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Definition of input data to assess GHG default emissions from biofuels in EU legislation

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Abstract

Directive EU 2018/2001 on the promotion of the use of energy from renewable sources fixes a minimum requirement for greenhouse gas (GHG) savings for biofuels and bioliquids for the period from 2021 to 2030, and sets the rules for calculating the greenhouse impact of biofuels, bioliquids and their fossil fuels comparators. To help economic operators to declare the GHG emission savings of their products, default and typical values for a number of specific pathways are listed in the annexes of the RED-recast (Annex V).

The EC Joint Research Centre (JRC) is in charge of defining input values to be used for the calculation of default GHG emissions for biofuels, bioliquids, solid and gaseous biomass pathways. An update of the GHG emissions in Annex V has been carried out for the new Directive for the post-2020 framework. This report describes the assumptions made by the JRC when compiling the new updated data set used to calculate default and typical GHG emissions for the different biofuels pathways as proposed in the new directive.

Executive summary

Directive EU 2018/2001 on the promotion of the use of energy from renewable sources has been officially ratified in December 2018 for the post-2020 framework. It is a new iteration of the Renewable Energy Directive RED, the so-called 'recast', work on which began in 2016. The Directive fixes a minimum requirement for greenhouse gas (GHG) savings for biofuels and bioliquids for the period from 2021 to 2030, and sets the rules for calculating the greenhouse impact of biofuels, bioliquids and their fossil fuels comparators. To help economic operators to declare the GHG emission savings of their products, default and typical values for a number of specific pathways are listed in the annexes of the RED-recast (Annex V). The Renewable Energy Directive (RED) (2009/28/EC) and the Fuel Quality Directive (FQD) (2009/30/EC), amended in 2015 by Directive (EU) 2015/1513 (so called 'ILUC Directive') are valid until 2020.

The Joint Research Center of the European Commission (JRC) is in charge of defining input values to be used for the calculation of default GHG emissions for biofuels, bioliquids, solid and gaseous biomass pathways.

This report describes the assumptions made by the JRC when compiling the new updated data set used to calculate default and typical GHG emissions for the different biofuels pathways included in Annex V of Directive EU 2018/2001 (1).

This final version updates and replaces the previous report (version 1c) published in July 2017 (2) after the publication of the Commission proposal COM(2016)767. The updated input data are based on additional information provided by companies for some pathways and additional research carried out by the JRC. The pathways mainly affected by these final updates are: palm oil, waste cooking oil, animal fat and HVO.

The input values described in this report can be directly used by stakeholders to better understand the default emissions in the directive and the results of JRC calculations.

The database consists of tables detailing the inputs and outputs of the processes used to build the biofuels pathways. Data were derived from reports and databases of emission inventories produced by international organizations, such as the Intergovernmental Panel for Climate Change (IPCC), peer-reviewed journal publications as well as original data provided by stakeholders and industrial associations.

The geographical scope is the European Union; therefore, the data are aimed at being representative of the supply to the EU market.

The report contains general input data used in various pathways (such as fossil fuel provision, supply of chemical fertilizers, pesticides and process chemicals; soil nitrous oxide (N_2O) emissions from biofuel crop cultivation, etc.) and specific data for liquid biofuels (20 pathways), e.g. ethanol, biodiesel, and Hydrotreated Vegetable Oil (HVO) production from various feedstocks and some second generation pathways (e.g. wheat straw to ethanol, forest residues to synthetic diesel, etc.).

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(1) Input data and methodology for the calculation of solid and gaseous biomass pathways (listed in Annex VI of the directive) have been described in SWD (2014) 259 and accompanying JRC report EN 27215: Giuntoli J., Agostini A., Edwards R., Marelli L., 'Solid and gaseous bioenergy pathways: input values and GHG emissions, 2017', JRC Science for Policy Report, EUR27215EN.

(2) Edwards R., Padella M., Giuntoli J., Koeble R., O'Connell A., Bulgheroni C., Marelli L., 2017. 'Definition of input data to assess GHG default emissions from biofuels in EU leglisaltion, version 1c - July 2017, JRC Science for Policy Report, EUR 28349EN.

For each pathway, the input data used in all processes (from cultivation of feedstock to conversion, transport and distribution of the final product), including their sources, are shown and described.

Furthermore, the report describes the review process undertaken by the JRC for the definition of input data and related methodological choices. In particular, it contains the main outcomes of four meetings organized by the JRC with the support of DG ENERGY of the European Commission for technical experts and stakeholders (experts workshops in 2011 and 2016, and stakeholders workshops in 2013 and 2016). Detailed comments were collected after all meetings and taken into account by the JRC to finalise the dataset and the calculations.

There are several possible sources of uncertainty and data variation. Firstly, the main factor is linked to the geographical variability of some processes (e.g. cultivation techniques and land productivity). The data are aimed at being representative for production of biofuels' consumed in the whole EU, therefore the dataset may not represent exactly each specific condition. In these cases, it is possible and recommended to economic operators to calculate actual values.

Secondly, technological differences may have significant impact; in this case, the values and pathways were disaggregated in order to represent the most common technological options.

Thirdly, for some processes there is a lack or scarcity of data; in this regard the largest possible set of modelling and empirical data has been analysed (e.g. publications, handbooks, emissions inventory guidebooks, LCA databases and, whenever available, data from stakeholders etc.).

1. Introduction

1.1 Background

European Union (EU) legislation contains a set of mandatory targets specific to the EU transport sector. As a part of the EU sustainability framework for biofuels and bioliquids the EU Renewable Energy Directive (RED) (2009/28/EC) and the Fuel Quality Directive (FQD) (2009/30/EC), contain also harmonized minimum greenhouse gas emission requirements which are mandatory for biofuels accounted towards their targets and/ or eligible for public support. For the post-2020 framework (2021-2030), Directive (EU) 2018/2001([3]) requires at least 50% savings of greenhouse gas (GHG) emissions compared to fossil fuels to be reached for biofuels and bioliquids produced in installations starting operation on or before 5 October 2015 and 60% for the ones produced in installations starting operation until 2020. Biofuels and bioliquids produced in installations starting operation from 2021 have to reach at least 65% GHG savings.

The rules for calculating the greenhouse impact of biofuels, bioliquids and their fossil fuels comparators are set in the same Directives.

To help economic operators calculate GHG emission savings, default and typical values are listed in annex V of the recast directive (EU 2018/2001).

The Directive also includes a specific requirement for the European Commission (EC) to keep the annex under review and, where justified, to add or revise typical and default values for biofuel production pathways including modifications to the methodology by adopting delegated acts.

For the preparation of new directive, the JRC received the mandate from the Commission's Directorate-General for Energy (DG Energy) to update the existing input database, and the list of biofuels and bioliquid pathways in Annex V of RED on the basis of the latest scientific evidence.

This report describes the assumptions made by the JRC when compiling the updated data set used for the different biofuels and bioliquid pathways.

1.2 Structure of the report

The report is basically divided in three parts. The first part (Chapters 2, 3, 4 and 5) describes the data that are used in numerous pathways and includes:

- fossil fuel provision;
- supply of chemical fertilizers, pesticides and process chemicals;
- diesel, drying, and plant protection use in cultivation;
- soil nitrous oxide (N_2O) emissions from biofuel crop cultivation;
- auxiliary plant processes (such as a natural gas boiler);
- fuel consumption for different means of transportation.

The second part (Chapter 6) describes the specific input data used in the processes that make up the liquid biofuel pathways. The pathways also identify which common data are used.

([3]) Directive (EU) 2018/2001 of 11 December 2018 on the promotion of the use of energy from renewable sources (recast).

The third part of the report (Chapter 7) describes the review process undertaken by the JRC for the definition of input data and related methodological choices. In particular, it contains the main outcomes of the four meetings organized by the JRC and DG ENERGY for technical experts and stakeholders:

- Experts workshop held in November 2011 in Ispra (IT);
- Stakeholders workshop held in May 2013 in Brussels (BE).
- Experts and stakeholders workshops held in September 2016 in Brussels (BE).

Detailed comments were collected after the stakeholders meetings in May 2013 and the workshops in September 2016 and taken into consideration by the JRC to finalise the dataset and the calculations. Values that were updated following stakeholders/experts comments are underlined along the report.

Detailed questions/comments received by the JRC in 2016 from experts and stakeholders and related JRC answers may be found in Appendix 1 of version 1c of the report (4).

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(4) Edwards R., Padella M., Giuntoli J., Koeble R., O'Connell A., Bulgheroni C., Marelli L., 2017. 'Appendix 1-Outcomes of stakeholders conusltations - Definition of input data to assess GHG default emissions from biofuels in EU leglisaltion, version 1c - July 2017', JRC Science for Policy Report, EUR 28349EN.

Part One — General input data and common processes

2. General input data for pathways

This section covers the processes with the input data used for the production and supply of fossil fuels, fertilizers, chemicals and for the European electricity mix.

The total emission factors for the whole supply chain are indicated in the table comments and are summarised in Table 47.

2.1 Fossil fuels provision

Diesel oil, gasoline and heavy fuel oil provision

The GHG emissions associated to diesel and gasoline are the ones reported in Directive (EU) 2015/652 (Part 2, point 5). Emissions associated with heavy fuel oil (HFO) (not reported in the directive) are estimated following the same methodology as in Directive 2015/652, combining refining emissions from JEC-WTTv4a (2014) and figures for crude oil production and transport emissions (EU-mix) from the OPGEE report (ICCT, 2014).

Table 1 Emissions associated to the production, supply and combustion of diesel, gasoline and heavy fuel oil

$gCO_{2\ eq}$/MJ final fuel	**DIESEL**	**GASOLINE**	**HFO**
Supply emissions	21.9	19.9	13.6
Combustion emissions	73.2	73.4	80.6
Total emissions	**95.1**	**93.3**	**94.2**

Sources

1 Directive (EU) 2015/652.

2 ICCT, 2014.

3 JEC-WTTv4a, 2014.

Electricity grid supply

The GHG emissions considered for the supply and consumption of electricity in the biofuel pathways are the ones reported for the EU mix (actual averages) pathway in JEC-WTWv4a (2014).

Table 2 EU mix electricity supply (based on actual averages) emissions

Pathway (JEC)	Emissions	Unit	Amount
EMEL1 (High Voltage)	CO_2	g/MJ	126.8
	CH_4	g/MJ	0.30
	N_2O	g/MJ	0.006
	Total $CO_{2\ eq}$	$gCO_{2\ eq.}/MJ_{el.}$	**136.0**
EMEL2 (Medium Voltage)	CO_2	g/MJ	131.6
	CH_4	g/MJ	0.31
	N_2O	g/MJ	0.006
	Total $CO_{2\ eq}$	$gCO_{2\ eq.}/MJ_{el.}$	**141.1**
EMEL3 (Low Voltage)	CO_2	g/MJ	139.9
	CH_4	g/MJ	0.33
	N_2O	g/MJ	0.01
	Total $CO_{2\ eq}$	$gCO_{2\ eq.}/MJ_{el.}$	**150.1**

Source

1 JEC-WTT v4a, 2014.

The transmission and distribution losses considered are reported in Table 3, Table 4 and Table 5.

Table 3 Electricity transmission losses in the high-voltage grid (380 kV, 220 kV, 110 kV)

	I/O	Unit	Amount	Source
Electricity	Input	MJ/MJe	1.015	1
Electricity (HV)	Output	MJ	1.0000	

Table 4 Electricity distribution in the medium-voltage grid (10 – 20 kV)

	I/O	Unit	Amount	Source
Electricity (High Voltage)	Input	MJe/MJe	1.038	2
Electricity (Medium Voltage)	Output	MJ	1.0000	

Table 5 Electricity distribution losses to low voltage (380 V)

	I/O	Unit	Amount	Source
Electricity (Medium Voltage)	Input	MJ/MJe	1.064	2
Electricity (Low Voltage)	Output	MJ	1.0000	

Sources

1 ENTSO-E, 2011.

2 AEEG, 2012.

Hard coal provision

Table 6 Emission factor: hard coal provision

	I/O	Unit	Amount
Hard coal	Output	MJ	1
Emissions			
CO_2	Output	g/MJ	6.50
CH_4	Output	g/MJ	0.39
N_2O	Output	g/MJ	2.50E-04

Comments

- The total emission factor for the supply of 1 MJ of hard coal is 16.2 $gCO_{2\ eq}$/MJ.
- The emission factor for combustion of 1 MJ of hard coal is 96.1 $gCO_{2\ eq}$/MJ.

Source

1 JEC-WTT v4a, 2014; EU coal mix.

Natural gas provision

The GHG emissions associated to natural gas supply are the ones reported in Directive (EU) 2015/652 (Part 2, point 5) for compressed natural gas EU mix, but without the emissions due to the compression of the gas which are taken from the JEC-WTT 4a report (3.3 gCO2 eq/MJ). These emissions are not included since the NG is considered at the level of medium pressure grid.

Table 7 Emission factor: natural gas provision (at MP grid)

	I/O	Unit	Amount
Natural gas	Output	MJ	1
Emissions			
CO_2	Output	g/MJ	5.4
CH_4	Output	g/MJ	0.17
N_2O	Output	g/MJ	1.67E-04

Comments

- The total emission factor for the supply of 1 MJ of natural gas is 9.7 $gCO_{2\ eq}$/MJ.
- The emission factor for combustion of 1 MJ of natural gas is 56.2 $gCO_{2\ eq}$/MJ.
- The value represents EU mix with a pipeline distribution distance of 2500 km.

Sources

1 Directive (EU) 2015/652.

2 JEC-WTT v4a, 2014.

2.2 Supply of process chemicals and pesticides

This section includes the input data used for the production and supply of various chemicals, fertilizers and pesticides used in biofuel pathways.

Many processes are linked in a 'supply chain', in order to provide the final product. Therefore emission factors for the whole supply chain (including upstream emissions) are indicated in the tables and comments and summarized in Table 47.

The inputs used in the production processes of the chemicals come from the sources mentioned at the end of each paragraph. Such sources have not to be intended as the reference for total emission factors.

2.2.1 Chemical fertilizers and pesticides

Phosphorus pentoxide (P2O5) fertilizer supply

Table 8 Supply of P2O5 fertilizer

	I/O	Unit	Amount
P_2O_5 fertilizer	Output	kg	1.0

Comment

- The total emission factor, including upstream emissions, to produce 1 kg of P_2O_5 fertilizer is 541.7 $gCO_{2\ eq}/kg_{P2O5}$ as reported in Fertilizers Europe (2014).

Source

1 Fertilizers Europe, 2014.

Potassium oxide (K2O) fertilizer supply

Table 9 Supply of K2O fertilizer

	I/O	Unit	Amount
K_2O fertilizer	Output	kg	1.0

Comment

- The total emission factor, including upstream emissions, to produce 1 kg of K_2O fertilizer is 416.7 $gCO_{2\ eq}/kg_{K2O}$ as reported in Fertilizers Europe (2014).

Source

1 Fertilizers Europe, 2014.

Limestone (aglime–CaCO3) supply chain

The supply chain for the provision of aglime fertilizer includes the processes for the mining, grinding and drying of limestone. The results are quoted per kilogram of CaO in the $CaCO_3$, even though the product is ground limestone. Limestone was once converted to CaO by strong heating (calcining), using fuel. But now, ~90 % of aglime is ground limestone (or dolomite), and even the small amount of CaO which is used on soil is a by-product of industrial processes.

Table 10 Limestone mining

	I/O	Unit	Amount	Source
Diesel	Input	MJ/kg	0.1067	1
Electricity (MV)	Input	MJ/kg	0.013	1
Limestone	Output	kg	1	

Source

1 GEMIS v. 4.93, 2014, '*Xtra-quarrying\limestone-DE-2010*'.

Table 11 Limestone grinding and drying for the production of CaCO3

	I/O	Unit	Amount	Source
Limestone	Input	kg/kg	1	
Electricity (Low VoltageV)	Input	MJ/kg	0.179	1
$CaCO_3$	Output	kg	1	

Comment

- In agricultural data, the use of limestone is quantified in terms of CaO equivalent. 1 kg of CaO-equivalent corresponds to 1.785 kg $CaCO_3$. The emissions for making it are 69.7 $gCO_{2eq}/kgCaO_{eq}$, This corresponds to 39.1 gCO_{2eq} per kg $CaCO_3$ as $CaCO_3$.

Source

1 GEMIS v. 4.93, 2014, *Nonmetallic minerals\CaCO₃ -powder-DE-2000.*

Pesticides supply chain

'Pesticides' is the name given to all 'plant health products' including pesticides, herbicides, fungicides and plant hormones.

Table 12 Supply of pesticides

	I/O	Unit	Amount
Hard coal	Input	MJ/kg	7.62
Diesel oil	Input	MJ/kg	58.1
Electricity	Input	MJ/kg	28.48
Heavy fuel oil (1.8 % S)	Input	MJ/kg	32.5
NG	Input	MJ/kg	71.4
Pesticides	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	11 209.6
CH_4	-	g/kg	11.98
N_2O	-	g/kg	1.68

Comment

- The total emission factor, including upstream emissions, to produce 1 kg of pesticides is is 12 010.7 $gCO_{2\ eq}$/kg.

Source

1 Kaltschmitt, 1997.

2.2.2 Chemicals and other conversion inputs

Calcium oxide (CaO) as a process chemical (not aglime)

Table 13 CaO as a process chemical

	I/O	Unit	Amount	Source
Electricity	Input	MJ/kg	0.13	1
Heat (from NG boiler)	Input	MJ/kg	5.20	1
Limestone	Input	kg/kg	1.78	1
CaO	Output	kg	1.0	
Emissions including upstream emissions				
CO_2	-	g/kg	1 188.47	
CH_4	-	g/kg	0.10	
N_2O	-	g/kg	0.008	

Comment

- The total emission factor for the supply of 1 kg of pure CaO as a process chemical (not agricultural lime) is 1 193.2 $gCO_{2\ eq}$/kg.

Source

1 GEMIS, v. 4.93, 2014; '*nonmetallic minerals\CaO-GGR-kiln-DE-2010*'

Hydrogen chloride (HCI) supply chain

Table 14 Supply of hydrogen chloride

	I/O	Unit	Amount
Chlorine	Input	kg/kg	0.97
Electricity	Input	MJ/kg	1.2
H_2	Input	kg/kg	0.03
HCl	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	977.07
CH_4	-	g/kg	2.91
N_2O	-	g/kg	0.038

Comment

- The total emission factor for the supply of 1 kg of HCl is 1 061.1 $gCO_{2\ eq}$/kg.

Source

1 Althaus et al., 2007, Ecoivent report no. 8.

Table 15 Supply of hydrogen via steam reforming of natural gas for HCl

	I/O	Unit	Amount
NG	Input	kg/kg	3.40
Electricity	Output	MJ/kg	6.00
H_2	Output	kg	1.0

Comment

- This still the usual way of making hydrogen in industry. The emissions from making hydrogen are incorporated in the total emissions for making hydrogen chloride in the previous table.

Sources

1 Scholz, 1992.

2 Pehnt, 2002.

Table 16 Supply of chlorine via membrane technology

	I/O	Unit	Amount	Source
Heat (from NG boiler)	Input	MJ/kg	0.27	1
Electricity	Input	MJ/kg	4.87	1
Na_2CO_3	Input	kg/kg	0.02	1
NaCl	Input	kg/kg	0.86	1
H_2	Output	MJ/kg	1.68	
Chlorine	Output	kg	1.0	

Comment

- Emissions are included in the hydrogen chloride table.

Source

1 GEMIS v. 4.93, 2014, *chem.-inorg\chlorine(membrane)-DE-2010*.

Sodium carbonate (Na2CO3) supply chain

Table 17 Supply of Na2CO3

	I/O	Unit	Amount	Source
NaCl	Input	kg/kg	1.55	1
NG	Input	MJ/kg	1.09	1
Coal	Input	MJ/kg	7.94	1
Coke	Input	MJ/kg	2.23	1
$CaCO_3$	Input	kg/kg	1.13	1
Na_2CO_3	Output	kg	1.0	
Emissions including upstream emissions				
CO_2	-	g/kg	1 133.5	
CH_4	-	g/kg	4.391	
N_2O	-	g/kg	0.006	

Comment

The total emission factor for the supply of 1 kg of sodium carbonate is 1 245.1 $gCO_{2\ eq}$/kg.

Source

1 GEMIS v. 4.93, 2014, *chem.-inorganic\sodium carbonate-DE-2010.*

Table 18 Coke production from hard coal

	I/O	Unit	Amount	Source
Hard coal	Input	MJ/MJ	1.43	1
Electricity	Input	MJ/MJ	0.01	1
Heat (from coke-oven gas)	Input	MJ/MJ	0.27	1
Coke	Output	MJ	1.0	
Heat	Output	MJ/MJ	0.11	1

Comment

- Emissions are included in the sodium carbonate table.

Source

1 GEMIS v. 4.93, 2014, *conversion\coke-DE-2010.*

Sodium chloride (NaCl) supply chain

Table 19 Supply of NaCl

	I/O	Unit	Amount	Source
Diesel	Input	MJ/kg	0.05	1
Electricity	Input	MJ/kg	0.06	1
Heat (NG boiler)	Input	MJ/kg	0.003	1
Explosives	Input	kg/kg	0.0004	1
NaCl	Output	kg	1.0	
Emissions including upstream emissions				
CO_2	-	g/kg	12.7	
CH_4	-	g/kg	0.019	
N_2O	-	g/kg	0.001	

Comment

- The total emission factor for the supply of 1 kg of NaCl is 13.3 gCO2 eq/kg.

Source

1 GEMIS v 4.93, 2014, Xtra-mining\sodium chloride-DE-2010.

Sodium hydroxide (NaOH) supply chain

Table 20 Supply of NaOH

	I/O	Unit	Amount	Source
Electricity	Input	MJ/kg	4.32	1
Heat (from NG boiler)	Input	MJ/kg	0.24	1
Na_2CO_3	Input	kg/kg	0.02	1
NaCl	Input	kg/kg	0.76	1
H_2	Output	kg/kg	0.02	1
NaOH	Output	kg	1.0	
Emissions including upstream emissions				
CO_2	-	g/kg	485.5	
CH_4	-	g/kg	1.445	
N_2O	-	g/kg	0.027	

Comment

- The total emission factor for the supply of 1 kg of NaOH is 529.7 $gCO_{2\ eq}$/kg.

Source

1 GEMIS v. 4.93, 2014, '*chem.-inorg\NaOH (membrane)-DE-2010*'.

Ammonia (NH3) supply chain

Table 21 Supply of NH3 – as process chemical in EU

	I/O	Unit	Amount
Natural gas	Input	MJ/kg	34.56
Electricity	Input	MJ/kg	0.50
NH_3	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	2 350.6
CH_4	-	g/kg	0.003
N_2O	-	g/kg	0.002

Comment

- The total emission factor for the supply of 1 kg of Ammonia is 2 351.3 $gCO_{2\ eq}$/kg.

Source

1 Hoxha, A. (Fertilizers Europe, personal communication, May 2014 and February 2011. Data apply to Fertilizers Europe members only).

Sulphuric acid (H2SO4) supply chain

Table 22 Supply of H2SO4

	I/O	Unit	Amount
Electricity	Input	MJ/kg	0.76
NG (for S mining)	Input	MJ/kg	1.64
S	Input	kg/kg	0.33
H_2SO_4	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	210.2
CH_4	-	g/kg	0.236
N_2O	-	g/kg	0.005

Comment

- The total emission factor for the supply of 1 kg of H_2SO_4 is 217.5 $gCO_{2\ eq}$/kg.

Source

1 Frischknecht et al., 1996.

Phosphoric acid (H3PO4) supply chain

Table 23 Supply of H3PO4

	I/O	Unit	Amount	Source
Electricity	Input	MJ/kg	11.30	1
H_2SO_4	Input	kg/kg	1.70	1
Heat (from heavy fuelled boiler)	Input	MJ/kg	3.60	1
Phosphate minerals	Input	kg/kg	1.80	1
H_3PO_4	Output	kg	1.0	
Emissions including upstream emissions				
CO_2	-	g/kg	2 808.9	
CH_4	-	g/kg	11.359	
N_2O	-	g/kg	0.107	

Comment

- The total emission factor for the supply of 1 kg of H_3PO_4 is 3 124.7 $gCO_{2\ eq}$/kg.

Source

1 GEMIS v. 4.93, 2014, *chem.-inorg\phosphoric acid-DE-2000.*

Cyclohexane (C6H12) supply chain

Table 24 Supply of cyclohexane

	I/O	Unit	Amount
Cyclohexane	Output	kg	1.0
Emissions			
CO_2	-	g/kg	723
CH_4	-	g/kg	0.00
N_2O	-	g/kg	0.00

Comment

- The total emission factor for the supply of 1 kg of C_6H_{12} is 723 $gCO_{2\ eq}$/kg.

Source

1 Macedo et al., 2004.

Lubricants supply chain

Table 25 Supply of lubricants

	I/O	Unit	Amount
Lubricants	Output	kg	1.0
Emissions			
CO_2	-	g/kg	947
CH_4	-	g/kg	0.00
N_2O	-	g/kg	0.00

Comment

- The total emission factor for the supply of 1 kg of lubricants is 947 $gCO_{2\ eq}$/kg.

Source

1 Köhler et al., 1996.

Alpha-amylase supply chain

Table 26 Supply of alpha-amylase enzymes

	I/O	Unit	Amount
Alpha-amylase	Output	kg	1.0
Emissions			
CO_2	-	g/kg	1 000
CH_4	-	g/kg	0.00
N_2O	-	g/kg	0.00

Comment

- The total emission factor for the supply of 1 kg of alpha-amylase is 1 000 $gCO_{2\ eq}$/kg.

Source

1 MacLean and Spatari, 2009 (based on Nielsen et al., 2007).

Gluco-amylase supply chain

Table 27 Supply of gluco-amylase enzymes

	I/O	Unit	Amount
Gluco-amylase	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	7 500
CH_4	-	g/kg	0.00
N_2O	-	g/kg	0.00

Comment

- The total emission factor for the supply of 1 kg of gluco-amylase is 7 500g$CO_{2\ eq}$/kg.

Source

1 MacLean and Spatari, 2009 (based on Nielsen et al., 2007).

Sodium methoxide (Na(CH3O)) supply chain

Table 28 Supply of sodium methoxide (NaCH3O)

	I/O	Unit	Amount
Methanol	Input	kg/kg	0.59
Na	Input	kg/kg	0.43
H_2	Output	kg/kg	0.02
Sodium methoxide	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	2 207.7
CH_4	-	g/kg	7.560
N_2O	-	g/kg	0.097

Comments

- The total emission factor for the supply of 1 kg of sodium methoxide is 2 425.5 g$CO_{2\ eq}$/kg.

Source

1 Du Pont, 2008.

Table 29 Supply of sodium via molten-salt electrolysis

	I/O	Unit	Amount
Electricity	Input	MJ/kg	43.20
NaCl	Input	kg/kg	2.54
Chlorine	Output	kg/kg	1.54
Na	Output	kg	1.0

Comment

- Emissions are included in the sodium methoxide table.

Table 30 Supply of methanol

	I/O	Unit	Amount
NG	Input	kg/kg	0.58
Air-O_2	Input	kg/kg	0.83
Methanol	Output	kg	1.0
Supply emissions			
CO_2	-	g/MJ	28.2
CH_4	-	g/MJ	0.0001
N_2O	-	g/MJ	0.0000

Comment

- The total emission factor for the supply of 1 MJ of methanol is 28.2 $gCO_{2\ eq}$/MJ. The emission factor for the combustion of 1 MJ of methanol is 68.9 $gCO_{2\ eq}$/MJ.

Source

1 Larsen, 1998.

n-hexane supply chain

Table 31 Supply of n-hexane

	I/O	Unit	Amount
Natural gas	Input	MJ/MJ	0.01
Hard coal	Input	MJ/MJ	0.01
Hydro Power	Input	MJ/MJ	0.00
Nuclear source	Input	MJ/MJ	0.01
Lignite	Input	MJ/MJ	0.01
Crude oil	Input	MJ/MJ	1.12
n-hexane	Output	MJ	1.0
Supply emissions			
CO_2	-	g/MJ	12.0
CH_4	-	g/MJ	0.015
N_2O	-	g/MJ	0.0003

Comment

- The total emission factor for the supply of 1 MJ of n-hexane is 12.5 $gCO_{2\ eq}$/kg.
  The emission factor for the combustion of 1 MJ of n-hexane is 68.1 $gCO_{2\ eq}$/MJ.

Source

1 Kaltschmitt, 1997.

Potassium hydroxide (KOH) supply chain

Table 32 Supply of potassium hydroxide (KOH) via electrolysis (membrane)

	I/O	Unit	Amount
Electricity	Input	MJ/kg	6.37
Steam (from NG boiler)	Input	MJ/kg	0.41
KCl	Input	kg/kg	1.33
H_2	Output	kg/kg	0.02
Chlorine	Output	kg/kg	0.63
KOH	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	403.0
CH_4	-	g/kg	0.395
N_2O	-	g/kg	0.021

Comment

- The total emission factor for the supply of 1 kg of KOH is 419.1 $gCO_{2\ eq}$/kg.

Source

1 European Commission, 2001.

Table 33 Supply of potassium chloride (KCl)

	I/O	Unit	Amount	Source
Electricity	Input	MJ/kg	0.10	1
Heat (from NG boiler)	Input	MJ/kg	0.43	1
KCl	Output	kg	1.0	

Comment

- Emissions are included in the potassium hydroxide table.

