola-2012 NSW dryland-central-east-canola-short fallow NSW dryland-central-west-canola
Queensland	4.10	Queensland Government, 2021. https://www.publications.qld.gov.au/dataset/agbiz-tools-plants-field-crops-and-pastures/resource/21dd0d6f-7908-4f03-8c7e-f0bfb3eeb5f2. Selected sheets: Canola dryland GM – SQ
South Australia (dryland)	8.96	SAGIT 2022. https://www.pir.sa.gov.au/__data/assets/pdf_file/0008/405872/gross-margins-guide-2022.pdf
South Australia (irrigated)	1.50	Department of Primary Industries, 2012. Winter crop gross margin budgets. https://archive.dpi.nsw.gov.au/content/agriculture/gross-margin-budgets/winter-crops. Selected sheets: NSW Canola Irrigated Murray Valley 2012 NSW Canola Irrigated Murrumbidgee Valley 2012 NSW Flood Irrigated Conventional OP Canola 2012
Western Australia	3.03	Farm Gross Margin documents, WA Gross Margin by region 2020 (Ross Kingwell, WA, Department of Agriculture, pers. comm.)

Tasmania	2.63	Department of Natural Resources and Environment Tasmania 2022. https://nre.tas.gov.au/agriculture/investing-in-irrigation/farm-business-planning-tools. Selected sheets: TAS High Rainfall Crop Gross Margins

Table 11. Sample calculation of pesticide quantity used in canola production for Tasmania.

Pesticide Name (active ingredient)	Pesticide product applied	Active ingredient in product	Active ingredient applied (kg/ha)
RoundupCT® (Glyphosate)	2.0 (l/ha)	450 (g/l)	0.9
Rifle 440® (Pendimethalin)	1.3 (l/ha)	440 (g/l)	0.572
Verdict® (Haloxyfop)	0.08(l/ha)	520 (g/l)	0.0416
Metarex® (Metaldehyde)	6.0(kg/ha)	50 (g/kg)	0.3
Astound® (Alpha-cypermethrin)	0.13(l/ha)	100 (g/l)	0.013
Onduty® (Imazapyr+Imazapic)	0.04(kg/ha)	700 (g/kg)	0.028
Talstar®(Bifenthrin)	0.1 (L/ha)	250 (g/L)	0.025
Mancozeb®(Mancozeb)	1 (kg/ha)	750 (g/kg)	0.75
		Total	**2.63**

3.5 Field operations

Cultivation practices are largely no or low-till for dryland farming in Australia. Table 12 gives the most recent survey data for cultivation practises for broad-acre cropping land in Australia, which apply to canola production (Australian Bureau of Statistics 2020). There is no tillage of broad-acre crops within the growing cycle, with tillage operations being pre-sowing for fallow weed control and seed bed preparation.

Table 12. Cultivation practices for broad-acre cropping systems in Australia

State	Cultivation practices		
	% area with No Tillage (no cultivation pre-sowing)	% area with Reduced Tillage (one cultivation pre-sowing)	% area with Full Tillage (≥ two cultivations pre-sowing)
New South Wales (dryland and irrigated)	67.0	17.6	15.4
Victoria	81.7	12.1	6.2
Queensland	51.4	17.6	31.0

South Australia (dryland and irrigated)	89.4	9.1	1.4
Western Australia	85.9	12.9	1.2
Tasmania	21.0	16.7	62.3

Based on the proportion of each tillage practice, the fuel use for canola production in the major producing States was calculated using an Australian based fuel calculator (Salam et al. 2010). For Queensland and Tasmania where there is little canola production, for simplicity the conservative assumption was made that all cultivation for canola was conventional tillage, with the number of tractor passes based on data form the relevant State Department of Agriculture publication (Table 10). Where conventional tillage is practised in the other States, the relevant State Department of Agriculture publications were used to determine the number of tillage passes. Overall use of diesel is summarised for each State (Table 13), taking into account the different tillage systems, application of pesticides and application of fertiliser/lime. The assumption is made that lime is applied every four years rather than annually. The EF for the production and use of diesel fuel was adopted from Australia's national greenhouse accounts (Commonwealth of Australia, 2021a, see Table 4). All diesel use is modelled as fossil diesel.

The fuel use as calculated (Salam et al. 2010) is corrected for the significant uptake of Controlled Traffic Farming (CTF). Percentages of CTF in broad-acre cropping were taken from 2021 survey results for the grains industry (Umbers, 2021), which include the portion of the property where CTF was used. The survey represented approximately 4.5% of grain farms in the cropping region, with producers randomly selected from the GRDC customer database and a response rate of 56% (Umbers, 2021). Since 2016, this mode of machinery operation has increased significantly in Australia, enabled by the technological advances in Global Positioning Systems onboard agricultural machinery. Umbers 2021 report level of CTF at the sub-region within State. For dryland regions, these values are aggregated to the State level. Irrigated canola was assumed to have the same level of CTF as dryland at the agroecological region level, however because irrigated inventory data are sampled from fewer regions the average percentages are different to the state dryland average.

For the area under CTF a reduction of 25% in fuel use per ha is adopted, based on a literature review (see Appendix C). This reduction was not applied to fuel use for irrigation.

Table 13. Summary of machinery operations, adoption of controlled traffic farming (CTF) and total fuel per hectare for canola production.

State	Machinery operations (number of passes/ha/year)						Fuel use (l/ha) without CTF	% of area with CTF	Fuel use[b] (l/ha) adjusted for %CTF
	Cultivation	Planting	Application of pesticides[a]	Application of fertiliser	Application of lime	Harvesting & windrowing			
New South	0.1	1.0	4.8	1.0	0.1	1.7	28.0	46	24.8

Wales (dryland)									
New South Wales (irrigated)	0.7	1.0	5.3	1.0	0.0	2.0	47.1	19	71.5
Victoria	0.1	1.0	5.4	1.0	0.1	1.8	25.0	34	22.9
Queens-land	0.1	1.0	4.0	1.0	0.1	1.6	49.4	50	43.2
South Australia (dryland)	0.0	1.0	4.9	1.8	0.0	1.8	28.4	18	27.1
South Australia (irrigated)	0.7	1.0	5.3	1.0	0.0	2.0	47.1	19	71.5
Western Australia	0.2	1.0	3.0	1.0	0.2	1.5	24.9	29	23.1
Tasmania	1.0	1.0	3.0	1.0	0.0	2.0	49.2	49	59.3

[a] Pesticides include herbicide for pre-planting weed control and in-crop applications of insecticides and fungicides.

[b] Fuel use for irrigated canola includes diesel for water pumping.

3.6 Quantity of soil conditioners applied

As lime is the predominant soil conditioner used to reduce soil acidity, and dolomite has very similar properties and GHG emissions factors, calculations were based on lime. In the absence of consistent national data on the quantity of soil conditioners applied to canola crops, a similar method to that used for N input was adopted. The amount of lime applied was calculated as the quantity required to maintain soil at a steady state of > 5 pH. Lime input was calculated as the quantity of lime required to achieve a zero net acid addition rate (NAAR; mol H+/ha/crop). In a system that has stable organic matter content in the soil, hydrogen ions accumulate with the addition of N fertiliser to the soil, the acidifying effect being dependent on the type of N fertiliser and the amount of nitrate leached out of the root zone. The ash alkalinity of exported products also affects soil acidity. Note canola is one of the few crops that has an alkalinising effect on soil pH rather than being a net exporter of cations in the harvested grain. These chemical relationships were modelled to estimate the NAAR of canola production (Baldock et al. 2009) and the application of this approach is given in Table 14.

In accordance with EU (2022), the CO_2 emission of full neutralisation of fertiliser-N-induced acidity via reaction with carbonates is attributed to fertiliser rather than lime. The calculation of this emission source excludes the alkaline effect of canola itself. Using the values of EU (2022), which are 0.783 kg CO_2/kg N (1.80 kg $CaCO_3$/kg N) for nitrate fertilisers and 0.806 kg CO_2/kg N (1.83 kg $CaCO_3$/kg N) for urea, and the equivalent value for MAP which is 2.354 kg CO_2/kg N (5.35 kg $CaCO_3$/kg N; Baldock et al. 2009), the CO_2 emissions of fertiliser N neutralisation are calculated using the data in Table 14 (effectively 0.44 kg CO_2/kg lime required).

These CO_2 emissions from fertiliser acidification are therefore larger than the emissions calculated from lime applied, as the latter include the negative acidification effect of canola itself (Table 14). No emissions are attributed to liming, as stipulated in EU (2022), other than manufacture and transport.

Table 14. Net Acid Addition Rate (NAAR) assumed for soils where canola is grown in each State and the corresponding quantity of lime required to keep soil pH stable.

State	Type of Fertiliser	Acid factor for N fertiliser (lime equivalent kg/kg N applied)	N applied (kg N/ha)	Lime required to offset acidification from N fertiliser (lime equivalent kg/ha)	Ash alkalinity of canola seed removed from farm (lime equivalent kg/tonne of canola seed	Yield of canola seed (tonne/ ha)	Total acidification from grain export (lime equivalent kmol/ha)	Lime required to give NAAR = 0 (lime kg/ha)
New South Wales (dryland)	MAP	5.35	3.50	18.7	**-14.5**	**1.18**	**-17.1**	**113**
	Urea	1.83	61.03	111.8				
	Total		**64.54**	**130.5**				
New South Wales (irrigated)	MAP	5.35	7.92	42.4	**-14.5**	**2.67**	**-38.7**	**292**
	Urea	1.83	157.51	288.5				
	Total		**165.43**	**330.9**				
Victoria (dryland)	MAP	5.35	4.68	25.0	**-14.5**	**1.58**	**-22.9**	**121**
	Urea	1.83	64.88	118.9				
	Total		**69.56**	**143.9**				
Queensland	MAP	5.35	2.74	14.7	**-14.5**	**0.92**	**-13.4**	**72**
	Urea	1.83	38.42	70.4				
	Total		**41.16**	**85.0**				
South Australia (dryland)	MAP	5.35	4.51	24.1	**-14.5**	**1.52**	**-22.1**	**111**
	Urea	1.83	59.30	108.6				
	Total		**63.81**	**132.8**				
South Australia (irrigated)	MAP	5.35	7.92	42.4	**-14.5**	**2.67**	**-38.7**	**258**
	Urea	1.83	138.85	254.3				
	Total		**146.77**	**296.7**				
Western Australia	MAP	5.35	3.59	19.2	**-14.5**	**1.21**	**-17.5**	**79**
	Urea/UAN	1.83/1.80	22.32/20.33	40.9/36.6				
	Total		**46.24**	**96.7**				
Tasmania	MAP	5.35	7.22	38.6	**-14.5**	**2.44**	**-35.3**	**245**
	Urea	1.83	131.84	241.5				
	Total		**139.06**	**280.2**				

The quantity of lime required to keep NAAR at zero was assumed to be the quantity of lime that is applied to soil in practice. As this is best practice, it is likely to be an over-estimation of lime actually being applied.

