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Greenhouse gas emissions from the cultivation of canola oilseed in Australia

Prepared to meet the requirements of the European Commission Directive 2009/28/EC on the promotion of the use of energy from renewable sources (Renewable Energy Directive – RED) and its amending Directive (EU) 2015/1513 of the European Parliament and of the Council

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Executive Summary

Australia is a major supplier of canola[1] into the European Union biodiesel market, with over 1.7 million tonnes exported annually to European countries. The European Commission's Renewable Energy Directive (RED) sets a mandated target of 35% greenhouse gas (GHG) savings, compared to fossil fuels, for biofuels entering the EU transportation fuel market. In January 2018, this target will increase to 50% for biofuel installations in operation at 5 October 2015. For installations commissioned since this date, the savings target is now 60%.

Currently, an international total default value of 38% savings in GHG emissions applies to canola, relative to emissions from the use of mineral diesel, and this has allowed Australian canola to enter the European Union (EU) biodiesel market without the need to verify GHG emissions. However, there is now a need to independently verify emissions associated with canola production, 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 grain importers 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.

Estimates of GHG emissions were undertaken at the State level as these regions within Australia are the most similar to NUTS2 regions in Europe. At a national level, GHG emissions associated with canola cultivation were 0.468 tonne CO_2-eq/tonne canola seed harvested. When converted to a dry matter (DM) basis, by adjusting for moisture content, the emissions were 0.497 tonne CO_2-eq/tonne canola seed DM. GHG emissions on a State basis ranged from 0.439 to 0.967 tonne CO_2-eq/tonne canola seed DM (expressed as tonne CO_2-eq per tonne of harvested grain at the farm-gate on a dry matter basis).

The greatest emissions from canola cultivation came from the manufacture of fertiliser, followed by N_2O from crop residues and CO_2 from fuel use, with direct + indirect N_2O emissions from soil also making a significant contribution. Variation in GHG emissions between the States was largely driven by climate variables such as rainfall and evapotranspiration, while high rainfall and irrigated systems, although having higher crop yields, had higher emissions largely associated with greater nitrogen inputs and N_2O emissions.

This report and the emissions calculations have been reviewed by three independent organisations – University of Melbourne (Australia), SGS Germany GmbH (Germany) and

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

Deutsches Blomasseforschungszentrum DBFZ (Germany). The final report incorporates the review feedback as an Appendix.

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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
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
P	Phosphorus
pH	Measure of soil acidity
RED	Renewable Energy Directive
UNFCCC	United Nations Framework Convention on Climate Change

1 Introduction

The European Commission's Renewable Energy Directive (RED) 2009/28/EC sets a mandated target of 20% final energy consumption from renewable sources by 2020 (European Commission 2009). Each EU country has committed to a National Renewable Energy Action Plan so that the overall pooled target reaches 20%. Individual country targets range from 10% in Malta to 49% in Sweden (European Commission 2015b). These plans include sectoral targets for electricity, heating and cooling, and transport. The RED requires that each country has at least 10% of their transport fuels originating from renewable sources by 2020.

On October 5, 2015, the Directive (EU) 2015/1513 amending the Directive 2009/28/EC entered into force (European Commission 2015a). The new Directive, among other things, introduced a 7% cap for biofuels produced from food and feed crops.

Currently greenhouse gas (GHG) emissions savings for biofuels need to be a minimum of 35% compared to fossil fuels, for fuel delivered at the bowser from an existing biofuel installation. In January 2018, this target will increase to 50% for these existing biofuel installations. For new installations commissioned post-5 October 2015, a higher target of 60% emissions saving is required from the date that they become operational.

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 38% savings in greenhouse gas emissions applies to canola biodiesel relative to emissions from the use of mineral diesel, which has allowed Australian canola to enter the EU biodiesel market without the need to verify GHG emissions. European Member States have produced "EU Country Reports" detailing the emissions associated with the agricultural production phase of biofuel feedstocks, including canola (European Commission 2016). This information accompanies the grain along the supply chain, enabling biofuel suppliers to demonstrate the required GHG savings at the point of sale to the consumer. For Australia to continue to export canola for biofuel in Europe, an equivalent report is required that provides a measure of GHG emissions for the cultivation phase of the grain.

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.

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

There is provision for non-EU countries to submit similar country reports (Directive 2009/28 EC and its amendment). 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 cultivation of canola (to the farm gate), for submission to the European Commission (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 <2 tonne/ha; Figure 2) compared to canola from other countries (Agriculture and Horticulture Development Board 2013; Ahlgren *et al.* 2011; Elsgaard 2010), as the majority of Australian canola is grown under low rainfall dryland conditions. Canola is normally grown in rotation with cereal and legume crops. Also a pasture phase of two to three years is common in cropping rotations in some parts of Australia. 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 (usually a cereal or legume). 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 2.95 million tonne/year over the period 2012 to 2015 (Australian Bureau of Statistics 2016). Australia is a major supplier of canola into the EU biodiesel market, with over 1.70 million tonne exported annually to European countries (Table 1).

Table 1. Average annual canola exports from Australia to Europe from 2012 to 2015.

State	Canola exports to Europe (tonne)
New South Wales (NSW)	260 051
Victoria (Vic)	282 117
Queensland (Qld)	0
South Australia (SA)	259 210
Western Australia (WA)	900 102
Tasmania (Tas)	0
Total	1 701 480

Source: (Australian Bureau of Statistics 2016).

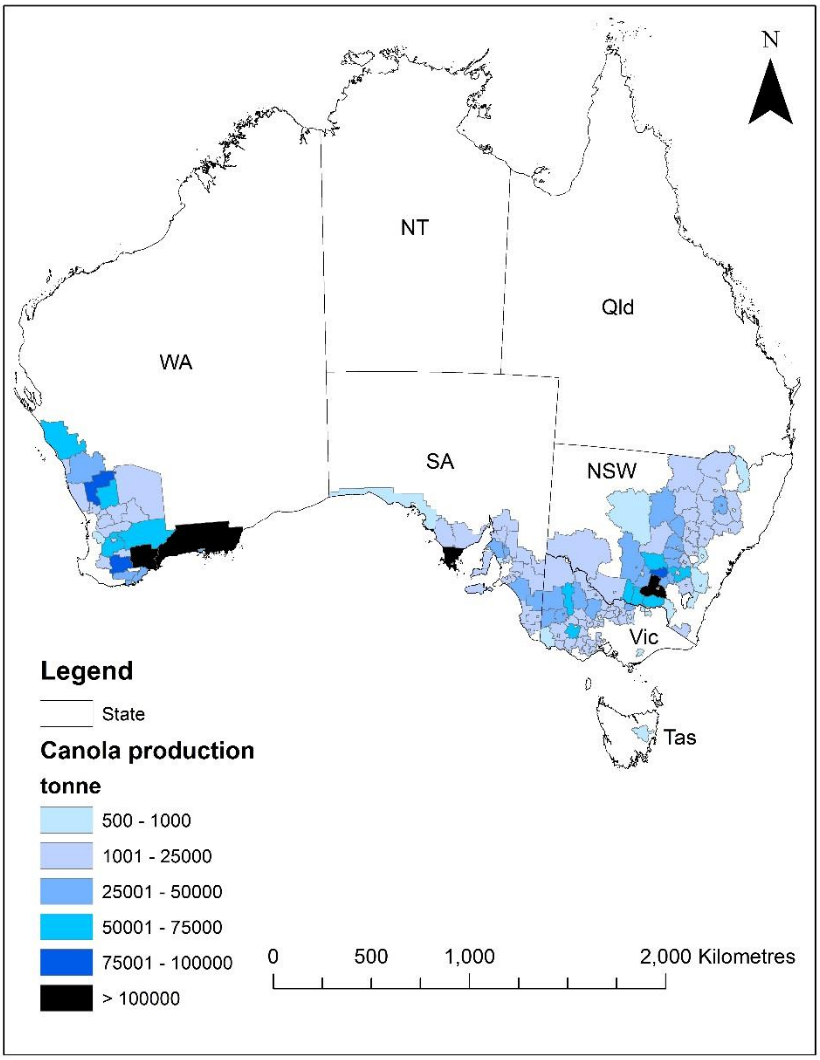

Figure 1. Average canola production quantities (2010/11-2013/14).

Source: (Australian Bureau of Statistics 2016)

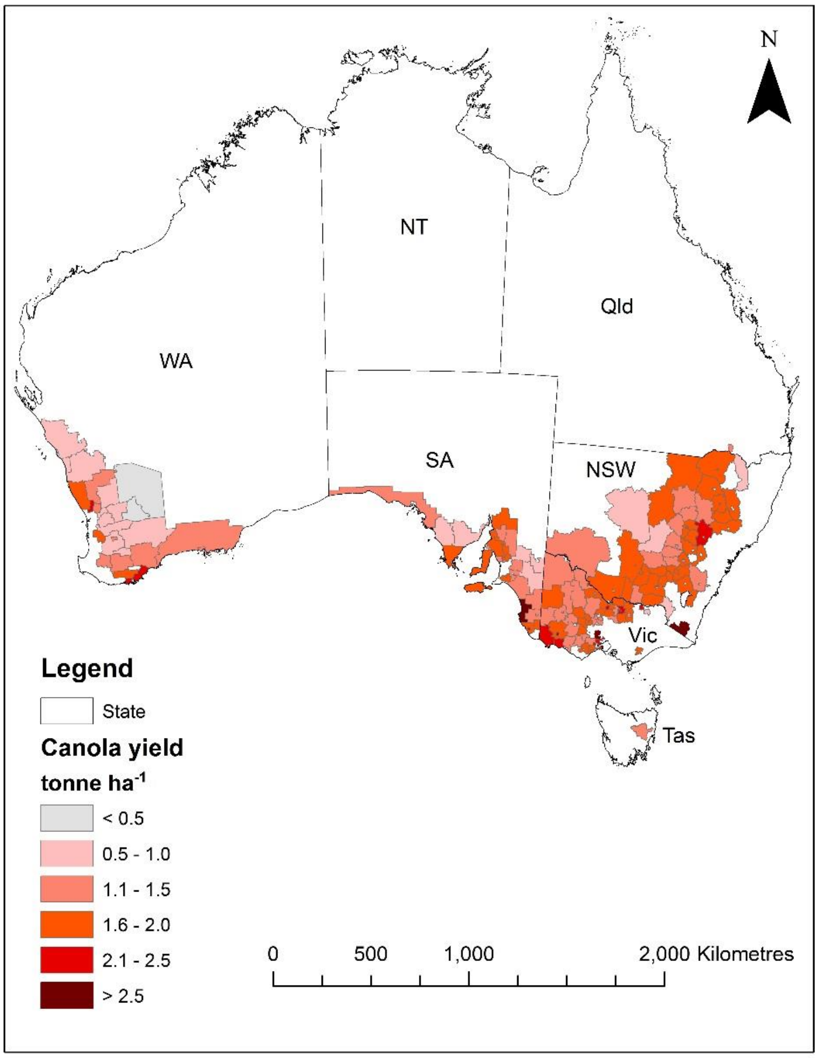

Figure 2. Average canola yield (2010/11-2013/14).