Source

1 GEMIS v. 4.93, 2014, Xtra-mining\potassium chloride-DE-2000.

Nitrogen gas (N2) supply chain

Table 34 Supply of nitrogen

	I/O	Unit	Amount	Source
Air	Input	kg/kg	1.01	
Electricity	Input	MJ/kg	0.40	1
N2	Output	kg	1.0	
Emissions including upstream emissions				
CO_2	-	g/kg	52.6	
CH_4	-	g/kg	0.125	
N_2O	-	g/kg	0.002	

Comment

- The total emission factor for the supply of 1 kg of N2 is 56.4 $gCO_{2\ eq}$/kg.

Source

1 GEMIS v. 4.93, 2014, Xtra-generic\N2 (gaseous).

Ammonium sulphate ((NH4)2SO4) supply chain

Table 35 Supply of ammonium sulphate ((NH4)2SO4)

	I/O	Unit	Amount
NH_3	Input	kg/kg	0.26
H_2SO_4	Input	kg/kg	0.74
$(NH_4)_2SO_4$	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	420.9
CH_4	-	g/kg	1.289
N_2O	-	g/kg	0.0002

Comment

- The total emission factor for the supply of 1 kg of $(NH_4)_2SO_4$ is 453.2 $gCO_{2\ eq}$/kg.

Source

Calculated (chemical reaction) by Ludwig-Bölkow-Systemtechnik GmbH (LBST), Germany.

Monopotassium phosphate (KH2PO4) supply chain

Table 36 Supply of monopotassium phosphate (KH2PO4)

	I/O	Unit	Amount
K_2CO_3	Input	kg/kg	0.51
H_3PO_4	Input	kg/kg	0.72
KH_2PO_4	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	238.7
CH_4	-	g/kg	0.910
N_2O	-	g/kg	0.012

Comment

- The total emission factor for the supply of 1 kg of KH_2PO_4 is 264.9 $gCO_{2\ eq}$/kg.

Source

Calculated (chemical reaction) by Ludwig-Bölkow-Systemtechnik GmbH (LBST), Germany.

Magnesium sulphate (MgSO4) supply chain

Table 37 Supply of magnesium sulphate (MgSO4)

	I/O	Unit	Amount
Magnesite	Input	kg/kg	0.70
H_2SO_4	Input	kg/kg	0.81
$MgSO_4$	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	191.4
CH_4	-	g/kg	0.036
N_2O	-	g/kg	-0.002

Comment

- The total emission factor for the supply of 1 kg of $MgSO_4$ is 191.8 $gCO_{2\ eq}$/kg.

Source

Calculated (chemical reaction) by Ludwig-Bölkow-Systemtechnik GmbH (LBST), Germany.

Table 38 Supply of magnesite

	I/O	Unit	Amount
Electricity	Input	MJ/kg	0.10
Diesel	Input	MJ/kg	0.33
Explosive	Input	kg/kg	0.0007
Magnesite	Output	kg	1.0

Comment

- Emissions are included in the magnesium sulphate table.

Source

The process is not available in the newer versions of GEMIS. However, process details can be found in GEMIS 4.93 for the mining of iron ore (e.g. Xtra-mining\Fe-ore-AU-2010, Xtra-mining\Fe-ore-CA-2010, Xtra-mining\Fe-ore-SE-2010). It has been assumed that the energy effort for the mining of magnesite is approximately the same as for iron ore.

Calcium chloride (CaCl2) supply chain

Table 39 Supply of calcium chloride (CaCl2)

	I/O	Unit	Amount
$CaCl_2$	Output	kg	1.0
Emissions			
CO_2	-	g/kg	38.6
CH_4	-	g/kg	0.002
N_2O	-	g/kg	0.001

Comments

- Supply emissions are not included because $CaCl_2$ has been considered as a waste from the manufacture of $NaCO_3$ (via Solvay process). Therefore, only transport emissions are considered.
- The total emission factor of 1 kg of $CaCl_2$ is 38.8 $gCO_{2\ eq}$/kg.

Antifoam supply chain

Table 40 Supply of antifoam (assumed to be propylene glycol)

	I/O	Unit	Amount
Propylene oxide	Input	kg/kg	0.80
Electricity	Input	MJ/kg	1.20
Heat (from NG boiler)	Input	MJ/kg	1.80
Propylene glycol	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	3 119.5
CH_4	-	g/kg	4.963
N_2O	-	g/kg	0.105

Comment

- The total emission factor for the supply of 1 kg of propylene glycol is 3 274.8 $gCO_{2\ eq}$/kg.

Source

1 Althaus et al., 2007, Ecoivent report no. 8.

Table 41 Supply of propylene oxide

	I/O	Unit	Amount
Chlorine	Input	kg/kg	1.29
Electricity	Input	MJ/kg	1.20
Heat (from NG boiler)	Input	MJ/kg	1.80
NaOH	Input	kg/kg	1.38
Propylene	Input	kg/kg	0.76
Propylene glycol	Output	kg	1.0

Comment

- Emissions are included in the antifoam (propylene glycol) table.

Sulfur dioxide (SO2) supply chain

Table 42 Supply of sulfur dioxide (SO2)

	I/O	Unit	Amount
Electricity	Input	MJ/kg	0.10
SO_2	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	52.0
CH_4	-	g/kg	0.034
N_2O	-	g/kg	0.001

Comment

- The total emission factor for the supply (including transport) of 1 kg of SO_2 is 53.3 $gCO_{2\ eq}$/kg.

Source

1 Verri and Baldelli, 2013.

Diammonium phosphate (DAP) supply chain

Table 43 Supply of diammonium phosphate (DAP)

	I/O	Unit	Amount
NH_3	Input	kg/kg	0.26
H_3PO_4	Input	kg/kg	0.74
Heat (from NG boiler)	Input	MJ/kg	0.41
Electricity	Input	MJ/kg	0.10
$(NH_4)_2HPO_4$	Output	kg	1.0
Emissions including upstream emissions			
CO_2	-	g/kg	653.2
CH_4	-	g/kg	0.808

Comment

- The total emission factor for the supply of 1 kg of diammonium phosphate is 674.4 $gCO_{2\ eq}$/kg.

Source

1 Mubarak, 2014.

2.2.3 Seeding material

Table 44 Emission factors for the supply of seeding material

	Net GHG emitted [g $CO_{2\,eq.}$/kg]	**CO_2 [g/kg]**	**CH_4 [g/kg]**	**N_2O [g/kg]**
Barley seeds	**310.6**	189.5	0.077	0.400
Maize seeds	**310.6**	189.5	0.077	0.400
Rye seeds	**312.1**	191.0	0.077	0.400
Triticale seeds	**300.2**	180.0	0.039	0.400
Wheat seeds	**283.9**	163.7	0.040	0.400
Sugar beet seeds	**3 651.7**	2 363.0	1.370	4.210
Sugar cane seeds	**4.97**	4.97	0.000	0.000
Rapeseed seeds	**756.5**	451.0	0.273	1.002
Sunflower seeds	**756.5**	451.0	0.273	1.002

Source

Emissions are estimated on the basis of inputs given in Kaltschmitt, 1997 (all crops except sugarcane) and Macedo, 2004 (for sugarcane).

2.3 N fertilizer manufacturing emissions calculation

Nitrogen fertilizer production emissions

- Average for all N fertilizer consumed in the EU, including imports.
- The data are principally from the emissions reporting by Fertilizers Europe (FE[5]) in the frame of Emissions Trading System (ETS). Data for imports also come via FE, who report data from a world survey of fertilizer plant emissions.
- We use only one value for N fertilizer manufacturing emissions: a weighted average for the urea and nitrate-type fertilizers used in EU. There are sparse data on which N fertilizers are used, where, and for which crop.
- Other figures for EU fertilizer emissions in the literature are sometimes extrapolated from individual factories, and/or do not include upstream emissions for natural gas.
- We also make our own calculation to ensure that upstream emissions from natural gas use are consistent with values used in other pathways.
- There is much scope for producers to reduce emissions by choosing fertilizer from a low-emission factory.

([5]) Fertilizers Europe: see http://www.fertilizerseurope.com online.

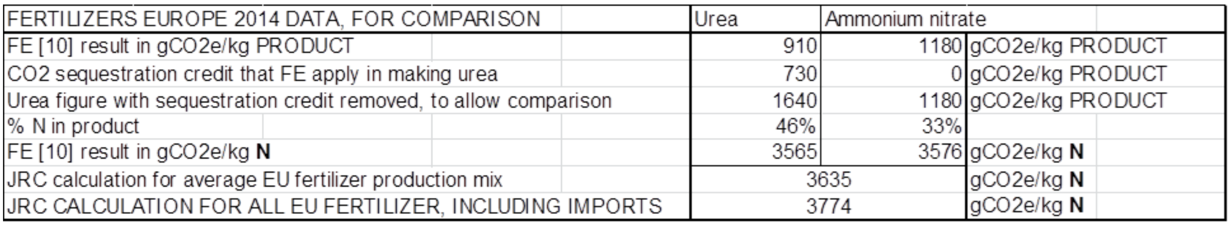
- Imported urea is assumed to come from the Middle East (expert judgment from Fertilizers Europe);
- The same default N fertilizer emissions are used for fertilizer applied to foreign crops (even though emissions from making fertilizers are generally higher outside EU, and especially in China).

Table 45 Nitrogen fertilizer mix used in the EU

	N-fertilizer (mix consumed in the EU) **g/kgN**
CO_2	3 079
CH_4	2.17
N_2O	2.15
CO_2 equiv.	3 774
Emissions from acidification by fertilizer, whether or not aglime is used	798
TOTAL EMISSIONS PER KG N	**4 572**

Comments

- For comparison: the previous RED N fert emissions for RED annex: about 6 000 gCO_2/kgN, **not** including acidification emissions. The reduction is due to a real improvement in fertilizer factory emissions.
- Fertilizers Europe, 2014 (Ref. 10) estimated average emissions for EU **production** of different fertilizers. The values for urea and AN were 3 365 and 3 576 repectively, if one corrects for the CO_2 sequestration that FE assign to sequestration of CO_2 in urea production (that is then released again in the field). The slight deviation from the JRC calculation is probably due to FE using different upstream emissions for NG or electricity. Neither FE or JRC include emissions for fertilizer distribution to farms. Imported fertilizer increases the JRC average emissions for fertilizer **used** in EU.



FERTILIZERS EUROPE 2014 DATA, FOR COMPARISON	Urea	Ammonium nitrate	
FE [10] result in gCO2e/kg PRODUCT	910	1180	gCO2e/kg PRODUCT
CO2 sequestration credit that FE apply in making urea	730	0	gCO2e/kg PRODUCT
Urea figure with sequestration credit removed, to allow comparison	1640	1180	gCO2e/kg PRODUCT
% N in product	46%	33%	
FE [10] result in gCO2e/kg **N**	3565	3576	gCO2e/kg **N**
JRC calculation for average EU fertilizer production mix	3635		gCO2e/kg **N**
JRC CALCULATION FOR ALL EU FERTILIZER, INCLUDING IMPORTS	3774		gCO2e/kg **N**

Emissions from acidification: N fertilizers cause acidification in the soil. The acid reacts with carbonate in the soil (or downstreams in river-beds or the sea), releasing CO_2. The carbonate can come from rock naturally present in the soil, or from applied agricultural lime. In either case, we attribute these emissions to fertilizer use rather than lime use. That is because in some cases more lime is used to counter natural soil acidity, and this gives different emissions per kg of lime. Refer to Section 3.10 for details of this calculation and of emissions from aglime use not attributable to fertilizer.**Figure** 1 explains the processes in the calculation of emissions from production of N fertilizer used in EU. The calculation uses the input data described in Table 46.

Figure 1 EU Nitrogen fertilizer production sources

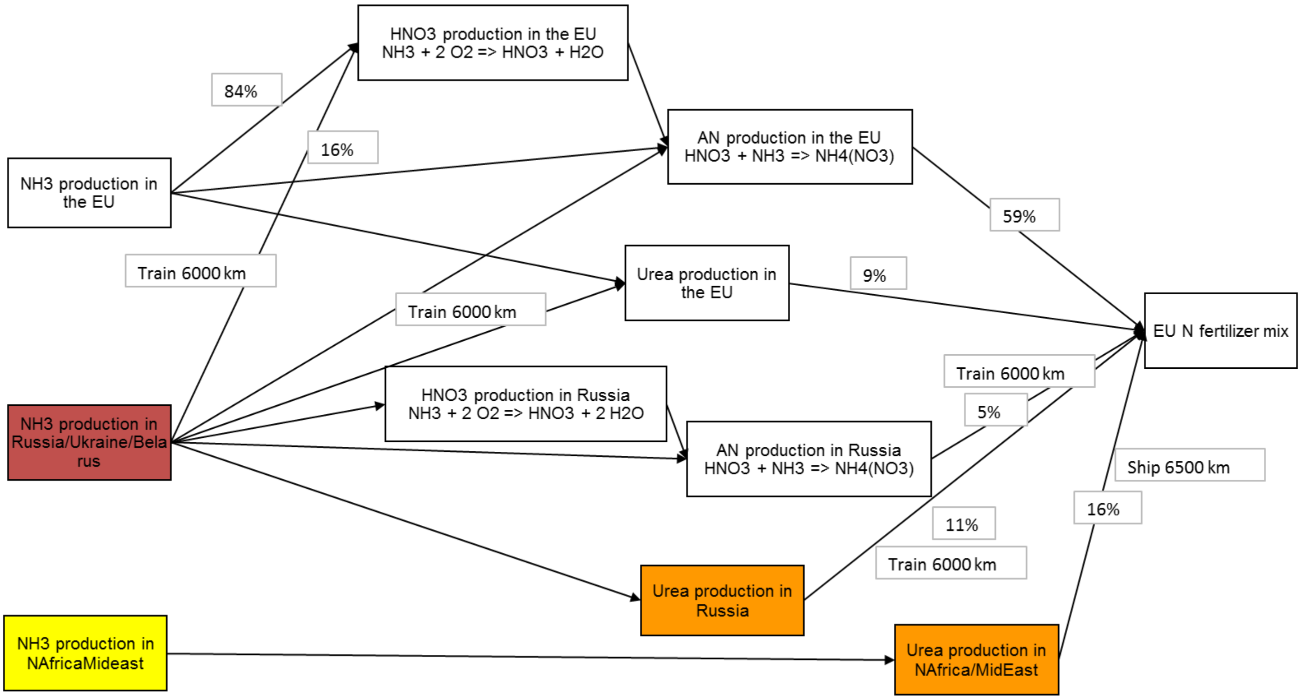


Table 46 Input data for fertilizer manufacturing emissions calculation

Ammonia production in the EU		
2011 average Fertilizers Europe total-energy use in EU ammonia plants* (Ref. 7)	35.3	GJ/t NH_3
2011 (last available information) energy use for EU ammonia other than NG (Ref. 8)	0.5	GJ/t NH_3
2011 EU NG use for ammonia (latest available information)	34.8	GJ/t NH_3
* Includes NG, electricity and other energy inputs. Does not include upstream energy losses. Assumption: fraction of imports (ammonia and solid fertilizers) remains constant at last-reported values: 2008-9		
N_2O emissions from nitric acid plants in EU		
2011 EU average (last reported "European reference"emissions reported by Fertilizers Europe, 2014) (Ref. 7)	0.87	kg N2O/t HNO3
2020 EU average (ETS benchmark) (Ref. 2)	1.0134	kg N2O/t HNO3
Note: For current emissions, we use the latest GHG emissions from EU ammonia and nitric acid plants reported by Fertilizers Europe.		
Minor inputs for EU fertilizer plants (EU data, but assumed the same for outside the EU)		
Electricity for ammonium nitrate plant 'is less than..' (Ref. 3)	1	GJ/t AN
Electricity for urea plant (Ref. 3)	5	GJ/t Urea
Calcium ammonium nitrate is assumed to have same emissions per tonne of N as ammonium nitrate (emissions from CaO are relatively small)		
Note: urea manufacture reacts to ammonia with otherwise-emitted CO_2. However, the CO_2 is lost when urea decomposes on the field. We count neither the sequestration nor the emission. However, in their carbon footprint calculations, Fertilizers Europe (Ref. 7) count both CO2 sequestration in the urea plant and CO2 emission when urea is used on the field.		
IMPORTED UREA		
Assumption: the part of urea that is imported to EU comes from North Africa, especially Egypt (Ref. 6) (China exports > 50% world urea with much higher (coal) emissions, but it is further away).		
Fraction of EU-consumed Urea-type fertilizers imported (see table Trade data below).	**75%**	
IMPORTED AMMONIUM NITRATE		
Imports are mostly from Russia, Ukraine and Belarus (Ref. 6): we represent them with weighted average of data for Russian and Ukrainian production.		
Fraction of EU-consumed AN -type fertilizer imported (Ref. 5)	**8%**	
N2O emissions from imported AN production are calculated from the total emissions in quoted in (Ref. 9) (which we understand come from a complete LCA by Integer Consultants), assuming emissions for AN from other sources are the same as in EU 2007.		
LCA emissions for AN supply 2013 (Ref. 9)		
	Russia	
	3130	g per kg AN
	0.35	N/AN
	8943	g per kg N in AN
Emissions from other-than-N2O*	3127	CO2e/kg N in AN

Emissions from N2O	5816	CO2e/kg N in AN
Emissions from N2O	19.52	gN2O/kg N in AN
*calculated by E3database using EU 2007 data on other emissions sources.		
IMPORTED AMMONIA		
Fraction of ammonia used in EU which is imported	16%	
Assumption: all ammonia imports are from Russia, Ukraine and Belarus (Ref. 6): we use weighted average data.		
UPSTREAM ELECTRICITY AND TRANSPORT ASSUMPTIONS		
Electricity for fertilizer production generated via a natural gas fuelled combined cycle (CCGT) power plant with an efficiency of 55%		
Transport from Russia to EU via train over a distance of 6000 km		
Maritime transport of urea from Damietta in Egypt to Rotterdam in the EU over a distance of 6500 km		
Electricity for the train derived from the Russian electricity mix		
Natural Gas consumption for ammonia and urea production outside EU (Fertilizers Europe, 2012) (on-site NG consumption only).		

	NG use MMbtu/tonne NH3 2014 [1]	**NG use MMbtu/tonne urea 2014**	**NG use GJ/tonne NH3 2014**	**NG use GJ/tonne urea 2014**	**NG use kWh/kg urea 2014**	**NG use kWh/kg N in urea 2014**
Russia, Ukraine, Belarus	36.9	26.9	34.938	25.5	7.0721	15.161
N.Africa	37	not reported	35.1	25.6	7.0990	15.219

Trade data

EU trade (2009) in kilo tonnes of nitrogen	**Ammonia**	**Ammonium nitrate**	**Calcium ammonium nitrate**		**Urea**	**Ammonium sulphate**		**Total**
	NH_3 (Ref. 4)	AN (Ref. 5)	CAN (Ref. 4)	AN+CAN	U (Ref. 5)	AS (Ref. 4)	U+AS	
Imports	3 173	165			1 524			
Exports	914							
EU consumption	13 975	2 097	2 811	4 907.5	2 024	745	2 769	7 676
% imported per type	**16 %**	**8 %**			**75 %**			
% of AN and urea in EU-consumed N fertilizer (in terms of N content)				**64 %**			**36 %**	

Sources

1 Hoxha, A., Fertilizers Europe, personal communication February 2012 (quoting forward projections by Fertecon, a fertilizer consultancy company).

2 Commission proposal for Emission Trading System (ETS) benchmarking of EU fertilizer industry (via Heiko Kunst, Climate Action, December 2010).

3 Werner, 2009.

4 IFA statistics for 2009, accessed February 2011.

5 Hoxha, A., Fertilizers Europe (former EFMA), personal communication, 20 February 2010 (for agricultural use only (important for urea and AN), average of 2008/9 and 2009/10 data).

6 Palliere, C., Fertilizers Europe (former EFMA), personal communication, December 2010.

7 Hoxha, A., Fertilizers Europe, personal communication, May 2014.

8 Hoxha, A., Fertilizers Europe, personal communication, February 2011.

9 Mackle, Fertilizers Europe, 2013, accessed May 2014.

10 Fertilizers Europe, 2014.

2.4 Summary of emission factors for the supply of main products

For ease of reference, Table 47 summarises the emission factors for provision of various fossil fuels, fertilizers, chemicals and other conversion inputs.

Table 47 Emission factors for fossil fuels, fertilizers and chemicals

Emission factors		Net GHG emitted [g $CO_{2\ eq.}$/MJ]	CO_2 [g/MJ]	CH_4 [g/MJ]	N_2O [g/MJ]
Natural Gas	Supply	9.7	-	-	-
	Combustion	56.24	-	-	-
	Total	**66.0**	-	-	-
EU el. mix (Low Voltage)	Supply	150.11	139.93	0.33	6.39E-03
	Use	0.0	0.0	0.00	0.000
	Total	**150.1**	139.93	0.33	6.39E-03
EU el. mix (Medium Voltage)	Supply	141.13	131.56	0.31	6.00E-03
	Use	0.0	0.0	0.00	0.000
	Total	**141.1**	131.56	0.31	6.00E-03
Hard coal	Supply	16.21	6.50	0.39	2.50E-04
	Combustion	96.11	96.11	-	-
	Total	**112.3**	102.62	0.39	2.50E-04
Lignite	Supply	1.74	1.68	1.44E-03	5.56E-05
	Combustion	115.0	115.0	-	-
	Total	**116.7**	116.68	1.44E-03	5.56E-05
Heavy fuel oil	Supply	13.63	-	-	-
	Combustion	80.58	80.58	-	-
	Total	**94.2**	-	-	-
Diesel	Supply	21.85	-	-	-
	Combustion	73.25	73.25	0.00	0.00
	Total	**95.1**	-	-	-
Gasoline	Supply	19.88	-	-	-
	Combustion	73.42	73.42	0.00	0.00
	Total	**93.3**	-	-	-

CHEMICAL FERTILIZERS AND PESTICIDES					
		Net GHG emitted	**CO_2**	**CH_4**	**N_2O**
N fertilizer	Supply [g/kg]	**4 571.9**	3 876.50	2.17	2.15
P2O5 fertilizer	Supply [g/kg]	**541.7**	-	-	-
K2O fertilizer	Supply [g/kg]	**416.7**	-	-	-
Aglime (as CaO)	Supply [g/kg]	**69.7**	66.06	0.11	0.003
Pesticides	Supply [g/kg]	**12 010.7**	11 209.6	11.98	1.68
CHEMICALS AND OTHER INPUTS					
CaO as process chemical	Supply [g/kg]	**1 193.2**	1 188.47	0.10	0.008
HCl	Supply [g/kg]	**1 061.1**	977.07	2.91	0.038
Na_2CO_3	Supply [g/kg]	**1 245.1**	1 133.52	4.39	0.006
NaCl	Supply [g/kg]	**13.3**	12.69	0.02	0.001
NaOH	Supply [g/kg]	**529.7**	485.52	1.45	0.027
Ammonia	Supply [g/kg]	**2 351.3**	2 350.61	0.003	0.002
H_2SO_4	Supply [g/kg]	**217.5**	210.23	0.24	0.005
H_3PO_4	Supply [g/kg]	**3 124.7**	2 808.91	11.36	0.107
Cyclohexane	Supply [g/kg]	**723**	723	-	-
Lubricants	Supply [g/kg]	**947**	947	-	-
Alpha-amylase	Supply [g/kg]	**1 000**	1 000	-	-
Gluco-amylase	Supply [g/kg]	**7 500**	7 500	-	-
$Na(CH_3O)$	Supply [g/kg]	**2 425.5**	2 207.74	7.56	0.097
Methanol	Supply [g/MJ]	28.2	28.19	0.0001	0.000
	Combustion [g/MJ]	68.9	68.89		
	Total [g/MJ]	**97.1**	97.08	0.0001	0.000
n-hexane	Supply [g/MJ]	12.5	12.03	0.01	2.78E-04
	Combustion [g/MJ]	68.1	68.06		
	Total [g/MJ]	**80.5**	80.08	0.01	2.78E-04
KOH	Supply [g/kg]	**419.1**	403.04	0.40	0.021
N2	Supply [g/kg]	**56.4**	52.62	0.12	0.002
$(NH_4)_2SO_4$	Supply [g/kg]	**453.2**	420.87	1.29	2.00E-04
KH_2PO_4	Supply [g/kg]	**264.9**	238.69	0.91	0.012
$MgSO_4$	Supply [g/kg]	**191.8**	191.37	0.04	-0.002
$CaCl_2$	Supply [g/kg]	**38.8**	38.6	0.002	0.001
Antifoam	Supply [g/kg]	**3 274.8**	3 119.49	4.96	0.105
SO_2	Supply [g/kg]	**53.3**	52.05	0.03	0.001
DAP	Supply [g/kg]	**674.4**	653.18	0.81	0.004

2.5 Diesel, drying and plant protection use in cultivation

Bonn University supplied new input data on diesel use, crop drying and pesticide application from the CAPRI database (6). Several pathways have been updated with the new data.

2.5.1 Diesel use in cultivation

The CAPRI data used to calculate diesel use in cultivation are shown in Table 48.

The diesel and "pesticide" (= sum of pesticides, herbicides, fugicides, plant hormones etc.) from CAPRI are per-ha for EU27 in 2004. They are converted to per-kg crop using the average yields in 2009-2014 from Faostat.

Table 48 Diesel use in cultivation derived from CAPRI data

Crop	**Total diesel input (a)**	**Average of 2009 and 2014 moist yield**	**MJ diesel/kg of moist crop**
	MJ/ha	**kg/ha**	**MJ/kg**
Barley	3 240	4 546	**0.7127**
EU maize	3 311	7 129	**0.4645**
Rapeseed	2 987	3 150	**0.9484**
Rye and meslin	3 014	3 622	**0.8320**
EU soya	3 184	2 742	**1.1609**
Sugar beet	3 457	80 760[b]	**0.0428**
Sunflower	3 288	1 912	**1.7199**
Soft wheat	3 276	5 797[c]	**0.5650**

(a) Total diesel input from CAPRI (in litre/ha) converted to MJ/ha using diesel LHV of 35.9 MJ/litre and weighted using percentage of tillage system per ha.

(b) The average equivalent yield at nominal 16% sugar for countries making sugar beet ethanol provided by the Confederation Internationale des Betteravies Europeans (CIBE, 2013) has been used.

(c) The yield for "common wheat" from Eurostat is increased by 2.3% to account for the higher yield of the part of feed-wheat that is from purpose-grown varieties with higher yields (see calculation in Section 3.7, Table 55).

Sources

1 CAPRI data converted to JRC format (M. Kempen, personal communication, March 2012).

2 Faostat and Eurostat (for common wheat) data for yields, accessed in October 2016.

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(6) See http://www.ilr.uni-bonn.de/agpo/rsrch/capri/capri_e.htm online.

3 CGB and CIBE, 2013. French Confederation of Sugar Beet producers and Confederation Internationale des Betteravies Europeans, response to Commission stakeholder meeting in Brussel, May 2013, received by JRC in June 2013.

2.5.2 Crop drying

These data were calculated from CAPRI results per crop.

Table 49 CAPRI drying data

Crop	**Average % of water removed from each crop**
Barley	**0.12**
Maize	**6.10**
Rapeseed	Unchanged
Rye and meslin	**0.23**
Sugar beet	Not dried
Sunflower	Unchanged
Soft wheat	**0.20**

Comments

- The average % of water removed from each crop for cereals has been calculated using CAPRI. Drying in France and Poland was set at zero. Also for many NUTS2 regions, drying is not needed according to CAPRI, and these are counted "zero" in the average % of drying that is needed. The final water content was set at 16%, on the basis that further drying for long-term storage can be reached by mixing in the store with drier grain, and by ventilation during storage. The average % of water removed from each crop is linked to our drying pathways, as explained in each pathway affected (wheat, maize, rye, barley, triticale) in Section 6.
- Drying of rapeseed and sunflower (not reported by CAPRI) has been corrected by Ludwig-Bölkow-Systemtechnik GmbH (LBST) (Weindorf, W., personal communication, 22 March 2012). There had been a misunderstanding of the text in the original literature. The diesel input for the drying process derived from Umweltbundesamt (the German Federal Environment Agency) (UBA, 1999) is indicated per kilogram of removed water, and not per tonne of rapeseed. The text in UBA (1999) states: 'Storage and drying (per t of mazie): 12.6 kWh electricity; 0.12 l of heating oil and 0.1 kWh of electricity per kg of water removed'. Initially, it had been assumed that the amount of heating oil is related to 1 t of rapeseed grain. According to LBST, the light heating oil is often used as heat source for drying (not for diesel engines, for mechanical drives for handling), and as a result, the consumption of light heating oil (considered here to equal diesel fuel in carbon intensity) depends on the water content. In contrast to the 0.1 kWh of electricity plus 0.12 l of heating oil (which are per tonne of removed water) the 12.6 kWh are probably the electricity requirement for handling and therefore per tonne of rapeseed grain.)

Sources

1 CAPRI data (M. Kempen, personal communication, October 2016).

2 UBA, 1999.

2.5.3 Pesticides

Pesticides use in kg/ha is back-calculated from CAPRI’s reported data (MJ primary energy for pesticides)/ha per crop.

Table 50 CAPRI data on primary energy for inputs, used to convert CAPRI output to our input data

Direct energy component	Cumulative energy demand	Unit
Diesel	45.7	MJ/l
Electricity (at grid)	11.7	MJ/kWh
Heating gas (in industrial furnace)	47.9	MJ/m3
Heating oil (in industrial furnace)	49.7	MJ/l

Source

1 Ecoinvent, 2003 (shown in Kranzlein, 2011, *CAPRI manual,* Chapter 7.5, 'Energy use in Agriculture').

Table 51 Pesticide use

Crop	kg pesticides/ha	g pesticide/kg of moist crop
Barley	3.915	0.861
EU maize	7.026	0.986
Rapeseed	6.610	2.099
Rye and meslin	1.696	0.468
EU soya	7.540	2.749
Sugar beet	18.030	0.223
Sunflower	2.603	1.362
Soft wheat	5.853	1.010

Sources

1 CAPRI data converted to JRC format using information in Ref. 2 and Ref. 3 (M. Kempen, personal communication, March 2012).