All soil conditioners are produced domestically, and an average State domestic transport distance of 244 km is assumed, based on the transport distances for each State given in Table 8.

3.7 Greenhouse gas emissions from cultivation

For N_2O emissions calculations, the REDII suggests the use of IPCC Methodology and specifies that all three IPCC tiers can be used. In addition, the IPCC guidelines on estimating N_2O emissions (IPCC, 2019) recommend that where countries have data to show that the Tier 1 default emissions factors are inappropriate for their country, they should utilise Tier 2 equations.

Australia has undertaken a large body of research on agricultural GHG emissions from cropping land and employs a Tier 2 method for the estimation of emissions from the use of synthetic fertiliser, management of crop residues and indirect N_2O emissions from leaching and volatilisation. The direct N_2O emission factor for crop residue decomposition used in Australia's national inventory is the Tier 1 default factor (IPCC, 2006) but, as described in Section 2.4, in the current analysis we use the updated Tier 1 emission factor for dry climates (IPCC, 2019) based on analysis detailed below.

A full description of the methods has been published by the Australian Government (Commonwealth of Australia, 2021) and accepted as the accounting method for UNFCCC GHG reporting. To apply Tier 2 methods at sub-national level as well as specifically for canola cultivation, additional analysis is required. The rules for determining whether leaching occurs and whether the low-rainfall or high-rainfall emission factor for direct N_2O should be used (see Table 4) are in accordance with the national approach (Commonwealth of Australia, 2021). In addition, analysis was performed on which fraction of the Australian cropping area meets the definition of dry climate which underlies the use of the dry-climate Tier 1 emission factor for crop residue (IPCC, 2019). These rules are:

- Leaching occurs where the ratio of evapotranspiration to mean annual rainfall is below 0.8 or larger than 1 (indicating irrigation);
- Low rainfall is defined as mean annual rainfall below 600 mm per year;
- Dry climate occurs where the ratio of mean annual rainfall to potential evaporation is below 1 (temperate zones) or where mean annual rainfall is below 1000 mm (tropical zones, mean annual temperature > 18^oC).

The results of this analysis are shown in Table 15. Climate data was sourced from the SILO climate database (Queensland Government, 2022) and spatially gridded land use data was sourced from ABARES (2021). For the calculation of the fraction of cropland subject to leaching and low rainfall, mean annual rainfall and evapotranspiration were assessed over the period 1976-2021 to align with calculations in the Australian GHG inventory (Commonwealth of Australia, 2021). For the fraction of cropland in the dry climate zone, the period 1985-2015 was used, in line with IPCC (2019).

Table 15. Details on crop residue management for canola regions in Australia and the proportions of the cropland area subject to leaching, low rainfall and dry climate, respectively (see text for definitions).

State	Crop residue management (2015-2019)[1]		% area of cropland subject to leaching	% area of cropland in low rainfall zone (<600 mm/year)	% area of cropland in dry climate zone
	% of area where above ground residue is burnt[2]	% of area where above ground residue is removed			
New South Wales (dryland and irrigated)	22	5	5.9	75	100
Victoria (dryland and irrigated)	21	7	8.2	92	100
Queensland	6	4	1.4	72	100
South Australia	12	9	0.7	99	100
Western Australia	6	11	1.5	97	100
Tasmania[3]	9	16	87	38	88

[1] Source: (Commonwealth of Australia, 2021)

[2] For control of herbicide resistant weed seedbanks

[3] For Tasmania 100% irrigation is assumed, so in practice the fractions are 100% and 0%.

3.7.1 Application of nitrogen fertilisers

Annual nitrous oxide (N_2O) production from the addition of synthetic fertilisers is calculated as (Commonwealth of Australia, 2021):

$E_{ij} = \Sigma_i \Sigma_j (M_{ij} \times EF_{ij} \times Cg)$

Where:

E_{ij} = annual emissions from fertiliser (Gg N_2O)

M_{ij} = mass of fertiliser applied in production system j (Gg N)

EF_{ij} = emission factor (Gg N_2O-N/Gg N applied) (EF = 0.0005 for fraction of cropping region <600mm annual rainfall; EF = 0.0085 for fraction of cropping regions >600mm annual rainfall and for irrigated crop. See Table 15 for fractions by State.)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

The emission of CO_2 released from urea after application has not been calculated separately, because the embedded emissions of urea do not take CO_2 uptake into account (see 3.3.4). The net contribution of urea production and use is therefore correct.

3.7.2 Application of crop residues

The mass of N in crop residues returned to soils is calculated as:

$M_{ijk} = (P_{ij} \times R_{AGj} \times (1 - F_{ij} - FFOD_{ij}) \times DM_j \times NC_{AGj}) + (P_{ij} \times R_{AGj} \times R_{BGj} \times DM_j \times NC_{BGj})$

Where:

M_{ij} = mass of N in crop residues (Gg N)

P_{ij} = annual production of crop (Gg)

R_{AGj} = above ground residue to crop ratio (kg crop residue/kg crop) (Canola = 2.08)

R_{BGj} = below ground-residue to above ground residue ratio (kg /kg) (Canola = 0.33)

DM_j = dry matter content (kg dry weight/kg crop residue) (Canola = 0.96)

NC_{AGj} = nitrogen content of above-ground crop residue (kg N/kg DM) (Canola = 0.009)

NC_{BGj} = nitrogen content of below-ground crop residue (kg N/kg DM) (Canola = 0.01)

F_{ij} = fraction of crop residue that is burnt (See Table 15)

$FFOD_{ij}$ = fraction of the crop residue that is removed (See Table 15)

Annual direct nitrous oxide production from the return of crop residues is calculated as:

$E_i = \Sigma_i \Sigma_k \Sigma_l (M_{ijkl} \times EF \times Cg)$

Where:

E_j = annual emissions from crop residues (Gg N_2O)

M_{ijkl} = mass of N in crop residues (Gg N)

EF = 0.005 (Gg N_2O-N/Gg N) IPCC (2019) default emission factor for dry climates (Table 15)

C_g = 44/28 factor to convert from elemental mass of N_2O to molecular mass

3.7.3 Leaching from soils and surface runoff

Indirect N_2O emissions from leaching and runoff are only assumed in areas where the ratio of evapotranspiration rate: rainfall lower than 0.8 or higher than 1 (Table 15).

Annual nitrous oxide production from leaching and runoff is calculated for inorganic fertiliser N applied to soils and crop residue (Commonwealth of Australia, 2021). The mass of inorganic fertiliser N applied to soils that is lost through leaching and runoff is calculated as:

$M_{ij=1} = M_{ij} \times FracWET_{ij} \times FracLEACH$

Where:

$M_{ij=1}$ = mass of synthetic fertiliser lost through leaching and runoff (Gg N)

M_{ij} = mass of fertiliser in each production system (Gg N)

$FracWET_{ij}$ = fraction of N available for leaching and runoff (by State, see Table 15)

FracLEACH = 0.24 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff.

The mass of crop residue that is lost through leaching and runoff is calculated as:

$M_{ij=4} = M_{ij}$ x $FracWET_{ij}$ x FracLEACH

Where:

$M_{ij=4}$ = mass of crop residue lost through leaching and runoff (Gg N)

M_{ij} = mass of crop residue N (Gg N)

$FracWET_{ij}$ = fraction of N available for leaching and runoff (by State, see Table 15)

FracLEACH = 0.24 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff.

Annual indirect nitrous oxide production from leaching and run off is calculated as:

$E = \Sigma_i \Sigma_j (M_{ij} \text{ x } EF_{ij} \text{ x } Cg)$

Where:

E = annual emissions from atmospheric deposition (Gg N_2O)

M_{ij} = mass of N lost through leaching and runoff (Gg N)

EF_{ij} = emissions factor (Gg N_2O-N/Gg N) (EF = 0.011)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

3.7.4 Atmospheric nitrogen deposition

As there is no animal waste or sewerage sludge applied to broad-acre cropping land in Australia, the only source of N for atmospheric deposition is from volatilisation of inorganic fertiliser. The mass of inorganic fertiliser N volatilised is calculated as (Commonwealth of Australia, 2021):

$M_{ij=1} = TM_{ij=1}$ x $FracGASF_j$

Where:

$M_{ij=1}$ =mass of synthetic fertiliser volatilised (Gg N)

TM_{ij} = total mass of fertiliser (Gg N)

$FracGASF_j$ = 0.11 (Gg N/Gg applied) IPCC (2019) default

Annual nitrous oxide production from atmospheric deposition is calculated as:

$E = \Sigma_i \Sigma_j (M_{ij} \text{ x } EF_{ij} \text{ x } Cg)$

Where:

E = annual emissions from atmospheric deposition (Gg N_2O)

M_{ij} = mass of N volatilised (Gg N)

EF_{ij} = emissions factor (Gg N_2O-N/Gg N) (EF = 0.0005 for cropping regions <600mm annual rainfall; EF = 0.0085 for cropping regions >600mm annual rainfall and for irrigated crop)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

3.7.5 Burning of agricultural residues

As the practice of burning canola stubble is close to 20% in some States, non-CO_2 GHG emissions from burning of residual crop material (CH_4, N_2O, CO, NO_x and NMVOCs) have been included in the overall estimate of GHG emissions. CO_2 emissions are not included as it is assumed an equivalent amount of CO_2 was taken up by the growing crop.