Source: (Australian Bureau of Statistics 2016)

2 Methodology

2.1 “NUTS2 equivalent” regions in Australia

The RED (European Commission 2009) 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 (Article 19 Paragraph 2).

According to Communication 2010/C 160/02 (Annex II), (European Commission 2010) these regional GHG emissions averages shall be calculated for “smaller geographical areas than those used in the calculation of the default values”. “Within the EU, the averages should be for NUTS2 areas or for a more fine-grained level”. Further, Communication 2010/C/160/02 states that for countries outside the EU, a similar level as the NUTS 2 level is appropriate for calculating averages.

The Directive 2015/1513 (European Commission 2015a) states that, in case of territories outside the Union, reports on cultivation emissions equivalent to the ones of EU Member States may be reported to the Commission after being drawn up by competent bodies.

In consideration of the above-mentioned requirement, the first step is to define equivalent NUTS2 regions for 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 2016). 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 23% of the New South Wales population living in Sydney, 28% of the Victorian population living in Melbourne, and 18% of the Queensland population living in Brisbane (Australian Bureau of Statistics 2015). 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.

State	Population (million)
New South Wales	7.62
Victoria	5.94
Queensland	4.78
South Australia	1.70
Western Australia	2.59
Tasmania	0.52

Source: (Australian Bureau of Statistics 2015).

2.2 System Boundary for the GHG calculations

Communication 2010/C 160/02 (Annex II) specifies that the GHG cultivation emissions estimated at a regional level should take into account soil characteristics, climate and expected raw material yields. The Communication also specifies that typical emissions from cultivation include seeds, fuel, fertiliser, pesticide, yield, and N_2O emissions from the field (European Commission 2010).

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 Directive 2009/28/EC, Annex V, Point C (European Commission 2009) 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

The EC communication on the practical implementation of the EU biofuels and bioliquids sustainability scheme (European Commission 2010) states that:

> *For the calculation of emissions from 'cultivation', the method allows for the use of averages (for a particular geographical area) as an alternative to actual values.*

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, 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 (Australian Bureau of Statistics 2016) for dryland production from 2010/11 to 2014/15 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 2013)
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 (Nick Drew, Fertilizer Australia, pers. comm.) and Centre for International Development (Center for International Development 2012)
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 2010/11 to 2014/15
Crop residue management	National data for broad-acre cropping land in Australia (Department of the Environment 2015b)
Tillage practices	National survey data for broad-acre cropping land in Australia (Australian Bureau of Statistics 2013).
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/)
Pesticide quantity	Various State Government Agriculture Department publications on pest control in canola
Fuel use	Australian-based fuel calculator (Salam *et al.* 2010)
Seeding rates	Seed calculator (Department of Agriculture and Food WA 2015) based on a 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 to determine rainfall and ET: rainfall was sourced from the Australian Bureau of Meteorology climate Data Services (http://www.bom.gov.au/climate/data-services).

A consistent approach was applied across each of the States. Data sources and methods applied are publically available for verification. The results are representative for the five year period from 2010/11 to 2014/15 and are expressed in tonne of CO_2-eq per tonne of canola seed on both wet and dry matter basis.

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_4:23 and N_2O:296, as specified in the RED.

GHG emissions factors (EF) for production of farm inputs such as fertiliser, lime and pesticides were sourced from ecoinvent 3.2 (Weidema *et al.* 2013), an international peer-reviewed database having a global geographic scope, and specified in the "List of Additional Standard Values" for BioGrace (BioGrace 2011), the calculation tool for biofuels approved by the EC. 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 came from ecoinvent 3.2.

On-farm emissions for direct and indirect N_2O from the use of nitrogen fertilisers and management of crop residues were estimated using IPCC Tier 2 approach for Australia, the official approved method for Australia's reporting requirements for the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (Department of the Environment 2015a). A detailed summary of EFs and their sources can be found in Table 4 and in Appendix A. In ecoinvent 3.2, fertiliser inventory is expressed on the basis of kg of N or P_2O_5 delivered by the fertiliser, rather than the weight of the fertiliser. EFs for fertiliser were recalculated per kg of fertiliser based on the proportion of each nutrient in the fertiliser, i.e. for multi-nutrient fertiliser, the ecoinvent 3.2 EFs for each nutrient were combined to give the total EF of producing the complete fertiliser product.

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 accounted for by adding the impacts of 3.6 kg of canola seed production from that State.	NSW Dryland 0.471 kg CO_2-eq/kg seed NSW Irrigated 0.890 kg CO_2-eq/kg seed Victoria Dryland 0.442 kg CO_2-eq/kg seed Victoria Irrigated 0.868 kg CO_2-eq/kg seed Queensland 0.737 kg CO_2-eq/kg seed South Australia 0.412 kg CO_2-eq/kg seed Western Australia 0.479 kg CO_2-eq/kg seed Tasmania 0.909 kg CO_2-eq/kg seed
Urea (kg)	ecoinvent 3.2: Urea, as N[GLO| market for | Alloc Def, An additional step to take out the international transport element of this process was undertaken as international transport to Australia was specifically calculated.	ecoinvent 3.2 EF = 3.1627 kg CO_2-eq/kg N Proportion N in urea = 0.46 Urea EF = 3.1627*0.46 = 1.455 kg CO_2-eq/kg urea

Mono ammonium phosphate (MAP) (kg)	ecoinvent 3.2: Nitrogen fertiliser, as N RER| monoammonium phosphate production | Alloc Def, U ecoinvent 3.2: Phosphate fertiliser, as P_2O_5 RER| monoammonium phosphate production | Alloc Def, U This process does not include any international transport. International transport to Australia was specifically calculated.	ecoinvent 3.2 EF = 2.8665 kg CO_2-eq/kg N Proportion N in MAP= 0.110 ecoinvent 3.2 EF = 1.4605 kg CO_2-eq/kg P_2O_5 Proportion P_2O_5 in MAP= 0.52 MAP EF = (2.8665*0.11) + (1.4605*0.52) = 1.075 kg CO_2-eq/kg MAP
Urea ammonium nitrate (UAN) (kg)	ecoinvent 3.2: Nitrogen fertiliser, as N RoW| urea ammonium nitrate production | Alloc Def, U This process does not include any transport. International transport to Australia was specifically calculated.	ecoinvent 3.2 EF = 5.9511 kg CO_2-eq/kg N Proportion N in UAN = 0.32 UAN EF = 5.9511*0.32 = 1.904 kg CO_2-eq/kg UAN
Lime (kg)	ecoinvent 3.2: Limestone, crushed, for mill RoW| production | Alloc Def, U ecoinvent 3.2: Transport, freight, lorry >32 metric ton, EURO3 GLO| market for | Alloc Def, U	ecoinvent 3.2 EF = 0.0028801 kg CO_2-eq/kg ecoinvent 3.2 EF = 0.092665 kg CO_2-eq/tonne.km
Herbicide, insecticide and fungicide (kg of active ingredient)	ecoinvent 3.2: Glyphosate GLO| market for | Alloc Def, U As glyphosate made up the bulk of pesticide use and has a higher EF than generic pesticide inventory in ecoinvent 3.2, the more conservative value was used to cover all pesticides.	ecoinvent 3.2 EF = 11.15 kg CO_2-eq/kg
Fertiliser transport – sea (tonne.km)	ecoinvent 3.2: Transport, freight, sea, transoceanic ship GLO| market for | Alloc Def, U	ecoinvent 3.2 EF = 0.011338 kg CO_2-eq/tonne.km
Fertiliser transport – rail (tonne.km)	ecoinvent 3.2: Transport, freight train RoW| market for | Alloc Def, U	ecoinvent 3.2 EF = 0.04677 kg CO_2-eq/tonne.km
Fertiliser transport – road (tonne.km)	ecoinvent 3.2: Transport, freight, lorry >32 metric ton, EURO3 GLO| market for | Alloc Def, U	ecoinvent 3.2 EF = 0.092665 kg CO_2-eq/tonne.km
Diesel (l)	ecoinvent 3.2: Fertilising, by broadcaster RoW| processing | Alloc Def, U	ecoinvent 3.2 EF = 27.143 kg CO_2-eq/ha Diesel used = 5.29 kg/ha Density of diesel = 0.842 kg/l =27.143/(5.29/0.842) kg CO_2-eq/l of Diesel =4.32 kg CO_2-eq/l
N_2O from N fertiliser (Gg)	Australian National Inventory Report (Department of the Environment 2015b)	EF = 0.0005 (Gg N_2O-N/Gg N applied) for <600mm rainfall

		EF = 0.0085 (Gg N_2O-N/Gg N applied) for >600mm rainfall and irrigated crop
N_2O from crop residues (Gg)	Australian National Inventory Report (Department of the Environment 2015b)	EF = 0.01 (Gg N_2O-N/Gg N) IPCC default emission factor
Indirect N_2O from leaching (N fertiliser + crop residue) (Gg)	Australian National Inventory Report (Department of the Environment 2015b)	EF = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching
Indirect N_2O from atmospheric deposition (Gg)	Australian National Inventory Report (Department of the Environment 2015b)	EF = 0.0005 (Gg N_2O-N/Gg N applied) for <600mm rainfall 0.0085 (Gg N_2O-N/Gg N applied) for >600mm rainfall and irrigated crop
Burning of residues (Gg of each element)	Australian National Inventory Report (Department of the Environment 2015b)	EF (Gg element /Gg burnt) = (CH_4=0.0035; CO=0.078; NMVOC=0.0091; N_2O=0.0076; NO_x=0.21)

3 Input data and calculation model

3.1 Cultivated areas and yields at the State level (NUTS 2 equivalent)

Data sourced from the Australian Bureau of Statistics (Australian Bureau of Statistics 2016) were used to estimate a five year average yield (2010/11-2014/15) 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 Murray irrigation region in Victoria, and in Tasmania. The area of irrigation for this study was drawn from Australian Bureau of Statistics data from 2010/11 to 2014/15. 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 2.1% of total area of canola planted, for Victoria was 1.5% of total area of canola planted, and for Tasmania was 47.3% of the area planted. In the other States the area irrigated was < 0.3% and not considered material. The yield for irrigation systems in New South Wales and Victoria 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. Due to the small area of canola cultivation in Tasmania (average 871 ha from 2010/11 to 2014/15) 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 Victoria were calculated as a weighted average based on the respective areas planted in each system.