2 Kraenzlein, 2011.

3 Kempen and Kraenzlein, 2008.

4 Faostat and Eurostat (for common wheat) data for yields (see Table 48), accessed in October 2016.

3. Soil emissions from biofuel crop cultivation

3.1 Background

Typical soil N_2O emission values for wheat, rapeseed, sugar beet and sunflower cultivation in the RED are based on results from the DeNitrification DeComposition (DNDC) biogeochemistry model runs for Europe. For oil palm, maize, soybean and sugar cane, typical soil N_2O emissions were calculated following the IPCC (2006) Tier 1 approach (with modifications for soybean and oil palm).

The RED (Article 19.2) and RED-2 (Article 29.2) ask EU Member States to apply a method for the calculation of the typical greenhouse gas (GHG) emissions from cultivation of agricultural raw materials at NUTS 2 level that takes into account soil characteristics, climate and expected raw material yields. These rules are complimented by the European Commission’s Communication on the practical implementation of the EU biofuels and bioliquids sustainability scheme and on counting rules for biofuels (7) as well as by Commission’s guidelines for the calculation of land carbon stocks for the purpose of Annex V of RED (8). However, no specific guidance on the calculation method is offered.

Soil N_2O field measurements are costly and are usually not available for all crops and environmental conditions in a country. Complex biogeochemistry models (like the DNDC, for instance) fulfil the RED specification in terms of considering environmental aspects, but would require extensive data input and specific expertise. The IPCC (2006) Tier 1 method to calculate N_2O emissions from managed soils is easy to apply, but it does not take into account varying environmental aspects. Therefore, we present an easily replicable approach, applicable for the major crops in most regions of the world that takes into account the influence of soil conditions and climate on the emission of N_2O from soils due to potential biofuel crop cultivation.

3.2 Pathways of N2O emission from managed soils

According to the IPCC (2006), the emissions of N_2O that result from fertilizer N inputs to agricultural soils occur through the following:

- **the direct pathway** (i.e. directly from the soils to which the N is added/released);
- **two indirect pathways**:
    - following volatilisation of NH_3 and NO_x from managed soils and the subsequent re-deposition of these gases and their products NH_4^+ and NO_3^- to soils and waters;
    - after leaching and run-off of N, mainly as NO_3^- (IPCC, 2006).

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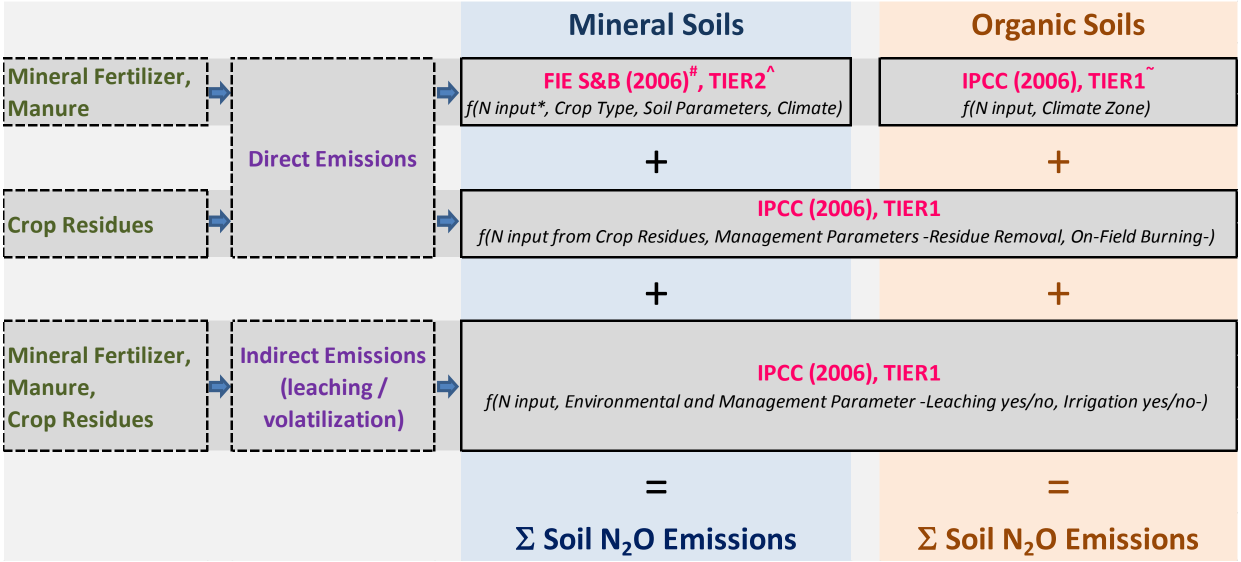
(7) 2010/C 160/2, 19.6.2010.

(8) Commission's Decision of 10 June 2010, 2010/335/EU, L 151/19, 17.6.2010.

3.3 General approach to estimate soil N2O emissions from cultivation of potential biofuel crops

In the IPCC Tier 1 method (IPCC, 2006) to calculate N_2O emissions from managed soils, the single global emission factor (EF_1) for direct emissions from mineral fertilizer and manure input is based on fertilizer-induced emissions (FIEs). FIEs are defined as the direct emissions from a fertilised plot, minus the emissions from an unfertilised control plot (all other conditions being equal to those of the fertilised plot), expressed as a percentage of the N input from fertilisation (Stehfest and Bouwman, 2006). In our approach, for mineral soils the IPCC Tier 1 emission factor EF_1 is substituted with Tier 2 disaggregated crop-specific emission factors for different environmental conditions (EF_{1ij}), by applying the statistical model developed by Stehfest and Bouwman (2006) to calculate crop- and site-specific FIEs (i.e. EF_{1ij}) as outlined in Figire 2.

Figure 2 Method applied to estimate N2O emissions from fertilized managed soils



$^{\#}$Fertilizer Induced Emissions (FIE) based on the model of Stehfest and Bouwman (2006). $^{\sim}$TIER 1 = global emission factor,$^{\wedge}$TIER 2 = crop and site specific emission factor,* from mineral fertilizer and manure

The model of Stehfest and Bouwman (2006) has not been validated for organic soils/peatlands. Hence, the IPCC (2006) the Tier 1 emission factor is maintained for direct emissions from fertilizer input to organic soils.

For all other N sources (crop residues, organic soils) and pathways (indirect emissions from mineral soils and organic soils), the IPCC (2006) Tier 1 method is applied. IPCC (2006) does not provide default values for crop residues from some of the potential biofuel crops. In such cases (e.g. oil palm and coconut), the missing parameters were taken from the literature. For soybean, the nitrogen content in below-ground biomass was updated based on recent findings (Singh, 2010; Chudziak & Bauen, 2013) (9).

Compost, sewage sludge, rendering waste and N input from grazing animals are not considered likely N sources in biofuel crop cultivation.

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(9) As described in Section 3.9, 'Correction of IPCC method for estimating N2O emissions from leguminous crops'.

Following the naming conventions in the IPCC (2006) guidelines (10), the calculation for a potential biofuel crop at a specific location and under a specific management system (e.g. fertilizer input), can be expressed as:

$$N_2O_{total} - N = N_2O_{direct} - N + N_2O_{indirect} - N$$

With

$$N_2O_{direct} - N = [(F_{SN} + F_{ON}) \bullet EF_{1ij}] + [F_{CR} \bullet EF_1]$$

for mineral soils and

$$N_2O_{direct} - N = [(F_{SN} + F_{ON}) \bullet EF_1] + [F_{CR} \bullet EF_1] + [F_{OS,CG,Temp} \bullet EF_{2CG,Temp}] + [F_{OS,CG,Trop} \bullet EF_{2CG,Trop}]$$

for organic soils and

$$N_2O_{indirect} - N = [((F_{SN} \bullet Frac_{GASF}) + (F_{ON} \bullet Frac_{GASM})) \bullet EF_4] + [(F_{SN} + F_{ON} + F_{CR}) \bullet Frac_{Leach-(H)} \bullet EF_5]$$

for both mineral and organic soils.

Crop residue N input is calculated for:

a) sugarbeet, sugarcane according IPCC (2006) Vol. 4 Chapter 11 Eq. 11.6, not considering below-ground residues and with the addition of N input from vignasse and filtercake in the case of sugarcane, as

$$F_{CR} = Yield \bullet DRY \bullet (1 - Frac_{Burnt} \bullet C_f) \bullet [R_{AG} \bullet N_{AG} \bullet (1 - Frac_{Remove})] + F_{VF}$$

b) coconut and oil palm plantations applying a fixed N input based on literature as IPCC (2006) provides no default calculation method (see Table 52)

c) for all other crops according IPCC (2006) Vol. 4 Chapter 11 Eq. 11.7a [11, 12], as

$$F_{CR} = (1 - Frac_{Burnt} \bullet C_f) \bullet AG_{DM} \bullet N_{AG} \bullet (1 - Frac_{Remove}) + (AG_{DM} + Yield \bullet DRY) \bullet R_{BG-BIO} \bullet N_{BG}$$

$$AG_{DM} = (Yield / 1000 \bullet DRY \bullet slope + intercept) \bullet 1000$$

Where

$N_2O_{total} - N$ = direct and indirect annual N_2O–N emissions produced from managed soils; kg N_2O–N ha^{-1} a^{-1}

$N_2O_{direct} - N$ = annual direct N_2O–N emissions produced from managed soils; kg N_2O–N ha^{-1} a^{-1}

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(10) Volume 4, Chapter 11.

(11) there was an error in Equation 11.7a which has been corrected in the latest version of the IPCC (2006) guidelines. This correction results in a significant increase of the nitrogen input from below-ground crop residues compared to previous calculations reported here.

(12) Equation 11.7A in IPCC (2006) Vol.4, Ch. 11 has been modified. The equation as it is given in IPCC (2006) considers that agricultural burning affects below-ground biomass in the same way as above-ground biomass, which seems unlikely and we do not consider this in GNOC. We reported this issue to IPCC and we are waiting for a reply. This change causes a small increase of N input from below-ground crop residues (only in regions where our data set assumes crop residue in-field burning - s. Table 261) compared to previous calculations reported here.

$N_2O_{indirect} - N$ = annual indirect N_2O–N emissions (i.e. annual amount of N_2O–N produced from atmospheric deposition of N volatilised from managed soils and annual amount of N_2O–N produced from leaching and run-off of N additions to managed soils in regions where leaching/run-off occurs); kg N_2O–N ha^{-1} a^{-1}

F_{SN} = annual synthetic N fertilizers input; kg N ha^{-1} a^{-1}

F_{ON} = annual animal manure N applied as fertilizer; kg N ha^{-1} a^{-1}

F_{CR} = annual amount of N in crop residues (above-ground and below-ground); kg N ha^{-1} a^{-1}

$F_{OS,CG,Temp}$ = annual area of managed/drained organic soils under cropland in temperate climate; ha a^{-1}

$F_{OS,CG,Trop}$ = annual area of managed/drained organic soils under cropland in tropical climate; ha a^{-1}

$Frac_{GASF}$ = 0.10 (kg N NH_3–N + NO_x–N) (kg N applied)$^{-1}$. Volatilisation from synthetic fertilizer

$Frac_{GASM}$ = 0.20 (kg N NH_3–N + NO_x–N) (kg N applied)$^{-1}$. Volatilisation from all organic N fertilizers applied

$Frac_{Leach-(H)}$ = 0.30 kg N (kg N additions) $^{-1}$. N losses by leaching/run-off for regions where leaching/run-off occurs

EF_{1ij} = Crop and site-specific emission factors for N_2O emissions from synthetic fertilizer and organic N application to mineral soils (kg N_2O–N (kg N input) $^{-1}$); The calculation of EF_{1ij} is described in Section 3.4

EF_1 = 0.01 [kg N_2O–N (kg N input) $^{-1}$]

$EF_{2,CG,Temp}$ = 8 kg N ha^{-1} a^{-1} for temperate organic crop and grassland soils

$EF_{2CG,Trop}$ = 16 kg N ha^{-1} a^{-1} for tropical organic crop and grassland soils

EF_4 = 0.01 [kg N_2O–N (kg N NH_3–N + NO_x–N volatilised) $^{-1}$]

EF_5 = 0.0075 [kg N_2O–N (kg N leaching/run-off) $^{-1}$]

$Yield$ = annual fresh yield of the crop (kg ha^{-1})

DRY = dry matter fraction of harvested product [kg d.m. (kg fresh weight)$^{-1}$] (see Table 52)

$Frac_{Burnt}$ = Fraction of crop area burnt annually [ha (ha)$^{-1}$] (see Table 261)

C_f = Combustion factor [dimensionless] (see Table 52)

R_{AG} = Ratio of above-ground residues dry matter to harvested dry matter yield for the crop [kg d.m. (kg d.m.)$^{-1}$] (see Table 52)

N_{AG} = N content of above-ground residues [kg N (kg d.m.)$^{-1}$] (see Table 52)

$Frac_{\mathrm{Remove}}$ = Fraction of above-ground residues removed from field [kg d.m. (kg AGDM)$^{-1}$] (see Table 260)

F_{VF} = Annual amount of N in sugarcane vignasse and filtercake returned to the field [kg N ha^{-1}], calculated as Yield * 0.000508. The amount of N in sugarcane vignasse and filtercake returned to the field per kg of sugar cane harvested is based on the data given in UNICA (2005)

AG_{DM} = Above-ground residue dry matter [kg d.m. ha^{-1}]

$slope$ = Slope values to calculate AGDM for the different crops from Yield are given in Table 52

$intercept$ = Intercept values to calculate AGDM for the different crops from Yield are given in Table 52

R_{BG-BIO} = Ratio of belowground residues to above-ground biomass [kg d.m. (kg d.m.)$^{-1}$] (see in Table 52)

Table 52 Crop specific parameters to calculate N input from crop residues

Crop	**Calculation method**	**DRY**	**LHV**	**N_{AG}**	**slope**	**intercept**	**R_{BG_BIO}**	**N_{BG}**	**Cf**	**R_{AG}**	**Fixed amount of N in crop residues (kg N ha^{-1})**	**Data sources***
Barley	IPCC (2006) Vol. 4 Ch. 11 Eq. 11.7a	0.865	17	0.007	0.98	0.59	0.22	0.014	0.8			1, 2
Cassava	IPCC (2006) Vol. 4 Ch. 11 Eq. 11.7a	0.302	16.15	0.019	0.1	1.06	0.2	0.014	0.8			1, 2
Coconuts	Fixed N from crop residues	0.94	32.07								44	1, 3
Cotton	No inform. on crop residues	0.91	22.64									
Maize	IPCC (2006) Vol. 4 Ch. 11 Eq. 11.7a	0.86	17.3	0.006	1.03	0.61	0.22	0.007	0.8			1, 2
Oil palm fruit	Fixed N from crop residues	0.66	24								159	1, 4
Rapeseed	IPCC (2006) Vol. 4 Ch. 11 Eq. 11.7a	0.91	26.976	0.011	1.5	0	0.19	0.017	0.8			1, 5
Rye	IPCC (2006) Vol. 4 Ch. 11 Eq. 11.7a	0.86	17.1	0.005	1.09	0.88	0.22	0.011	0.8			1, 6
Safflower seed	No inform.on crop residues	0.91	25.9									
Sorghum (grain)	IPCC (2006) Vol. 4 Ch. 11 Eq. 11.7a	0.89	17.3	0.007	0.88	1.33	0.22	0.006	0.8			1, 7
Soybeans	IPCC (2006) Vol. 4 Ch. 11 Eq. 11.7a	0.87	23	0.008	0.93	1.35	0.19	0.087	0.8			1, 8
Sugar beets	IPCC (2006) Vol. 4 Ch. 11 Eq. 11.6	0.25	16.3	0.004					0.8	0.5		1, 9
Sugar cane	IPCC (2006) Vol. 4 Ch. 11 Eq. 11.6	0.275	19.6	0.004					0.8	0.43		1, 10
Sunflower seed	IPCC (2006) Vol. 4 Ch. 11 Eq. 11.7a	0.9	26.4	0.007	2.1	0	0.22	0.007	0.8			1, 11
Triticale	IPCC (2006) Vol. 4 Ch. 11 Eq. 11.7a	0.86	16.9	0.006	1.09	0.88	0.22	0.009	0.8			1, 2
Wheat	IPCC (2006) Vol. 4 Ch. 11 Eq. 11.7a	0.84	17	0.006	1.51	0.52	0.24	0.009	0.9			1, 2

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1 References for parameters DRY and LHV see Appendix 1. Fuel/feedstock properties of this report

2 IPCC (2006) Vol. 4 Chapter 11 Table 11.2 (Factor a=Slope, b=Intercept, N_{AG}, $R_{BG\text{-}BIO}$ and N_{BG}) and Chapter 2 Table 2.6 (Factor Cf). For Cassava and Triticale the general values for "Tubers" and "Cereals" respectively, are considered.

3 Magat (2002), Mantiquilla et al. (1994), Koopmans and Koppejan (1998), Bethke (2008) (data compilation by W. Weindorf. Ludwig Boelkow Systemtechnik GmbH, Ottobrunn, Germany)

4 Schmidt (2007) (data compilation by R. Edwards, JRC, Ispra, Italy)

5 N_{AG} and N_{BG} from Trinsoutrot et al. (1999) Table 1. Residue to seed ratio and factor a is based on Scarlat et al. (2010) Table 1. Ratio of belowground residues to above-ground biomass ($R_{BG\text{-}BIO}$) assumed to be the same as for beans and pulses in IPCC (2006) Vol. 4 Chapter 11 Table 11.2.

6 IPCC (2006) Vol. 4 Chapter 11 Table 11.2, value for R_{BG_BIO} assumed to be similar to Grains

7 IPCC (2006) Vol. 4 Chapter 11 Table 11.2, value for R_{BG_BIO} assumed to be similar to Maize

8 IPCC (2006) Vol. 4 Chapter 11 Table 11.2, except N_{BG} which is underestimated in IPCC (2006) according Chudziak and Bauen (2013).

9 Due to lack of information on below-ground residues for sugar beet, a modified method was used which does not take into account the below-ground biomass. The value for RAG and N content of above-ground residues was adopted from the EDGAR database (European Commission Joint Research Centre (JRC) / Netherlands Environmental Assessment Agency (PBL), 2010). However there is large disagreement between the R_{AG} and N_{AG} values for Sugar beets applied in different countries (see Adolfsson, 2005).

10 Sugarcane is a semi-perennial crop. Sugarcane is typically replanted every six or seven years. For this period the root system remains alive. As IPCC (2006) does not provide default values, a modified method was used which does not take into account the below-ground biomass. The value for RAG and N content of above-ground residues was adopted from the EDGAR database (European Commission Joint Research Centre (JRC) / Netherlands Environmental Assessment Agency (PBL), 2010).

11 Del Pino Machado, A.S. (2005) gives 0.0072 kg N per kg per dry matter of sunflower shoots. Corbeels et al. (2000) report a 0.0067 kg N per kg per dry matter in stalks. For GNOC a value of 0.007 kg N per kg above-ground residues dry matter was applied. Value - a - for the calculations of N input from crop residues according IPCC (2006) is based on the average of the “residue to crop production” values given for sunflower in Table 1 of Scarlat et al. (2010) Ratio of belowground residues to above-ground biomass and NBG assumed to be the same as IPCC (2006) gives for maize.

3.4 Determining crop- and site-specific fertilizer-induced emissions (EF1ij)

The Stehfest and Bouwman (2006) statistical model (hereafter referred to as the S&B model) describes on-field N_2O emissions from soils under agricultural use, based on the analysis of 1 008 N_2O emission measurements in agricultural fields under different environmental conditions and for 6 agricultural land use classes, as:

$$E = \exp(c + \sum ev)$$

where

E = N_2O emission (in kg N_2O-N ha^{-1} a^{-1})

c = constant (see Table 53)

ev = effect value for different drivers (see Table 53)

Table 53 Constant and effect values for calculating N2O emissions from agricultural fields after S&B

Constant value	-1.516	
Parameter	**Parameter class or unit**	**Effect value (ev)**
Fertilizer input		0.0038 * N application rate in kg N ha^{-1} a^{-1}
Soil organic C content	<1 %	0
	1-3 %	0.0526
	>3 %	0.6334
pH	<5.5	0
	5.5-7.3	-0.0693
	>7.3	-0.4836
Soil texture	Coarse	0
	Medium	-0.1528
	Fine	0.4312
Climate	Subtropical climate	0.6117
	Temperate continental climate	0
	Temperate oceanic climate	0.0226
	Tropical climate	-0.3022
Vegetation	Cereals	0
	Grass	-0.3502
	Legume	0.3783
	None	0.5870
	Other	0.4420
	Wetland rice	-0.8850
Length of experiment	1 yr	1.9910

For the calculations, the potential biofuel crops are assigned to the different vegetation classes as shown in Table 54.

Table 54 Potential biofuel crops assignment to S&B vegetation classes

Potential biofuel crop	S&B vegetation class
Barley	Cereals
Cassava	Other
Coconut	Other
Maize	Other (^{a})
Oil palm	Other
Rapeseed	Cereals (^{b})
Rye	Cereals
Safflower	Other
Sorghum	Cereals
Soybean	Legumes
Sugar beet	Other
Sugar cane	Other
Sunflower	Other
Triticale	Cereals
Wheat	Cereals

^{a}) Following the classification of crop types in Stehfest and Bouwman (2006), row crops are summarised in the vegetation class 'other'.

^{b}) Re-evaluating the S&B collection of measurement sites "Rapeseed" showed emissions more similar to the "Cereals" S&B vegetation class than to the row crops vegetation class "Other".

Applying the S&B model, the EF_{1ij} for the biofuel crop i at location j is calculated as:

$$EF_{1ij} = (E_{\text{fert},ij} - E_{\text{unfert},ij})/N_{\text{appl},ij}$$

where

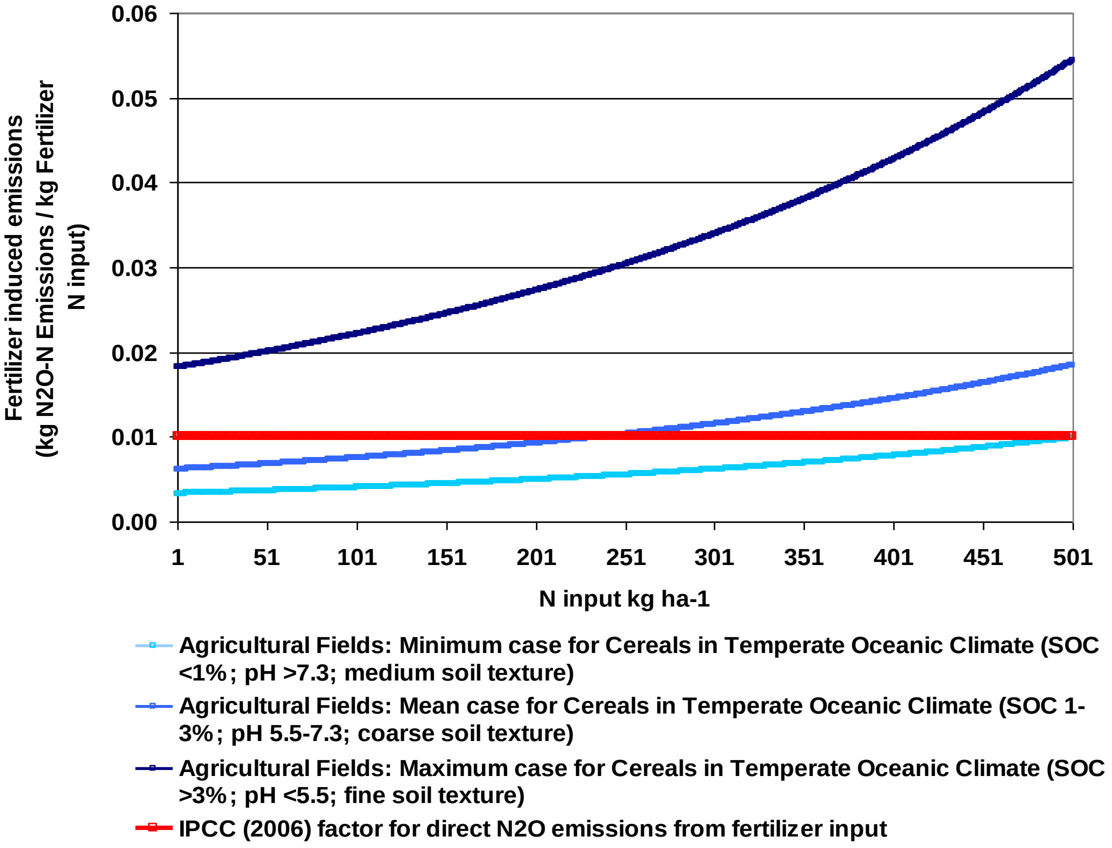
$E_{\text{fert},ij}$ = N_2O emission (in kg N_2O-N ha^{-1} a^{-1}) based on S&B, where the fertilizer input is actual N application rate (mineral fertilizer and manure) to the biofuel crop i at location j

$E_{\text{unfert},ij}$ = N_2O emission of the biofuel crop i at location j (in kg N_2O-N ha^{-1} a^{-1}) based on S&B. The N application rate is set to 0, all the other parameters are kept the same

$N_{\text{appl},ij}$ = N input from mineral fertilizer and manure (in kg N ha^{-1} a^{-1}) to the biofuel crop i at location j

Figure 3 shows the potential variation of the of EF_{1ij} based on the S&B model as described above, for cereals cultivated in temperate oceanic climate on different soils (low-medium-high soil organic carbon content, low-medium-high pH, fine-coarse soil texture), and for different levels of fertilizer N input. The red line represents the IPCC (2006) factor (EF_1) for direct N_2O emissions from fertilizer input based on a global mean of the EF_{1ij}. EF_1 is replaced in our approach by the crop- and site- specific EF_{1ij} for direct emissions from mineral fertilizer and manure N input, based on the crop- and site-specific EF_{1ij}, applying the S&B model.

Figure 3 Variation of fertilizer-induced emissions from agricultural soils under different environmental conditions and fertilizer input rates applying the S&B model



3.5 The Global crop- and site-specific Nitrous Oxide emission Calculator (GNOC)

To calculate soil N_2O emissions from potential biofuel feedstocks for the varying environmental conditions and management systems, we built the Global Nitrous Oxide Calculator (GNOC). Following the combined S&B/IPCC (2006) approach described previously, the GNOC allows calculation of crop- and site-specific soil N_2O emissions for a 5 min. by 5 min. (~10 km by 10 km) grid, globally, for the year 2000. The choice of the reference year was driven by the availability of the required data sets at high resolution. To minimise inconsistencies in the results due to varying detail or accuracy levels for different parts of the world, only spatial data sets with a global coverage were taken into consideration. Note that, in order to calculate default values, the inputs of nitrogen and the crop yields were adjusted using the latest-available data, as explained in section 3.7.

Main input data sets for the GNOC

Crop area and yield

Maps indicating area and yield for individual crops (grid cell size of 5 min. by 5 min.), based on remote sensing information and Food and Agriculture Organization of the United Nations (FAO) crop statistics for the year 2000, have been produced by Monfreda et al. (2008). Note that the yields were adjusted using the latest-available data for the purposes of calculating N2O emissions for default values.

N from mineral fertilizer

GNOC was set up for the year 2000, because that is the year for which we have comprehensive GIS data on crop distribution. However, for calculating default values, nitrogen inputs and yields were updated to the latest available data, as explained in section 3.7. Crop- and country-specific mineral fertilizer N rates are available from the FAO (2010) for the years ~2000. The IFA provides country-level total consumption of mineral fertilizer N (IFA, 2010). To cover lacking crop-specific N fertilizer input for some countries, the fertilizer rates were estimated based on crop-specific N fertilization rates for other countries, as well as on crop area and yield data from Monfreda et al. (2008). Crop-specific N input from the FAO or estimated values are calibrated to meet the IFA country totals. N input has been disaggregated to the 5 min. by 5 min. grid cell using crop area and yield data from Monfreda et al. (2008) and information on soil organic carbon content from the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009).

N from manure and other applied organic fertilizers

"Other applied organic fertilizers" includes digestate from biogas, and this is included in national statistics of "applied manure". Country-level manure N application for the year 2000 is available from the European Commission's Emissions Database for Global Atmospheric Research (EDGAR) v4.1 (2010). The N content of the manure was taken from the IPCC (2006) ([13]). Then part of the manure-N was allocated to cropland, proportional to the area of cropland compared to grassland in each country.

The manure-N allocated to cropland was further allocated to crops in proportion to the allocation of synthetic fertilizer. We would have preferred a more detailed approach, but data is very scarce: only a few countries provide estimates of manure-N per crop; these estimates have large statistical errors, and, perhaps because of this, there seems to be no consistent pattern of which crops get the highest proportion of their N requirements from manure. Nevertheless, it is clear that crops that use little synthetic nitrogen (e.g.

([13]) Volume 4, Chapter 10.

soybeans) also receive little manure, whereas highly-fertilized crops, such as maize, tended to receive more. On this basis, it is more accurate to assume that average manure-N application to a crop is proportional to its use of synthetic nitrogen, than to assume that all crops receive the same manure-N per hectare.