The mass of fuel burnt is calculated as:

$M_{ij} = P_{ij} \times R_j \times S_j \times DM_j \times Z \times F_{ij}$

Where:

M_{ij} = mass of residue burnt from crop (Gg)

P_{ij} = annual production of crop (Gg)

R_j = residue to crop ratio (kg crop residue/kg crop) (Canola = 2.08)

S_j = fraction of crop residue remaining at burning (Canola = 0.5)

DM_j = dry matter content (kg dry weight/kg crop residue) (Canola = 0.96)

Z = burning efficiency (fuel burnt/fuel load) = 0.96

F_{ij} = fraction of the annual production of crop that is burnt (See Table 15)

The mass of fuel burnt is converted to an emission of CH_4 by multiplying by the carbon content of the fuel, and an EF. That is:

$E_{ij} = M_{ij} \times CC_j \times EF_g \times Cg$

Where:

E_{ij} = annual emission from burning crop residue (Gg)

CC_j = carbon mass fraction in crop residue (Canola = 0.4)

EF_g = emission factor (Gg element /Gg burnt) (Table 4)

C_g = factor to convert from elemental mass of gas to molecular mass

For N_2O an additional term in the algorithm, the nitrogen to carbon ratio (NC_j), is required in order to calculate the fuel nitrogen content. Hence:

$E_{ijk} = M_{ij} \times NC_j \times EF_g \times C_g$

Where:

E_{ij} = annual emission from burning crop residue (Gg)

NC_j = nitrogen content in above ground residue (Canola = 0.009)

EF_g = emission factor (Gg element /Gg burnt) (Table 4)

C_g = factor to convert from elemental mass of gas to molecular mass

3.7.6 Lime application

For lime application, the annual emissions of CO_2 are calculated as (Commonwealth of Australia, 2021):

$E_{ij} = ((M_{ij} \times FracLime_{ij} \times P_{j=1} \times EF_{j=1}) + (M_{ij} \times (1- FracLime_{ij}) \times P_{j=2} \times EF_{j=2})) \times C_g / 1000$

Where: E_{ij} = annual emission of CO_2 from lime application (Gg)

M_{ij}= mass of limestone and dolomite applied to soils (t)

$FracLime_{ij}$ = fraction limestone (assumed to be 1 for canola production)

$P_{j=1}$ = fractional purity of limestone = 0.9

$P_{j=2}$ = fractional purity of dolomite = 0.95

$EF_{j=1}$ = 0.12 IPCC (2006) default emission factor for limestone

$EF_{j=2}$ = 0.13 IPCC (2006) default emission factor for dolomite

C_g= 44/12 factor to convert elemental mass of CO_2 to molecular mass

3.8 Soil carbon stores

There is the opportunity to include soil carbon accumulation via improved agricultural management) such as shifting to reduced or zero-tillage, improved crop/rotation, the use of cover crops, including crop residue management, and the use of organic soil improver (REDII, Annex V.C). Net removals due to soil carbon accumulation shall only "be taken into account only if solid and verifiable evidence is provided that the soil carbon has increased or that it is reasonable to expect to have increased over the period in which the raw materials concerned were cultivated".

Compared to the time period covered in the previous country report (Eady, 2017) there has been an increase in no-till practices across all states except Western Australia (Table 12). In addition, the increase in use of controlled traffic farming may have led to increased soil carbon sequestration (e.g., Antille et al. 2015). However, the available data on the effects of these changes is not sufficient to be confident of calculating effects across all growing regions. For the increase in dual-purpose canola as a cultivation system, no appropriate discussion of the effect on soil carbon is available in the literature. Therefore, the conservative assumption that no soil carbon accumulation has taken place was maintained.

4 Results and discussion

The GHG emissions arising from the cultivation of canola are summarised in Table 16. At a national level, GHG emissions associated with canola cultivation were 0.433 tonne CO_2-eq /tonne canola seed harvested. When converted to a dry matter (DM) basis, by adjusting for moisture content, the emissions were 0.460 tonne CO_2-eq/tonne canola seed DM. GHG emissions by State ranged from 0.441 to 0.873 tonne CO_2-eq /tonne canola seed DM. State values reflect a production-weighted average for grain from dryland, irrigated and dual-purpose systems, as these are not segregated for export.

Table 16 Greenhouse gas emissions arising from the cultivation of canola in the States of Australia (tonne CO_2-eq/tonne canola seed harvested on dry matter basis).

	Soil N2O		**Crop residue**	**Embedded**			**Fuel use**	**Fertiliser acidification**	**Seed**	**Total**
	Direct	Indirect		Fertiliser	Pesticide	Lime				
New South Wales	0.060	0.015	0.056	0.229	0.038	0.002	0.065	0.041	0.002	0.508
Single purpose	0.057	0.011	0.066	0.248	0.047	0.002	0.075	0.044	0.002	0.554
Dual purpose	0.039	0.007	0.026	0.162	0.018	0.001	0.029	0.028	0.002	0.313
Irrigated	0.261	0.136	0.066	0.327	0.007	0.003	0.096	0.058	0.001	0.954
Victoria	0.023	0.009	0.062	0.221	0.036	0.002	0.050	0.040	0.002	0.444
Single purpose	0.024	0.009	0.065	0.226	0.038	0.002	0.052	0.041	0.002	0.458
Dual purpose	0.017	0.006	0.030	0.161	0.017	0.001	0.024	0.029	0.002	0.288
Queensland	0.061	0.008	0.063	0.239	0.054	0.002	0.167	0.043	0.003	0.641
South Australia	0.016	0.004	0.059	0.214	0.068	0.002	0.062	0.039	0.002	0.466
Single purpose	0.012	0.002	0.061	0.216	0.071	0.002	0.064	0.039	0.002	0.469
Dual purpose	0.009	0.001	0.028	0.155	0.032	0.001	0.029	0.028	0.002	0.285
Irrigated	0.232	0.125	0.061	0.288	0.007	0.003	0.096	0.052	0.001	0.865
Western Australia	0.014	0.003	0.058	0.225	0.030	0.002	0.069	0.037	0.002	0.441
Single purpose	0.014	0.003	0.059	0.225	0.031	0.002	0.069	0.037	0.002	0.441
Dual purpose	0.010	0.002	0.023	0.159	0.012	0.001	0.027	0.026	0.002	0.263
Tasmania*	0.240	0.127	0.057	0.298	0.013	0.003	0.079	0.054	0.001	0.873

*Model for Tasmania assumes 100% irrigation; see 3.1

The greatest contribution to GHG emissions (national average) came from the manufacture of fertiliser, with 50% of the total emissions, followed by CO_2 from fuel use (14%). N_2O from crop residues and direct N_2O emissions in response to chemical fertiliser application accounted for about 13% and 6%, respectively, but these fractions varied significantly between states.

Under the RED, results for GHG emissions for cultivation are reported as gCO2eq/MJ of fatty acid methyl ester (FAME). The results for Australian canola are presented in this format in Table 17, based on the conversion factor of 0.0655 kg dry feedstock/MJ FAME biodiesel from rapeseed and an allocation of 0.586, values provided by Renewables & CCS Policy, Directorate General for Energy (ENER), European Commission.

Table 17 As Table 16, in g CO_2-eq/MJ FAME.

	Soil N2O		**Crop residue**	**Embedded**			**Fuel use**	**Fertiliser acidification**	**Seed**	**Total**
	Direct	Indirect		Fertiliser	Pesticide	Lime				
New South Wales	2.29	0.56	2.17	8.80	1.48	0.08	2.48	1.56	0.09	19.5
Single purpose	2.19	0.44	2.55	9.52	1.80	0.08	2.88	1.70	0.09	21.2
Dual purpose	1.48	0.28	0.99	6.20	0.70	0.06	1.12	1.09	0.09	12.0
Irrigated	10.03	5.21	2.55	12.54	0.26	0.11	3.68	2.22	0.04	36.6
Victoria	0.89	0.34	2.39	8.48	1.38	0.07	1.90	1.52	0.07	17.0
Single purpose	0.90	0.35	2.50	8.68	1.44	0.08	1.99	1.56	0.07	17.6
Dual purpose	0.67	0.24	1.15	6.19	0.66	0.06	0.92	1.10	0.07	11.0
Queensland	2.36	0.31	2.43	9.17	2.06	0.08	6.42	1.65	0.12	24.6
South Australia	0.62	0.17	2.27	8.21	2.59	0.07	2.39	1.49	0.07	17.9
Single purpose	0.45	0.07	2.35	8.30	2.74	0.07	2.45	1.51	0.07	18.0
Dual purpose	0.34	0.05	1.06	5.96	1.23	0.06	1.10	1.07	0.07	10.9
Irrigated	8.91	4.79	2.35	11.06	0.26	0.10	3.68	1.99	0.04	33.2
Western Australia	0.52	0.10	2.24	8.65	1.17	0.07	2.64	1.44	0.09	16.9
Single purpose	0.52	0.10	2.25	8.65	1.17	0.07	2.64	1.44	0.09	16.9
Dual purpose	0.38	0.07	0.88	6.11	0.46	0.05	1.04	0.99	0.09	10.1
Tasmania	9.23	4.89	2.18	11.45	0.50	0.10	3.04	2.06	0.05	33.5

5 Sensitivity analysis

This analysis of greenhouse gas emissions for canola production has been undertaken with the best and latest data, taking into account regional characteristics for climate, soils and farm practices and drawing on publicly available official statistics and publications. The calculations undertaken followed REDII requirements. However, a certain level of uncertainty is associated with any GHG calculation. A useful approach to explore the impact of uncertainty is to undertake a sensitivity analysis, that is, to systematically check how much the final result changes when figures are varied one at a time. Major input parameters that were tested for sensitivity are listed in Table 18. Each of these input parameters was varied by +15% and -15% to establish the spread in results that would be apparent if the figures were varied up or down in value. The effect on the Australian average value for GHG emissions, 0.460 tonne CO2-eq/tonne canola seed on DM basis, was assessed.