Table 5. Average production statistics for Australian canola seed for the five year period from 2010/11 to 2014/15 with yield adjusted to a dry matter basis.

State	Area planted (ha)	Production (tonne harvested)	Yield (tonne harvested/ha)	Dry Matter (%)	Yield (tonne DM/ha)
New South Wales (dryland)	705 564	1 019 231	1.445	94.4	1.364
New South Wales (irrigated)	15 453	46 360	3.000	94.4	2.832
Victoria (dryland)	455 695	639 399	1.403	94.2	1.322
Victoria (irrigated)	6 845	20 536	3.000	94.2	2.827
Queensland	1 398	1 156	0.827	94.4[a]	0.780
South Australia	289 696	386 117	1.333	94.2	1.255
Western Australia	1 209 966	1 345 694	1.112	94.1	1.046
Tasmania (irrigated)	871	1 413	1.622	94.2[a]	1.529

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

3.2 Seeding rate

Typical seeding rates (kg/ha) for canola were estimated from the equation below, using a seed calculator (Department of Agriculture and Food WA 2015) 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 Source Documents in Table 9 and for large size open pollinated seed under reasonable establishment conditions (Bucat and Seymour 2017). Seed input was accounted for by adding the impacts of 3.6 kg of canola seed production from that State. First the result for each State (in kg CO_2-eq/kg canola seed) was determined (without accounting for seed), this value was used as the EF for seed. The quantity of seed used for planting (3.6 kg/ha) was multiplied by the seed EF and the result added to give the overall GHG emissions for canola produced in each State.

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 regional estimation of N fertiliser use for canola (source documents listed in Table 9) and industry review (via the Project Steering Committee). 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, and stubble removal. A copy of the Generic Yield and Nitrogen Calculator can be obtained from the author at sandra.eady@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 in the soil (from crop residues, mineralisation, and fixation by a prior legume crop) are stable and that all of the fertiliser N required ends up either in the harvested product or is lost to the system (i.e. N in the soil organic matter pools on-farm are stable and the system is in a steady state).

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 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 2013). 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 6. The mix of fertiliser used for each State was calculated by first determining how much mono ammonium phosphate was needed to deliver 8kg 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 an approximate 57:43 mix of urea and urea ammonia nitrate. This gave a tailored fertiliser mix for each state as shown in Table 6.

Table 6. Main nitrogen fertiliser type used in each State for broad-acre cropping and the quantity of each fertiliser used in canola production.

State	Main type of N fertiliser	Quantity fertiliser applied (kg of product/ha/crop)		
		Mono ammonium phosphate (kg of product)	Urea (kg of product)	Urea ammonium nitrate (kg of product)
New South Wales (dryland)	urea, ammonium phosphates	51	127	0
New South Wales (irrigated)	urea, ammonium phosphates	106	404	0
Victoria (dryland)	urea, ammonium phosphates	49	122	0
Victoria (irrigated)	urea, ammonium phosphates	106	396	0
Queensland	urea, ammonium phosphates	29	70	0
South Australia	urea, ammonium phosphates	47	111	0
Western Australia	urea, ammonium phosphates, urea ammonium nitrate	39	54	58
Tasmania	urea, ammonium phosphates	57	213	0

Source: (Australian Bureau of Statistics 2013)

The place of manufacture of fertiliser (28% domestic and 72% imported) was based on fertiliser industry data from 2010 to 2015 (Nick Drew, Fertilizer Australia, pers. comm.). The source country for imported fertilisers was established using data from the Centre for International Development for 2012 (Center for International Development 2012), identifying countries where fertiliser imports to Australia typically originate from.

3.3.3 Greenhouse gas emissions associated with fertilizer production

Emissions factors assumed for the production of different fertilisers (Table 4) and their transport were sourced from ecoinvent 3.2 (Weidema *et al.* 2013). The assumed nutrient content for N and P in each fertiliser is that specified in ecoinvent (46% N in urea; 11% N in MAP and 22.7% P in MAP; and 32% N in UAN on w/w basis) and this is consistent with data for Australian fertilisers published by suppliers (Impact Fertilisers 2016a, 2016b; Incitec Pivot Fertilisers 2016). 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 7. Fertiliser EF factors plus the transport contribution to an overall EF for fertiliser delivered to the agricultural field are given in Table 8.

Table 7. Distance assumed for domestic and international transport of fertiliser to the agricultural field.

State	Transport Mode	Transport Distance Domestic Fertiliser (km)	Transport Distance for Imported Fertiliser (km) (with the percentage share imported from each country)					
			Qatar (39%)	Saudi Arabia (22%)	Indonesia (13%)	China (11%)	Kuwait (6%)	Russia (9%)
New South Wales (dryland and irrigated)	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 (dryland and irrigated)	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
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 8. 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 (dryland and irrigated)	1.075	1.455	1.904	0.038	0.194
Victoria (dryland and irrigated)	1.075	1.455	1.904	0.025	0.177
Queensland	1.075	1.455	1.904	0.028	0.180
South Australia	1.075	1.455	1.904	0.012	0.162
Western Australia	1.075	1.455	1.904	0.019	0.141
Tasmania	1.075	1.455	1.904	0.013	0.169

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 9). As the majority of pesticide use was glyphosate for fallow weed control, the ecoinvent 3.2 EF adopted for all pesticides was the value for glyphosate (11.15 kg CO_2-eq/kg active ingredient) rather than the emissions factor for generic pesticide (11.05 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 10. 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 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 9. Quantity of pesticide applied to canola crop from pre-planting to post-harvest.

State	Quantity of pesticide active ingredient applied to canola crop from pre-planting to post-harvest (kg a. i./ha/year)	Source Documents
New South Wales (dryland)	2.80	www.dpi.nsw.gov.au/agriculture/farm-business/budgets/winter-crops 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	www.dpi.nsw.gov.au/agriculture/farm-business/budgets/winter-crops NSW irrigated Murray-valley-budgets-Canola NSW irrigated Murrumbidgee-winter-budgets-Canola NSW irrigated-central-conventional OP-Canola
Victoria (dryland)	2.32	www.dpi.nsw.gov.au/agriculture/farm-business/budgets/winter-crops 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 https://grdc.com.au/Resources/Publications/2015/02/2015-Farm-Gross-Margin-Guide SA 2015 Gross Margin Guide pdf
Victoria (irrigated)	1.37	www.dpi.nsw.gov.au/agriculture/farm-business/budgets/winter-crops NSW irrigated Murray-valley-budgets-Canola NSW irrigated Murrumbidgee-winter-budgets-Canola NSW irrigated-central-conventional OP-Canola VIC irrigated, Northern VIC - Canola
Queensland	0.39	https://publications.qld.gov.au/dataset/agbiz-tools-plants-field-crops-and-pastures QLD Canola-Dryland-GM
South Australia	1.51	https://grdc.com.au/Resources/Publications/2015/02/2015-Farm-Gross-Margin-Guide SA 2015 Gross Margin Guide
Western Australia	2.96	Farm Gross Margin documents prepared by Ross Kingwell, WA Department of Agriculture (pers. comm.) WA Gross Margin by region Ross Kingwell-2014
Tasmania	1.68	www.dpipwe.tas.gov.au/Documents/Crop-GMs-Meander-Valley.xls TAS Crop GMs Meander Valley – Canola Irrigated

Table 10. Sample calculation of pesticide quantity used in canola production for Tasmania.

Pesticide Name (active ingredient)	Pesticide product applied (kg/ha)	% active ingredient in product	Active ingredient applied (kg/ha)
RoundupCT® (Glyphosate) (http://www.sinochem.com.au/product/roundup-ct/)	2.0	45%	0.9
Stomp 440® (Pendimethalin) (http://www.herbiguide.com.au/Labels/PEN33_61322-1209.PDF)	1.3	44%	0.572
Verdict® (Haloxyfop) ((http://www.herbiguide.com.au/Labels/HAL520_50643-0714.PDF))	0.08	52%	0.0416
Mesurol®(Methiocarb) adopted for Metarex® (Metaldehyde) (http://www.bayercropscience.com.au/resources/uploads/label/file7267.pdf)	5.5	2%	0.11
Astound® (Alpha-cypermethrin) (http://www.nufarm.com/assets/23088/1/ASTOUND_DUO_label_191012.pdf)	0.26	10%	0.026
Onduty® (Imazapyr+Imazapic) (http://www.herbiguide.com.au/Labels/IMAIMAP_58868-0710.PDF)	0.04	70%	0.028
		Total	**1.68**

3.5 Field operations

Cultivation practices are largely no or low-till for dryland farming in Australia. Table 11 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 2013). 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 11. 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%	16%	17%
Victoria (dryland and irrigated)	78%	11%	11%
Queensland	50%	17%	33%
South Australia	77%	18%	5%
Western Australia	89%	10%	1%
Tasmania	16%	15%	69%

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 9). 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 12), 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 (4.32 kg CO_2-eq/l) for the production and use of diesel fuel was sourced from ecoinvent 3.2.

Table 12. Summary of machinery operations and total fuel per hectare for canola production.

State	Machinery operations (number of passes/ha/year)						Fuel use (l/ha/crop)
	Cultivation	Planting	Application of pesticides[a]	Application of fertiliser	Application of lime	Harvesting & windrowing	
New South Wales (dryland)	0.5	1	5.7	0.9	0.25	2	24.9
New South Wales (irrigated)	3.0	1	4.0	1.3	0.25	2	63.0
Victoria (dryland)	0.4	1	5.8	0.8	0.25	2	23.8
Victoria (irrigated)	2.8	1	4.0	1.5	0.25	2	59.7
Queensland	3.0	1	1.0	1.0	0.25	2	63.4
South Australia	0.5	1	5.7	0.7	0.25	2	23.2
Western Australia	0.1	1	3.9	1.0	0.25	2	19.2
Tasmania	2.0	1	6.0	2.0	0.25	2	48.8

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

3.6 Quantity of soil conditioners (lime and gypsum) applied

As lime is the predominant soil conditioner used, and it has a similar GHG emissions factor to gypsum, 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 13.