The GNOC online tool is designed to calculate total N2O emissions per hectare of cropland, and is not concerned with how much of this should be attributed to crops and how much to livestock production. Therefore all the nitrogen applied as manure is taken into account. However, as explained in section 3.8, when we apply GNOC to calculating default values, we should only consider emissions from the part of the manure-N that is available for crop growth, and not the part that is present in excess, which should be attributed to livestock.

N input from crop residues

N input from crop residues was calculated based on crop area and yield data from Monfreda et al. (2008), and by applying the default method described in IPCC (2006) ([14]), with modifications for certain crops based on EDGAR v4.1 (2010) and as described in Chapter 4.3.

Soil properties

Required soil properties were calculated based on the Harmonized World Soil Database Version 1.1, March 2009 (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009) by Hiederer (2009).

Ecological zones

A ecological zones map as defined in the IPCC (2006) ([15]) for the calculation of carbon stock changes was prepared and made available online by Hiederer et al. (2010).

Areas where leaching/run-off occurs

The IPCC (2006) ([16]) defines the area where leaching/run-off occurs as areas where Σ(rain in rainy season) - Σ (PE - potential evaporation - in same period) > soil water holding capacity, or where irrigation (except drip irrigation) is employed. The rainy season(s) can be taken as the period(s) when rainfall > 0.5 * pan evaporation. A global map delineating areas where leaching/run-off occurs was compiled based on climate and soil information, as described in Hiederer et al. (2010).

GNOC results for rapeseed cultivation in Europe

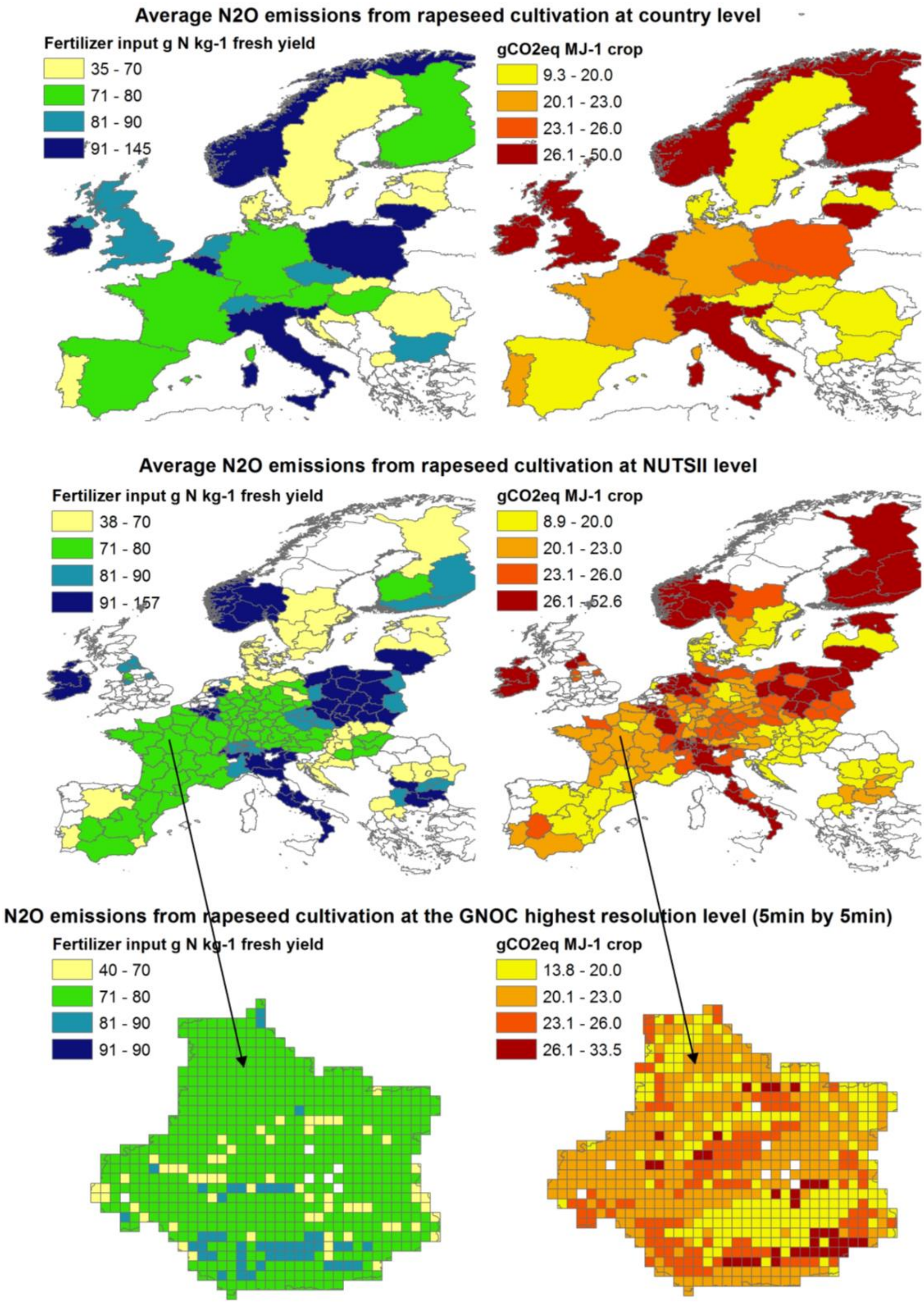
Based on GNOC, the country level N_2O emissions, e.g. from rapeseed (see Figure 4) vary considerably in Europe, reflecting to a certain extent the fertilizer input. However looking at the emissions at higher resolutions (NUTS II, 5 minutes grid), the variation on sub-country level can be as pronounced as the variation between the countries depending on management and environmental conditions.

([14]) Volume 4, Chapter 11.

([15]) Volume 4, Chapter 3 and Chapter 4.

([16]) Volume 4, Chapetr 11.

Figure 4 Fertilizer application (mineral fertilizer + 50% of manure) and soil N2O emissions (expressed as gCO2eq MJ-1 of fresh crop) from rapeseed cultivation at different spatial levels based on GNOC (reference year for fertilizer input and yield: 2000)

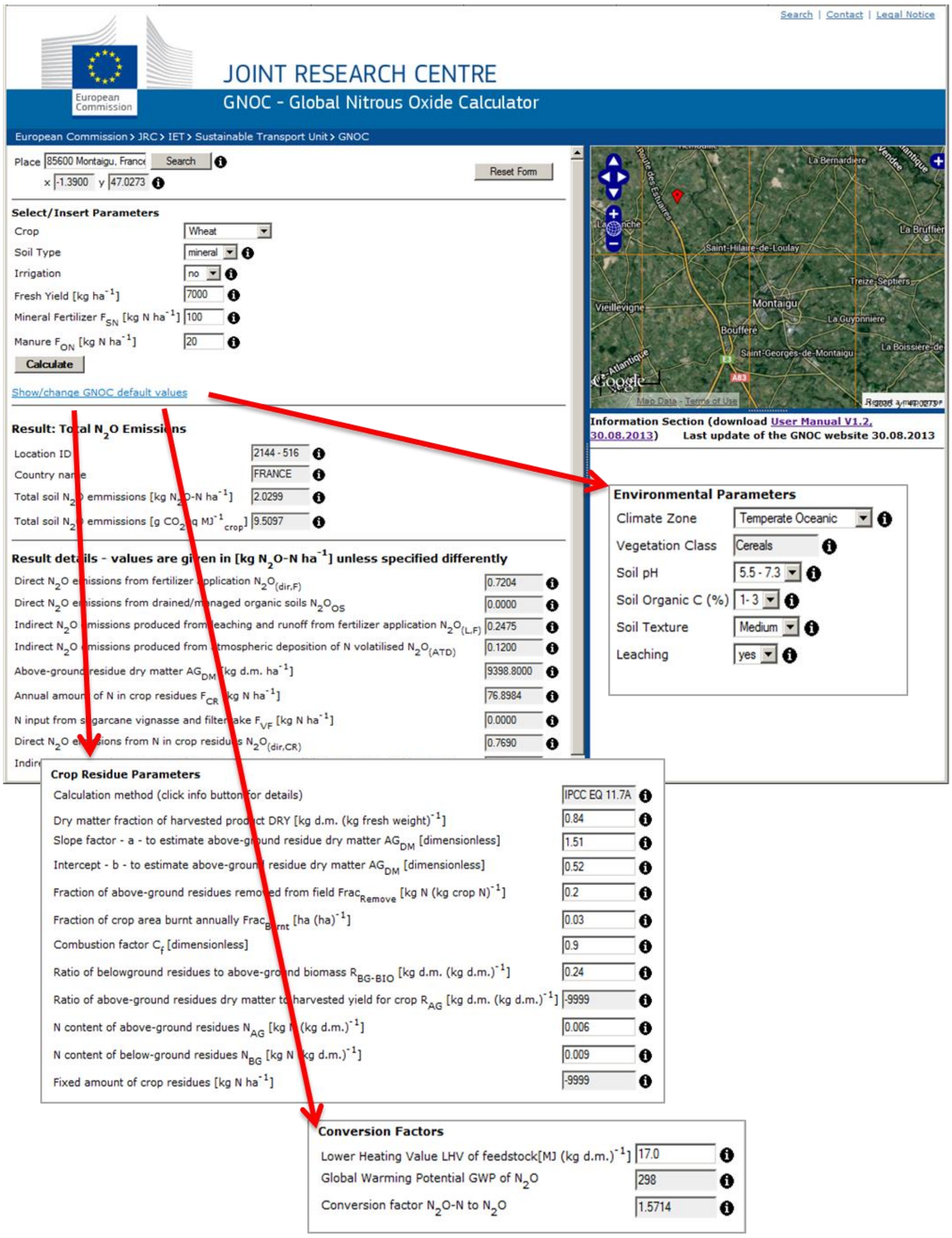


3.6 The GNOC online tool

The GNOC method allows the calculation of N_2O emissions from a wide range of potential biofuel crops, taking into account the influence of varying environmental conditions, as requested by the RED. An online tool (Figure 5) is available at http://gnoc.jrc.ec.europa.eu/ allowing the user to calculate soil N_2O emissions for a selected place based on

- GNOC default environmental and management data for this place as well as
- site specific information provided by the user (e.g. from field survey or high resolution maps).

Figure 5 The GNOC online tool



Place 85600 Montaigu, France
x -1.3900 y 47.0273

Select/Insert Parameters

Crop	Wheat
Soil Type	mineral
Irrigation	no
Fresh Yield [kg ha^{-1}]	7000
Mineral Fertilizer F_{SN} [kg N ha^{-1}]	100
Manure F_{ON} [kg N ha^{-1}]	20

Result: Total N_2O Emissions

Location ID	2144 - 516
Country name	FRANCE
Total soil N_2O emmissions [kg N_2O-N ha^{-1}]	2.0299
Total soil N_2O emmissions [g CO_2eq $MJ^{-1}{}_{crop}$]	9.5097

Result details - values are given in [kg N_2O-N ha^{-1}] unless specified differently

Direct N_2O emissions from fertilizer application $N_2O_{(dir,F)}$	0.7204
Direct N_2O emissions from drained/managed organic soils N_2O_{OS}	0.0000
Indirect N_2O emissions produced from leaching and runoff from fertilizer application $N_2O_{(L,F)}$	0.2475
Indirect N_2O emissions produced from atmospheric deposition of N volatilised $N_2O_{(ATD)}$	0.1200
Above-ground residue dry matter AG_{DM} [kg d.m. ha^{-1}]	9398.8000
Annual amount of N in crop residues F_{CR} [kg N ha^{-1}]	76.8984
N input from sugarcane vignasse and filter cake F_{VF} [kg N ha^{-1}]	0.0000
Direct N_2O emissions from N in crop residues $N_2O_{(dir,CR)}$	0.7690
Indire	

Information Section (download User Manual V1.2, 30.08.2013) Last update of the GNOC website 30.08.2013

Environmental Parameters

Climate Zone	Temperate Oceanic
Vegetation Class	Cereals
Soil pH	5.5 - 7.3
Soil Organic C (%)	1 - 3
Soil Texture	Medium
Leaching	yes

Crop Residue Parameters

Calculation method (click info button for details)	IPCC EQ 11.7A
Dry matter fraction of harvested product DRY [kg d.m. (kg fresh weight)$^{-1}$]	0.84
Slope factor - a - to estimate above-ground residue dry matter AG_{DM} [dimensionless]	1.51
Intercept - b - to estimate above-ground residue dry matter AG_{DM} [dimensionless]	0.52
Fraction of above-ground residues removed from field $Frac_{Remove}$ [kg N (kg crop N)$^{-1}$]	0.2
Fraction of crop area burnt annually $Frac_{Burnt}$ [ha (ha)$^{-1}$]	0.03
Combustion factor C_f [dimensionless]	0.9
Ratio of belowground residues to above-ground biomass R_{BG-BIO} [kg d.m. (kg d.m.)$^{-1}$]	0.24
Ratio of above-ground residues dry matter to harvested yield for crop R_{AG} [kg d.m. (kg d.m.)$^{-1}$]	-9999
N content of above-ground residues N_{AG} [kg N (kg d.m.)$^{-1}$]	0.006
N content of below-ground residues N_{BG} [kg N (kg d.m.)$^{-1}$]	0.009
Fixed amount of crop residues [kg N ha^{-1}]	-9999

Conversion Factors

Lower Heating Value LHV of feedstock[MJ (kg d.m.)$^{-1}$]	17.0
Global Warming Potential GWP of N_2O	298
Conversion factor N_2O-N to N_2O	1.5714

3.7 GNOC results

The update of the JEC-WTW data with GNOC results on soil N_2O emissions from biofuel crop cultivation required some adjustments and corrections.

- Mean emissions of the potential biofuel crop will not equal global mean emissions, but rather the weighted average emissions from suppliers of each crop to the EU market (including EU domestic production).
- A correction for changes in yields and fertilizer input since the year 2000 (see Table 55).

The final soil N_2O emissions are presented in Figure 6 as:

1. The weighted average N_2O emissions from biofuel crop cultivation in the year 2000 based on the GNOC (green bars).
2. The weighted global results from running the GNOC with the default IPCC Tier 1 emission factors for direct and indirect N_2O emissions from crop cultivation in the year 2000 (blue bars).
3. The weighted global average GNOC results corrected for more recent yield (average of 6 years, from 2009 to 2014) and fertilizer input (year 2010/11 for not EU countries and year 2013/14 for EU countries) – red bars. These form the basis for the update of the RED default values.

The share of oilpalm cultivated on organic soils for the year 2000 is estimated by considering equal distribution of oilpalm on all soil types present. According to a recent analysis of high resolution satellite data by Miettinen et al., (2012), the area of oil palm plantations in Indonesia and Malaysia more than doubled between 2000 and 2010. Several authors (Wahid et al., MPOB, 2010; Sheil et al., 2009 cited by Miettinen et al., 2012) also noted that the share of Malaysian oil palm plantations on peatland had increased from 8% in 2003 to 13% in 2009, suggesting that a rapid increase in the area of oil palm cultivation in the region had taken place disproportionately on peatland areas. By 2009, nearly 30% of all oil palm plantations in Malaysia were located on peat soil (Wahid et al., MPOB, 2010). Considering the shares of oil palm plantations on peatland from Miettinen et al. (2012) and Gunarso et al. (2013), combined with recent data from Miettinen et al. (2016), we calculated that of the palm oil, 14% was grown on peatland (see text box in Section 6.11 for more details on the calculation).

At global average level, the crop type is the main parameter that makes a difference between N_2O emissions based on the IPCC (2006) TIER1 approach compared to the method applied in GNOC (see Figure 6). Emissions from cereal feedstock (e.g. wheat, barley, rye) and rapeseed ([17]) based on GNOC are lower than those calculated by applying the IPCC (2006) Tier 1 approach because the S&B 'effect value' for this vegetation class is lowest, leading to EF_{1ij} below the IPCC (2006) default of 0.01 kg N_2O-N per kg of N input. Oilseed and row crops (S&B vegetation type 'other', e.g. sugar beet, maize, sunflower) tend to have higher average emissions based on the GNOC, compared to those generated by applying the IPCC (2006) TIER 1. Emissions from oil palm cultivation are similar for both calculation methods applied.

This picture changes at a higher spatial level. Here, soil parameters like pH, texture and soil carbon content may generate a higher variation in N_2O emissions (based on the GNOC) from one specific crop grown on different soils, than between crops at average global level.

([17]) In GNOC we apply the cereals effect value to rapeseed as explained in Section 3.4.

Looking at the partitioning of the N_2O sources and pathways we observe large differences between the crops (Figure 7). For the non-leguminous annual crops and sugarcane, the fertilizer application (mineral fertilizer and manure) is the major source of direct N_2O emissions from the soil (50% – 70%). Nitrogen from crop residues left in the field contributes between 17 and 35% to the total emissions. The N_2O emissions caused by N supply from returning sugarcane vignasse to the field are considered as part of the fertilizer application emissions in the calculations.

The situation is different in the perennial oilpalm plantation. There, the fertilizer supply is mainly resulting from incorporation of residues from the previous palms when replanting and/or from residues left in the field during the plantations lifetime. Crop residue N contributes with 40% to total N_2O emissions, while the share of N_2O from fertilizer input is less than 20%.

Fertilizer input to leguminous crops (i.e. soybean) is usually low as nitrogen from the atmosphere is fixed biologically. According to our data almost ~95% of the N_2O emissions in soybean cultivations are related to N from crop residues remaining in the field.

Based on our analysis only a small share of potential biofuel crops – with the exception of oilpalm – is produced on organic soils. We calculated < 1.5% of potential biofuel feedstock (except oil palm) cultivated on organic soils on average for all biofuel feedstock and countries. However the share of cultivated organic soils varies between countries and feedstock and the related emissions may contribute up to 10% to total emissions as in the case of rye (see Figure 7). According to IPCC (2006) TIER 1 each ha of crop cultivated organic soil releases an extra 8 kg N_2O-N (16kg N_2O-N in tropical regions) which would emissionwise correspond to the application of 800 kg (or 1600 kg in the tropics) of fertilizer N.

Indirect emissions from leaching and volatilization/re-deposition of N input by mineral fertilizer and manure range from 10% to 15% of the total N_2O emissions except for the crops dominantly grown in warm/dry areas where leaching is reduced and/or where crop residues are the dominant source of N supply.

Table 55 Changes in crop yield and mineral fertilizer input between 2000 and 2013/14

	GNOC Yield (2000) in kg ha^{-1}	FAO Yield (2009/14) in kg ha^{-1}	GNOC Mineral Fertilizer Input (2000) in kg ha^{-1}	Mineral Fertilizer Input (2013/14) in kg ha^{-1}	Mineral Fertilizer Input (2013/14) in kg/tonne crop	Comments (Explanation below table)
barley	3 997	4 546	100	96	21.1	**1**
maize	5 616	6 965	106	110	15.8	**1**
oilpalm	17 333	18 327	78	93	5.1	**1**
rapeseed	2 260	3 150	139	142	45.1	**1**
rye	2 942	3 622	76	65	17.9	**1**
soybean	2 438	2 778	11	5	1.6	**1**
sugarbeet	52 395	80 760	143	115	1.4	**1**
sugarcane	69 988	76 002	66	69	0.9	**1**
sunflower	1 367	1 912	43	49	25.6	**1**
triticale	3 986	4 163	108	87	20.9	**1**
feed-wheat	4 543	5 797	101	114	19.7	**2, 3**

1 Yields and fertilizer input are weighted averages from suppliers of each crop to the EU market (including EU domestic production). Yields are from Faostat and Eurostat for common wheat (average yields for the time period 2009 and 2014). Fertilizer input is from IFA for countries outside EU (2010/11, the latest available year) or from Fertilizers Europe for EU countries (year 2013/14, provided by Fertilizers Europe in August 2016).

2 Calculation of Average Yield of Ethanol-Wheat in EU:

28% of common EU wheat is grown as feed wheat. 72% of common EU wheat is bread wheat variety. Average common wheat yield Y = 0.28F + 0.72B. Also feed-wheat varieties have 5% higher yield than bread wheat varieties.

F = 1.05B. B = F/1.05

Y = 0.28F + (0.72/1.05)F = 0.966F

Or F = 1.0355Y and B = F/1.05 = 0.9862Y

Wheat for ethanol is 3/4 feed wheat variety + 1/4 bread-wheat variety. YE = yield of wheat for ethanol

= 3/4(1.0355Y) + 1/4(0.9862Y)

YE = 1.023Y

So ethanol-wheat yield is 2.3% higher than average EU wheat yield.

3 Mineral fertilizer input per tonne of wheat is 7% lower than indicated by Fertilizers Europe, because we have taken into consideration not only the yield difference between all "common-wheat" and the feed wheat, as explained above, but also the reduced amount of N that farmers put on feed-quality wheat. See text box at the end of this section for details.

Figure 6 Weighted global average N2O soil emissions from biofuel feedstock cultivation. Results are weighted by feedstock quantities supplied to the EU market (including EU domestic production). The graph shows emissions based on GNOC calculations for the year 2000, emissions obtained following the IPCC (2006) TIER 1 approach and using the same input data as for the GNOC calculations and the GNOC results corrected for average yield and fertilizer input of 2013/14.

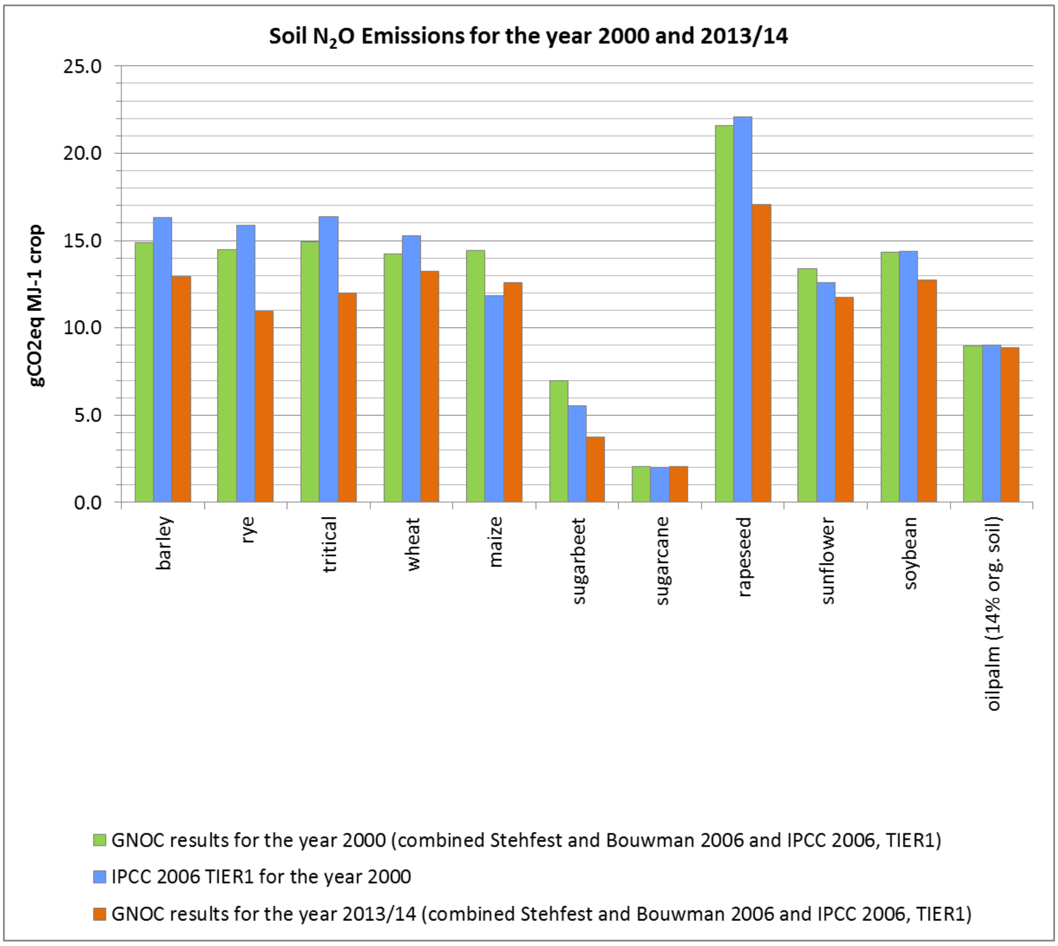


Figure 7: Share of N2O emission sources and pathways of the weighted global average N2O soil emissions in 2013/14.

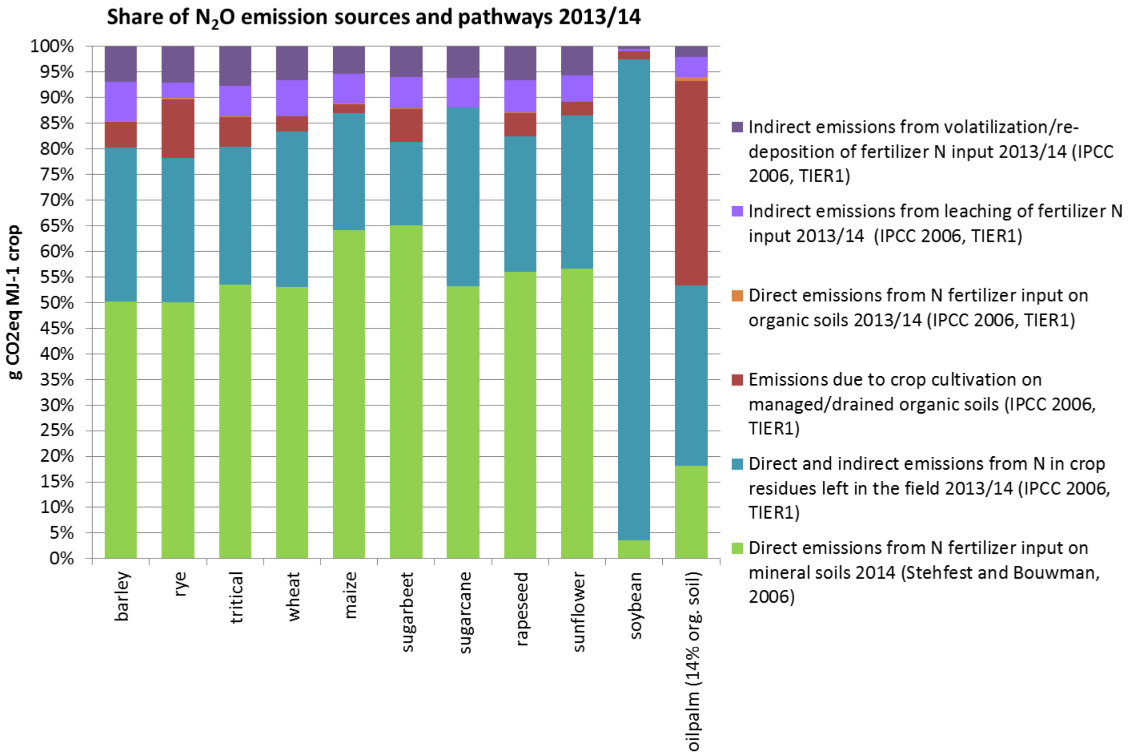


Table 56 Soil nitrous oxide emissions from biofuel feedstock cultivation in 2013/14. The values are weighted averages from suppliers of each crop to the EU market (including EU domestic production).

Biofuel feedstock	Fresh Yield (2009/14) kg ha^{-1} (Input to GNOC)	Mineral fertilizer input (2013/14) kg N ha^{-1} (Input to GNOC)	Manure input - 50% - (2013/14) kg N ha^{-1}	Soil N_2O emissions (2013/14) $gCO_2eq\ MJ^{-1}$ of crop
barley	4 546	96.0	16.5	13.0
rye	3 622	65.0	12.5	11.0
triticale	4 163	87.0	15.7	12.0
wheat	5 797	114.2	20.6	13.2
maize	6 965	110.0	19.0	12.6
sugarbeet	80 760	115.0	23.3	3.7
sugarcane	76 002	69.2	19.9	2.0
rapeseed	3 150	142.0	21.5	17.0
sunflower	1 912	48.9	7.8	11.8
soybean	2 778	4.6	0.8	12.8
oilpalm	18 327	93.4	8.8	8.9

Note: Soil N_2O emissions expressed in gCO_2eq/kg of dry crop can be calculated by multiplying the gCO_2eq/MJ of crop reported in the table by the LHV of the crop. LHV (and moisture content) of each feedstock are available in the respective sections in Chapter 6 where cultivation data are reported.

WHY DO WE SUBTRACT 7% OF FERTILIZER N/TONNE FEED-WHEAT?

We use data from Fertilizers Europe (2016) on the N fertilizer per ha used on different EU crops. That gives data on N use per ha for all EU wheat: that includes common wheat (feed-quality and bread-quality) and durum wheat. First, we calculate the N per tonne of soft wheat, by dividing the average N/ha by the average yield for common wheat (reported by EUROSTAT). This removes the lower yield of durum wheat as a source of error.

However, bioethanol is made from feed-quality wheat, which has lower protein content than other (bread-quality) soft wheat, which is used for food wheat, and needs less fertilizer. In NW Europe, especially UK, purpose-made feed wheat varieties are grown that show higher yield as well: part of the EU feed wheat supply comes from these varieties; the rest comes from wheat that was grown as bread wheat but could not find a market. Nevertheless, farmers who foresee this would not give so much (protein-boosting) fertilizer in the last months. There is no EU-wide data on the N use on feed wheat, the fraction of feed wheat or the use of purpose-made feed wheat varieties. Therefore we are obliged to use expert opinion and the data we found on reduced N use on feed wheat in UK.