Table 18 Sensitivity of results for greenhouse gas emissions from the cultivation of canola when input parameters are varied by ± 15%.

Input parameter	National GHG emissions for -15% (kg CO_2-eq/t DM)	National GHG emissions for -15% percent change	National GHG emissions for 15% (kg CO_2-eq/t DM)	National GHG emissions for 15% percent change
Yield (t/ha)	0.477	3.6%	0.448	-2.7%
% dry matter content	0.456	-0.9%	0.464	0.9%
% of area irrigated	0.459	-0.2%	0.461	0.2%
Fertiliser input (kg N/ha)	0.420	-8.7%	0.500	8.7%
% area stubble burnt	0.458	-0.4%	0.462	0.4%
% area no till	0.465	1.1%	0.455	-1.1%
% area subject to leaching	0.459	-0.3%	0.461	0.3%
Fuel use (l/ha)	0.450	-2.1%	0.469	2.1%
Pesticide use (kg a.i./ha)	0.455	-1.0%	0.465	1.0%
Lime input (kg/t)	0.460	-0.06%	0.460	0.06%
EF direct N_2O	0.455	-1.0%	0.464	1.0%
EF indirect N_2O	0.459	-0.1%	0.460	0.1%
EF crop residues	0.453	-1.6%	0.467	1.6%
EF for fertiliser manufacture	0.428	-7.0%	0.492	7.0%
CTF application	0.461	0.2%	0.459	-0.2%
CTF fuel saving	0.461	0.2%	0.459	-0.2%
Dual purpose fraction	0.462	0.6%	0.457	-0.6%
Feed quantity in dual purpose	0.462	0.5%	0.458	-0.4%

This analysis shows that the results for GHG emissions for canola production are most sensitive to N fertiliser input, emissions associated with manufacture of fertiliser and yield. The assumptions adopted for fuel use, tillage, pesticide use and for the emission factor for crop residue N_2O were next in importance, while variation in the assumed level of irrigation, stubble management practices, area subject to leaching, and direct and indirect N_2O emission factors have a minor impact on results (less than 1% response to 15% variation). Sensitivity to lime input only influences the emissions of production and transport of lime, as the emissions from lime applied remain lower than the emissions of neutralisation of fertiliser acidification across the sensitivity range (see 3.6). Sensitivity to the main parameters used in the modelling of controlled traffic farming and dual-purpose canola cultivation was low.

6 Review of the report

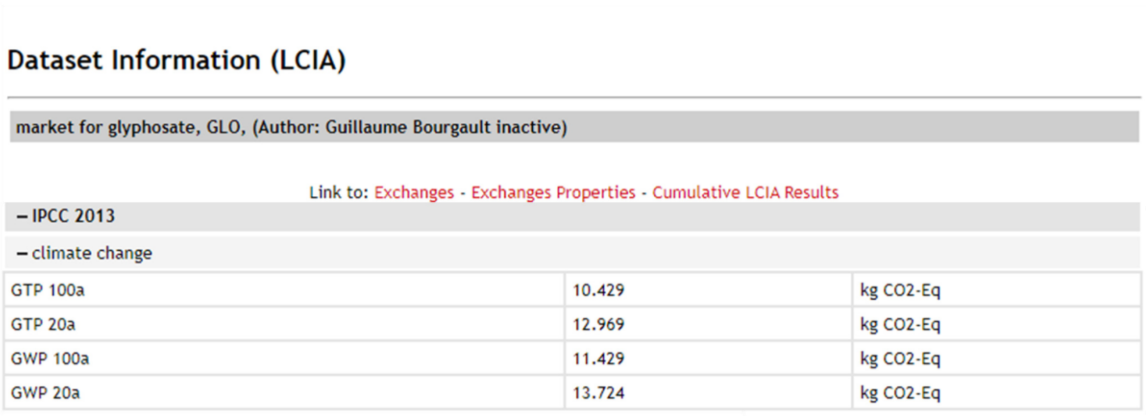
The Australian Country Report was reviewed in Australia by Professor Richard Eckard, Director, Primary Industries Climate Challenges Centre, University of Melbourne. The Report was also independently reviewed by the European organisation SGS Germany GmbH. A summary of the review findings is given in Appendix D.

Part II Appendices

Appendix A Inventory used for (embedded) emission factors

Calculations underlying the embedded emission factors for urea, UAN and MAP. The emission factors are derived using ecoinvent 3.8, applying a correction for sequestration credit and for the difference in emission factor between ecoinvent 3.8 and EC (2019) for European production (see 3.3.4). The values indicated with * are taken from EC (2019).

	kg CO2-eq/kg excluding infrastructure processes	corrected for sequestration credit	with corrected factor applied	correction factor derived for EU production
Urea {RoW}| urea production | Cut-off, U	1.493	2.226	1.929	
Urea {CN}| urea production | Cut-off, U	2.580	3.313	2.871	
Urea ammonium nitrate mix {RoW}| urea ammonium nitrate production | Cut-off, U	1.635	1.874	1.624	
Urea ammonium nitrate mix {CN}| urea ammonium nitrate production | Cut-off, U	2.685	2.924	2.534	
Monoammonium phosphate {RoW}| monoammonium phosphate production | Cut-off, U	0.789	0.789	0.789	
Monoammonium phosphate {CN}| monoammonium phosphate production | Cut-off, U	1.134	1.134	1.134	
Ammonium nitrate {RER}| ammonium nitrate production | Cut-off, U	*1.362*	*1.362*	*1.180**	*0.87*
Urea {RER}| urea production | Cut-off, U	*1.160*	*1.893*	*1.640**	*0.87*



Dataset Information (LCIA)

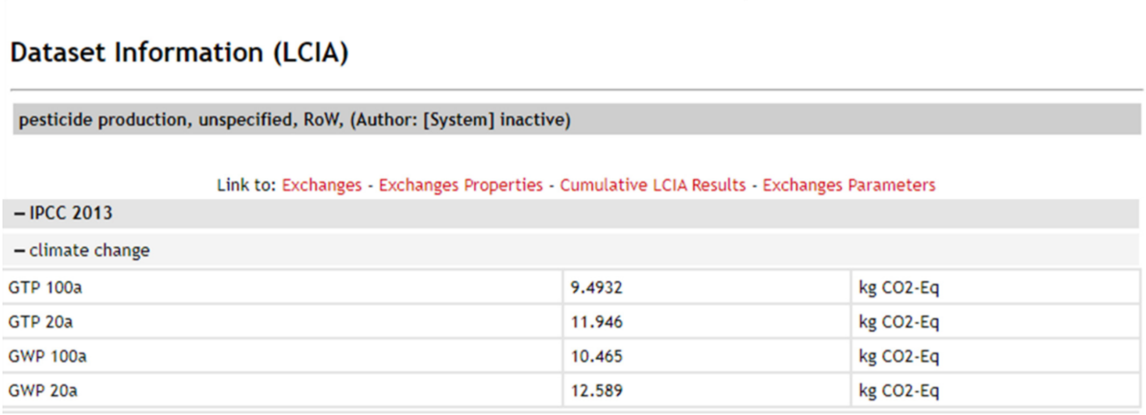
market for glyphosate, GLO, (Author: Guillaume Bourgault inactive)

Link to: Exchanges - Exchanges Properties - Cumulative LCIA Results

− IPCC 2013

− climate change

GTP 100a	10.429	kg CO2-Eq
GTP 20a	12.969	kg CO2-Eq
GWP 100a	11.429	kg CO2-Eq
GWP 20a	13.724	kg CO2-Eq



Dataset Information (LCIA)

pesticide production, unspecified, RoW, (Author: [System] inactive)

Link to: Exchanges - Exchanges Properties - Cumulative LCIA Results - Exchanges Parameters

− IPCC 2013

− climate change

GTP 100a	9.4932	kg CO2-Eq
GTP 20a	11.946	kg CO2-Eq
GWP 100a	10.465	kg CO2-Eq
GWP 20a	12.589	kg CO2-Eq

Dataset Information (LCIA)

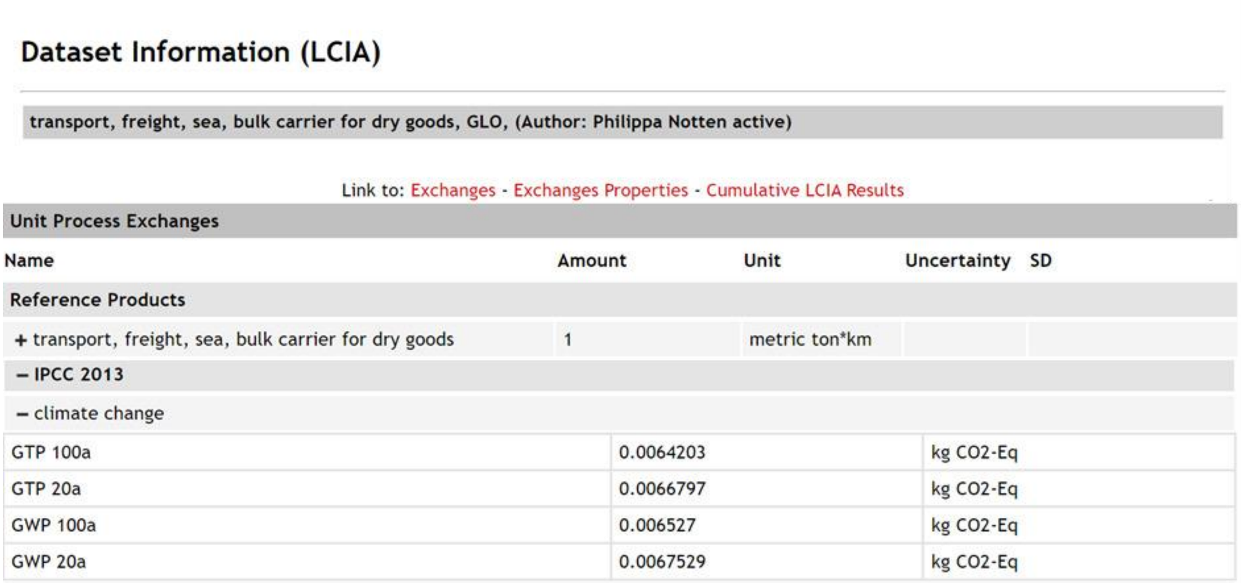
limestone production, crushed, for mill, RoW, (Author: Geneviève Martineau inactive)