Table 13. 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 (kgN/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 kg/ha)	Lime required to give NAAR = 0 (lime kg/ha)
New South Wales (dryland)	MAP	5.4	5.60	30.2				
	Urea/UAN	1.8	58.33	105.0				
	Total		**63.93**	**135.2**	**-14.5**	**1.445**	**-21.0**	**114**
New South Wales (irrigated)	MAP	5.4	11.63	62.8				
	Urea/UAN	1.8	185.72	334.3				
	Total		**197.35**	**397.1**	**-14.5**	**3.000**	**-43.5**	**354**
Victoria (dryland)	MAP	5.4	5.44	29.4				
	Urea/UAN	1.8	56.09	101.0				
	Total		**61.53**	**130.3**	**-14.5**	**1.403**	**-20.4**	**110**
Victoria (irrigated)	MAP	5.4	11.63	62.8				
	Urea/UAN	1.8	182.03	327.7				
	Total		**193.66**	**390.5**	**-14.5**	**3.000**	**-43.5**	**347**
Queensland	MAP	5.4	3.20	17.3				
	Urea/UAN	1.8	32.12	57.8				
	Total		**35.32**	**75.1**	**-14.5**	**0.827**	**-12.0**	**63**
South Australia	MAP	5.4	5.17	27.9				
	Urea/UAN	1.8	50.90	91.6				
	Total		**56.06**	**119.5**	**-14.5**	**1.333**	**-19.3**	**100**
Western Australia	MAP	5.4	4.31	23.3				
	Urea/UAN	1.8s	43.44	39.1				
	Total		**47.75**	**101.5**	**-14.5**	**1.112**	**-16.1**	**85**
Tasmania	MAP	5.4	6.29	34.0				
	Urea/UAN	1.8	98.07	176.5				
	Total		**104.36**	**210.5**	**-14.5**	**1.622**	**-23.5**	**187**

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. However, the modelled results were consistent with the limited amount of direct data available from a survey undertaken in 2011/12 on general use of lime in agriculture for cropping and pastures (Australian Bureau of Statistics 2013).

All soil conditioners are produced domestically with an average State domestic transport distance of 240 km, based on the transport distances for each State given in Table 7.

3.7 Greenhouse gas emissions from cultivation

For N_2O emissions calculations, the EC suggests the use of IPCC Methodology (Communication 2010/C 160/02, Annex II) and specifies that all three IPCC tiers can be used. In addition, the IPCC guidelines on estimating N_2O emissions (Inter-Governmental Panel on Climate Change 2006) 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, decomposition of crop residues, management of crop residues and indirect N_2O emissions from leaching and volatilisation. A full description of the methods has been published by the Australian Department of the Environment (Department of the Environment 2015a, 2015b) and accepted as a Tier 2 accounting method for Kyoto Protocol and UNFCCC GHG reporting. Hence, the estimation of on-farm GHG emissions for this study are based on the Tier 2 method employed by Australia for its national GHG accounts.

To apply Tier 2 methods additional detail is required on the way in which crop residues are managed, the proportion of cropland subject to leaching (evapo-transpiration: rainfall ratio <0.8 and > 1) and where annual rainfall is < or > 600mm/year (Table 14). Climate data was sourced from Bureau of Meteorology Climate Data Services (http://www.bom.gov.au/climate/data-services).

Table 14. Details on crop residue management for canola regions in Australia and the proportion of the land area subject to leaching and in different rainfall zones.

State	Crop residue management[1]		% area of cropland subject to leaching	% area in <600mm/year rainfall zone
	Fraction of area where above ground residue is burnt[2]	Fraction of area where above ground residue is removed		
New South Wales (dryland and irrigated)	0.22	0.05	0.82	79.8
Victoria (dryland and irrigated)	0.21	0.07	3.55	91.3
Queensland	0.06	0.04	0.56	60.9
South Australia	0.12	0.09	0.46	98.6
Western Australia	0.06	0.11	0.26	98.4
Tasmania	0.09	0.16	49.15	39.2

[1] Source: (Department of the Environment 2015b).

[2] For control of herbicide resistant weed seedbanks. Source: (Australian Bureau of Statistics 2013).

3.7.1 Application of nitrogen fertilisers

Annual nitrous oxide (N_2O) production from the addition of synthetic fertilisers is calculated as (Department of the Environment 2015b):

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

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 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

3.7.2 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 = 2.10)

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 14)

$FFOD_{ij}$ = fraction of the crop residue that is removed (See Table 14)

Annual 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 = 0.01 (Gg N_2O-N/Gg N) IPCC default emission factor

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 is <0.8 or >1 (which would occur under irrigation). The proportion of cropping regions in each State where leaching occurs is given in Table 14. Climate data to determine ET: rainfall was sourced from the Australian Bureau of Meteorology Climate Data Services (http://www.bom.gov.au/climate/data-services).

Annual nitrous oxide production from leaching and runoff is calculated for inorganic fertiliser N applied to soils and crop residue (Department of the Environment 2015b).

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 (ET: rainfall <0.8 and > 1)

FracLEACH = 0.3 (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 (ET: rainfall <0.8 and > 1)

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff.

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 (Department of the Environment 2015b):

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

Where:

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

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

$FracGASF_j$ = 0.1 (Gg N/Gg applied) IPCC (2006) 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 = 2.11)

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 14)

The mass of fuel burnt is converted to an emission of CH_4, CO or NMVOC 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) (CH_4=0.0035; CO=0.078; NMVOC=0.0091)

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

For N_2O and NO_x 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) (N_2O=0.0076; NO_x=0.21)

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 (Department of the Environment 2015b).

:

E_{ij} = ((M_{ij} x $FracLime_{ij}$ x $P_{j=1}$ x $EF_{j=1}$) + (M_{ij} x (1- $FracLime_{ij}$) x $P_{j=2}$ x $EF_{j=2}$)) x 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 carbon accumulation in soils resulting from management practices that have changed since 1 January 2008, such as no-till, improved crop rotations, increased use of cover crops, improved fertiliser or manure management, and use of compost. At this point in time, there is no strong peer-reviewed evidence that these practices, implemented within the time frame specified in the RED, have added soil carbon to broad-acre cropping soils in Australia (Sanderman 2010).

4 Results

The GHG emissions arising from the cultivation of canola are summarised in Table 15. At a national level, GHG emissions associated with canola cultivation were 0.468 tonne CO_2-eq/tonne canola seed harvested. When converted to a dry matter (DM) basis, by adjusting for moisture content, the emissions were 0.497 tonne CO_2-eq/tonne canola seed DM. GHG emissions on a State basis ranged from 0.439 to 0.967 tonne CO_2-eq/tonne canola seed DM (expressed as tonne CO_2-eq per tonne of harvested grain at the farm-gate on a dry matter basis). State values for New South Wales and Victoria reflect a weighted average for grain from dryland and irrigated systems, which are not segregated for export.

Table 15. Greenhouse gas emissions arising from the cultivation of canola in the States of Australia (tonne CO_2-eq/tonne canola seed on dry matter basis).

State	Soil N_2O		Crop residue	Manufacturing		Fuel use	Lime	Seed	Total
	Direct	Indirect		Fertiliser	Pesticide				
New South Wales (dryland)	*0.046*	*0.005*	*0.115*	*0.195*	*0.023*	*0.079*	*0.035*	*0.001*	*0.500*
New South Wales (irrigated)	*0.276*	*0.123*	*0.115*	*0.275*	*0.006*	*0.096*	*0.053*	*0.001*	*0.944*
New South Wales	0.051	0.008	0.115	0.197	0.023	0.079	0.036	0.001	0.509
Victoria (dryland)	*0.026*	*0.005*	*0.113*	*0.192*	*0.020*	*0.078*	*0.035*	*0.001*	*0.470*
Victoria (irrigated)	*0.271*	*0.121*	*0.113*	*0.268*	*0.005*	*0.091*	*0.052*	*0.001*	*0.922*
Victoria	0.030	0.007	0.113	0.193	0.019	0.078	0.035	0.001	0.476
Queensland	0.076	0.008	0.118	0.188	0.006	0.351	0.034	0.003	0.784
South Australia	0.013	0.002	0.113	0.184	0.013	0.080	0.034	0.001	0.439
Western Australia	0.013	0.002	0.112	0.237	0.032	0.079	0.034	0.002	0.511
Tasmania	0.270	0.121	0.107	0.265	0.012	0.138	0.052	0.002	0.967

Under the RED, results for GHG emissions for cultivation are reported as g CO_2 eq/MJ of fatty acid methyl ester (FAME). The results for Australian canola are presented in this format in Table 16, 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 16. Greenhouse gas emissions arising from the cultivation of canola in the States of Australia (g CO_2-eq/MJ FAME).

State	Soil N_2O		Crop residue	Manufacturing		Fuel use	Lime	Seed	Total
	Direct	Indirect		Fertiliser	Pesticide				
New South Wales (dryland)	*1.766*	*0.192*	*4.414*	*7.485*	*0.883*	*3.032*	*1.343*	*0.038*	*19*
New South Wales (irrigated)	*10.594*	*4.721*	*4.414*	*10.555*	*0.230*	*3.685*	*2.034*	*0.038*	*36*
New South Wales	1.958	0.307	4.414	7.561	0.883	3.032	1.382	0.038	**20**
Victoria (dryland)	*0.998*	*0.192*	*4.337*	*7.370*	*0.768*	*2.994*	*1.343*	*0.038*	*18*
Victoria (irrigated)	*10.402*	*4.644*	*4.337*	*10.287*	*0.192*	*3.493*	*1.996*	*0.038*	*35*
Victoria	1.151	0.269	4.337	7.408	0.729	2.994	1.343	0.038	**18**
Queensland	2.917	0.307	4.529	7.216	0.230	13.472	1.305	0.115	**30**
South Australia	0.499	0.077	4.337	7.062	0.499	3.071	1.305	0.038	**17**
Western Australia	0.499	0.077	4.299	9.097	1.228	3.032	1.305	0.077	**20**
Tasmania	10.363	4.644	4.107	10.171	0.461	5.297	1.996	0.077	**37**

5 Sensitivity analysis and discussion

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, drawing on publically available official statistics and publications. The calculations undertaken have followed RED requirements. However, a certain level of uncertainty is associated with the GHG calculations. 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 17. 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, 0.497 tonne CO_2-eq/tonne canola seed on DM basis, was assessed.

Table 17. 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% ($t\ CO_2$-eq/tonne DM)	National GHG emissions for -15% percent change	National GHG emissions for +15% ($t\ CO_2$-eq/tonne DM)	National GHG emissions for +15% percent change
Yield (t/ha)	0.515	3.6%	0.483	-2.8%
% moisture content	0.498	0.2%	0.496	-0.2%
% of area irrigated	0.496	-0.2%	0.498	0.2%
Fertiliser input (kg N/ha)	0.459	-7.6%	0.535	7.6%
% area crop residue burnt	0.497	0.0%	0.497	0.0%
% area minimum till	0.501	0.8%	0.493	-0.8%
% area subject to leaching	0.497	0.0%	0.497	0.0%
Fuel use (l/ha)	0.485	-2.4%	0.509	2.4%
Pesticide use (kg a.i./ha)	0.493	-0.8%	0.501	0.8%
Lime input (kg/t)	0.492	-1.0%	0.502	1.0%
EF direct N_2O	0.493	-0.8%	0.501	0.8%
EF indirect N_2O	0.492	-1.0%	0.503	1.2%
EF crop residues	0.482	-3.0%	0.512	3.0%
EF for fertiliser manufacture	0.468	-5.8%	0.526	5.8%

From this analysis it is clear that the most sensitive drivers of GHG emissions for canola production are N fertiliser input, emissions associated with manufacture of fertiliser, release of N_2O from decomposition of crop residues, and yield, as a ± 15% variation in these parameters changes the results by up to 0.076 tonne CO_2-eq/tonne DM. The assumptions adopted for fuel use and indirect N_2O emissions are next in importance, while variation in the assumed level of irrigation, stubble management practices, area subject to leaching, pesticide and lime use, and direct N_2O emissions have a minor impact on results.