In UK, farmers growing for feed market apply about 30/190 = 16% less N per ha than if they are aiming at bread wheat: ADAS (2013). The UK average N per ha is ~190 for all wheat types, but 2/3 of UK area is sown with feed varieties and 1/3 with bread varieties (ADAS, 2013). Therefore UK feed wheat gets 180 kgN/ha and bread wheat 210 kgN/ha on average. So purpose-grown feed wheat in UK gets 86% of the N per ha on bread wheat. In the absence of any other data for purpose-grown feed wheat, we assume the same ratio applies in rest of EU.

Furthermore, purpose-grown feed wheat, which is mostly grown in NW Europem, uses varieties which yield about 5% more than bread wheat HGCA (2013). Therefore purpose-grown feed wheat uses 86/105 = 82% of the N per tonne of wheat needed for bread wheat.

In UK, 1/3 of wheat sown as bread wheat ends up as surplus-to-demand or below-standard for bread use, and is sold as feed wheat ADAS (2013). In the absence of EU-wide data, we assume the same fraction applies in rest of EU. In EU27, 54% of wheat is used for food (bread-quality), and 46% for feed or ethanol ('industrial') (USDA, 2013; USDA, 2012). So we estimate that 18% of EU wheat is grown as bread wheat but used as feed wheat, whilst 28% of EU wheat is purpose-grown feed quality.

By algebra, the average N/tonne of purpose-grown feed wheat in EU is 1/(0.28+0.72/.86) = 89.5% of the average N per tonne of wheat in EU27 (whilst bread wheat requires 1/(0.28*.86+0.72)=104% of average N per tonne). However, not all feed wheat used for ethanol is purpose-grown: on the basis of expert advice, we assume 1/4 of it is surplus or below-standard bread wheat (less than EU average of 1/2 for all feed wheat, because some ethanol producers contract farmers in advance)). Therefore on average the N on ethanol wheat in EU is 89.5*3/4 + 104/4 = 93% of the average N/tonne of wheat in EU.

Ref:

ADAS (2013), Personal Communication, R. Syvester-Bradley (ADAS) to JRC, May 2013.

USDA (2013), EU27 grain and feed annual GAIN report 1301.

USDA (2012), EU27 biofuels annual GAIN report NL2020.

HGCA (2013), HGCA recommended winter wheat varieties 2013 http://www.hgca.com/document.aspx?fn=load&media_id=8326&publicationId=6392.

3.8 Manure calculation

When calculating N2O emission we consider only 50 % of the N in applied manure and other organic fertilizers

Summary

- The contribution of manure to N_2O emissions is minor in most parts of the world; exceptions are parts of EU and US.
- Manure use tends to be concentrated around livestock farms.
- Not all the nitrogen applied in manure is available for crops: we only consider the available fraction in calculating N2O emissions. Although the rest of the nitrogen also generates N_2O, it does not contribute to crop growth; therefore we attribute those emissions to manure production in the livestock sector.
- An average of about 42% of manure-N is available in the first year of application, but crops inherit N also from previous manure applications: the total available nitrogen from manure is at least 50% of the applied manure-N on average.
- The assumption of 50% N availability is also consistent with data on manured area and the fraction of N for crops coming from manure.

Details

Our data on synthetic nitrogen applied to crops are not based on recommendations, but on actual sales data. Therefore emissions from manure-nitrogen are additional; they do not substitute those from synthetic nitrogen.

In most of the world, the contribution of manure to the total nitrogen supply of crops is very limited: it becomes important only in areas with large indoor production of livestock, such as some parts of EU and US. Very few countries provide estimates of manure-N per crop; these estimates have large statistical error, and, perhaps because of this, there seems no consistent pattern of which crops get the highest proportion of their N requirements from manure. Nevertheless, it is clear that crops which need little nitrogen, such as soybeans, get less manure than high-intensity crops like maize. Therefore, in allocating total national manure application to different crops and grassland, we preferred to assume that nitrogen from manure is proportional to synthetic nitrogen use per crop, rather than the alternative assumption that manure is distributed uniformly on all cropland.

Statistics are available for total manure-nitrogen application per country. We derived this data in the Edgar Database; it only counts the manure that is applied by farmers to fields (thus excluding manure deposited directly during grazing), and it also takes into account loss of nitrogen during storage.

Fraction of manure-nitrogen attributed to crops

A partnership led by AEA Technologies made a report for DG-ENV,‘Study on variation of manure N efficiency throughout Europe’ (AEA, 2011).

In particular it shows a table (table 16, repeated as table 3 in the summary) which shows different Member States’ estimates of the fraction of N in different types of fertilizer *that is released in the year it is applied*. We calculated an average value of 42%, weighted by the application (in terms of N) of each type of manure in each EU country; data we derived from EUROSTAT.

However, crops also receive nitrogen from manure that was applied in previous years, and this should be taken into account (AEA, 2011), because it also contributes to the total nitrogen supply and reduces the average requirement for synthetic nitrogen. AEA (2011) also offers a detailed discussion of the release of N from manure in subsequent years. The fraction of the N in manure that is made available in subsequent years varies depending principally on the rainfall, temperature and nature of the manure. The report concludes *"Most authors reported only small percentages of N availability for successive years most of them being c. 2-3% of extra N available per year reaching average values from 60 to 80% for the total N recovery in a 6 to10 year period."*

This would indicate the correct fraction of manure-N to consider in cultivation emissions is 60-80%. But this may be slightly exaggerated, because most of the authors they review also reported higher-than-average N availabilities in the first year. However, it is reasonable to conclude that the % N released in subsequent years is at least (2% for 6 years = 12%). Adding this to the average release of 42% of the nitrogen in the first year indicates a total N release from manure of at least 54%. We take the round figure of 50% because the Member States' estimates of % nitrogen availability in the AEA report are almost all rounded to the nearest multiple of 10%.

Therefore, in using the GNOC tool to calculate the average contribution of N from manure to the N_2O emissions from crops, we consider half the N content of the manure. In the GNOC methodology this approximately halves the contribution of manure to N_2O emissions in cultivation.

In processing GNOC data, we need to make an additional assumption about how the manure is distributed to different crops, for all countries. The only international data on N applications we have per-crop per-country is for synthetic N, so we need to find a relation between manure application and synthetic nitrogen application.

For a given country, we assume that the ratio of (manure N)/(synthetic N) is the same for all crops. This assumption gives estimates of manure use per crop which are closer to those reported in national surveys than our previous assumption that assumed the same kg manure per hectare for all crops in a region. (This assumption was adopted in JEC-WTWv4 and the draft input data for update of RED annex V, presented to stakeholders in April 2013: however we realized that it systematically over-estimated manure on low-intensity crops). Nevertheless USDA, 2009, as well as European manure use surveys, (DEFRA, 2016 and AGRESTE, 2014), show variations in the fraction of manure used for different crops, which vary by country and which we cannot fully capture with a general rule that can be applied to all countries.

Our data on synthetic nitrogen use is ultimately derived from sales data, so it is independent of the amount of manure used on a crop. That means assuming a higher fraction of N from manure for a crop would not decrease the amount of synthetic fertilizer in the calculations.

3.9 Correction of IPCC method for estimating N2O emissions from leguminous crops

For the calculation of N supply from crop residues remaining in the field to the soil and the subsequent N_2O emissions we rely on the TIER 1 approach as described in the IPCC (2006) guidelines.

Between 1996 and 2006, the IPCC changed their default emission guidelines for soybeans: this had the effect of drastically reducing the N_2O emissions calculated for soybean. We think the true emissions actually lie between the two, as described below. This discussion originated from the staff of E4tech in the United Kingdom in 2008, working on behalf of the United Kingdom's Renewable Fuels Agency (RFA). The resulting correction to the N_2O emissions for leguminous plants was incorporated in RFA default values for soybeans.

In 2013 E4tech staff (Chudziak & Bauen, 2013) drafted a paper on "A revised default factor for the below ground nitrogen associated with soybeans" describing their findings in detail and concluding with the suggesting to revise the below-ground residue N content of soybean in the IPCC 2006 guidelines from currently 0.008 to 0.087.

The JRC agrees with Chudziak & Bauen (2013) that the 2006 IPCC (Tier 1) approach significantly underestimates the N_2O emissions from soybeans and probably also other leguminous plants.

The old 1996 IPCC methodology for calculating N_2O emissions from soil (used in v. 2 of JEC-WTW) did not consider below-ground nitrogen (BGN) in plants at all, but did assume that the nitrogen naturally fixed by leguminous plants (such as soybean) contributed to the release of N_2O. This would mean that the nitrogen-fixing bacteria in the roots were emitting N_2O at the same time as they were fixing nitrogen from the air.

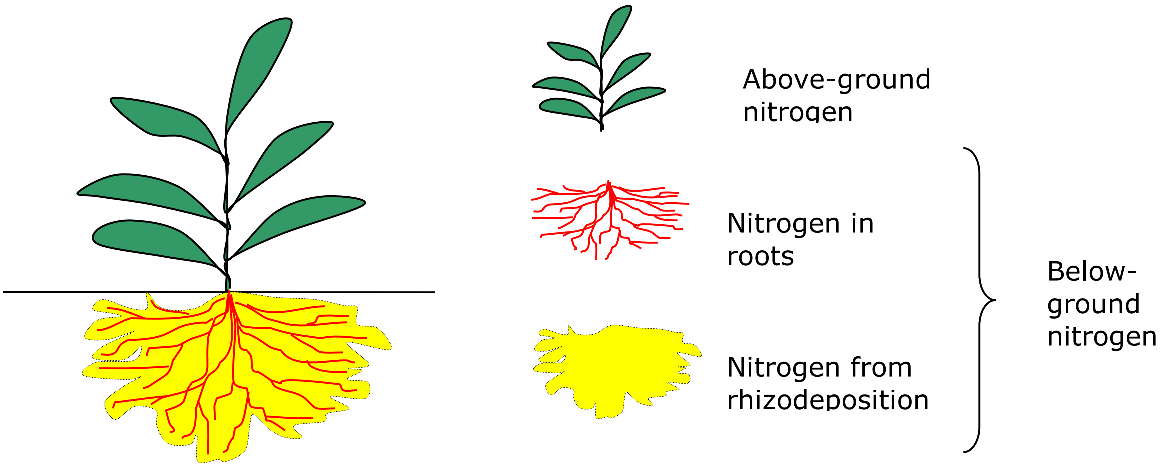
The distribution of biologically fixed nitrogen in leguminous plants is shown in Figure 8.

However, a paper in 2005 by Rochette and Janzen argued that there was little evidence for significant N_2O emissions from legumes during the nitrogen fixation process. Therefore, in the revised 2006 methodology (published in 2007), the IPCC no longer include emissions directly from the natural nitrogen-fixing process. On the other hand, the 2006 guidelines **do** take into account the contribution of below-ground N content of the plants themselves to the nitrogen pool in the soil which contributes to N_2O emissions.

The IPCC attribute these extra emissions to the current crop. However, Rochette (2004) shows that most of these will actually take place during the following season. He found that although the soil mineral N content under legumes were up to 10 times greater than they were under grass, this was not closely related to the N_2O emissions measured during the growth phase of the plant. However, he found greater emissions of N_2O after the plant had been harvested, and these were strongly dependent on the soil type.

So for the current season, what **should** be taken into account is the contribution of BGN from the residues of the **previous** crop. From the point of view of a national average, it does not matter much to which crop a certain amount of soil nitrogen is attributed. But it does make a difference if you are calculating N_2O emissions **per crop** in a rotation. Of course the distinction is not important if the **same** crop is grown in successive years, which is generally the case in Brazil and Argentina, which supply most of the soybean to EU.

Figure 8 Distribution of biologically fixed nitrogen in leguminous plants



Part of the nitrogen biologically fixed by soy plants ends up in the above- and below-ground crop residues, and in principle, the IPCC (2006) takes emissions from this into account. However, we think the IPCC has seriously underestimated the amount of BGN, by underestimating the below-ground biomass and by disregarding nitrogen from rhizodeposition.

Rhizodeposition (Jensen, 1995) is the process whereby N enters the soil from the plant roots in the form of NH_4, NO_3, amino acids and cell lysates, as well as through decay of sloughed-off and senescent roots. It can now be quantified through techniques such as 15N shoot labelling (Khan et al., 2002). The literature shows that leguminous plants such as soy exude significant volumes of N from their roots (Martens, 2006).

Table 11.2 of the 2006 IPCC guidelines gives default factors for estimation of N added to soil from crop residues. According to this, only 16 % (= .19/1.19) of the soybean plant residues are in the underground biomass, and they all have the same nitrogen concentration. These default factors are based on an extensive literature review, with references provided in Annex 11A.1. The default value for BGN content of soybean is taken from a 1925 paper. Whilst E4tech could not obtain a copy of this reference, their review of more recent literature suggests that such a dated work will have missed not only the N released by rhizodeposition, but also that in fine root hairs that are very difficult to collect using the old techniques of physical root recovery. Aruja et al. (2006) confirm that the roots recoverable by traditional methods only contain between 5 % and 10 % of the total N accumulated by the plant. For comparison, Alves (2003) reports results using modern techniques of between 30 % and 35 % of total plant N (18). This implies the IPCC has underestimated nitrogen in the roots by at least a factor of 3.

If we include also nitrogen from rhizodeposition, the IPCC defaults might seem even further off. Khan (2002b) concluded that the traditional methods only recovered 20 % to 30 % of the total BGN (including that from rhizodeposition) obtained using N-labelling methods. Mayer (2003) found that N rhizodeposition represented about 80 % of the below-ground plant N. These studies suggest that the N from rhizodeposition is roughly four times the BGN in the roots, so at least an order of magnitude greater than the BGN calculated from IPCC defaults.

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(18) Similarly, Rochester (1998) found that ~40 % of the N in legumes either resided in, or was released from nodulated roots, and this is confirmed by Russel and Fillery (1996). Rochester (2001) states: 'In the past, belowground N has either been ignored or grossly underestimated when N balances have been calculated for legume crops.'

Based on available data and literature analysis, we believe that in reality only the part of the biologically fixed nitrogen released by rhizodeposition counts towards N_2O emissions from the soil during a particular growing season. The rhizodeposition gradually builds up during the season, but after the harvest all plant residues gradually decay and release their nitrogen into the soil. There are not enough data to estimate the amount of rhizodeposited nitrogen from soy by direct measurements of soil nitrogen. A more pragmatic and accurate approach is to back-calculate the total **effective** BGN, from the combination of below-ground biomass itself plus rhizodeposition, from the measured nitrous oxide emissions from soybeans grown without synthetic nitrogen. That figure would reflect the actual nitrogen content in the soil that is giving rise to N_2O emissions.

In reference to IPCC Table 11.2 (IPCC, 2006), for the N_2O emissions calculation, it is irrelevant whether this is done by changing the default value 'R_{BG-BIO}', (ratio of below-ground to above-ground biomass) or 'N_{BG}', the effective nitrogen concentration in the below-ground biomass (kgN/kg dry matter). We have chosen, in accordance with Chudziak & Bauen (2013) to change only the second value; this is equivalent to assuming that the contribution of dead roots to the mass of below-ground biomass is small.

Chudziak & Bauen (2013) started off by averaging measurements of N_2O emissions from unfertilised soybean cultivations at 7 sites quoted by S&B. The result is 1.261 kg N-N_2O/ha^{-1}. Using the IPCC default **direct** emissions factor of 0.01 kg N-N_2O/kg N(CR), the total amount of nitrogen which gave rise to those emissions is 126.1 kg N/ha. By subtracting the nitrogen in the above-ground residues from this, the total amount of N from below-ground biomass can be calculated. Following the IPCC (2006) TIER 1 approach Chudziak & Bauen (2013) calculated 28.4 kg N ha^{-1} in above-ground residue biomass at a soybean fresh yield of 2600 kg/ha (soybean average yield in Argentina, Brazil and the US given by FAO for the year 2006)([19]). Subtracting this from the total N in plant-residue leaves us with an effective 97.7 kgN ha^{-1} in below-ground biomass. Still following IPCC (2006) TIER 1 approach ([20]) the below-ground biomass at the given soybean yield is 1124 kg dry matter ha^{-1}.

The new co-efficient for N in below-ground biomass is obtained by dividing N in below-ground biomass by below-ground residue dry matter: N_{BG} = 97.7/1124 = **0.087 kg N/kgDM below-ground biomass**. The JRC recommends using this in place of the default value of 0.008 in Table 11.2 of IPCC (2006), in order to calculate N_2O emissions from soy which are comparable with measurements.

Checking the results against below-ground-N measurements

We can check whether this value is reasonable by looking at which value it implies for the fraction of the total nitrogen associated with the plant. This can be checked against measurements in the literature, which mostly range from 30 % to 35 %, according to Alvez (2003) and a wider literature survey by E4tech.

The nitrogen concentration in the dry matter of soybeans is 6.5 % according to the NREL (2005), corresponding to 154 kg N ha^{-1} in beans at a fresh yield of 2600 kg ha^{-1}. The total plant N is this plus BGN and above-ground nitrogen in residues. Adding this all up using the figures above gives a total of 280 kgN/ha associated with the plant. Then the fraction of BGN implied by our method is 35 %. This is indeed within the range of

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([19]) N in above-ground residues (kg ha^{-1})= (Fresh yield (t ha^{-1})* dry matter fraction *slope + intercept) *1000 * N content of above-ground residue dry matter. For soybean IPCC (2006) gives: Dry matter fraction = 0.91, slope = 0.93, intercept = 1.35), N content of above-ground residue dry matter = 0.008

([20]) Below-ground residue dry matter (kg ha^{-1}): Above-ground biomass dry matter (kg ha-1) * Ratio of below-ground residues to above-ground biomass. For soybean IPCC (2006) gives: Ratio of below-ground residues to above-ground biomass = 0.19.

measured values, giving us confidence that we are at least approximately correct.

Checking the calculated N_2O emissions against mesurements

In GNOC we implemented the revised factor for N in below-ground soybean residue biomass (NBG = 0.087) and we checked GNOC based country average emissions against N_2O field measurements from the Stehfest & Bouwman, 2006 (S&B) data collection and additional measurements in Argentina presented in Alvarez et al. (2012). The filled circles in Figure 9 show the measurement data from the beforementioned sources. The measurement data is ordered by country and in ascending order of the N_2O emissions.

The S&B data set includes 17 measurements in 3 different countries (US, Canada and China). In addition, data from 4 plots under different management (tillage/no tillage, soybean monoculture, soybean-maize rotation) are available from Argentina. At 11 sites the experiment covered 365 days (dark green circles), at 6 sites the measurements refer only to the soybean vegation period of about 120 days (light green circles). We did not exclude those, even though the measurements do not include e.g. potential emissions resulting from crop residue de-composition during the fallow period. We assume that those measurements represent minimum N_2O emissions from soybean cultivation at this location throughout one year. Except 2 of the 4 Chinese sites (dark blue circles) all measurements were carried out in soybean cultivation without additional fertilizer input.

From the S&B data collection it is not possible to estimate the amount of N supplied by crop residues. It is mentioned that there were no (above-ground) residues left on the field at the US, Canadian and Chinese sites. However, it can be assumed that the below-ground part of the residues remained in the soil. Yield data, as well as information whether the measurements refer to monocultural sites or soybean is grown in rotation with other crops is not available. Two of the Argentinian sites are soybean monocultures and two are maize-soybean rotations. In both cases the residues from the previous crop remained in the field.

GNOC based country average N_2O emissions from soybean cultivation (orange dashed line in Figure 9) refer to an average fertilizer application per ha of 2.5 kg N in Argentina, ~25 kg N in the US and Canada and 84 kg N in China (see violet dashed line in in Figure 9). The country average per ha yields for the year 2000, which are the basis to calculate the N supply from crop residues, were 2.4 – 2.5 t in Argentina, Canada and the US and 1.7 t in China. The management data considered in GNOC gives 35 and 50% of above-ground soybean residues burnt or removed in Argentina and China respectively. This equals a reduction of N supplied by total (above- and belowground) crop residues of ~11% for China and of ~8% for Argentina.

We also calculated a "no fertilizer" case for soybean in the above-mentioned countries. The results are drawn as brown dashed line in in Figure 9. GNOC results include direct emissions as well as indirect emissions from leaching, in case of fertilizer application also volatilization/re-deposition. These indirect pathways are not covered by the measurement data presented.

The red dashed line in in Figure 9 gives country average emissions under unfertilized conditions if the default IPCC (2006) factor for N in below-ground biomass (NBG) of 0.008 is applied. At 15 out of the 17 measurement locations the emissions measured in the field exceed the country average emissions calculated using the IPCC (2006) default NBG. The average emissions over all unfertilized measurement sites are 1.29 kg N_2O-N ha^{-1} this compares to an average emission in the 4 countries of 0.28 kg N_2O-N ha^{-1} if a NBG of 0.008 and of 1.15 kg N_2O-N ha^{-1} if the suggested NBG of 0.087 is applied in GNOC (no fertilizer input assumed).

For Argentina the country level GNOC results are at the lower end of what has been observed from the measurements. As country level fertilizer inputs in GNOC (violet dashed line) are close to 0 they don't have a major impact on the final emissions.

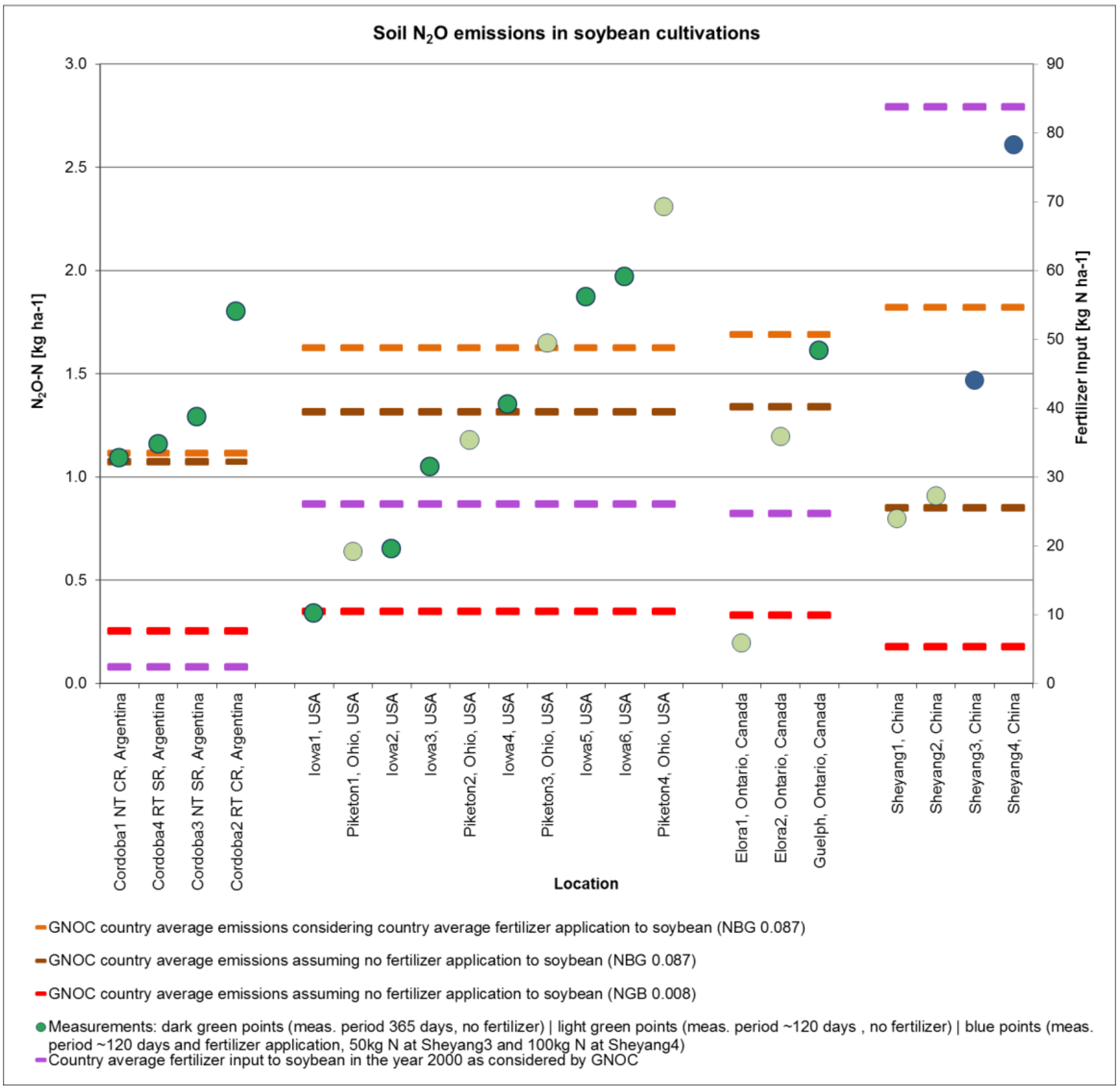
Measurement data in the US was available from 2 measurement projects in 2 states. Average emissions from these unfertilized measurements are 1.3 kg N_2O-N ha^{-1}, this matches the GNOC result for 0 fertilizer application (1.32 kg N_2O-N ha^{-1}). Emissions estimated using the GNOC default country-average N input to soybean are 1.63 kg N_2O-N ha^{-1}.

Canadian sites show a mean emission of 1.01 kg N_2O-N ha^{-1} while GNOC gives 1.69 N_2O-N ha^{-1}. However, only one measurement covered an entire year. There, emissions above the GNOC country average value were observed.

Looking at the Chinese sites the GNOC results match quite well with the observations under 0 fertilizer input and are in the same range when comparing the emissions under fertilized conditions. IPCC (2006) TIER 1 describes the amount of crop residues (and the N input from this source) as a function of the yield. Average soybean yield for the year 2000 (GNOC default) was fairly lower in China than in the other countries presented in the graph. This, together with the ~50% removal of above-ground residues we assume in GNOC, results in lower average emissions under zero fertilizer input in China compared to the other countries.

Although the measurements don't cover all possible environmental and management conditions, the presented results underpin the findings of Chudziak & Bauen (2013) that N supply from below-ground soybean residues is around 10 times higher than currently suggested by the IPCC(2006) TIER 1 approach.

Figure 9 Measurements of soil N2O emissions from soybean cultivation (S&B, 2006 and Alvarez et al. 2012) and country level results based on GNOC



NBG: Nitrogen in belowground residues

Management at the Argentinian measurement sites;

Cordoba1 NT CR, Argentina: No tillage, residues from previous crop: maize

Cordoba2 RT CR, Argentina: Reduced tillage, residues from previous crop: maize

Cordoba3 NT SR, Argentina: No tillage, residues from previous crop: soybean

Cordoba4 RT SR, Argentina: Reduced tillage, residues from previous crop: soybean

3.10 Emissions from acidification and liming methodology

Emissions from neutralisation of fertilizer acidification and application of aglime

This is a correction to calculations for the RED (2009)

In the calculations of GHG emissions from biofuel cultivation for Annex V of the RED, (and also in JEC-WTW v3), we did not account for CO_2 release from neutralization of acidity from nitrogen fertilizers, nor from other aglime reactions in the soil. Now these emissions are included, as described below.

Reduction in upstream emissions: we now consider only crushed limestone

Nowadays, the great majority of aglime is ground limestone (CaCO3) or sometimes dolomite (CaCO3.MgCO3). We now consider ground limestone exclusively in calculating emissions from aglime supply and application. In our previous calculations, for RED Annex V and JEC-WTW v1–v3, we did not account for any emissions from applying aglime to soils, and included 15 % calcined limestone in aglime production emissions.

Calcined limestone, CaO or Ca(OH)2, is more costly and is only used when a quick effect is needed. Calcined limestone does not emit CO_2 during neutralisation of acid in the soil, but the CO_2 and fossil fuel emissions released during production made it, overall, more GHG-intensive than ground limestone.

(A) Adding neutralisation contribution to fertilizer emissions

Acidification from N fertilizer causes emissions whether or not aglime is applied

Most N fertilizers generate acid as they are oxidised by bacteria in the soil. Some farmers apply aglime to neutralise the acid. However, we shall attribute CO_2 emissions for the neutralisation of this acidity to the fertilizer rather than to the aglime, because most of the neutralisation emissions occur regardless of whether the farmer applies aglime, through reactions with carbonates naturally present in the soil or lower down in the watershed (Semhi, 2000; West, 2005; Perrin, 2010; Brunet, 2011). The carbonate which is dissolved by acidity resulting from N fertilizer is not sequestered at sea or anywhere else (West 2005; Gandois, 2011).

Oxidation of nitrogen fertilizers in the soil forms acid that is neutralized by agricultural lime or naturally-occurring carbonates in the soil.

In version 1b of JRC's draft report "Definition of input data to assess GHG default emissions from biofuels in EU legislation", circulated for comments in 2016 to experts and stakeholders, JRC made a literature study that defined a range of uncertainty in the emissions resulting from this neutralization reaction. In comments to the report, ePURE 2016 pointed us to Fertilizers Europe report (Fertilizers Europe, 2014), quoting "KTBL 2005" for the reaction of this acidity with agricultural lime. Considering the most-used fertilizers in EU and the world, this amounts to 0.27 kg CO_2 per kg of ammonium nitrate and 0.36 kg CO_2 per kg urea. Given that ammonium nitrate contains 33.5% N and urea 46% N, this corresponds to 0.783 kg CO_2 per kg of N and 0.806 kg CO_2 per kg of N respectively. The weighted average value for the mix of N fertilizer types used in EU is 0.798 kgCO_2 per kg of N.

Therefore, to account for acidification due to fertilizer use in the field, we add 0.798 kgCO_2 emissions per kg of N fertilizer applied to the crop. This is done at the stage where the per-crop nitrogen fertilizer production emissions are calculated.