Link to: Exchanges - Exchanges Properties - Cumulative LCIA Results - Exchanges Parameters

− IPCC 2013

− climate change

GTP 100a	0.0026833	kg CO2-Eq
GTP 20a	0.0030179	kg CO2-Eq
GWP 100a	0.0028273	kg CO2-Eq
GWP 20a	0.0031399	kg CO2-Eq



Dataset Information (LCIA)

transport, freight, sea, bulk carrier for dry goods, GLO, (Author: Philippa Notten active)

Link to: Exchanges - Exchanges Properties - Cumulative LCIA Results

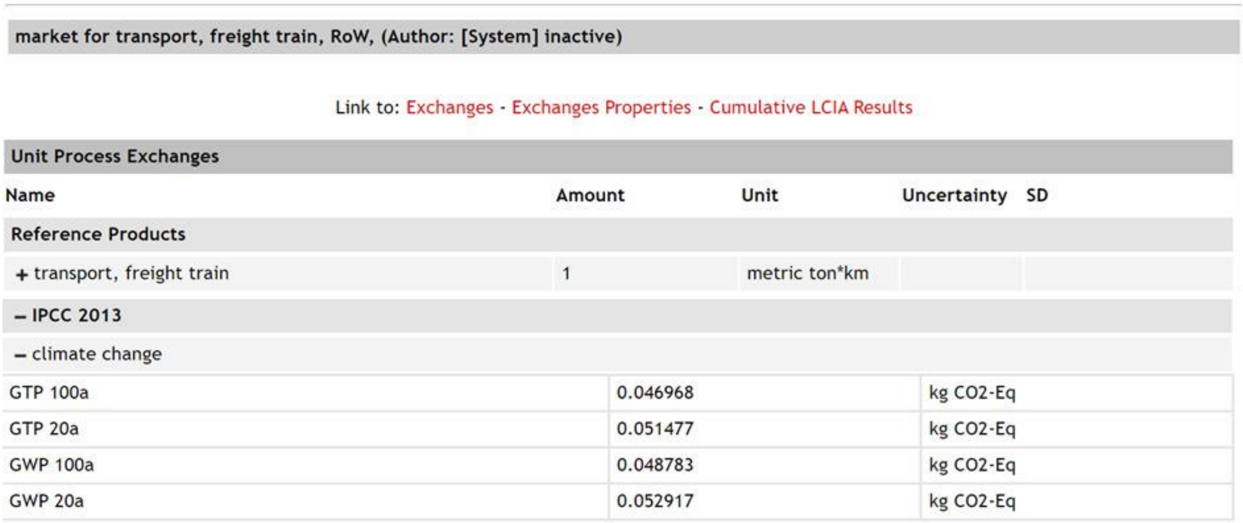
Unit Process Exchanges

Name	Amount	Unit	Uncertainty	SD
Reference Products				
+ transport, freight, sea, bulk carrier for dry goods	1	metric ton*km		

− IPCC 2013

− climate change

GTP 100a	0.0064203	kg CO2-Eq
GTP 20a	0.0066797	kg CO2-Eq
GWP 100a	0.006527	kg CO2-Eq
GWP 20a	0.0067529	kg CO2-Eq



market for transport, freight train, RoW, (Author: [System] inactive)

Link to: Exchanges - Exchanges Properties - Cumulative LCIA Results

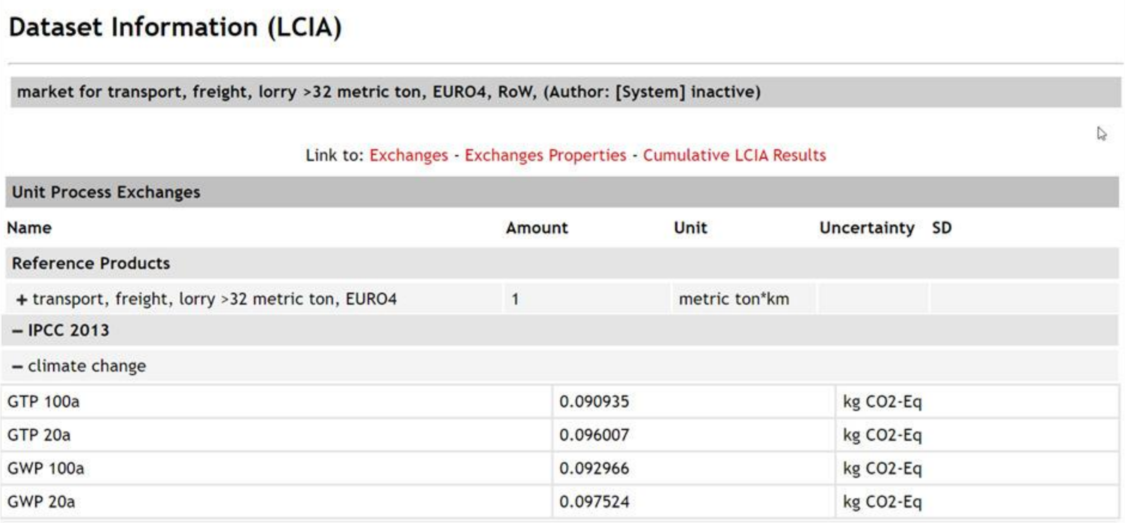
Unit Process Exchanges

Name	Amount	Unit	Uncertainty	SD
Reference Products				
+ transport, freight train	1	metric ton*km		

− IPCC 2013

− climate change

GTP 100a	0.046968	kg CO2-Eq
GTP 20a	0.051477	kg CO2-Eq
GWP 100a	0.048783	kg CO2-Eq
GWP 20a	0.052917	kg CO2-Eq



Dataset Information (LCIA)

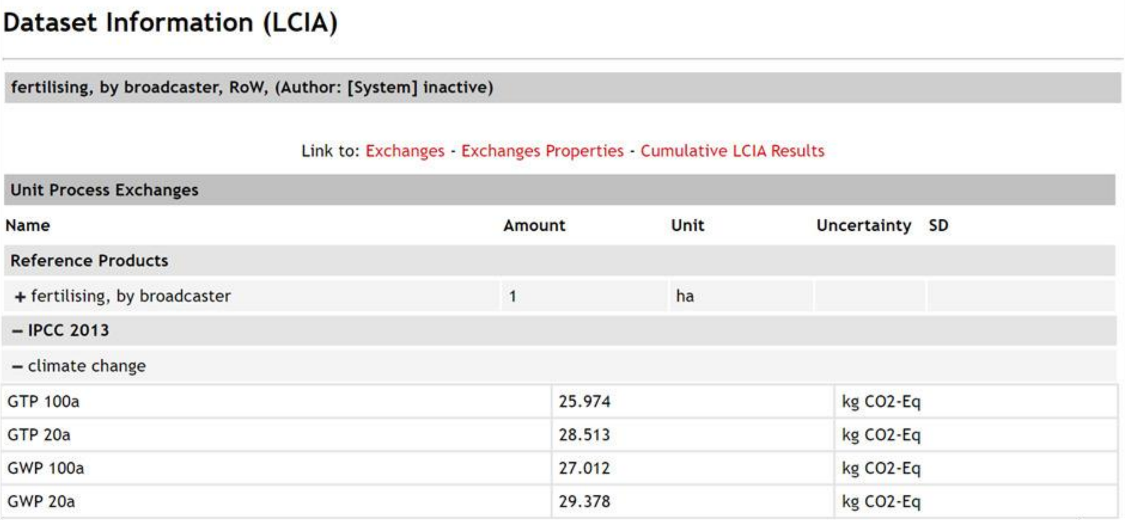
market for transport, freight, lorry >32 metric ton, EURO4, RoW, (Author: [System] inactive)

Link to: Exchanges - Exchanges Properties - Cumulative LCIA Results

Unit Process Exchanges

Name	Amount	Unit	Uncertainty	SD
Reference Products				
+ transport, freight, lorry >32 metric ton, EURO4	1	metric ton*km		
– IPCC 2013				
– climate change				

GTP 100a	0.090935	kg CO2-Eq
GTP 20a	0.096007	kg CO2-Eq
GWP 100a	0.092966	kg CO2-Eq
GWP 20a	0.097524	kg CO2-Eq



Dataset Information (LCIA)