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 two European organisations - DBFZ Deutsches Biomasseforschungszentrum and SGS Germany GmbH. A summary of the review findings is given in Appendix B.

7 Acknowledgements

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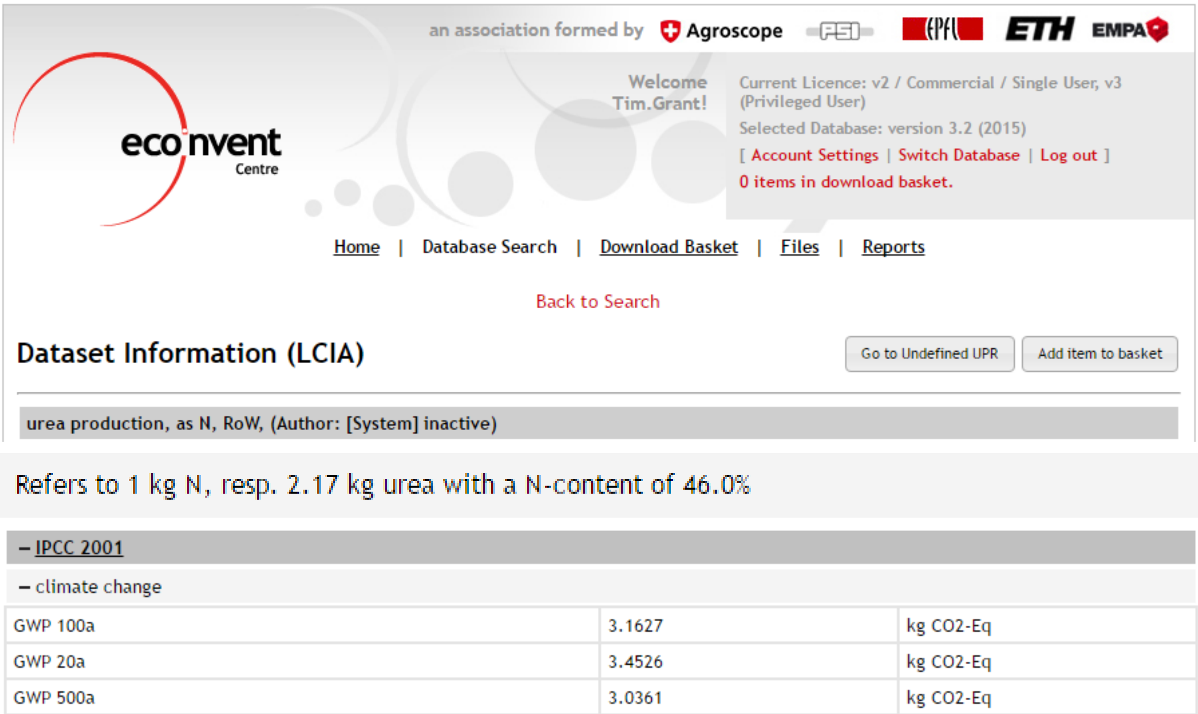
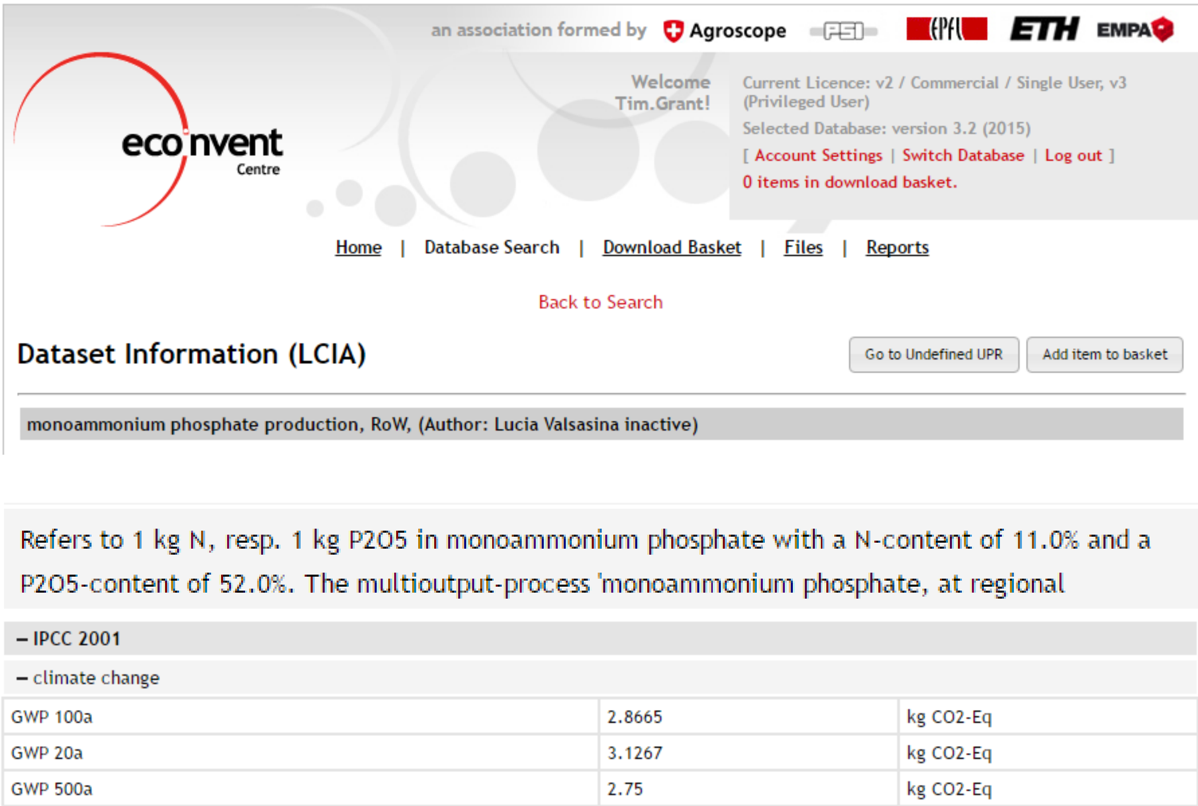
Appendix A – ecoinvent 3.2 inventory used for Emissions Factors

Input or activity	Activity name	Data source	IPCC 2001 GWP 100a
Urea	urea production, as N, RoW|urea, as N [kg]	https://v32.ecoquery.ecoinvent.org/Details/LCIA/38486728-1e47-48fd-8d09-84cbd5ff136c/06590a66-662a-4885-8494-ad0cf410f956	3.1627



Input or activity	Activity name	Data source	IPCC 2001 GWP 100a
Mono ammonium phosphate (MAP)	monoammonium phosphate production, RoW| nitrogen fertiliser, as N [kg]	https://v32.ecoquery.ecoinvent.org/Details/LCIA/3db7bdc5-9307-4c16-81dc-a6240e66523b/06590a66-662a-4885-8494-ad0cf410f956	2.8665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monoammonium phosphate production, RoW, (Author: Lucia Valsasina inactive)

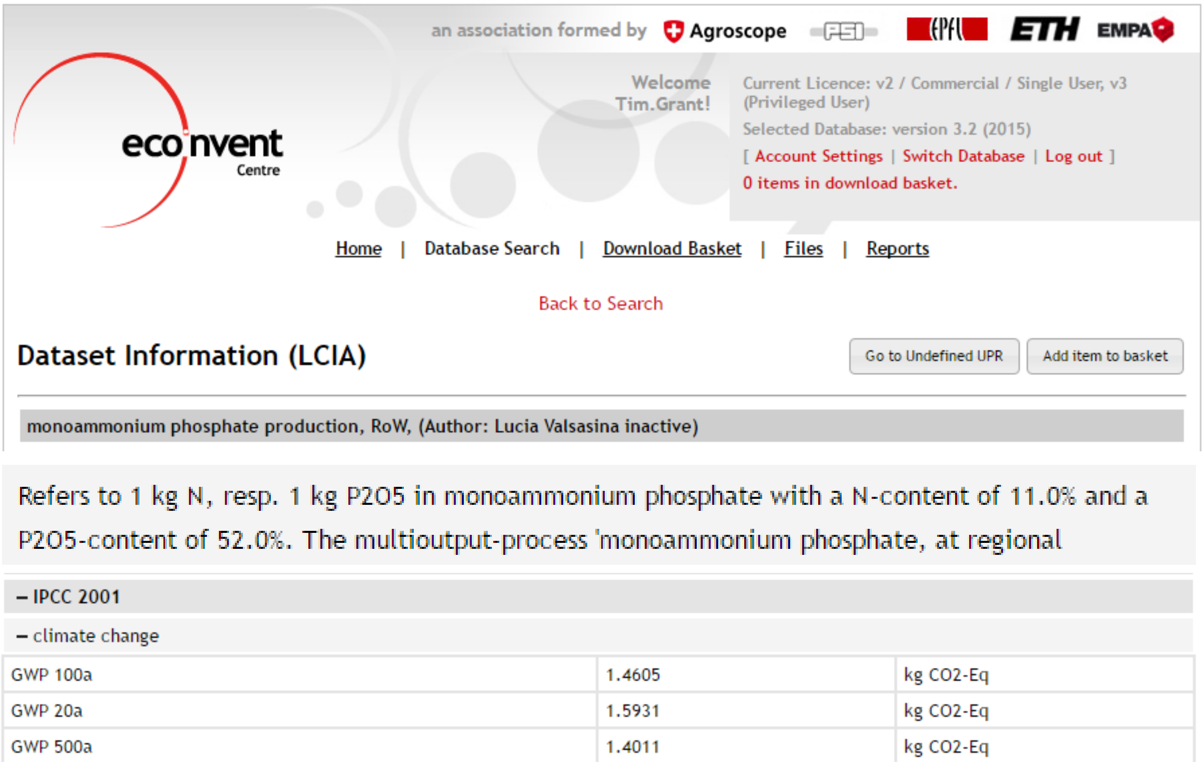
Refers to 1 kg N, resp. 1 kg P2O5 in monoammonium phosphate with a N-content of 11.0% and a P2O5-content of 52.0%. The multioutput-process 'monoammonium phosphate, at regional