Notes:

- At least part of the reason that applying urea to a given field gives lower acidification emissions (according to Fertilizers Europe) than the same quantity of nitrogen as ammonium nitrate, is that part of its ammonia content evaporates.

However that ammonia would cause acidification elsewhere when it is oxidized in soils or watersheds. So, arguably, one should use the higher ammonium nitrate figure also for urea. However, we have kept the Fertilizers Europe numbers.

- Sodium nitrate and calcium nitrate are speciality fertilizers that cause no acidification in the field, but additional CO_2 emissions arise when they are manufactured from alkali or lime.
- On the other hand, most of the other N fertilizers used, such as ammonium sulphate and aqueous ammonia, give at least double the acidification per tonne of N.

  Calcium ammonium nitrate is just AN pre-mixed with a variable quantity of lime.

Table 57 Calculating CO2 emissions from acid formed from synthetic N in the soil

	Ammonium Nitrate	**Urea**
kg CO_2 per kg of PRODUCT	0.27	0.36
% N in product	33.5%	46%
kg CO_2 per kg of Nitrogen	0.806	0.783
Fraction of fertilizer type in EU mix (% of all N fert)	64%	36%
Contributions to weighted average	0.515	0.282
EU-average kg CO2 per kg of Nitrogen	**0.798**	

Source

Fertilizers Europe, 2014.

Calculation of emissions from liming

According to IPCC guidelines on national GHG inventories (IPCC, 1997), the entire content of aglime (0.44kg CO_2 per kg $CaCO_3$ equivalent) is emitted after it is applied to the soil. But we will consider more recent results (West, 2005; Perrin, 2008) that show some of the CO_2 is sequestered rather than emitted. This depends on the pH of the soil.

- *On acid soils*

  Where pH is less than ~6.4) ([21]), aglime is dissolved by soil acids to form predominantly CO_2 rather than bicarbonate. Then almost all of the CO_2 in the aglime is released (Biasi, 2008; West, 2005). By stoichiometry, that is 0.44 kgCO_2/kg aglime.

- *On more neutral soil*

  Above ~pH 6.4 aglime is dissolved mainly as bicarbonate, and part of its CO_2 content is sequestered in the end. The bicarbonate is either decomposed by

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([21]) JRC calculation based on equilibrium constants of bicarbonate reactions. At this pH, dissolved CO_2 and bicarbonate are in equal concentrations (Schulte, 2011) modified from Drever (1982). These are for 25ºC, so there may be a small error, depending on soil temperature.

acidity deeper in the soil (releasing the aglime's CO_2) or is exported to the ocean, where some is sequestered (West, 2005) ([22]).

The flows in Figure 2 of West (2005) indicate that from 15.17 Mtonnes of bicarbonate ions produced by dissolution of lime (consuming 12.44 Mtonnes of $CaCO_3$ by stoichiometry), a net 0.98 Mtonnes of CO_2 are emitted if the whole system, from soil to ocean, is considered ([23]). So if soil pH > 6.4, we will assume that 0.98/12.44 = 0.079 kgCO_2 are emitted per kg of aglime applied, apart from the emissions due to neutralisation of the acidification from fertilizer.

The average liming emissions per crop are calculated on a GIS basis using the GNOC database-calculator, as explained in section 3.11. The method considers the total aglime use and pH of the soils used to grow grass and different crops.

Avoiding double-counting

So far, we have explained separately how we estimated emissions from N fertilizer acididity, and how we estimated emissions from aglime. But very often, aglime is used to counter acidity from N fertilizers. In these cases the emissions would be double-counted. To avoid this, we subtract the CO_2 emission from acidication of nitrogen fertilizer (0.798 kgCO_2/kgN – see above) from our estimate of emissions from liming. The remaining net emissions from liming then represent the emissions from the agricultural lime that is used to counter naturally-occurring acidity in the soil.

In some cases, the emissions from fertilizer acidification exceed those attributed to liming, which results in apparently negative net liming emissions. But this just means that not all of the fertilizer-acidity is neutralized by aglime; some is neutralized by naturally-ocurring carbonates. In this case, the net liming emissions are zero, but the fertilizer-acidification emissons occur anyway. So in these cases, we consider net liming emissions, and keep the same fertilizer-acidification emissions.

Summary: aglime rules

If soil pH > 6.4 (that applies to most crops on temperate mineral soils)

Emissions attributed to aglime = (kg aglime applied)*0.079 - (kg of N applied)*0.59 (in kg of CO_2/kg lime).

If the result is negative, the CO_2 emissions attributed to lime are zero (it means they are already covered by the neutralisation emissions attributed to the N fertilizer: insufficient lime in this range of soil pH usually means the N-acidity is also being neutralised by carbonates in the soil).

If soil pH < 6.4

Emissions attributed to aglime = (kg aglime applied)*0.44 - (kg of N applied)*0.59 (in kg of CO_2/kg lime).

If the amount of aglime applied is less than the amount needed to neutralise acidity from the fertilizer, then no emissions are allocated to soil reactions of lime: they are already

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([22]) All the papers reviewed assume that, as a soluble species, the bicarbonate content of soils or river basins must be roughly steady in the long term, so in the end effectively all bicarbonate produced from aglime dissolution is either decomposed by acidity in the soil (releasing all the carbon content as CO_2) or is exported to the ocean. In the ocean, a part of the bicarbonate is converted back to carbonate, releasing some of the CO_2 (see discussion and references in West (2005)), whilst some CO_2 in the bicarbonate is sequestered as dissolved bicarbonate in the ocean, as well as in deposited carbonate.

([23]) Oh (2006) shows that **in the frame of a river basin**, aglime may actually lead to slight sequestration of CO_2, but that does not consider what happens to the bicarbonate after it is exported to the ocean.

covered by the emissions attributed to N fertilizer application (the residual emissions from fertilizer acidification are taking place downstream from the soil).

Estimate of aglime emissions per country per crop

Crop groups: The Malaysian Palm Oil Board (MBOP) assures us that no aglime is used in growing oil-palms, as they are acid-tolerent. For other crops, aglime application is calculated as described in section 3.11.

Emissions from neutralising acid from synthetic: the part of the total lime emissions attributed to mineral fertilizer N input. But some of these emissions come from natural carbonates in soil, not only from applied lime (kg mineral fertilizer N applied * 0.798).

Emissions from neutralising acid N in manure: Emissions attributed to 50 % of the manure N input (kg manure N applied * 0.5 * 0.798).

How to read the table

The red text in Table 58 provides input for the further GHG calculations.

Column 3 shows the extra CO_2 emissions which should be added to fertilizer provision to account for emissions from neutralising the acidity generated by the synthetic nitrogen.

(kg lime applied * 0.079 if $pH > 6.4$ and kg lime applied * 0.44 if $pH < 6.4$).

In some fields, this is more than the emissions from aglime, because the acidity is neutralised by natural carbonates on or off the field.

Column 5 shows the remaining emissions from application of aglime (after subtracting, field by field, the emissions already attributed to synthetic fertilizer reduction). This is caused by neutralisation of pre-existing soil acidity and a little from neutralising acid from N in manure.

Table 58 Emissions from liming and from neutralization of acid from fertilizer N input. Results are global weighted average emissions from suppliers of each crop to the EU market (including EU domestic production)

Column	1	2	3	4	5
CROP GROUP	AVERAGE AGLIME INPUT BASED ON GNOC (kg CaCO$_3$ ha^{-1})	AVERAGE AGLIME INPUT per MJ CROP (g CaCO$_3$ MJ^{-1} crop)	EMISSIONS FROM NEUTRALIZING ACID FROM SYNTHETIC FERTILIZER N (gCO$_2$ MJ^{-1} crop)	EMISSIONS FROM NEUTRLAZING ACID FROM N IN Manure (gCO$_2$ MJ^{-1} crop)	REMAING CO$_2$ EMISSIONS FROM LIME AND MANURE (gCO$_2$ MJ^{-1} crop)
barley	216.93	3.63	1.35	0.27	0.47
maize	107.68	1.25	1.02	0.14	0.00
rapeseed	245.15	4.05	2.07	0.27	0.00
rye	273.26	6.27	1.39	0.36	1.65
soybean Brazil	500.14	10.00	0.15	0.15	4.31
soybean US	229.35	4.53	0.34	0.07	1.56
soybean Argentina	376.44	7.71	0.01	0.03	3.40
soybean EU	95.31	1.66	0.44	0.31	0.45
sugarbeet	217.99	1.08	0.57	0.11	0.00
sugarcane	406.02	1.08	0.14	0.02	0.32
sunflower	73.00	2.2	1.05	0.26	0.00
triticale	243.27	4.12	1.46	0.29	0.60
wheat	177.55	2.57	1.21	0.22	0.00
Oil palm	See Section 6.11				

3.11 Global crop-specific calculation of CO2 emissions from agricultural lime application and fertilizer acidification

Global CO$_2$ emissions caused by agricultural lime application are calculated for a 5 min. by 5 min. (~10 km by 10 km) grid, similar to the approach used for soil N$_2$O emissions. For soil parameters, crop species distribution and fertilizer N input, we resorted to the same data set used to calculate soil N$_2$O emissions.

As a prerequisite for the emission calculations, the site-specific lime application to a certain crop within a 5 min. by 5 min. grid cell had to be estimated.

Country level limestone (CaCO$_3$) and dolomite (CaMg(CO$_3$)$_2$) consumption to counteract acidification of soil (and water bodies) is available from the EDGAR v4.1 database (EC-JRC/PBL). In the following, we refer to lime but mean the sum of limestone and dolomite.

The data of the EDGAR v4.1 database originate from the reporting of Annex I ([24]) countries to the UNFCCC. Data on lime consumption for the year 2000 are taken from the (mainly year 2008) submissions of the common reporting format (CRF) tables. In EDGAR v4.1, all the lime use reported in CRF Table 5 (IV) is taken into account, regardless of whether lime is applied to agricultural soils, forests or lakes. In the case of Non-Annex I countries ([24]) which are not obliged to report emissions to UNFCCC, the estimated amount of lime applied is based on the calculated need to balance the use of ammonium fertilizers. It is assumed that all calcium is applied as lime. It should be noted that in reality, several factors affect soil acidity and, subsequently, liming need, and therefore the estimates are highly uncertain (EC-JRC/PBL).

As the EDGAR v4.1 data set does not distinguish lime input to different land uses/covers, the UNFCCC CRF submissions (2008) for the year 2000 (UNFCCC, 2012) were re-screened and the shares of input into land uses other than that of cropland were subtracted in our calculations for those countries providing the information. Country-level data as extracted from the EDGAR v4.1 database and the shares of lime input to other land uses/cover are listed in Table 59.

There are various shortcomings to using the EDGAR v4.1 data set for the calculations of CO_2 emissions from liming of potential biofuel crops. However, to our knowledge, this is the only global data set on lime and dolomite application based on values reported officially by the individual Annex I countries.

The first of two main shortcomings is that only a few countries report the share of lime applied to land use/cover other than cropland. Especially in developed countries with high shares of managed grasslands/pastoral systems (e.g. New Zealand), the uncertainty in the share of lime input to grassland soils could lead to considerable error in the estimates of the liming in croplands.

Furthermore, for most countries it is unknown how much of the lime consumption in Table 59 was applied to arable land and how much to other areas, such as permanent pastures.

Non-Annex I countries did not submit lime inputs to UNFCCC, so the EDGAR dataset estimated the amount of lime at country level on the basis of how much would be needed to counter the acidity from their use of nitrogen fertilizers. But this ignores the agricultural lime that these countries apply to counter naturally-occurring acidity in their soils. This could lead to considerable errors for countries with large areas of recently-converted acidic soils.

The only non-Annex I countries that affect estimates of *default* cultivation emissions in the RED are Brazil and Argentina, which both export soybean and soybean oil to EU. Furthermore, Brazil is the principle exporter of ethanol from sugar-cane. Therefore we applied a correction to the liming emissions data for these countries, which is described in more detail at the end of this section.

Our approach calculates the proportions of lime applied to grassland and crops on a GIS basis, according to the soil pH and the target pH for grassland and cropland. To break down country-level lime consumption to site-specific application rates, we followed the Agricultural Lime Association (ALA) recommendations (2012) developed in partnership with the University of Hertfordshire's Agriculture & Environment Research Unit (AERU). The application rates recommended are aimed at a target soil pH of 7.0 for arable and 6.5 for permanent grassland. This holds for mineral soils. For organic soils, the target pH is 0.3 and 0.7 pH units lower for arable land and grassland respectively. The ALA

([24]) Annex 1 in the United Nations Framework Convention on Climate Change lists those countries which are signatories to the Convention and committed to emission reductions. Non-Annex 1 countries are developing countries, and they have no emission reduction targets.

recommendations depend on soil pH and texture as well as organic matter content, and on whether the soil is cultivated as arable land or grassland (see Table 60).

Based on globally available information on soil pH, organic matter and texture from the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009) ([25]) and the harvested area of the single crops in the year 2000 (Monfreda et al., 2008), the theoretically required lime input according the recommendations of the ALA (2012) can be calculated for the harvested area of each crop in each 5 min. by 5 min. grid cell. Figure 12 illustrates the underlying data sets for global pH and harvested crop area. The lime was distributed to harvested area (accounts for multiple cropping) rather than to cropland area (physical land area), assuming that areas with double or triple cropping receive higher fertilizer input and need higher rates of lime application to counteract acidity caused by fertilizer N. The final lime input to the grid cell was calibrated in order to fit with the country level lime input from the EDGAR 4.1 database.

We compared the results of the disaggregation with field-level data provided in the literature for Germany and the United Kingdom (see Section 3.12): in both cases, the estimated lime input per ha of this work is in the range of what is mentioned in the literature.

The total emissions from lime application to the crop on a grid cell bases were calculated as:

CO_2 Emissions$_{limetot}$ in kg = kg lime applied * 0.079 if pH ≥ 6.4 and

CO_2 Emissions$_{limetot}$ in kg = kg lime applied * 0.044 if pH < 6.4

However, emissions from lime input required to neutralise fertilizer acidity are attributed to the emissions caused by the fertilizer. These emissions need to be subtracted from the total emissions caused by lime application, to avoid double counting. As explained above, Fertilizers Europe indicate that the neutralisation of 1 t of nitrogen in synthetic fertilizer releases 0.798 t CO_2.

From the global data set on crop-specific synthetic fertilizer input data ([26]), the emissions caused by neutralisation of fertilizer input were calculated on the grid cell basis for each crop as:

CO_2 Emission$_{synthfert}$ in kg =kg synthetic N applied * 0.798

If, for a specific crop in a grid cell, the CO_2 emissions from lime input exceed the CO_2 emissions needed to neutralise synthetic fertilizer N input, we attribute the difference in emissions to lime application. Due to the method of accounting for N input from mineral fertilizer and manure to a specific crop, we also take into account 50 % of the manure input given in the global fertilizer data set, assuming that in the case of biofuel crops we underestimate the total amount of mineral fertilizer, to which (in most cases) no manure is applied ([27]). The emissions resulting from neutralising 50 % of N applied as manure (CO_2 Emissions$_{50\%man}$) to the biofuel crops in our database are calculated the same way as for synthetic fertilizer; we consider that in reality, this manure will be applied as synthetic fertilizer to biofuel crops. However, the emissions are not added to the synthetic fertilizer, but to the final lime emissions (CO_2 Emissions$_{lime\_net}$), so as to ensure that globally, emissions attributed to synthetic fertilizer are not overestimated.

([25]) The calculations are based on the dominant soil type in a soil mapping unit of the Harmonized World Soil Database.

([26]) For a description of the crop-specific mineral fertilizer input, see Section 3.5.

([27]) For a discussion of the 50 % manure input, see Section 3.6.

Hence, if CO_2 $\text{Emissions}_{limetot} \geq CO_2$ $\text{Emission}_{synthfert}$

we calculate

CO_2 $\text{Emissions}_{lime\_net} = CO_2$ $\text{Emissions}_{limetot} + CO_2$ $\text{Emissions}_{50\%man} - CO_2$ $\text{Emission}_{synthfer}$

otherwise if CO_2 $\text{Emissions}_{limetot} < CO_2$ $\text{Emission}_{synthfert}$

we set

CO_2 $\text{Emissions}_{lime\_net} = CO_2$ $\text{Emissions}_{50\%man}$

Country-and crop-specific emissions (in kg CO_2 MJ^{-1} of fresh crop) attributed to lime application are calculated then as sum of the CO_2 $\text{Emissions}_{lime\_net}$ from each grid cell for each crop in the country divided by the country's total yield of the crop (in MJ fresh crop).

Country-and crop-specific emissions (in kg CO_2 MJ^{-1} of fresh crop) attributed to synthetic fertilizer input are calculated then as the sum of the CO_2 $\text{Emissions}_{synthfer}$ from each grid cell for each crop in the country, divided by the country's total yield of the crop (in MJ fresh crop).

Final emissions (see Table 58) attributed to a specific biofuel crop equal the global weighted average emissions from suppliers of each crop to the EU market (including EU domestic production).

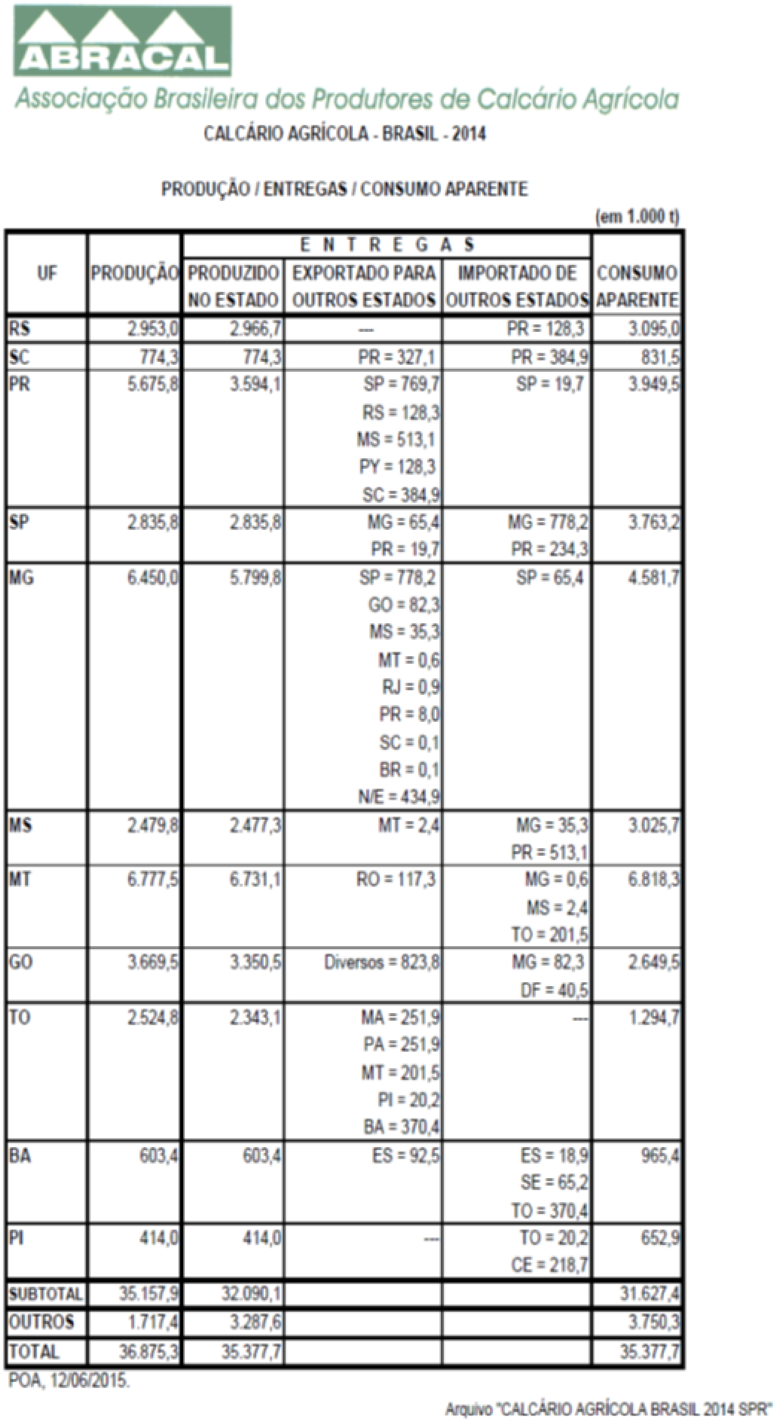
Correction for Brazil and Argentina

Brazil's high share of soils susceptible to acidification led its government to instigate a programme in 1998 to improve Brazilian agriculture productivity by intensification of liming. According to national statistics (Bernoux et al., 2003), 19 812 ktonnes of lime were consumed in the year 2000. In 2014, agricultural lime use had grown to 35 378 ktonnes, according to the Brazilian Association of Agricultural Lime Producers (ABRACAL). This is five times higher than that given in the EDGAR v4.1 data set (6 980 ktonnes).

In Argentina, the Institute for Geology and Mineral Resources (IGRM) reports that 13 000 kilotonnes of limestone and dolomite were used to combat soil acidity in agriculture: a value over 30 times higher than estimated in the EDGAR v4.1 data set (424 ktonnes).

These large deviations indicate that using the data from EDGAR would significantly under-estimate liming emissions from Brazil and Argentina.

Figure 10 Consumption of agricultural lime in Brazil (2014), source: Brazilian Association of Agricultural Lime Producers (ABRACAL).



ABRACAL
Associação Brasileira dos Produtores de Calcário Agrícola

CALCÁRIO AGRÍCOLA - BRASIL - 2014

PRODUÇÃO / ENTREGAS / CONSUMO APARENTE

(em 1.000 t)

UF	PRODUÇÃO	ENTREGAS			CONSUMO APARENTE
		PRODUZIDO NO ESTADO	EXPORTADO PARA OUTROS ESTADOS	IMPORTADO DE OUTROS ESTADOS	
RS	2.953,0	2.966,7	---	PR = 128,3	3.095,0
SC	774,3	774,3	PR = 327,1	PR = 384,9	831,5
PR	5.675,8	3.594,1	SP = 769,7 RS = 128,3 MS = 513,1 PY = 128,3 SC = 384,9	SP = 19,7	3.949,5
SP	2.835,8	2.835,8	MG = 65,4 PR = 19,7	MG = 778,2 PR = 234,3	3.763,2
MG	6.450,0	5.799,8	SP = 778,2 GO = 82,3 MS = 35,3 MT = 0,6 RJ = 0,9 PR = 8,0 SC = 0,1 BR = 0,1 N/E = 434,9	SP = 65,4	4.581,7
MS	2.479,8	2.477,3	MT = 2,4	MG = 35,3 PR = 513,1	3.025,7
MT	6.777,5	6.731,1	RO = 117,3	MG = 0,6 MS = 2,4 TO = 201,5	6.818,3
GO	3.669,5	3.350,5	Diversos = 823,8	MG = 82,3 DF = 40,5	2.649,5
TO	2.524,8	2.343,1	MA = 251,9 PA = 251,9 MT = 201,5 PI = 20,2 BA = 370,4	---	1.294,7
BA	603,4	603,4	ES = 92,5	ES = 18,9 SE = 65,2 TO = 370,4	965,4
PI	414,0	414,0	---	TO = 20,2 CE = 218,7	652,9
SUBTOTAL	35.157,9	32.090,1			31.627,4
OUTROS	1.717,4	3.287,6			3.750,3
TOTAL	36.875,3	35.377,7			35.377,7

POA, 12/06/2015.

Arquivo "CALCÁRIO AGRÍCOLA BRASIL 2014 SPR"

Figure 11 Limestone and dolomite used in Argentina, source: Institute for Geology and Mineral Resources (IGRM)

Minerales para el agro

Minerales	Aporte agrícola	Provincias Productoras	Prod. en tn.
Calizas y dolomitas	Calcio y magnesio corrigen acidez edáfica	San Juan, Córdoba, Mendoza, Bs. As., Neuquén, Catamarca, Jujuy, Entre Ríos, Río Negro, Tucumán, San Luis	13.000.000
Yeso y otros sulfatos	Azufre. Corrigen alcalinidad y salinidad	San Juan, Mendoza, Bs. As., Neuquén, Catamarca, Jujuy, Entre Ríos, Río Negro, Tucumán, La Pampa, Chubut y Stgo. del Estero	1.100.000
Sales potasio	Potasio	Mendoza	Sin datos
Boratos	Boro	Varias	630.000
Minerales metálicos	Micronutrientes: Zn, Fe, Mn.	Salta, Catamarca, Jujuy	Sin datos
Turba, perlita, vermiculita	Correctores de suelo	Salta, Catamarca, Tierra del Fuego, Córdoba y Mendoza	35.000

Fuente: Instituto de Geología y Recursos Minerales

DIARIO DE CUYO

As explained before in this section, the agricultural lime use in Brazil is about 5 times higher than assumed in the calculations so far, and >30 times higher in Argentina. The obvious correction is to multiply the calculated values of lime use per hectare for all crops in these countries by these factors. However, there are two mitigating factors that should be taken into account, and are important in the case of Brazil and Argentina.

One mitigating effect is that some of the lime is used to prepare new land for agriculture, so it should be attributed to land use change emissions, rather than continuing cultivation. That is important, because although the % of new land converted is small compared to the total cultivated area, the generally acidic nature of the natural land in these countries means that massive doses of lime are often needed to make new land cultivatable.

A second mitigating effect is double cropping: as explained above, we distributed lime considering harvested area, on the basis that multiple harvests in one year would require more lime to counter multiple fertilizer applications. However, in the case of Brazil and Argentina, most of the lime is used to counter natural soil acidity, rather than the acidity due to fertilizer use; so the amount of lime needed does not depend much on the number of harvests in these countries.

Taking these effects into consideration reduced the total lime attributed to the crops by about 40%.

Table 59 Limestone and dolomite consumption for the years 2000, as reported in EDGAR v4.1 database (EC-JRC/PBL), and share of limestone and dolomite applied to land use/cover other than cropland

Country	Limestone and dolomite consumption in the year 2 000 (1 000 t)	Percentage of limestone and dolomite input to land use other than cropland	Country	Limestone and dolomite consumption in the year 2 000 (1 000 t)	Percentage of limestone and dolomite input to other land use than cropland
Albania	16		South Korea	**64**	
Algeria	92		Kyrgyzstan	**99**	
Argentina	424		Latvia	**5**	
Armenia	25		Lebanon	**103**	
Australia	2 404		Libya	**9**	
Austria	205		Lithuania	**29**	
Azerbaijan	8		former Yugoslav Republic of Macedonia	**24**	
Bangladesh	77		Malaysia	**1 695**	
Belarus	3 375		Mexico	**4 768**	
Belgium	91		Moldova	**6**	
Brazil	6 983		Morocco	**561**	
Bulgaria	2		Nepal	**18**	
Cameroon	17		Netherlands	**255**	
Canada	558		New Zealand	**1 279**	
Chile	54		Nicaragua	**25**	
China	5 033		Nigeria	**14**	
Colombia	311		Norway	**340**	**19.6 (Lakes)**
Costa Rica	107		Pakistan	**259**	
Côte d'Ivoire	29		Peru	**185**	
Croatia	13		Philippines	**1 122**	
Cuba	240		Poland	**2 542**	
Cyprus	16		Portugal	**67**	
Czech Republic	1 087	**3.9 (Grassland)**	Romania	**382**	
Denmark	737		Russia	**9 267**	
Dominican Republic	176		Saudi Arabia	**122**	
Ecuador	37		Senegal	**50**	
Egypt	2 223		Serbia and Montenegro	**50**	
El Salvador	325		Slovakia	**2**	
Estonia	46		Slovenia	**2**	
Ethiopia	76		South Africa	**230**	

Country	**Limestone and dolomite consumption in the year 2 000 (1 000 t)**	**Percentage of limestone and dolomite input to land use other than cropland**	**Country**	**Limestone and dolomite consumption in the year 2 000 (1 000 t)**	**Percentage of limestone and dolomite input to other land use than cropland**
Finland	918		Spain	**1 680**	
France	2 273		Sri Lanka	**259**	
Georgia	47		Sudan	**122**	
Germany	4 402	**6.9 (Forest)**	Sweden	**272**	
Greece	598		Switzerland	**45**	
Guatemala	281		Syria	**286**	
Hungary	147		Taiwan	**1 044**	
Iceland	5		Tajikistan	**16**	
India	4 336		Tanzania	**35**	
Indonesia	1 553		Thailand	**1 717**	
Iran	656		Tunisia	**208**	
Iraq	65		Turkey	**1 698**	
Ireland	665	**89.8 (Grassland)**	Turkmenistan	**265**	
Israel	71		Ukraine	**2 776**	
Italy	1 009		United Kingdom	**2242**	**37.9 (Grassland)**
Japan	1 989		United States	**20 556**	
Jordan	26		Uruguay	**41**	
Kazakhstan	100		Uzbekistan	**719**	
Kenya	83		Venezuela	**188**	
North Korea	186		Vietnam	**1 365**	

Table 60 Lime application recommendations (Agricultural Lime Association, 2012). Values are the amount of ground limestone (with a neutralising value of 54 and 40 % passing through a 150 micron mesh) required to achieve the target soil pH. The Agricultural Lime Association considers a optimum pH between 6.8 and 7.0 for general cropping. For permanent grassland the optimum pH is slightly lower.