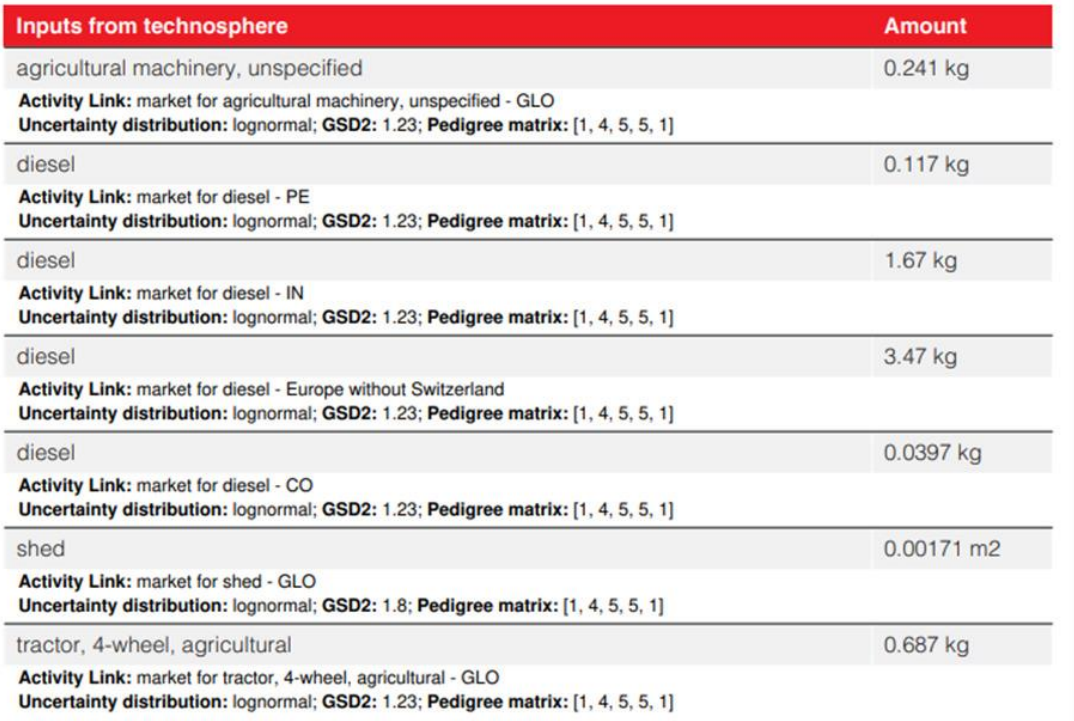
fertilising, by broadcaster, RoW, (Author: [System] inactive)

Link to: Exchanges - Exchanges Properties - Cumulative LCIA Results

Unit Process Exchanges

Name	Amount	Unit	Uncertainty	SD
Reference Products				
+ fertilising, by broadcaster	1	ha		
– IPCC 2013				
– climate change				

GTP 100a	25.974	kg CO2-Eq
GTP 20a	28.513	kg CO2-Eq
GWP 100a	27.012	kg CO2-Eq
GWP 20a	29.378	kg CO2-Eq



Inputs from technosphere	Amount
agricultural machinery, unspecified **Activity Link:** market for agricultural machinery, unspecified - GLO **Uncertainty distribution:** lognormal; **GSD2:** 1.23; **Pedigree matrix:** [1, 4, 5, 5, 1]	0.241 kg
diesel **Activity Link:** market for diesel - PE **Uncertainty distribution:** lognormal; **GSD2:** 1.23; **Pedigree matrix:** [1, 4, 5, 5, 1]	0.117 kg
diesel **Activity Link:** market for diesel - IN **Uncertainty distribution:** lognormal; **GSD2:** 1.23; **Pedigree matrix:** [1, 4, 5, 5, 1]	1.67 kg
diesel **Activity Link:** market for diesel - Europe without Switzerland **Uncertainty distribution:** lognormal; **GSD2:** 1.23; **Pedigree matrix:** [1, 4, 5, 5, 1]	3.47 kg
diesel **Activity Link:** market for diesel - CO **Uncertainty distribution:** lognormal; **GSD2:** 1.23; **Pedigree matrix:** [1, 4, 5, 5, 1]	0.0397 kg
shed **Activity Link:** market for shed - GLO **Uncertainty distribution:** lognormal; **GSD2:** 1.8; **Pedigree matrix:** [1, 4, 5, 5, 1]	0.00171 m2
tractor, 4-wheel, agricultural **Activity Link:** market for tractor, 4-wheel, agricultural - GLO **Uncertainty distribution:** lognormal; **GSD2:** 1.23; **Pedigree matrix:** [1, 4, 5, 5, 1]	0.687 kg

Ecoinvent Description of N and P Content for Monoammonium Phosphate Fertiliser

Dataset Description

General comment

This dataset is a weighted average from the respective regional datasets.
This dataset represents the production of 1 kg of monoammonium phosphate (MAP) with 8.4% N and 52% P2O5. Monommonium phosphate is an intermediate used to produce compound fertilisers, but is also used directly. MAP is produced with ammonia, phosphate rock and energy. The input and energy requirements are modeled based on Davis & Hagelund (1999).
The main data sources for this dataset is Fertilizers Europe (2014). Additional data sources are listed as follows.
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Althaus H.-J., Chudacoff M., Hischier R., Jungbluth N., Osses M. and Primas A. (2007) Life Cycle Inventories of Chemicals. ecoinvent report No. 8, v2.0. EMPA Dübendorf, Swiss Centre for Life Cycle Inventories, Dübendorf, CH.

Included activities start

The activity includes all the raw and processed materials necessary to produce this product. Liquid ammonia, phosphate rock, steam and electricity are included. Direct emissions include ammonia to air.

Included activities end

The activity ends with the final product being ready for transportation at the production site.

Appendix B Detailed Fertiliser Emissions Factor Calculation

Sample calculation for 1 kg of fertiliser transportation			
Description	**Value**	**Units**	**Remarks**
State	New South Wales (NSW)		
Port	Sydney		
Origin of imported fertilsier	Jeddah, Saudi Arabia		
Shipping distance from Jeddah to Sydney	14,081	km	From online distance calculator
Median distance from Port to Farm in NSW	412	km	from AEGIC 2018
Transportation distance by Rail	206		Assumed to be 50% by rail
Transportation distance by Road	206		Assumed to be 50% by road
Emission Factor for Rail transporation	0.0488	kgCO2eq/tkm	From ecoinvent
Emission Factor for Road transporation	0.093	kgCO2eq/tkm	From ecoinvent
Emission Factor for Ship transporation	0.0065	kgCO2eq/tkm	From ecoinvent
Emissions per kg of fertiliser transportation	**0.1207**	**kgCO2eq/kg**	(Distance x EF)/1000
Domestic Fertiliser			
Transportation distance by Road	412	km	From AEGIC 2018, assumed all is transported by road
Emission Factor for Road transporation	0.093	kgCO2eq/tkm	From ecoinvent
Emissions per kg of fertiliser transportation	**0.0383**	**kgCO2eq/kg**	(Distance x EF)/1000
Share of imported fertiliser	**69%**		
Share of domestic fertiliser	**31%**		
Average emission from fertiliser transport	**0.0952**	**kgCO2eq/kg**	
Sample calculation for 1 kg of fertiliser production			
Share of UREA in total fertiliser	53%		Calculated in the tool
Share of UAM in total fertiliser	21%		Calculated in the tool
Share of MAP in total fertiliser	27%		Calculated in the tool
Emission Factor for UREA	2.040	kgCO2eq/kg	From ecoinvent
Emission Factor for UAN	1.731		
Emission Factor for MAP	0.830	kgCO2eq/kg	From ecoinvent
Average emission from fertiliser production	**1.652**	**kgCO2eq/kg**	
Contribution analysis			
Average emission from fertiliser transport	0.0952	kgCO2eq/kg	**5.4%**
Average emission from fertiliser production	1.652	kgCO2eq/kg	**94.6%**

Appendix C Details for Controlled Traffic Farming

Controlled Traffic Farming (CTF) is a method of crop production where all machinery that travels over a paddock uses the same permanent tracks, resulting in the traffic lanes and the crop zone being distinctly and permanently separated. Since 2016, this mode of machinery operation has increased significantly in Australia (Table 19, Umbers 2021), enabled by the technological advances in Global Positioning Systems onboard agricultural machinery. Umbers 2021 reported level of CTF at the sub-region within State, surveying approximately 4.5% of grain farms in the cropping region. For dryland regions, these values are aggregated to the State level. Irrigated canola was assumed to have the same level of CTF as dryland at the agroecological region level, however because irrigated inventory data are sampled from fewer regions the results are different to the state dryland average.

Table 19 Proportion of cropping area where Controlled Traffic Farming is used in Australia (Umbers 2021)

State	% Controlled Traffic Farming
NSW	46
NSW irrigated	19
Vic.	34
Qld.	50
SA	18
SA irrigated	19
WA	29
Tas.	49

Without CTF, wheel traffic covers approximately 80-90% of the area cropped for conventional tillage, 60-65% of the area for minimum tillage and 45% of the area for no-tillage systems (Luhaib et al. 2017; Chan et al. 2006). This traffic causes subsurface soil compaction which has a detrimental effect on soil structure, nitrogen use efficiency, water infiltration and yield (Isbister et al. 2013; Hussein et al. 2021). The incidence of soil compaction and its detrimental effects have been observed consistently across of range of soil types in Australia from the heavy clay soils in Queensland through to sandy soils in Western Australia (Webb et al. 2004; Tullberg 2010; Ellis et al. 2011).

Compaction also increases the shear force required for operations where an implement is drawn through the soil. To ameliorate the detrimental effects of compaction, periodic deep ripping is required to break up compressed soil layers. CTF is an important tool for reducing compaction as it reduces the trafficked area to approximately 11-15% of the paddock depending on the lane width chosen (Condon and Condon 2016).

CTF results in a reduction in fuel use when compared to uncontrolled machinery traffic. This arises from three sources in a normal crop cycle:

1. Reduced draft (energy use) for operating implements that are drawn through the growing zone of the soil (ploughs, scarifies, planters, fertilisers)
2. Reduced rolling resistance for tractors, self-propelled sprayers and harvesters travelling over well compacted permanent tracks
3. Reduced overlap of operations e.g. spraying, planting, fertilising.

The reduction in fuel use for each of these sources has been estimated for a range of studies and summarised in Table 20.

Table 20 Reduction in fuel use with Controlled Traffic Farming from reduced draft, rolling resistance and overlap.