– IPCC 2001

– climate change

GWP 100a	2.8665	kg CO2-Eq
GWP 20a	3.1267	kg CO2-Eq
GWP 500a	2.75	kg CO2-Eq

Mono ammonium phosphate (MAP)	monoammonium phosphate production, RoW| phosphate fertiliser, as P2O5 [kg]	https://v32.ecoquery.ecoinvent.org/Details/LCIA/a293d904-9c95-4dfc-b15e-70687486db7c/06590a66-662a-4885-8494-ad0cf410f956	1.4605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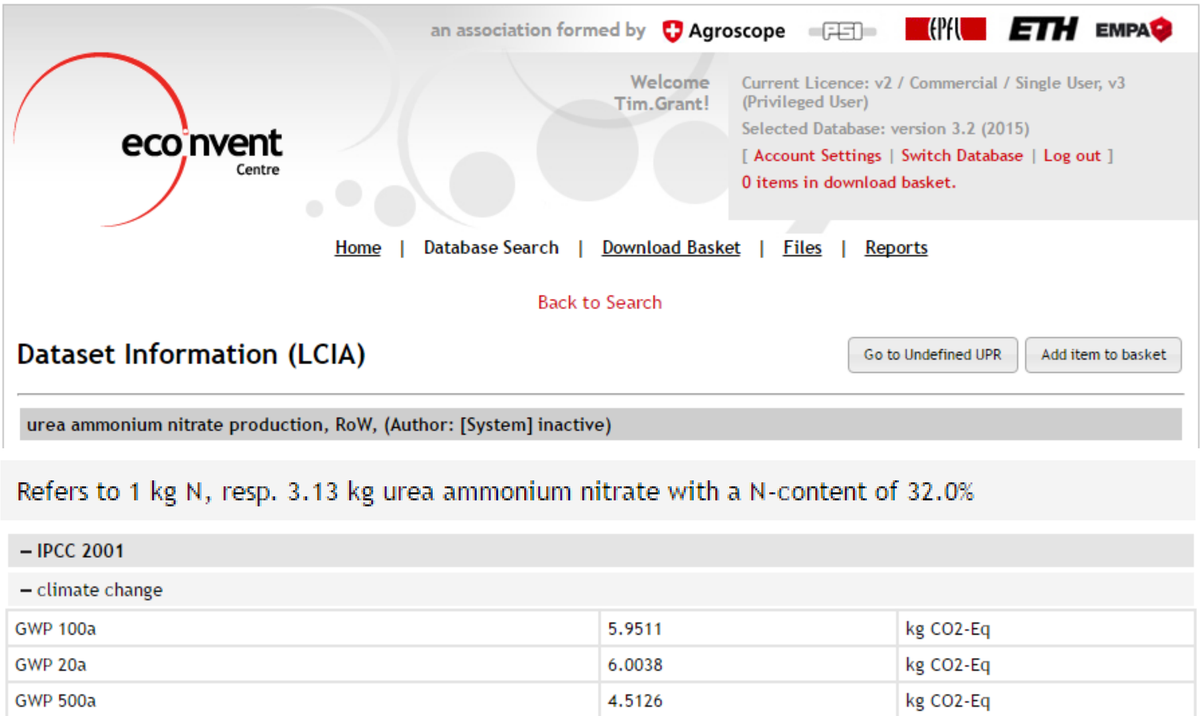
– IPCC 2001

– climate change

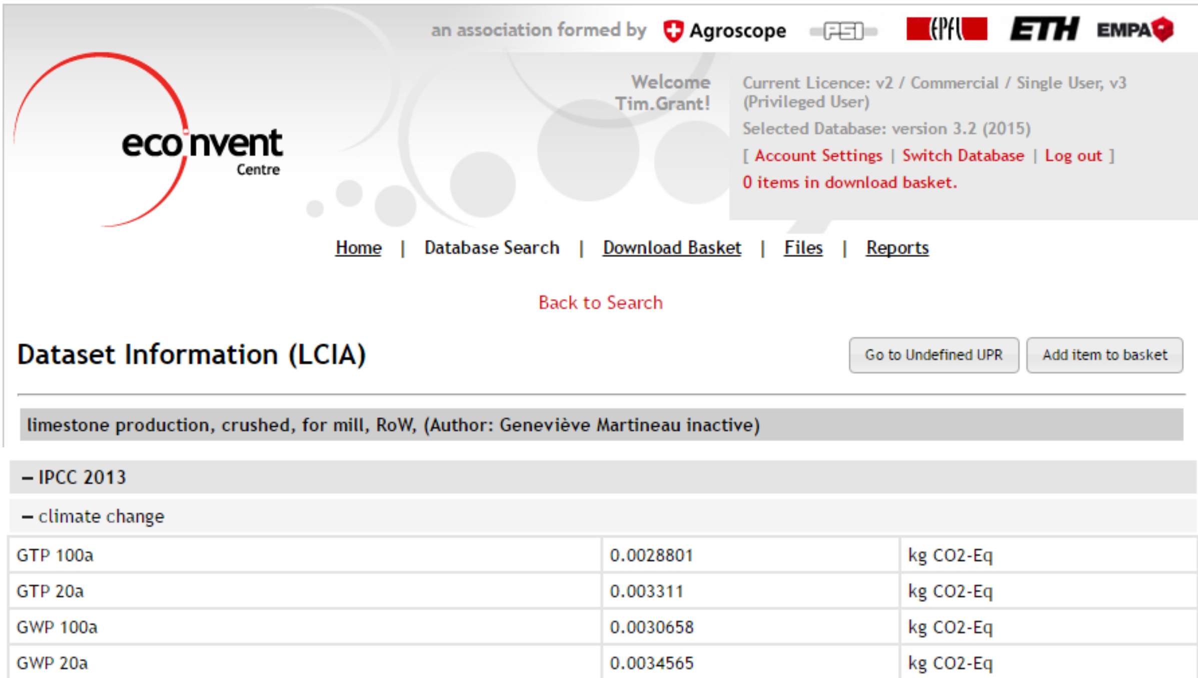
GWP 100a	1.4605	kg CO2-Eq
GWP 20a	1.5931	kg CO2-Eq
GWP 500a	1.4011	kg CO2-Eq

Urea ammonium nitrate (UAN)	urea ammonium nitrate production, RoW | nitrogen fertiliser, as N [kg]	https://v32.ecoquery.ecoinvent.org/Details/LCIA/ba67822c-4509-4f27-92e8-5c2653e0053e/06590a66-662a-4885-8494-ad0cf410f956	5.9511



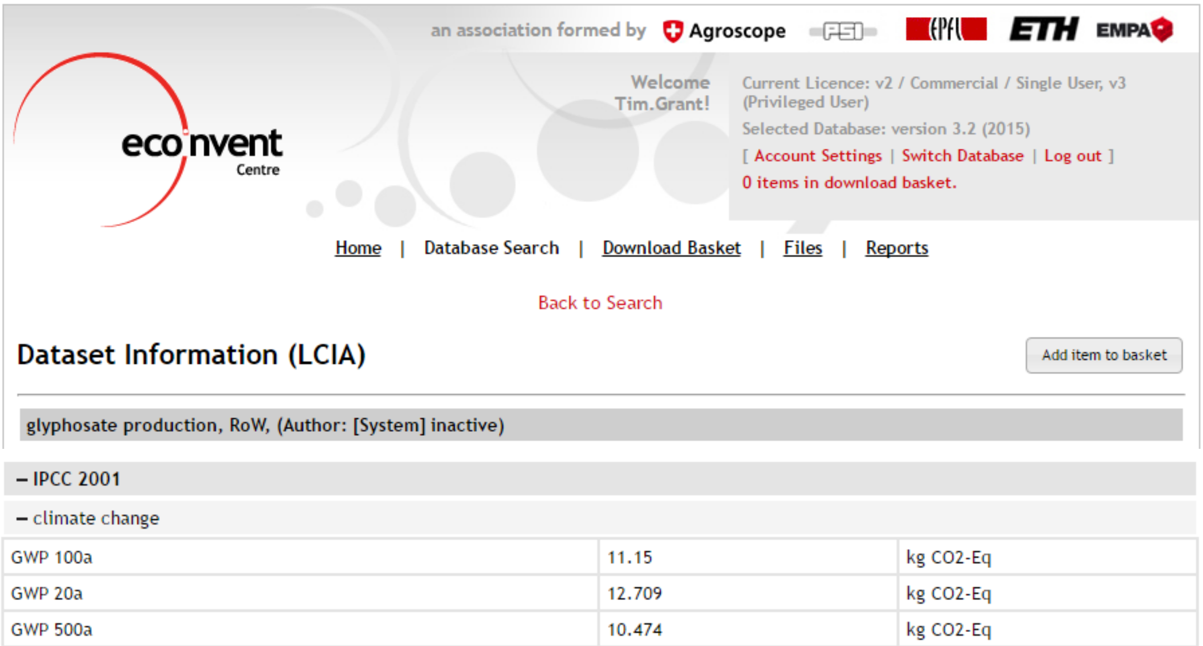
GWP 100a	5.9511	kg CO2-Eq
GWP 20a	6.0038	kg CO2-Eq
GWP 500a	4.5126	kg CO2-Eq

Lime	limestone production, crushed, for mill, RoW | limestone, crushed, for mill [kg]	https://v32.ecoquery.ecoinvent.org/Details/LCIA/e0e330bb-b4ff-466f-921b-16d4951f09ec/06590a66-662a-4885-8494-ad0cf410f956	0.0028801