	Arable land					Grassland				
Measured pH	**Sand and loamy sands**	**Sandy loams and silt loams**	**Clay loams and clays**	**Organic soils (10 %–25 % organic matter)**	**Peaty soils above 25 % organic matter**	**Sand and loamy sands**	**Sandy loams and silt loams**	**Clay loams and clays**	**Organic soils (10 %–25 % organic matter)**	**Peaty soils above 25 % organic matter**
	Recommended lime application (t/ha)									
7	0	0	0	0	0	0	0	0	0	0
6.9	2	2	2	0	0	0	0	0	0	0
6.8	2	2	2	0	0	0	0	0	0	0
6.7	2	2	2	0	0	0	0	0	0	0
6.6	2	3	3	2	0	0	0	0	0	0
6.5	3	4	4	2	0	0	0	0	0	0
6.4	4	4	5	3	0	2	2	2	0	0
6.3	4	5	6	4	0	2	2	2	0	0
6.2	5	6	6	5	2	2	2	2	0	0
6.1	5	6	7	6	3	2	2	2	2	0
6	6	7	8	7	5	2	3	3	2	0
5.9	7	8	9	8	6	3	3	4	2	0
5.8	7	8	10	9	9	3	4	4	3	0
5.7	8	9	10	10	10	4	4	5	4	2
5.6	8	10	11	11	11	4	5	5	5	2
5.5	9	11	12	12	13	5	5	6	5	4
5.4	10	11	12	13	14	5	6	7	6	5
5.3	10	12	13	14	16	5	6	7	7	6

	Arable land					Grassland				
Measured pH	Sand and loamy sands	Sandy loams and silt loams	Clay loams and clays	Organic soils (10 %–25 % organic matter)	Peaty soils above 25 % organic matter	Sand and loamy sands	Sandy loams and silt loams	Clay loams and clays	Organic soils (10 %–25 % organic matter)	Peaty soils above 25 % organic matter
5.2	11	13	14	15	18	6	7	7	7	7
5.1	11	13	15	16	19	6	7	7	7	7
5	12	14	16	17	21	7	7	7	7	7
4.9	13	15	16	18	22	7	7	7	7	7
4.8	13	15	17	19	24	7	7	7	7	7
4.7	14	16	18	20	26	7	7	7	7	7
4.6	14	17	19	21	27	7	7	7	7	7
4.5 (28)	15	17	20	22	29	7	7	7	7	7

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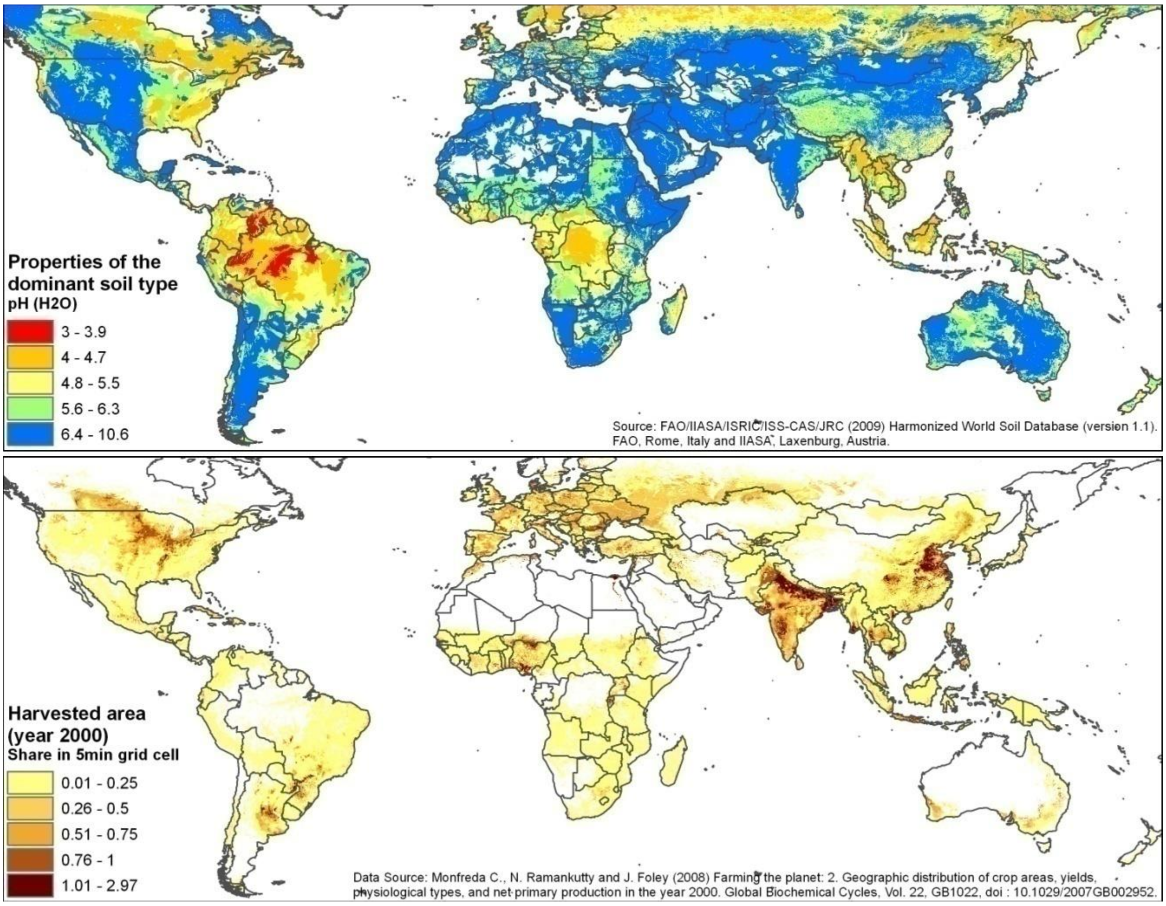
(28) For this work, we assume the lime application to soils with pH < 4.5 to be the same as for pH 4.5 soils.

Figure 12 Global distribution of soil pH (FAO/IIASA/ISRIC/ISS-CAS/JRC) and harvested area (Monfreda et al., 2008)



Source: FAO/IIASA/ISRIC/ISS-CAS/JRC (2009) Harmonized World Soil Database (version 1.1). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

Data Source: Monfreda C., N. Ramankutty and J. Foley (2008) Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. Global Biochemical Cycles, Vol. 22, GB1022, doi : 10.1029/2007GB002952.

3.12 Lime application in the United Kingdom and Germany: survey data vs disaggregated country total lime consumption

Farm- and field-level information on lime application is scarce. For most countries, lime application in agriculture is given as a country total derived from lime consumption/production in the country. In many cases, even the shares of lime applied to either arable land or grassland are unknown. To check the results of the disaggregation of country level lime consumption to crop level application as described in the previous chapter, we compared the results with field data described in the literature.

United Kingdom

In the United Kingdom, the Department for Environment, Food and Rural Affairs (Defra) is sponsoring an annual survey about fertilizer use on farm crops in Great Britain (29) since 1983. In 2000, approximately 1 400 farms were surveyed (Defra, 2001). Lime application is assessed at farm and field level for four different liming products (ground limestone, ground chalk, magnesian limestone and sugar beet lime). Input of all other types of liming products are summarised under the group 'others' (Table 61).

Defra lime application data (30) are compared with the results of the disaggregation of country-level lime consumption to the crop level for the year 2000.

In the United Kingdom 2.242 million tonnes of $CaCO_3$ (limestone and dolomite) were applied to agricultural fields (EC-JRC/PBL); 37.9 % was applied to grassland, leaving 1.39 million tonnes for arable land (31). From the disaggregation described in the previous section we can calculate an average input of 0.28 tonnes of $CaCO_3$ ha^{-1} yr^{-1} to arable land for which lime application is recommended. This is the case for around 4.9 million ha or 91.2 % of the arable land.

Lime application recommendations usually give application rates to reach the optimum pH level for the crop cultivation. Thus, the application has to be repeated only if the desired pH level decreases again below a critical threshold. A repetition rate frequently mentioned in lime application recommendations is 5 to 10 years, but it may vary strongly depending on the soil properties, climatic conditions and farming practices.

The Defra (2001) survey (Table 61) gives the percentage of crop area receiving dressing and the amount of liming product applied in 2000. Depending on the crop, lime is applied in quantities of 1.1 tonnes CaO per ha to 2.7 tonnes CaO per ha on ~5 % to 35 % of the crops area. On average, for all tilled crops, 2.5 tonnes CaO from all liming products are applied to 8.4 % of the tilled crops area. Ground limestone, ground chalk and magnesian limestone contribute with 2.2 tonnes of CaO ha^{-1} on 7.7 % of the tilled crops area. From our analysis of the spatial data on soil properties in the United Kingdom (32) we calculated that around 91.2 % of the arable crops area needs lime application to reach optimum pH for cultivation. If we assume that over time all the area will be limed, we can calculate the number of years until all the whole area is limed once by dividing 91.2 % by 7.7 % (the annual share of area limed with ground limestone, ground chalk and magnesian limestone given by Defra). Hence, in 11.8 years, all arable crops growing on soils with non-optimal pH will have been limed once. Assuming liming practices constant over time, a single field gets one application every 11.8 years, on average. The annual application rate of lime can be calculated by dividing the application of 4 tonnes of

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(29) Wales, England and Scotland.

(30) Excluding 'sugar beet lime' and 'other'.

(31) This excludes permanent grassland.

(32) This includes Northern Ireland. It is assumed that conditions in Northern Ireland (share of crop area requiring liming and liming frequency) are not significantly different from the mean conditions in Great Britain.

$CaCO_3$ ha^{-1} (or 2.2 tonnes of CaO ha^{-1}) by 11.8 years. This results in an average application rate of 0.34 tonnes of $CaCO_3$ ha^{-1} yr^{-1} on arable land based on Defra survey data. This compares to 0.28 tonnes of $CaCO_3$ ha^{-1} yr^{-1} on arable land with non-optimal pH conditions, from the spatial disaggregation of country-level lime application (see Table 62).

Table 61 Lime application at field level (Defra, 2001) and estimation of mean annual application rates on tillage crops in the year 2000

	Crop area receiving dressing (%)						Average field rate of CaO equivalent (tonnes/ha)								Calculation of $CaCO_3$ input per ha		
Crop type	Ground limestone	Ground chalk	Magnesian limestone	Sugar beet lime	Other	All	Ground limestone	Ground chalk	Magnesian limestone	Sugar beet lime	Other	All	Fields limed	Total no of fields	Liming frequency (years)	Weighted average application rate of ground limestone, ground chalk and magnesian limestone (tonnes of $CaCO_3$ ha^{-1})	Annual application rate (tonnes of $CaCO_3$ ha^{-1} yr^{-1})
Spring wheat													3	62			
Winter wheat	4.0	0.8	0.9	0.2		5.9	2.3	2.0	2.4	2.8		2.3	149	2796	16.0	4.1	0.25
Spring barley	4.9	0.8	5.0	0.3		11.0	2.0	1.8	2.4	3.3		2.2	119	881	8.5	3.9	0.45
Winter barley	6.5	0.2	1.5	0.4		8.6	2.4	2.1	1.8	3.4		2.4	78	841	11.1	4.1	0.37
Oats	2.5		2.3			4.8	2.2		1.5			2.0	12	199	19.0	3.3	0.18
Rye/triticale/durum wheat													3	51			
Seed potatoes													1	21			
Early potatoes													0	14			
2nd early/main crop potatoes													0	227			
Sugar beet	10.6	9.3	5.3	10.7		35.9	2.5	2.1	1.9	2.9		2.7	89	273	3.6	4.0	1.10
Spring oilseed rape	1.2	4.7	2.0		4.4	12.3	1.2	1.5	2.0		0.4	1.1	7	73	11.5	2.8	0.24
Winter oilseed rape	7.5	1.0	1.8	0.9		11.2	2.3	2.0	2.2	1.6		2.3	47	525	8.9	4.0	0.45
Linseed													0	60			
Forage maize	15.2	1.8	3.5			20.5	2.7	2.5	1.6			2.5	27	149	4.4	4.5	1.00
Root crops for stockfeed	11.9		2.9	0.7		15.5	1.9		2.2	1.1		1.9	11	78	6.2	3.5	0.57
Leafy forage crops	5.0	0.4	13.3			18.7	1.7	1.5	2.6			2.0	14	56	4.9	4.2	0.85
Arable silage/other fodder crop	0.4		12.4			12.8	2.5		2.7			2.5	5	40	7.1	4.8	0.67

	Crop area receiving dressing (%)						Average field rate of CaO equivalent (tonnes/ha)								Calculation of $CaCO_3$ input per ha		
Crop type	**Ground limestone**	**Ground chalk**	**Magnesian limestone**	**Sugar beet lime**	**Other**	**All**	**Ground limestone**	**Ground chalk**	**Magnesian limestone**	**Sugar beet lime**	**Other**	**All**	**Fields limed**	**Total no of fields**	**Liming frequency (years)**	**Weighted average application rate of ground limestone, ground chalk and magnesian limestone (tonnes of $CaCO_3$ ha^{-1})**	**Annual application rate (tonnes of $CaCO_3$ ha^{-1} yr^{-1})**
Peas — human consumption													2	96			
Peas — animal consumption	1.9	3.8	1.9			7.6	2.5	0.8	2.6			1.6	7	112	12.0	3.0	0.25
Beans — animal consumption	0.3	1.7		0.3		2.3	1.2	0.6		1.2		1.3	5	170	45.6	1.2	0.03
Vegetables (brassicae)													4	56			
Vegetables (other)	5.2	0.5	0.7	2.5		8.9	2.5	4.0	2.1	1.3		2.7	14	126	14.3	4.6	0.32
Soft fruit													1	47			
Top fruit	4.9	1.9				6.8	0.3	0.2				0.1	8	78	13.4	0.5	0.04
Other tillage		0.4	0.3					0.1	0.1				5	117	130.3	0.2	0.00
All tillage	4.8	1.1	1.8	0.7		8.4	2.3	2.0	2.2	2.7		2.5	611	7148	11.8	4.0	0.34
Grass under 5 years	2.7	0.2	1.9			4.8	2.4	1.3	2.4			2.2	102	1280	19.0	4.2	0.22
Grass 5 years and over	1.6	0.1	1.3	0.3		3.3	2.2	2.8	2.4	2.1		2.1	130	2744	30.4	4.1	0.14
All grass	1.8	0.1	1.4	0.3		3.6	2.2	2.3	2.4	2.1		2.1	232	4024	27.6	4.1	0.15
All crops and grass	3.3	0.6	1.6	0.5		6.0	2.3	2.0	2.3	2.5		2.3	843	11172	16.6	4.0	0.24

[#] 1kg of $CaCO_3$ corresponds to 1.7857 kg of CaO.

Table 62 Lime application in the United Kingdom in the year 2000, based on this study

Crop	**Crop area where lime applications is recommended (ha)**	**Annual lime (limestone and dolomite) application rate (tonnes of $CaCO_3$ ha^{-1} yr^{-1})**
Wheat	1 648 298	0.29
Barley	1 061 485	0.34
Other cereals	95 219	0.32
Rye	4 787	0.27
Triticale	9 592	0.30
Potato	146 029	0.32
Sugar beet	159 844	0.26
Rapeseed	412 317	0.32
Oilseeds	68 062	0.32
Forage	968 124	0.17
Fibres	15 077	0.30
Pulses	199 277	0.32
Vegetables	105 234	0.30
Fruits	8 785	0.29
All crops	4 902 130	0.28

Germany

Study 1

For wheat and rye, De Vries (2006) suggests 0.3 t to 0.4 t of CaO (0.54 - 0.71 tonnes of $CaCO_3$) per ha and year on soils in Mecklenburg-Vorpommern (north-eastern Germany).

Study 2

Ahlgrimm et al. (2000) cited in Hirschfeld et al. (2008) assume 0.35 t CaO (~0.63 t $CaCO_3$ per ha) as a kind of default value for all crops under conventional farming.

Study 3

On the basis of statistical data in Germany, Knappe et al. (2008) classified different farm types and assessed the fertilizer/lime application requirement based on nutrient balances.

For conventional farming based on manure and mineral fertilizer input, Knappe et al. (2008) ([33]) calculated an annual deficit of ~0.16 - 0.25 tonnes CaO (0.29 - 0.45 tonnes $CaCO_3$) to neutralise acidification from fertilizer N input on arable land and 0.07 tonnes CaO (~ 0.12 tonnes of $CaCO_3$) on permanent grassland.

In conventional farming systems, when applying mineral fertilizer in combination with sewage sludge or compost (Knappe et al., 2008) ([34]), the additional liming requirements decrease depending on the amount of sewage sludge or compost applied. There might be even a CaO surplus, especially in case of compost application.

In their approach, they do not consider lime application for optimising soil pH.

Results of our work:

From our study we get 0.48 t $CaCO_3$ per ha in Germany as average input for all arable crop species on soils where lime is applied.

([33]) See Tables C14 and C17.

([34]) See Tables C15 and C16.

4. Utilities and auxiliary processes

This section contains the processes for utilities such as boilers and power plants that are used throughout the various pathways in Chapter 6.

Natural Gas boiler

Table 63 Process for a NG boiler (10 MW)

	I/O	Unit	Amount	Source
NG	Input	MJ/MJ_{heat}	1.111	1, 2
Electricity	Input	MJ/MJ_{heat}	0.020	2
Steam	Output	MJ	1.0	
Emissions				
CH_4	Output	g/MJ_{heat}	0.0028	1
N_2O	Output	g/MJ_{heat}	0.0011	1

Comments

- Electricity taken from the grid at 0.4kV.
- Thermal efficiency = 90 % (based on LHV).
- CO_2 emissions from natural gas combustion are considered to be 56.2 gCO_2/MJ.

Sources

1 GEMIS v. 4.93, 2014, *gas-boiler-DE 2010.*

2 GEMIS v. 4.93, 2014, *gas-heat plant-medium-DE 2010.*

Natural Gas Combined Heat and Power (CHP)

Table 64 Process for a NG CHP to supply power and heat (before allocation)

	I/O	Unit	Amount
NG	Input	MJ/MJ_{heat}	2.387
Steam	Output	MJ	1.00
Electricity	Output	MJ/MJ_{heat}	0.790
Emissions			
CH_4	Output	g/MJ_{heat}	0.010
N_2O	Output	g/MJ_{heat}	0.002

Comments

- CO_2 emissions from natural gas combustion are considered to be 55.1 gCO_2/MJ.

Source

1 TAB, 1999.

The Natural Gas input is allocated between steam and electricity by ***exergy*** following the methodology set in Annex V part C - Directive (EU) 2018/2001 (see following table).

Table 65 Allocation calculation for NG CHP

	Unit	Amount
Electrical efficiency	%	33%
Thermal efficiency	%	42%
Temperature of steam	°C	150
Carnot factor electricity		1.000
Carnot factor steam		0.355
Allocation factor electricity		0.690
Allocation factor steam		0.310
NG input electricity generation BEFORE allocation	MJ/MJ of electricity	3.021
NG input electricity generation AFTER allocation	**MJ/MJ of electricity**	**2.085**
NG input steam generation BEFORE allocation	MJ/MJ of steam	2.387
NG input steam generation AFTER allocation	**MJ/MJ of steam**	**0.739**
Overall carnot efficiency		48%
NG input		2.085

Lignite Combined Heat and Power (CHP)

Table 66 Process for a lignite CHP (before allocation)

	I/O	Unit	Amount	Sources
Lignite	Input	MJ/MJ_{heat}	1.405	1
Steam	Output	MJ	1.0	
Electricity	Output	MJ/MJ_{heat}	0.222	1
Emissions				
CH_4	Output	g/MJ_{heat}	0.001	2
N_2O	Output	g/MJ_{heat}	0.004	2

Comments

- CO_2 emissions from lignite combustion are considered to be 115 gCO_2/MJ.

Sources

1 Larivé, J-F., CONCAWE, personal communication, February 2008.

2 GEMIS v. 4.93, 2014, '*lignite-cogen-SE-DE-rhine-2000*'.

The lignite input is allocated between steam and electricity by ***exergy*** following the methodology set in Annex V part C - Directive (EU) 2018/2001.

Table 67 Allocation calculation for lignite CHP

Lignite/coal CHP	**Unit**	**Amount**
Electrical efficiency	%	16%
Thermal efficiency	%	71%
Temperature of steam	°C	150
Carnot factor electricity		1.000
Carnot factor steam		0.355
Allocation factor electricity		0.385
Allocation factor steam		0.615
Lignite input electricity geneation BEFORE allocation	MJ/MJ of electricity	6.322
Lignite input electricity geneation AFTER allocation	**MJ/MJ of electricity**	**2.435**
Lignite input steam geneation BEFORE allocation	MJ/MJ of steam	1.405
Lignite input steam geneation AFTER allocation	**MJ/MJ of steam**	**0.864**
Overall carnot efficiency		41%
Lignite input		2.435

Wood chip–fuelled CHP

Table 68 Process for a wood chip-fuelled CHP (before allocation)

	I/O	**Unit**	**Amount**	**Source**
Wood chips	Input	MJ/MJ_{heat}	2.132	1
Steam	Output	MJ	1.0	
Electricity	Output	MJ/MJ_{heat}	0.361	1
Emissions				
CH_4	Output	g/MJ_{heat}	0.0008	2
N_2O	Output	g/MJ_{heat}	0.0043	2

Comments

- Represents a plant with a capacity of 34.2 MW of steam. Thermal efficiency should be considered as obtained at optimum load. The CHP can be dimensioned on a different electricity load and thus reach a lower thermal efficiency.

Source

1 Punter et al., 2004.

2 Vitovec, 1999.

The wood chip input is allocated between steam and electricity by exergy following the methodology set in Annex V part C - Directive (EU) 2018/2001.

Table 69 Allocation calculation for wood chips CHP

	Unit	**Amount**
Electrical efficiency	%	17%
Thermal efficiency	%	47%
Temperature	°C	150
Carnot factor electricity		1.000
Carnot factor steam		0.355
Allocation factor electricity		0.505
Allocation factor steam		0.495
Wood chip input electricity generation BEFORE allocation	MJ/MJ of electricity	5.903
Wood chip input electricity generation AFTER allocation	**MJ/MJ of electricity**	**2.979**
Wood chip input steam generation BEFORE allocation	MJ/MJ of steam	2.132
Wood chip input steam generation AFTER allocation	**MJ/MJ of steam**	**1.056**
Overall carnot efficiency		34%
Wood chip input		2.979

5. Transport processes

This section contains all the processes that pertain to fuel consumption for all the vehicles and means of transportation used in all the pathways.

The section is structured by road, maritime, inland and rail transportation.

The processes are recalled in each pathway in Chapter 6.

5.1 Road transportation

40 t truck (27 t payload)

The common means of transport considered for road transport is a 40 t truck with a payload of 27 t.

For the transport of solid materials, a flatbed truck transporting a container is considered. The weight of such a “tank” is considered, for the sake of simplicity, to be 1 t.

For the transport of liquids and pellets (35), special tank trucks are used. It is assumed that such trucks have the same general fuel efficiency and general payload of the truck for solids but with a higher, 2 t, weight for the tank, to account for the pneumatic system.

The truck fuel consumption is linearised on the weight transported and on the distance. The amount of tonnes per kilometre is calculated from the formula (in this case, for solid fuels transport):

$$\mathrm{Distance}\left[\frac{\mathrm{t}\cdot\mathrm{km}}{\mathrm{MJ}_{\mathrm{goods}}}\right]=\frac{(27)[t]\cdot x[km]}{(27-\mathrm{tank})[t]\cdot LHV_{dry}\left[\frac{MJ_{goods}}{kg_{dry}}\right]\cdot Solids\left[\frac{kg_{dry}}{kg_{tot}}\right]}$$

This value is calculated and reported for each pathway in the following chapters of this report, and the specific LHV and moisture content of the analysed materials will also be highlighted.

In order to obtain the final fuel consumption of the transportation process, the 'distance' process needs to be multiplied by the fuel consumption of the vehicle considered. For the case of a 40 t truck, this value and the associated emissions are reported in Table 70.

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(35) For wood chips, the payload of a typical trailer truck with a gross weight of 40 t is taken to be 90 m^3 (e.g. “Schubboden”). The mass of the semitrailer tractor amounts to about 7.6 t (see e.g.: MERCEDES-BENZ 1844 LS 4x2, 400 kW) and the mass of the trailer for the transport of wood chips (92 m^3) ranges between 7.5 and 7.9 t. Then the net payload amounts to (40-7.6-7.5…7.9) t = 24.5…24.9 t. For the DAF CF 75.360 the empty mass is indicated with 6.5 t which would lead to a net payload of up to 26 t.

Table 70 Fuel consumption for a 40 t truck (27 t payload)

	I/O	Unit	Amount	Source
Diesel	Input	MJ/tkm	0.81	1
Distance	Output	tkm	1.00	
Emissions				
CH_4	Output	g/tkm	0.0034	1
N_2O	Output	g/tkm	0.0015	1

Comments

- The return voyage (empty) is taken into account in this value.
- This process is commonly used for the transportation of solids and liquids.
- The fuel consumption corresponds to 30.53 l/100 km.
- The fuel consumption and emissions are a weighted average of Tier 2 values among different Euro classes based on the fleet composition indicated in the COPERT model.

Source

1 EMEP/EEA air pollutant emission inventory guidebook, Technical report N12/2013. Part B 1.A.3.b.i-iv.

40 t truck (27 t payload) for sugar cane

Table 71 Fuel consumption for a 40 t truck, weighted average for sugar cane transport

	I/O	Unit	Amount
Diesel	Input	MJ/tkm	1.37
Distance	Output	tkm	1.00
Emissions			
CH_4	Output	g/tkm	0.0006
N_2O	Output	g/tkm	0.0039

Source

1 Macedo et al., 2004.

MB2213 Dumpster truck

Table 72 Fuel consumption for a MB2213 dumpster truck used for filter mud cake

	I/O	Unit	Amount
Diesel	Input	MJ/tkm	3.60
Distance	Output	tkm	1.00
Emissions			
CH_4	Output	g/tkm	0.000
N_2O	Output	g/tkm	0.000

Source

1 Macedo et al., 2004.

MB2318 Tanker truck for seed cane

Table 73 Fuel consumption for a MB2318 truck used for seed cane transport

	I/O	Unit	Amount
Diesel	Input	MJ/tkm	2.61
Distance	Output	tkm	1.00
Emissions			
CH_4	Output	g/tkm	0.000
N_2O	Output	g/tkm	0.000

MB2318 Tanker truck for vinasse

Table 74 Fuel consumption for a MB2318 tanker truck used for vinasse transport

	I/O	Unit	Amount
Diesel	Input	MJ/tkm	2.16
Distance	Output	tkm	1.00
Emissions			
CH_4	Output	g/tkm	0.000
N_2O	Output	g/tkm	0.000

Source

1 Macedo et al., 2004.

12 t truck (6.35 t payload)

This process represents a smaller truck used for the transportation of specific materials such as fresh fruit bunches (FFBs).

Table 75 Fuel consumption for a 12 t truck

	I/O	Unit	Amount	Source
Diesel	Input	MJ/tkm	2.24	1,2
Distance	Output	tkm	1.00	
Emissions				
CH_4	Output	g/tkm	0.002	3
N_2O	Output	g/tkm	0.0015	3

Comment

- Process used for transport of FFBs in the palm oil pathway.

Sources

1 Lastauto Omnibus Katalog, 2010.

2 Choo et al., 2011.

3 GEMIS v.4.93, 2014, *'truck-Diesel-EU-2010'.*

5.2 Maritime transportation

Handymax bulk carrier (37 000 t payload)

The only use for shipping by bulk carrier is a share of 4.4% of the transport of rapeseed.

The average size of vessels carrying rapeseed is considered larger than that for wood-chips, characterized by deadweight 40 000 tonnes, which falls into the 'handymax' size class.

This size does not lie in the centre of any size class reported by the International Maritime Organization (IMO) report (Ref. 1), so we interpolated between adjacent size classes to get the best estimate of emissions.

Ref. 1 reports estimated CO_2 emissions from different categories of ship. To make this consistent with those in other processes, we back-calculated the fuel corresponding to those emissions according to the assumptions used by IMO, and then applied the carbon intensity for heavy fuel oil, as used in other processes.

Table 76 Fuel consumption for a Handymax bulk carrier for goods with bulk density > 0.6 t/m3 (weight-limited load)

	I/O	Unit	Amount
Heavy fuel oil	Input	MJ/tkm	0.101
Distance	Output	tkm	1.000

Comments

- Valid for payloads with bulk density >0.6 t/m^3.
- The return voyage is considered empty and it is included in the value.
- LHV heavy fuel oil = 40.5 MJ/kg.
- Oil consumption = 2.49 gHFO/tkm.

Sources

1 IMO, 2009.

Product tanker (12 617 t payload)

This process is used to account for the direct import of ethanol produced from sugar cane.

This size does not lie in the centre of any size class reported by the International Maritime Organization (IMO) report (Ref. 1), so we interpolated between adjacent size classes to get the best estimate of emissions.

Ref. 1 reports estimated CO_2 emissions from different categories of ship. To make this consistent with those in other processes, we back-calculated the fuel corresponding to those emissions according to the assumptions used by IMO, and then applied the carbon intensity for heavy fuel oil, as used in other processes.

Table 77 Fuel consumption for a product tanker (12 617 t payload) for sugarcane ethanol transport

	I/O	Unit	Amount
Heavy fuel oil	Input	MJ/tkm	0.115
Distance	Output	tkm	1.000

Comments

- Assumption: av. 90 % loading on outward trip and 85 % loading on the return trip (Ref. 2).
- Heavy fuel oil consumption = 2.84 gHFO/tkm.
- LHV heavy fuel oil = 40.5 MJ/kg.

Sources

1 IMO, 2009.

2 Odfell Tankers AS, Bergen, Norway, 26 January 2012, personal communication.

Product tanker (deadweight: 15 000 t)

This process is used to account for the transportation of final fuels.

This size does not lie in the centre of any size class reported by the International Maritime Organization (IMO) report (Ref. 1), so we interpolated between adjacent size classes to get the best estimate of emissions.