Source Contributing to Reduction in Fuel Use	Amount of Reduction in Fuel Use	Conditions	Reference
Combined	Up to 25%	WA sandy soils	Webb et al. 2004
Combined	About 25%	WA sandy soils	Blackwell et al. 2004
Combined	25%	WA sandy soils	Isbister et al. 2013
Combined	50%	Queensland clay	Tullberg 2000
Combined	18%	Northern China Plains for cultivation	Chen and Yang 2015
Combined	12%	Northern China Plains for planting wheat in No tillage system	Chen and Yang 2015
Reduced draft	36%	Conventional tillage	Tullberg 2000; Luhaib et al. 2017
Reduced draft	27%	Minimum tillage	Tullberg 2000; Luhaib et al. 2017
Reduced draft	19%	No tillage	Tullberg 2000; Luhaib et al. 2017
Reduced draft	77%	Conventional tillage	Tullberg et al. 2007; Luhaib et al. 2017
Reduced draft	59%	Minimum tillage	Tullberg et al. 2007; Luhaib et al. 2017
Reduced draft	40%	No tillage	Tullberg et al. 2007; Luhaib et al. 2017
Reduced draft + Reduced rolling resistance	46%	Planter used in No tillage system	Tullberg 2010
Reduced rolling resistance	33%	Harvester used in No tillage system	Tullberg 2010
Reduced rolling resistance	50%	Sprayer used in No tillage system	Tullberg 2010
Reduced rolling resistance	10%	WA sandy soils	Webb et al. 2004
Reduced overlap	10%		Isbister et al. 2013
Reduced overlap	5%		Webb et al. 2004

Reduced overlap	7-10%		Blackwell et al. 2004

When fuel reductions are estimated as components of the three sources of savings, the total saving appears to be over-estimated (about 82%) compared to observations of combined savings (25-50% for Australian conditions). To take a conservative approach, a value of 25% saving was applied to fuel use for all machinery operations until there are better estimates available for specific tillage systems. This saving can be applied to all machinery operation processes.

Appendix D Review Statements

1. Prof. Richard Eckard, University of Melbourne
2. Patrik Winkler, Lennart Herbers & Sarah Bossen, SGS Germany Knowledge Solutions

THE UNIVERSITY OF
MELBOURNE

Dr Maartje Sevenster
CSIRO Agriculture and Food
Canberra, ACT, 2601, Australia

9th May 2022

Re. Review: Greenhouse gas emissions from the cultivation of canola oilseed in Australia

I have reviewed the above report, which was "Prepared to meet the requirements of the European Commission Directive 2018/2001/EU of the European Parliament and of the Council (REDII) on the promotion of the use of energy from renewable sources" dated May 2022.

The report is clearly written and represents a comprehensive life cycle assessment. The emission factors used are consistent with the agreed method for Australia's reporting requirements for the United Nations Framework Convention on Climate Change, as reflected in the Australian National Greenhouse Gas Inventory 2019. In most cases this method uses Australian-specific Tier 2 emission factors, but in limited cases needs to revert to IPCC Tier 1 where the Australian inventory does not have its own Tier 2 factors. The on-farm emissions calculations are consistent with the NGGI 2019, apart from where the report clearly states e.g. the global warming potentials are based on REDII requirements.

The report covers all the major canola growing regions of Australia and the activity data appears comprehensive and align with my knowledge of the Australian canola industry. Assumptions on fertiliser use and tillage practices appear defensible and logical. The sensitivity analysis covered all the major aspects that I would have considered important. Some of the Scope 3 emissions used had to be sourced from additional publications and databases, all of which were cross-checked and found to be in line with other data sources. The LCA presented in the report covers all the pre-farm and on-farm aspects that would be expected and was developed by recognised experts in LCA.

I provided initial feedback to the authors on the first draft of the report, highlighting areas where assumptions, emission factors and calculations needed to be checked and further referenced. All emission factors used are correct and my editorial comments on the report have been accepted. Therefore, I would consider the calculations and assumptions in the final report now to be robust, transparent, and defensible.

I met with the team that conducted the study and compared their calculations with our Grains Greenhouse Accounting Framework (G-GAF version 10.6; 2022 revision https://piccc.org.au/resources/Tools). After adjusting for the differences between the method of calculation, both calculations were in agreement, giving me confidence that the results presented in this report are robust and align with the methodologies as stated.

In my view, the final report is now therefore a comprehensive and accurate representation of Australian canola production and associated life cycle greenhouse gas emissions.

Yours sincerely,

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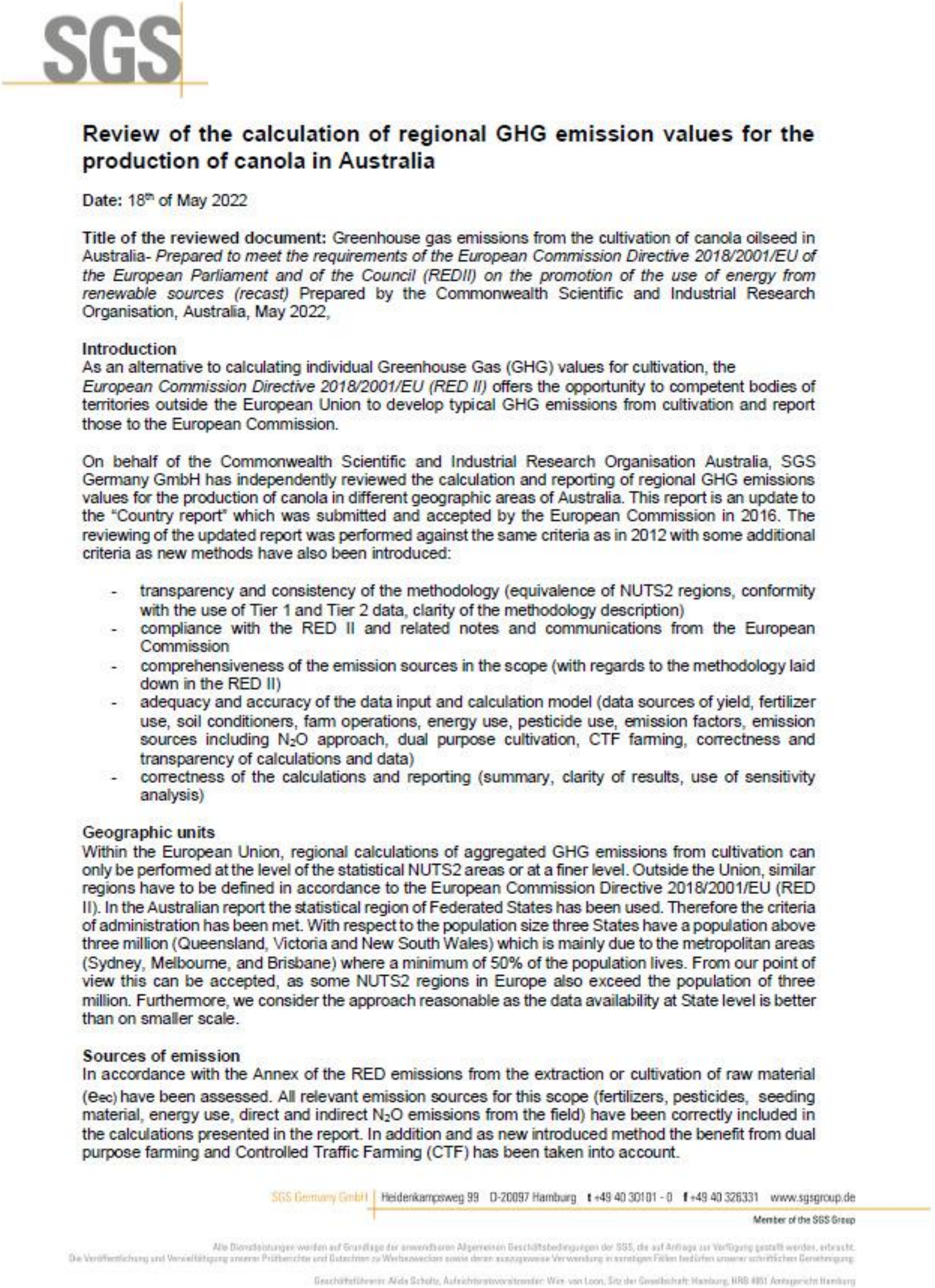

SGS

Review of the calculation of regional GHG emission values for the production of canola in Australia

Date: 18th of May 2022

Title of the reviewed document: Greenhouse gas emissions from the cultivation of canola oilseed in Australia- *Prepared to meet the requirements of the European Commission Directive 2018/2001/EU of the European Parliament and of the Council (REDII) on the promotion of the use of energy from renewable sources (recast)* Prepared by the Commonwealth Scientific and Industrial Research Organisation, Australia, May 2022,

Introduction

As an alternative to calculating individual Greenhouse Gas (GHG) values for cultivation, the *European Commission Directive 2018/2001/EU (RED II)* offers the opportunity to competent bodies of territories outside the European Union to develop typical GHG emissions from cultivation and report those to the European Commission.

On behalf of the Commonwealth Scientific and Industrial Research Organisation Australia, SGS Germany GmbH has independently reviewed the calculation and reporting of regional GHG emissions values for the production of canola in different geographic areas of Australia. This report is an update to the "Country report" which was submitted and accepted by the European Commission in 2016. The reviewing of the updated report was performed against the same criteria as in 2012 with some additional criteria as new methods have also been introduced:

- transparency and consistency of the methodology (equivalence of NUTS2 regions, conformity with the use of Tier 1 and Tier 2 data, clarity of the methodology description)
- compliance with the RED II and related notes and communications from the European Commission
- comprehensiveness of the emission sources in the scope (with regards to the methodology laid down in the RED II)
- adequacy and accuracy of the data input and calculation model (data sources of yield, fertilizer use, soil conditioners, farm operations, energy use, pesticide use, emission factors, emission sources including N_2O approach, dual purpose cultivation, CTF farming, correctness and transparency of calculations and data)
- correctness of the calculations and reporting (summary, clarity of results, use of sensitivity analysis)

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 the European Commission Directive 2018/2001/EU (RED II). In the Australian report the statistical region of Federated States has been used. Therefore the criteria of administration has been met. With respect to the population size three States have a population above three million (Queensland, Victoria and New South Wales) which is mainly due to the metropolitan areas (Sydney, Melbourne, and Brisbane) where a minimum of 50% of the population lives. From our point of view this can be accepted, as some NUTS2 regions in Europe also exceed the population of three million. Furthermore, we consider the approach reasonable as the data availability at State level is better than on smaller scale.