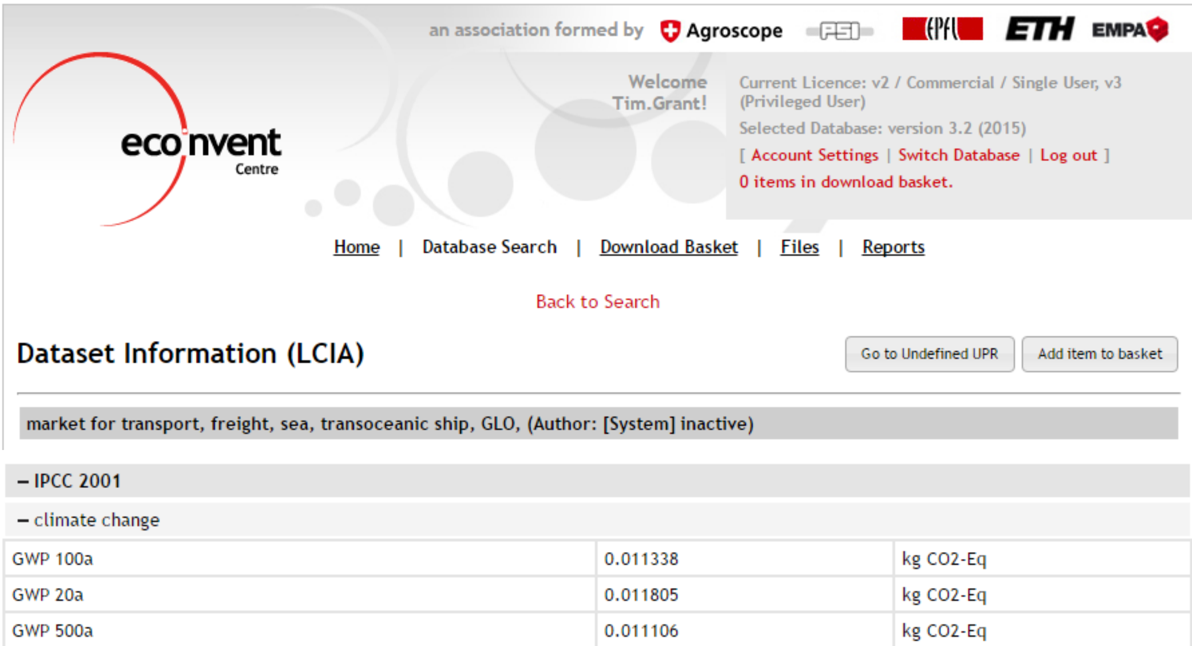


GTP 100a	0.0028801	kg CO2-Eq
GTP 20a	0.003311	kg CO2-Eq
GWP 100a	0.0030658	kg CO2-Eq
GWP 20a	0.0034565	kg CO2-Eq

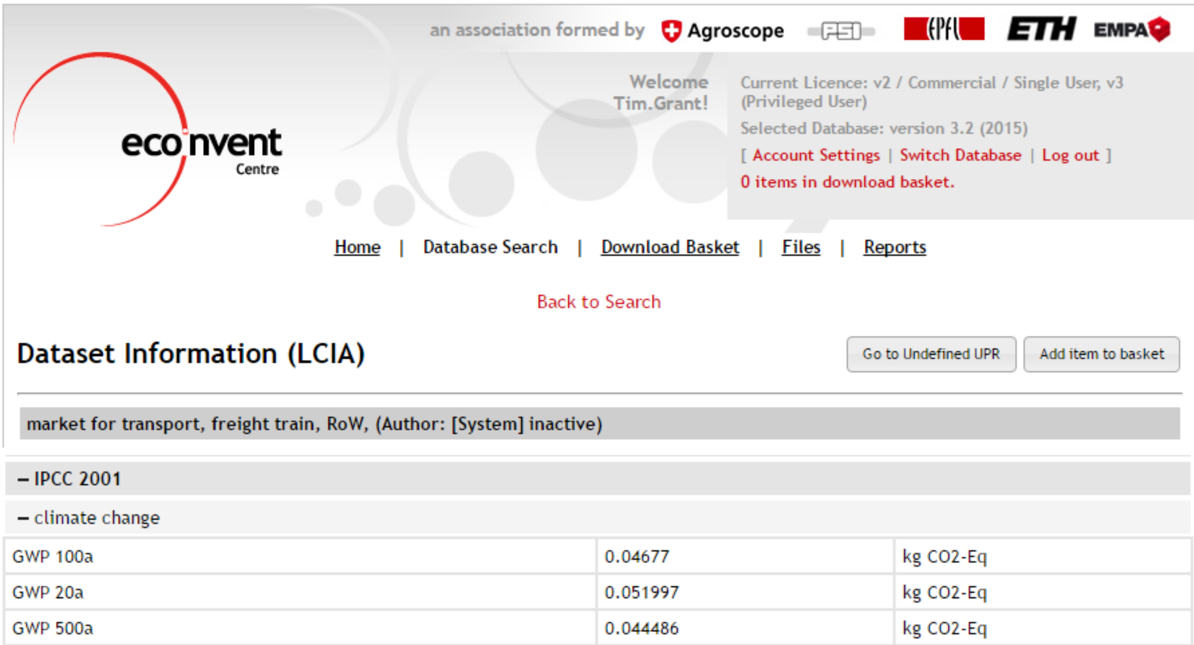
Herbicide, insecticide and fungicide	glyphosate production, RoW | glyphosate [kg]	https://v32.ecoquery.ecoinvent.org/Details/LCIA/989b2036-67c6-4f0f-8457-a6e796809574/06590a66-662a-4885-8494-ad0cf410f956	11.15



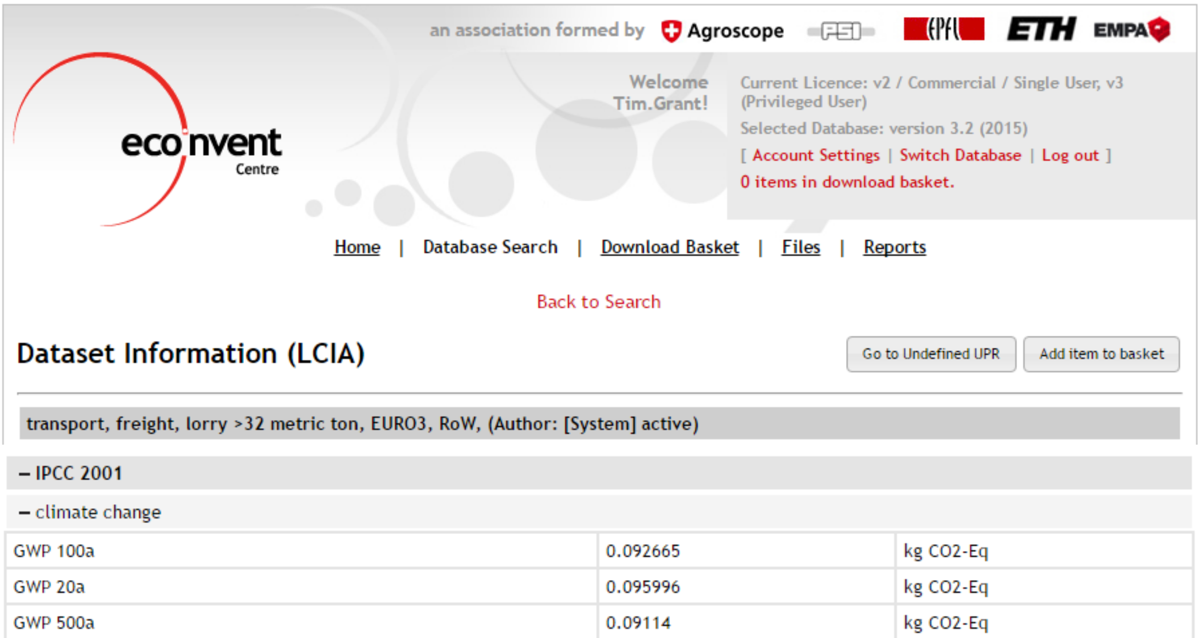
Fertiliser transport – sea	transport, freight, sea, transoceanic ship, GLO | transport, freight, sea, transoceanic ship [metric ton*km]	https://v32.ecoquery.ecoinvent.org/Details/LCIA/d38b25b1-df7c-4c17-8af6-0e8395f913ff/06590a66-662a-4885-8494-ad0cf410f956	0.011338



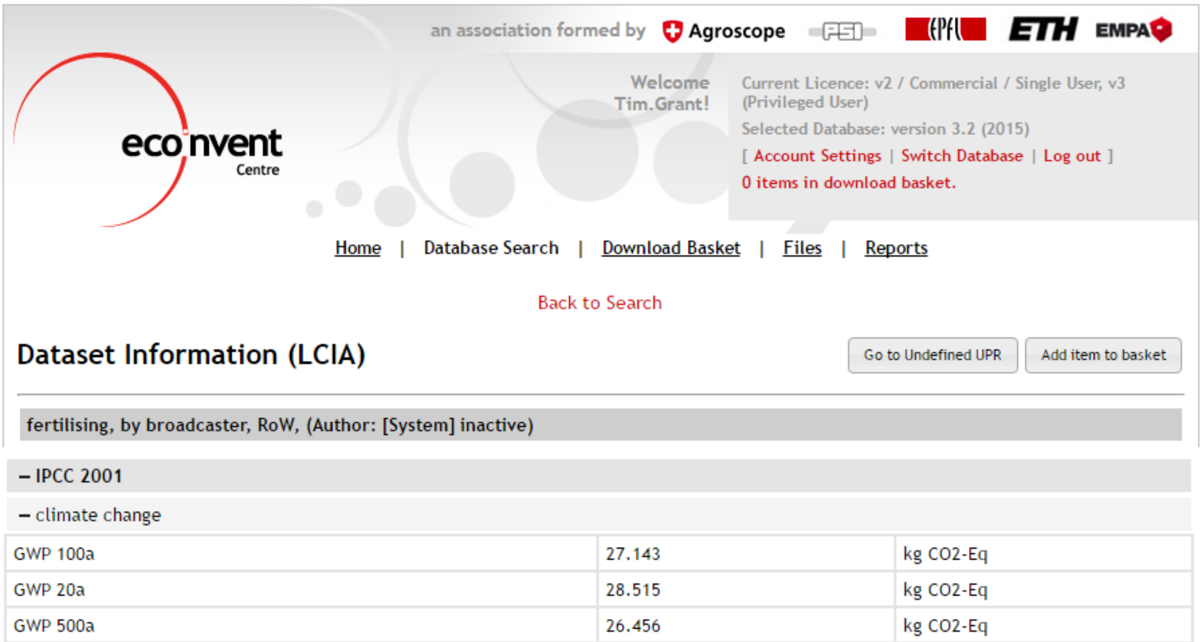
Fertiliser transport – rail	market for transport, freight train, RoW | transport, freight train [metric ton*km]	https://v32.ecoquery.ecoinvent.org/Details/LCIA/91eb7c4a-0c38-4dbb-aabd-5436a7a0384e/06590a66-662a-4885-8494-ad0cf410f956	0.04677