Sources of emission

In accordance with the Annex of the RED emissions from the extraction or cultivation of raw material (e_{ec}) have been assessed. All relevant emission sources for this scope (fertilizers, pesticides, seeding material, energy use, direct and indirect N_2O emissions from the field) have been correctly included in the calculations presented in the report. In addition and as new introduced method the benefit from dual purpose farming and Controlled Traffic Farming (CTF) has been taken into account.

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

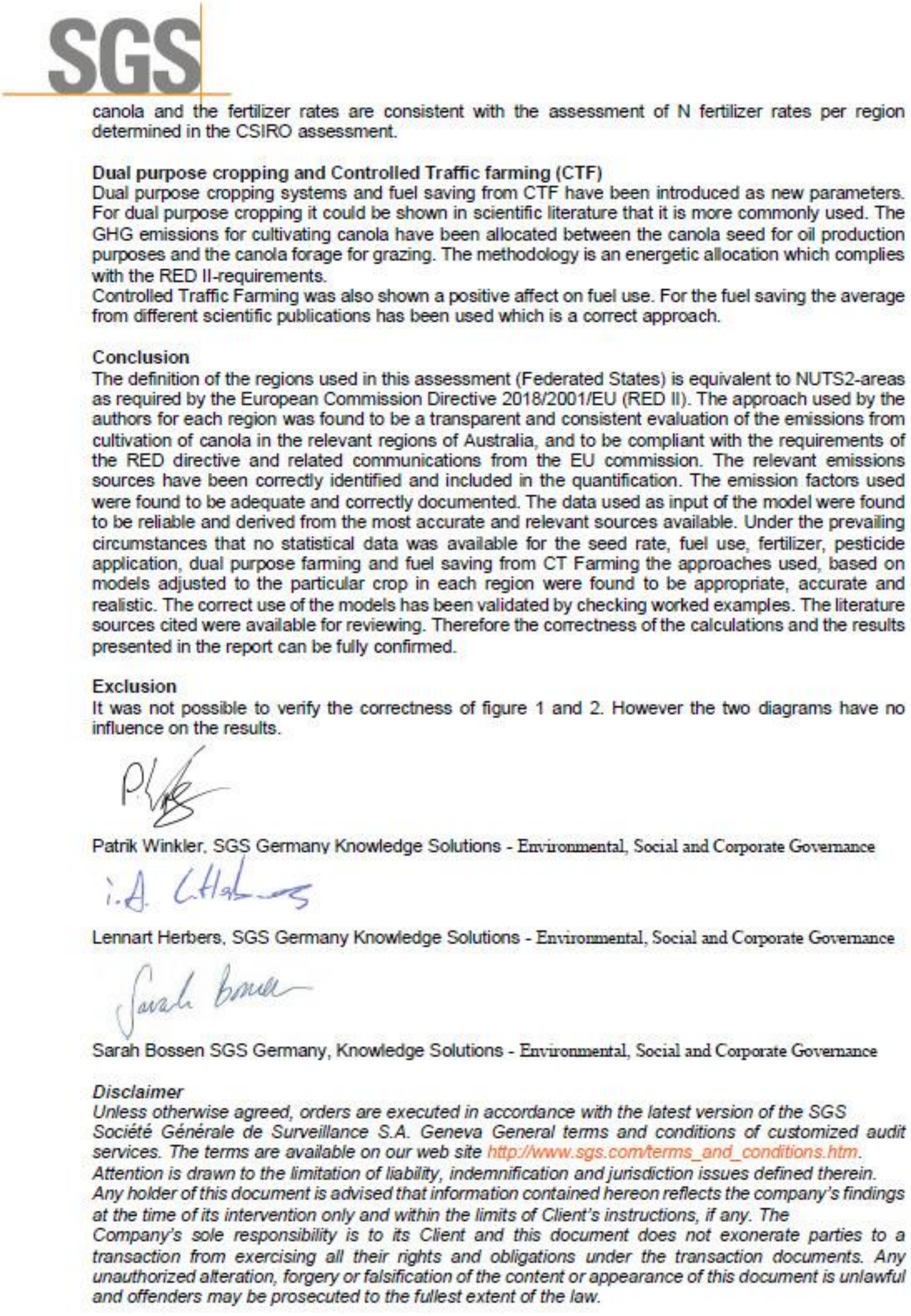
1. Official statistics from the Australian Bureau of Statistics, Department of the Environment and Australian Bureau of Meteorology:
   Data for dryland canola harvest yield, types of fertiliser, crop residue management, tillage practices, and climate data.
2. Customized data from the Australian Bureau of Statistics:
   Proportion of canola grown under dryland and irrigated system.
3. Publications from the State Departments of Agriculture/Primary Industries, as well as laboratory analysis and Industry Technical documents:
   Data for irrigated canola harvest yield, pesticide inputs, P requirements of crop, dry matter and protein content of canola grain, and transport distances.
4. Application of published scientific models and publications:
   Data for N requirement of the crop, lime inputs, seed rates, place of fertilizer manufacture, and fuel use by farm machinery as well as climate data for rainfall and evapotranspiration, area of dual purpose cropping, reduction of fuel use in CT farming
5. Industry or scientific expert opinion:
   Seeding rate for canola, place of fertiliser manufacture, application of nitrogen after grazing (dual purpose farming)
6. The National Inventory Report 2019. '(The Australian Government Submission to the United Nations Framework Convention on Climate Change. Australian National Greenhouse Accounts) was used to quantify the field emissions.

Overall assessment of data quality and transparency:
All data sources were available for reviewing. As main data source official statistics and Australian national publications have been used. Some of the data was customized by the respective authority but could be retraced correctly. Therefore the quality of the data and transparency of the calculation in the report are very high.

Overall assessment of accuracy of calculations:
The methodology of the calculation and the calculation itself has been verified. They are consistent and in compliance with the requirements from the RED II and the respective communications of the European Commission. The result tables of the calculation could be correctly reproduced from the primary data of the GHG emissions presented in the report. In few minor cases verification of calculation was based on worked examples (pesticide use) or presentation of the results in the used calculation model (e.g. number of machinery operations, fuel use).

Assessment emissions factors:
The emission factors were correctly sourced from the recognized LCA database Ecoinvent (version 3.8). For fertilizers transport emissions have been added considering the geographical origin of the fertilizers. The data source and the correct calculation of these transport emissions have also been successfully verified.

On-field N_2O-emissions:
Direct and indirect field emissions of N_2O from nitrogen cycle have been included (including direct N_2O emissions from fertilizer use, decomposition of crop residues, burning of crop residues and indirect N_2O emissions from leaching and volatilization). Mainly Tier 2 of the IPCC methodology has been used for this purpose. The calculations use the methodology from Australia's national GHG inventory (National Inventory Report 2019). For the calculation of the N_2O emissions from crop residue decomposition the new Tier 1 emission factor from IPCC 2019 is used. The justification for using this emission factor has been given and could be verified correctly. The methodology for calculation N_2O emissions is compliant with the RED II requirements. The calculation has been appropriately adjusted to the particular case of



canola and the fertilizer rates are consistent with the assessment of N fertilizer rates per region determined in the CSIRO assessment.

Dual purpose cropping and Controlled Traffic farming (CTF)
Dual purpose cropping systems and fuel saving from CTF have been introduced as new parameters. For dual purpose cropping it could be shown in scientific literature that it is more commonly used. The GHG emissions for cultivating canola have been allocated between the canola seed for oil production purposes and the canola forage for grazing. The methodology is an energetic allocation which complies with the RED II-requirements.
Controlled Traffic Farming was also shown a positive affect on fuel use. For the fuel saving the average from different scientific publications has been used which is a correct approach.

Conclusion
The definition of the regions used in this assessment (Federated States) is equivalent to NUTS2-areas as required by the European Commission Directive 2018/2001/EU (RED II). The approach used by the authors for each region was found to be a transparent and consistent evaluation of the emissions from cultivation of canola in the relevant regions of Australia, and to be compliant with the requirements of the RED directive and related communications from the EU commission. The relevant emissions sources have been correctly identified and included in the quantification. The emission factors used were found to be adequate and correctly documented. The data used as input of the model were found to be reliable and derived from the most accurate and relevant sources available. Under the prevailing circumstances that no statistical data was available for the seed rate, fuel use, fertilizer, pesticide application, dual purpose farming and fuel saving from CT Farming the approaches used, based on models adjusted to the particular crop in each region were found to be appropriate, accurate and realistic. The correct use of the models has been validated by checking worked examples. The literature sources cited were available for reviewing. Therefore the correctness of the calculations and the results presented in the report can be fully confirmed.

Exclusion
It was not possible to verify the correctness of figure 1 and 2. However the two diagrams have no influence on the results.

Patrik Winkler, SGS Germany Knowledge Solutions - Environmental, Social and Corporate Governance

i.A.

Lennart Herbers, SGS Germany Knowledge Solutions - Environmental, Social and Corporate Governance

Sarah Bossen SGS Germany, Knowledge Solutions - Environmental, Social and Corporate Governance

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NSW southern zone east Canola-After-Cereal

NSW Southern-west-budgets-Canola

NSW North-West-canola-2012

NSW North-East-canola-2012

NSW dryland-central-east-canola-short fallow

NSW dryland-central-west-canola

NSW Canola Irrigated Murray Valley 2012

NSW Canola Irrigated Murrumbidgee Valley 2012

NSW Flood Irrigated Conventional OP Canola 2012

NSW southern zone east Canola-After-Cereal

NSW Southern-west-budgets-Canola

NSW North-West-canola-2012

NSW North-East-canola-2012

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