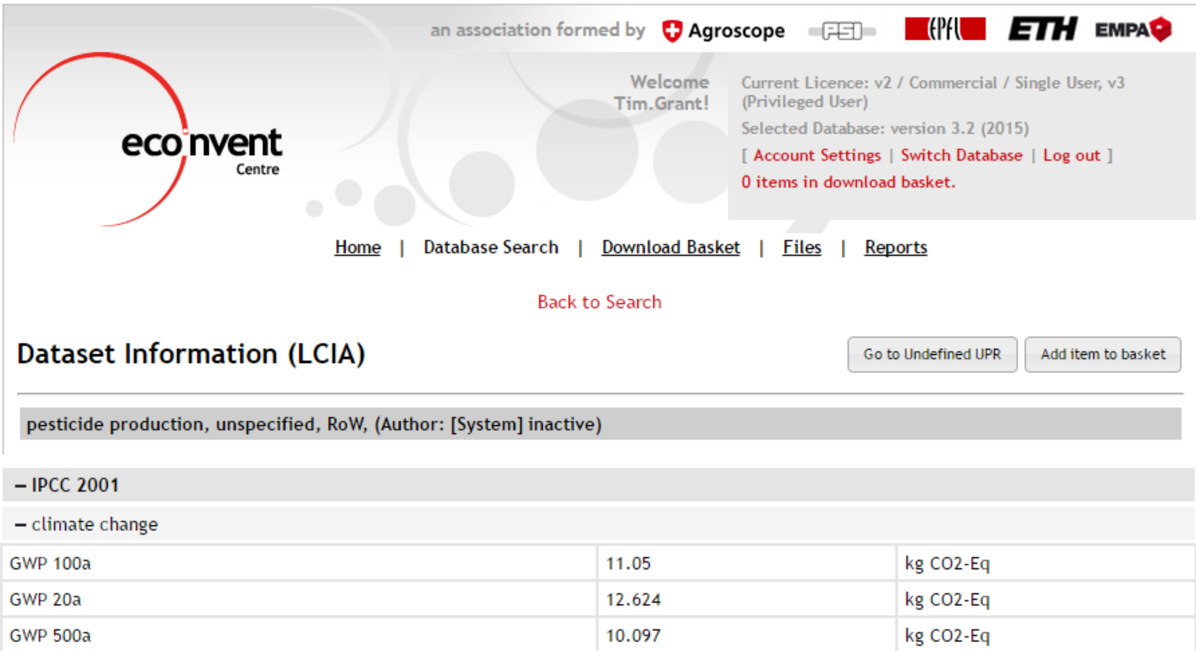
Fertiliser transport – road	market for transport, freight, lorry >32 metric ton,EURO3 | transport, freight, lorry >32 metric ton, EURO3 [metric ton*km]	https://v32.ecoquery.ecoinvent.org/Details/LCIA/aa3f3de6-4a42-48d3-b0f3-cdebf32a4d72/06590a66-662a-4885-8494-ad0cf410f956	0.092665



Fuel use	fertilising, by broadcaster, RoW | fertilising, by broadcaster [ha]	https://v32.ecoquery.ecoinvent.org/Details/LCIA/2ea9a9cf-e2c3-4817-a250-8e360f9a355e/06590a66-662a-4885-8494-ad0cf410f956	27.143



Pesticide	pesticide production, unspecified, RoW | pesticide, unspecified [kg]	https://v32.ecoquery.ecoinvent.org/Details/LCIA/db149d4e-b56c-42f5-ab34-ad2fe80f1c15/290c1f85-4cc4-4fa1-b0c8-2cb7f4276dce	11.05



Appendix B – Detailed Fertiliser Emissions Factor Calculation

The base calculation to obtain an overall EF for fertiliser (Table 8), that includes the transport component, is demonstrated below. This covers one example of fertiliser from Saudi Arabia, where the fertiliser manufacturing facility is located close to the port (hence no land transport leg in the originating country), to New South Wales.

	Sample calculation for 1 kg of fertiliser transportation			
	Description	**Value**	**Units**	**Remarks**
	State	New South Wales (NSW)		
	Port	Sydney		
Imported Fertiliser	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 supply Chain report
	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	0.047	kgCO2eq/tkm	From ecoinvent
	Emission Factor for Road transporation	0.093	kgCO2eq/tkm	From ecoinvent
	Emission Factor for Ship transporation	0.011	kgCO2eq/tkm	From ecoinvent
	Emissions per kg of fertiliser transportation	**0.188**	**kgCO2eq/kg**	(Distance x EF)/1000
Domestic Fertiliser	Transportation distance by Road	412	km	From AEGIC supply Chain report, assumed all is transported by road
	Emission Factor for Road transporation	0.093	kgCO2eq/tkm	From ecoinvent
	Emissions per kg of fertiliser transportation	**0.038**	**kgCO2eq/kg**	(Distance x EF)/1000
	Share of imported fertiliser	**72%**		
	Share of domestic fertiliser	**28%**		
	Average emission from fertiliser transport	**0.146**	**kgCO2eq/kg**	
	Sample calculation for 1 kg of fertiliser production			
	Share of UREA in total fertiliser	71%		Calculated in the tool
	Share of MAP in total fertiliser	29%		Calculated in the tool
	Emission Factor for UREA	1.455	kgCO2eq/kg	From ecoinvent
	Emission Factor for MAP	1.075	kgCO2eq/kg	From ecoinvent
	Average emission from fertiliser production	**1.346**	**kgCO2eq/kg**	
	Contribution analysis			
	Average emission from fertiliser transport	0.146	kgCO2eq/kg	**9.8%**
	Average emission from fertiliser production	1.346	kgCO2eq/kg	**90.2%**

Appendix C – Review Documents

1. Richard Eckard, University of Melbourne, Australia
2. Stefan Majer, DBFZ Deutsches Biomasseforschungszentrum, Germany
3. Sarah Bossen and Francois Ducarme, SGS Germany GmbH, Germany

Professor Richard Eckard
Director, Primary Industries Climate Challenges Centre

THE UNIVERSITY OF MELBOURNE

FACULTY OF VETERINARY & AGRICULTURAL SCIENCES

12 April 2016

Prof Ross Kingwell
Australian Export Grains Innovation Centre
3 Baron-Hay Court
South Perth, Western Australia 6151
Australia

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

The report is well structured, clearly written and easy to navigate, with obvious attention to detail in adhering to both the EU Renewable Energy Directive and the Australian National Inventory Report Tier 2 methods (Chapter 5, Agriculture, NGGI 2016).

The report covers all the major canola growing regions of Australia and the inputs into the calculations appear sensible, defensible and align with my knowledge of the industry. Where assumptions are made, these have been adequately referenced. 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.

I provided initial feedback to the authors on the first draft of the report, highlighting areas where assumptions and calculations need to be checked and further referenced. These have been corrected and edited. Therefore, I would consider the calculations and assumptions in the final report now to be robust, transparent and defensible.

The on-farm emissions calculations are consistent with the NGGI 2016, apart from where the report clearly states e.g. the global warming potentials are based on RED requirements. Note that I was not in a position to check the EU-specific methods, some LCA assumptions and ecoinvent 3.1 methods. I would suggest the authors request EU referees to check these independently. However, 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.

It was not possible to recalculate the data tabulated in the Results section, using our Grains Greenhouse Accounting Framework (G-GAF version 9; 2016 revision) directly, given the units and input data were different. We therefore arranged a meeting with members of the project team and compared each calculation individually, ensuring the identical input data and assumptions. This process identified some errors both ways. After correcting these calculations, and ensuring these changes were made by the authors, I am confident that these are now correct as per the Australian NGGI 2016 method described by the authors. The GAF calculators are publically available and can be used to cross-check the report if needed.

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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Ihre Nachricht vom / Your Message from	Ihr Zeichen / Your sign	Unser Zeichen / Our sign	Datum / Date
		SM	25.07.2016

Review of the report on "Greenhouse gas emissions from the cultivation of canola oilseed in Australia"

The report on "Greenhouse gas emissions from the cultivation of canola oilseed in Australia" provided by the Commonwealth Scientific and Industrial Research Organisation is very well structured, easy to read as well as clear and transparent on the description of the applied methodology and the assumptions made. The objective of the report is the derivation of emission factors for canola production in Australia similar to the NUTS2 values for rapeseed production in EU member states. The selected regions cover the major canola growing regions of Australia. The selection and classification appears to be compliant with and comparable to the definition of NUTS2 regions in Europe. The assumptions made on fertiliser use and tillage practices for these NUTS2 regions are described transparently and have been adequately referenced.

The calculation of GHG emissions from canola production in the various Australian regions covers all relevant agricultural input parameters and the calculation approach is consistent with the methodology of the Directives 2009/28/EC and 2015/1513/EC. Noteworthy is the very detailed calculation on direct and indirect nitrous oxide emissions. In general, the presented results could be reproduced based on the description of the methodology and the main assumptions included in the report.

An important parameter with a significant impact on the results is the choice of emission factors. With these factors upstream emissions from the production of agricultural inputs such as fertilisers, herbicides and diesel can be included in the calculations. The emission factors used in this report are often below the factors used by the JRC and recognised tools such as BioGrace (http://biograce.net). Since the methodology of the EU RED generally allows deviation from these factors as long as the emission factors are transparent and based on scientific and peer reviewed publications, the selection of emission factors in this report is defensible.

We have provided feedback to the authors on an earlier version of the report, highlighting some issues related to the tracebility of the emission factors used in the report and some minor points regarding the reports structure and readability. The report was edited accordingly.

To summarise, I consider the calculations and assumptions in this report to be transparent as well as consistent with the methodology of the Directives 2009/28/EC and 2015/1513/EC and thus to be robust.

Yours sincerely

i.a. Stefan Majer

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

Date: 23rd of August 2016

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 2009/28/EC on the promotion of the use of energy from renewable sources (Renewable Energy Directive – RED) and it's amending Directive (EU) 2015/1513 of the European Parliament and of the Council*
Prepared by the Commonwealth Scientific and Industrial Research Organisation, Australia
August 2016

Introduction
As an alternative to calculating individual Greenhouse Gas (GHG) values for cultivation, the Renewable Energy Directive (Directive 2009/28/EC, called RED) and its amendment (Directive (EU) 2015/1513) offer 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. The reviewing was performed against the following criteria:

- transparency and consistency of the methodology (equivalence of NUTS2 regions, conformity with the use of Tier 2 data, clarity of the methodology description)
- compliance with the RED 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)
- 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, 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 guidelines of the Communication 2010/C160/02 by the European Commission. 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 20% 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, direct and indirect N_2O emissions from the field) have been included in the calculations presented in the report.

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 fertilizer, 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.

5. Industry expert opinion

   Seeding rate for canola and place of fertilizer manufacture.

6. The National GHG Inventory Report (Department of the Environment 2015, National Inventory Report 2013. Commonwealth of Australia, Canberra)

   Quantification of 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. 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 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.

Assessment emissions factors:
The emission factors were correctly sourced from the recognized LCA database Ecoinvent (version 3.2). 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, management of crop residues and indirect N_2O emissions from leaching and volatilization). 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 2013). They are compliant with the RED 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.

Conclusion

The definition of the regions used in this assessment (Federated States) is equivalent to NUTS2-areas as required by EU-Communication 2010/C160/02. 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 and pesticide application, 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.

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