Ref. 1 reports estimated CO2 emissions from different categories of ship. To make this consistent with those in other processes, we back-calculated the fuel corresponding to those emissions according to the assumptions used by IMO, and then applied the carbon intensity for heavy fuel oil, as used in other processes.

Table 78 Fuel consumption for a product tanker (deadweight: 15 000 t) for ethanol transport

	I/O	Unit	Amount
Heavy fuel oil	Input	MJ/tkm	0.169
Distance	Output	tkm	1.000

Table 79 Fuel consumption for a product tanker (deadweight: 15 000 t) for FAME and HVO transport

	I/O	Unit	Amount
Heavy fuel oil	Input	MJ/tkm	0.164
Distance	Output	tkm	1.000

Comments

- IMO average on % of load for outward and return trip: 64 % (Ref. 1).
- Heavy fuel oil consumption = 3.90 gHFO/tkm.
- LHV heavy fuel oil = 40.5 MJ/kg.

Source

1 IMO, 2009.

Product tanker (22 560 t payload)

This process is used to account for the direct import of vegetable oil from palm and waste cooking oil.

This size does not lie in the centre of any size class reported by the International Maritime Organization (IMO) report (Ref. 1), so we interpolated between adjacent size classes to get the best estimate of emissions.

Ref. 1 reports estimated CO_2 emissions from different categories of ship. To make this consistent with those in other processes, we back-calculated the fuel corresponding to those emissions according to the assumptions used by IMO, and then applied the carbon intensity for heavy fuel oil, as used in other processes.

Table 80 Fuel consumption for a product tanker (22 560 t payload) for pure vegetable oil transport

	I/O	Unit	Amount
Heavy fuel oil	Input	MJ/tkm	0.095
Distance	Output	tkm	1.000

Comments

- Assumption: av 90 % loading on outward trip and 85 % loading on the return trip (Ref. 1).
- Heavy fuel oil consumption = 2.36 gHFO/tkm.
- LHV heavy fuel oil = 40.5 MJ/kg.

Sources

1 IMO, 2009.

2 Odfell Tankers AS, Bergen, Norway, 26 January 2012, personal communication.

Additional notes:

Personal communication (18 May 2012) with Arild Viste (AV) of Odfjell Tankers provided the following clarifications:

- Average size of ship for ethanol transport from Brazil: 14–16 ktonnes dwt.
- Stowage ratio (design density of cargo) for chemical tankers 0.8 to 0.85, so ethanol loading is (just) volume-limited.
- Because of fast growth in Brazil, at present there are actually more liquid chemicals going to South America from Europe/Africa than vice versa, but this varies with time.
- The largest component of liquid chemicals returning to South America is phosphoric acid from Morocco to Brazil, used to make fertilizers.
- AV agrees that on a world scale, the IMO '68 %' is a good guess for average of full load carried, but it is higher on the South America route for chemicals.
- Palm oil from Asia represents a more complicated issue, but the situation is similar.
- Larger ships have lower average percentage filling of cargo-carrying capacity.
- In both directions, the ships typically make several calls at several ports to fill up for the Atlantic crossing.

5.3 Inland water transportation

Bulk carrier barge (8 800 t payload)

This process represents a barge used to carry bulk materials on inland waters. It is used for the transport of rapeseed and soy beans feedstocks.

Table 81 Fuel consumption for a bulk carrier for inland navigation

	I/O	Unit	Amount	Source
Diesel	Input	MJ/tkm	0.324	1,2
Distance	Output	tkm	1.00	
Emissions				
CH_4	Output	g/tkm	0.093	3
N_2O	Output	g/tkm	0.0004	3

Comments

- Empty return trip included.
- Used for rapeseed supply.
- Used for soy beans supply.

Sources

1 Frischknecht et al., 1996.

2 Ilgmann, 1998.

3 GEMIS v. 4.93, 2014, *ship-freight-DE-domestic-2010.*

Oil carrier barge (1 200 t payload)

Used for transportation of FAME and ethanol on inland waters.

Table 82 Fuel consumption for an oil carrier barge for inland navigation

	I/O	Unit	Amount	Source
Diesel	Input	MJ/tkm	0.504	1
Distance	Output	tkm	1.00	
Emissions				
CH_4	Output	g/tkm	0.030	1

Comments

- Empty return trip included.

Source

1 Frischknecht et al., 1996.

5.4 Rail transportation

Freight train (diesel)

The distance parameter is calculated as described above for the road and maritime transport, and the specific values are reported for each pathway in the following sections. The fuel consumption is reported below.

Table 83 Fuel consumption for a freight train run on diesel fuel (in the United Sates)

	I/O	Unit	Amount
Diesel	Input	MJ/tkm	0.252
Distance	Output	tkm	1.00
Emissions			
CH_4	Output	g/tkm	0.005
N_2O	Output	g/tkm	0.001

Comment

- This process is used for the transportation of soybean.

Source

1 GEMIS v. 4.93, 2014, *Train-diesel-freight-CA-2010.*

Freight train (electric)

This process represents the fuel consumption for rail transportation with electric carriages.

Table 84 Fuel consumption for a freight train run on grid electricity

	I/O	Unit	Amount
Electricity	Input	MJ/tkm	0.210
Distance	Output	tkm	1.00

Source

1 GEMIS v. 4.93, 2014, *Train-el-freight-DE-2010.*

5.5 Pipeline transportation

Table 85 Fuel consumption for the pipeline distribution of FAME (5 km)

	I/O	Unit	Amount
FAME	Input	MJ/MJ_{FAME}	1.00
Electricity	Input	MJ/MJ_{FAME}	0.0002
FAME	Output	MJ	1.00

Source

1 Dautrebande, 2002.

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Part Two — Liquid biofuels processes and input data

6. Biofuels processes and input data

List of liquid biofuels pathways

- Ethanol pathways
  - Wheat to ethanol
  - Maize to ethanol
  - Barley to ethanol
  - Rye to ethanol
  - Triticale to ethanol
  - Sugar beet to ethanol
  - Sugar cane to ethanol
- Biodiesel pathways
  - Rapeseed to biodiesel
  - Sunflower to biodiesel
  - Soybean to biodiesel
  - Palm oil to biodiesel
  - Waste cooking oil to biodiesel
  - Animal fat
- Hydrotreated Vegetable Oil processing (HVO)
- Pure plant oil pathways: same input data as in corresponding biodiesel pathways (excluding transesterification)
- Advanced biofuel pathways
  - Black liquor gasification process
  - Wood residues/Farmed wood to Synthetic diesel
  - Wood residues/Farmed wood to Methanol
  - Wood residues/Farmed wood to DME
  - Wheat straw to ethanol

Note on Yields

For almost all crops, we are consistently using the average yield of the last 6 years (from 2009 to 2014) available in Faostat or Eurostat (data accessed in October 2016).

Why Camelina and Jatropha are not included in the report

Camelina is a flowering plant of the family of the Brassicaceae (like broccoli, cauliflower and rapeseed). It is traditionally grown on marginal land and can be planted as a rotation crop for wheat, in the 'fallow' period, so it is a promising sustainable alternative energy crop. Historically, *Camelina* has been used as a crop for animal feed and vegetable oil in northern Europe and in the Russian–Ukrainian area from the Neolithic period to the years from 1930 to 1940.

Unfortunately, *Camelina* is no longer cultivated in relevant quantities, and there is no established market for either *Camelina* seeds or *Camelina* oil. Consequently, reliable technical and market data are missing and we do not have a database large enough to propose a default pathway for *Camelina*.

We have studied an experimental *Camelina* pathway based on the (scarce) bibliography available, involving test cultivations performed in the northern states of the United States, seed crushing in the central United States, transport of *Camelina* oil from the United States to the EU, and (by HVO process) production of jet fuel in Europe. However, these values refer only to pilot-stage projects, not to large-scale productions, and the hypotheses of delivering *Camelina* produced in Montana, United States, to Europe is quite unrealistic, from a market perspective. In fact, American stakeholders are strongly interested in *Camelina* jet fuel; it is unlikely that the rising American *Camelina* market will supply European needs, because of the very high internal demand and very low production.

From a European market perspective, it should be much more interesting to build a *Camelina* pathway on cultivation data referring to the following (suitable) production areas: Romania, Spain, northern Europe, Russia and the former Soviet Union areas. Unfortunately, there are no data on *Camelina* cultivation from these countries.

Jatropha has not been included in the report after the experts and stakeholders workshops in September 2016. At the meeting, industry indicated *Jatropha* production remains negligible in the European biofuel market.

Lower heating value (LHV) definitions

There are two definitions of LHV which are used in the calculations.

1. LHV of the dry fraction of a moist biomass. This is our basic accounting unit.

2. $\text{LHV}_{\text{-vap}}$ = Same as (1) but minus the heat needed to evaporate the moisture content. This is used **ONLY** for allocating emissions by energy-content.

In formula[36]:

1. $Energy\ content\ of\ wet\ biomass = LHV\ dry \cdot M\ wet\ biomass \cdot (1 - mass\ \%\ of\ water]/100)$

2. $LHV_{\text{-vap}} = LHV\ dry \cdot (1 - [mass\ \%\ of\ water]/100) - 2.441 \cdot [mass\ \%\ of\ water/100]$

in which

- *Energy content of wet bimass* is the total amount of energy (MJ) of the dry fraction of the biomass (MJ)

- *LHV dry* is the lower heating value of the dry biomass (MJ per kg of dry biomass);

- $M_{\text{wet biomass}}$ is the mass of the wet biomass (kg wet biomass);

- *[mass % of water]* is the water content of the wet biomass, in percent of total mass of the wet biomass;

- $LHV_{\text{-vap}}$ is the lower heating value of the wet biomass (MJ per kg wet biomass);

- *2.441* is the latent heat of vaporisation of water at 25°C expressed in MJ per kg water

Definition (2) cannot be used as an accounting unit because:

- Materials apparently increase in LHV as they dry out;

- No conservation of energy in processing, as the water content of products is not the same as feedstocks.

([36]) Reference: Biograce II, methodological background.

Update of lower heating values (LHV) in biodiesel pathways

LHV of crude and refined vegetable oils

Refined vegetable oils have a measured LHV of about **37.0** MJ/kg (Mehta and Anand, 2009). According to the ECN Phyllis ([37]) database of biomaterials, the LHV of refined vegetable oil is **37.2,** and of crude vegetable oils, **36.0**.

The JRC considers that crude vegetable oils used for biodiesel do not differ greatly from refined vegetable oil LHV (as discussed below), so for simplicity, we assumed that the LHV of crude vegetable oils is also **37** MJ/kg.

DIESTER ([38])/EBB state that refining vegetable oil removes about 2.5 % of the mass (so the raw oil is on average above the minimum specification below), but all the compounds removed (except moisture) have an LHV fairly similar to (maybe up to ~20 % lower than) oil.

Moisture content is < 0.5 % in the FEDIOL raw rapeseed specification, so the raw oil LHV cannot possibly be more than (0.5 %+2 %*0.2)*37 = 0.3 MJ/kg lower than that of the refined oil: it must be > 36.7 MJ/kg.

FEDIOL specifications for crude rapeseed oil

- Free fatty acids (as oleic): Max 2.00 %.
- Moisture content, Volatile Matter and Impurities: Max 0.50 %.
- Lecithin gum (expressed as Phosphorus): Max 750ppm = ~2 % by weight of $C_{43}H_{88}NO_9P$.
- Erucic acid (a fatty acid): Max 2.00 %.

Chemicals removed in refining

DIESTER informed the JRC that the refining for biodiesel consists of the following.

- Neutralising (and removing) fatty-acids and lecithin (similar or slightly lower LHV than oil).
- Removing any water associated with these.
- Removing gums (slightly lower LHV than oil).
- For sunflower: removing wax (winterisation = cooling and centrifuging). Wax has similar LHV to oil (the CH_2 chains are merely longer)

Density of vegetable oils

The density of refined vegetable oils (Noureddini et al., 1992; Dorfman, 2000) at 20C is around 0.92 kg/litre. Discussion: according to Noureddini et al. (1992), the density of rapeseed is particularly low, at ~.910; palm's is highest at ~0.924, whilst soybean, maize and sunflower are ~0.922). The density of crude vegetable oils at 20C (CODEX STANDARD 210-1999) is not significantly different from this:

- crude rapeseed 0.9145 +/- 0.0045;
- crude soy 0.920 +/- 0.005;

([37]) Energy research Centre of the Netherlands (ECN): see http://www.ecn.nl/phyllis/ online.

([38]) Diester Industrie: see http://www.sofiproteol.com online.

- crude palm 0.925 +/- 0.003, (40C data corrected to 20C using expansion coefficient in Noureddini et al. (1992);
- crude sunflower 0.9205 +/- 0.0025.

Sources

1 Mehta and Anand, 2009.

2 Noureddini, et al., 1992.

3 Dorfman, 2000.

4 CODEX standard for named vegetable oils. CODEX STAN 210-1999 (http://www.codexalimentarius.org) accessed January 2013.

Calculation of consistent LHVs for by-products: DDGS from ethanol production and Oilseed cakes from oil pressing

We have relatively reliable data on the lower-heating-values LHV of crops, because we can compare measured data with LHVs calculated from the composition of the crop, which is avaiable from several sources.

However, measurements of the LHV of cakes and DDGS are much more rare, and furthermore, they have a large range of composition, depending on the efficiency of oil extraction or the composition of the cereal. It is important that we make the LHV of the by-products consistent with the process yield and the LHV of the crop (and product).

The oil crushing has no effect on the heat content of the components, so we can calculate the LHV of the oilseed cake by balancing the LHV of the crop going in and the products coming out. We use a similar procedure for calculating the LHV of DDGS that is consistent with those used for the cereals and ethanol; in this case there is a small loss of heat energy in the conversion of starch to ethanol, which we take into account.

Average cereal pathway

An average cereal pathway has been calculated for the mix of cereals in EU ethanol production.

The latest available data is from ePURE (2016), giving data for 2015. We took one year only because the data shows consistent historical trends, rather than quasi-random variation from year to year. However, in that dataset all "other cereals" than wheat and maize were aggregated. We disaggregated in proportion to the last split reported by Ecofys, 2014 (data for 2012).

We ignored the contribution of ‘other starch-rich crops’, as do all other sources of data, such as USDA GAIN reports.

Data on the contribution of different cereals to the EU ethanol feedstock excluding maize are shown in Table 86.

Table 86 Cereal share of ethanol feedstock in the EU

% ethanol feedstock \ cereal crop	**Wheat**	**Maize**	**Barley**	**Rye**	**Triticale**	**Non-cereal**
Ref 2	37.0%	31.3%	1.1%	2.5%	0.8%	27.3%
…normalized to 100% cereals	50.9%	43.1%	1.5%	3.4%	1.1%	
Data for 2015 in billion litres of ethanol (Ref 1)	1.89	2.12	0.43			1.35
…normalized to 100% cereals	42.57%	47.75%	9.68%			
….with disaggregated "other cereals"	42.57%	47.75%	2.42%	5.50%	1.76%	
Mix of non-maize cereals	**81%**		**5%**	**11%**	**3%**	

Sources

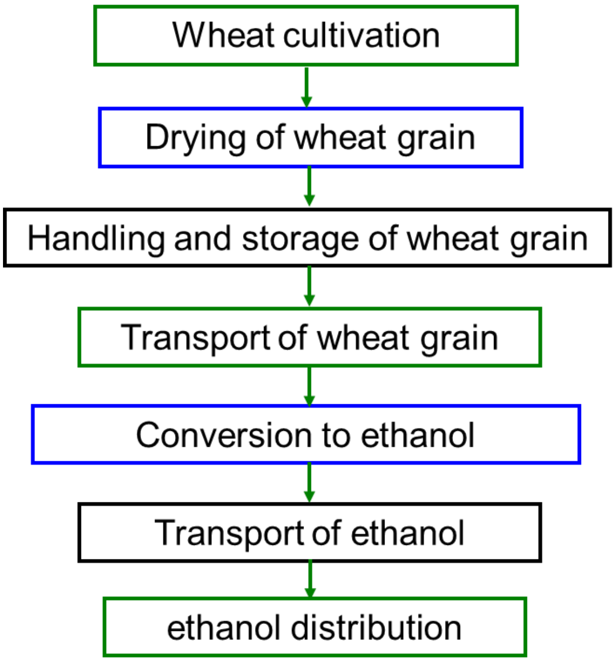
1 ePURE, 2016, European renewable ethanol industry – Annual statistics report 2016, September 2016.

2 Ecofys, 2014, Renewable energy progress and biofuels sustainability (BIENL13010), November 2014.

6.1 Wheat grain to ethanol

Description of pathway

The following processes are included in the 'wheat grain to ethanol' pathway.



The data for each process are shown below; significant updates are described in more detail with relevant references.

Step 1: Wheat cultivation

The new data for wheat cultivation are shown in Table 87.

The updated data include:

- diesel and pesticide use in wheat cultivation updated using data from CAPRI (see Section 2.5);
- $CaCO_3$ fertilizer use calculated by the JRC (see Section 3.10);
- N_2O emissions calculated by JRC using the JRC GNOC model (see Section 3.7);
- CO_2 emissions from neutralisation of other soil acidity calculated by the JRC (see Section 3.10);
- K_2O and P_2O_5 updated using the most recent data available (2013/2014);
- seeding material updated using data from Faostat, latest available year (2013).

In the following table, source numbers in **bold** represent the main data source; additional references are used to convert data to 'per MJ of crop'.

Table 87 Cultivation of wheat

	I/O	Unit	Amount	Source	Comment
Diesel	Input	MJ/MJ_{wheat}	0.0384	3, **5**	See CAPRI data
N fertilizer	Input	kg/MJ_{wheat}	0.0013	**2**, 3	See GNOC data
$CaCO_3$ fertilizer	Input	kg/MJ_{wheat}	0.0026	6	See liming data
K_2O fertilizer	Input	kg/MJ_{wheat}	0.0002	3, **4**	3.2 kg K_2O/tonne moist crop
P_2O_5 fertilizer	Input	kg/MJ_{wheat}	0.0003	3, **4**	4.1 kg P_2O_5/tonne moist crop
Pesticides	Input	kg/MJ_{wheat}	0.0001	3, **5**	See CAPRI data
Seeding material	Input	kg/MJ_{wheat}	0.0004	**1**, 3	36 kg/(ha*yr)
Wheat	Output	MJ	1.0000		
Field N_2O emissions		g/MJ_{wheat}	0.0444	2	See GNOC data
CO_2 from neutralisation of other soil acidity		g/MJ_{wheat}	0.0000	6	See liming data

Comments

- LHV (dry crop) = 17.0 MJ/kg dry wheat grain (Ref. 3).
- 13.5 % water content (Ref. 5).
- The raw input data in the table are either provided 'per tonne of moist crop' or converted from 'per-ha' using yields in tonnes of moist crop per ha. Here, the moist yields are for the traded moisture content of wheat. This varies slightly by country, but on average is about 13.5 % in EU. However, the freshly-harvested crop has a higher average moisture content; consistent with the CAPRI estimates of the amount of water removed, the average initial moisture content must be 13.5 % + 0.2 % = 13.7 %.

Sources

1 Faostat, accessed in October 2016.

2 Edwards and Koeble, 2012 (see Chapter 3).

3 Kaltschmitt and Hartmann, 2001.

4 Fertilizers Europe, received by JRC in August 2016 (2013-2014 data) and Eurostat, 2016 (for common wheat yield, average 2009-2014)

5 CAPRI data, 2012 converted to JRC format (see Section 2.5).

6 JRC: Acidification and liming data (see Section 3.10).

Step 2: Drying of wheat grain

Data on drying, derived from CAPRI (see Section 2.5), are shown in Table 88.

Table 88 Drying of wheat grain

	I/O	Unit	Amount	Source
Light heating oil	Input	MJ/MJ$_{wheat}$	0.00029	**1**, 2
Natural gas	Input	MJ/MJ$_{wheat}$	0.00029	**1**, 2
Electricity	Input	MJ/MJ$_{wheat}$	0.00005	**1**, 2
Wheat	Input	MJ/MJ$_{wheat}$	1.0000	
Wheat	Output	MJ	1.0000	

Comments

- 0.2 %: average % of water removed to reach traded water content, according to CAPRI data (see Section 2.5).
- 2.16 MJ heating oil/tonne of crop at traded water content for 0.1% drying (*).
- 2.16 MJ NG/tonne of crop at traded water content for 0.1% drying (*).
- 0.36 MJ electricity/tonne of crop at traded water content for 0.1% drying (**).

(*) UBA (Ref. 2) reports that 0.1% drying of grains needs 1.2 kWh= 4.32 MJ of heating oil per tonne of grain. Ecoinvent (Ref. 3) propose 5 MJ heating oil is needed per kg water evaporated (~0.1% in 1 tonne grain), on the basis of a survey of European literature. UBA data on total MJ heating fuel will be considered, assuming that half comes from NG and half from light heating oil, on the basis of discussions with national experts, as no EU-wide data is available. Also LPG is used, but this is an intermediate case.

(**) For electricity, UBA (Ref. 2) reports 0.1% drying of grains needs 0.1 kWh= 0.36MJ per tonne of grain. Ecoinvent (Ref. 3) reports a higher value (about 1kWh = 3.6 MJ electricity) perhaps including electricity for handling and storage. UBA data has been considered.

Sources

1	CAPRI data (M. Kempen, personal communication, October 2016).
2	UBA, 1999.
3	Nemecek and Kägi, 2007.

Step 3: Handling and storage of wheat grain

Data on handling and storage of wheat grain are shown in Table 89.

Table 89 Handling and storage of wheat grain

	I/O	Unit	Amount	Source
Wheat	Input	MJ/MJ_{wheat}	1.0081	2
Electricity	Input	MJ/MJ_{wheat}	0.0004	1
Wheat	Output	MJ	1.0000	

Comment

- UBA (Ref. 3) proposes 12.6 kWh electricity per tonne of grain for ventilation during storage of rapeseed. For wheat, Kenkel (Ref. 2) reports average of 19 kWh/tonne for Oklahoma, and Kaltschmitt and Reinhardt (Ref. 1) only 1.6 kWh/tonne. Data from Ref. 1 has been used.

Sources

1 Kaltschmitt and Reinhardt, 1997.

2 Kenkel, 2009.

3 UBA, 1999.

Step 4: Transportation of wheat grain

Table 90 Transport of wheat grain via 40 t truck (payload 27 t) over a distance of 100 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{wheat}	0.0068
Wheat	Input	MJ/MJ_{wheat}	1.0100
Wheat	Output	MJ	1.0000

Comment

- Fuel consumption for a 40 t truck is reported in Table 70.

Source

1 Kaltschmitt and Hartmann, 2001.

Step 5: Conversion of wheat grain to ethanol

Table 91 Conversion of wheat grain to ethanol

	I/O	Unit	Amount	Source	Comment
Wheat	Input	MJ/MJ$_{ethanol}$	1.8586	**2**, 3, **4**, 5, **7**, **8**, **9**	3.39 t wheat grain @ 13.5 % H_2O/t ethanol
Electricity	Input	MJ/MJ$_{ethanol}$	0.0491	**2**, 5, **7**, **9**	1.32 GJ/t ethanol
Steam	Input	MJ/MJ$_{ethanol}$	0.3737	**2**, 5, **7**, **9**	10.0 GJ/t ethanol
NH_3	Input	kg/MJ$_{ethanol}$	0.0002	**2**, 5, **7**	1.8 kg/dry t of wheat grain
NaOH	Input	kg/MJ$_{ethanol}$	0.0005	**2**, 5, **7**	4.3 kg/dry t of wheat grain
H_2SO_4	Input	kg/MJ$_{ethanol}$	0.0004	**2**, 5, **7**	4.1 kg/dry t of wheat grain
CaO	Input	kg/MJ$_{ethanol}$	0.0000	**2**, 5, **7**	0 kg/dry t of wheat grain
Alpha-amylase	Input	kg/MJ$_{ethanol}$	0.00005	**2**, 5, **6**, **7**	0.43 kg/dry t of wheat grain
Gluco-amylase	Input	kg/MJ$_{ethanol}$	0.00001	**2**, 5, **6**, **7**	0.59 kg/dry t of wheat grain
Ethanol	Output	MJ	1.0000		

Comments

- 1.227 tonnes DDGS (Distillers Dried Grain Solubles) (at 10 % water) / tonne ethanol (see Table 93).
- LHV$_{-vap}$ DDGS = 16.04 MJ/kg of wet DDGS (see Table 93).
- The values shown in column 'Comment' are averages of data from various sources converted to the same unit (see Table 92, 'adopted value' for additional details).

Sources

1 Kaltschmitt and Hartmann, 2001.

2 Buchspies and Kaltschmitt, 2016 (data from Crop Energies AG).

3 Kaltschmitt and Reinhardt, 1997.

4 Lywood, W., ENSUS plc, personal communication, 3 December 2010.

5 Hartmann, 1995.

6 MacLean and Spatari, 2009.

7 ADEME, 2010.

8 Stölken, 2009.

9 Power et al., 2008.

Table 92 Data used to calculate the 'adopted value' from various sources

	Unit	Ref. 2	Ref. 7	Ref. 8	Ref. 4	Ref. 9	Adopted value
Wheat	t wheat grain @ 13.5% water per t ethanol	3.39	3.47	3.36	3.33	3.39	**3.39**
Electricity	GJ/(t ethanol)	1.08	1.42	-	-	1.45	**1.32**
Steam	GJ/(t ethanol)	10.8	10.2	-	-	9.0	**10.0**
NH3	kg/dry t of wheat grain	3.2	0.5	-	-	-	**1.8**
NaOH	kg/dry t of wheat grain	5.9	2.7	-	-	-	**4.3**
H_2SO_4	kg/dry t of wheat grain	5.9	2.3	-	-	-	**4.1**
CaO	kg/dry t of wheat grain	-	-	-	-	-	**0.0**
Alpha-amylase	kg/dry t of wheat grain	1.02	-	-	0.8(*)	-	**0.43**
Gluco-amylase	kg/dry t of wheat grain		-	-	1.1(*)	-	**0.59**
DDGS (**)	t dry DDGS/(t ethanol)	1.104	-	-	-	-	**1.104**

(*) These values are from Ref. 6: they are used only to estimate the proportion of alpha and gluco-amylase.

(**) **Adopted value of dry DDGS per tonne of ethanol**: The amount of DDGS depends on the ethanol yield: the more ethanol, the less DDGS. We averaged the ethanol yield from all the sources, but we only have DDGS data from some of them. Therefore adopting average DDGS data would be inconsistent with the adopted yield.

As the yield from Ref. 2 is the same as the average, we adopt their DDGS data, which seems to be consistent with the other sources bearing in mind ethanol-yield differences.

The composition and hence LHV of the DDGS depends on the composition of the cereals used. To ensure consistency with the ethanol yield, we calculate the LHV of DDGS by mass and energy balance (in Table 93). This gives a figure for the LHV of all the dry matter that does not leave as ethanol, or fermented CO_2. However, this is consistently slightly less than the amount of DDGS reported by plant-owners. This implies that a small amount of organic material is lost elsewhere. This could be losses in handling, or losses in dilute waste streams that are not always evaporated to recover their solids. It could also be burning or decomposition of components during drying. Therefore, when we have a reported mass of DDGS that is consistent with the adopted ethanol yield, we combine the calculated average LHV with the reported mass of DDGS. This is the case for the maize and wheat processes. For other cereals (barley, rye and triticale), we assume the same % mass-losses as for the wheat-ethanol process.

Table 93 LHV of wheat DDGS by mass and energy balance

Mass balance	**Unit**	**Amount**	
Wheat moisture	%	13.5%	m
Dry wheat	%	86.5%	1-m
Ethanol yield	kg/kg moist wheat	0.295	Et
Ethanol / starch by stoichiometry*	kg/kg	0.568	Em
Starch to ethanol in wheat	kg/kg moist wheat	0.520	St = Et/Em
Dry DDGS	kg/kg moist wheat	0.345	Dd = 1-m-St
Dry DDGS including process chemicals	kg/kg moist wheat	0.357	Dd + pc
DDGS @ 10% moisture	kg/kg moist wheat	0.396	Dm = Dd + pc/0.9
DDGS/EtOH	kg/kg	1.343	Dr =Dm/Y
Energy balance	**Unit**	**Amount**	
Wheat LHV (dry)	MJ/kg dry wheat	17	Hwd
Wheat LHV (@13.5% moisture)	MJ/kg moist wheat	14.71	Hwm = Hwd *(1-m)
Ethanol LHV	MJ/kg moist wheat	7.91	He = Et x 26.81
Reaction heat efficiency by stoichiometry*	%	95.88%	Ee
Starch energy used	MJ/kg moist wheat	8.25	Hs = He/Ee
Energy in DDGS	MJ/kg moist wheat	6.45	Hd = Hwm-Hs
Energy out/energy in	MJ/MJ	97.69%	(Hd + He) / Hwm
Allocation to ethanol	%	55.1%	He / (He + Hd)
DDGS LHV (dry)	MJ/kg	**18.09**	Hd / Dd + pc
DDGS LHV (@10% moisture)	MJ/kg	**16.28**	Hd / Dm
DDGS LHV$_{-vap}$ @10% moisture (for allocation purposes only)	MJ/kg	**16.04**	

***Fermentation stoichiometry**

	Starch			**Ethanol**		**Efficiency**
	C6H10O5	**+ H2O**	**->**	**2 x C2H6O**	**+ 2 x CO2**	
Mass	162	18		92	88	56.8%
LHV kJ/kg	15.88			26.81		
Energy MJ	2572.56			2466.52		95.9%

Step 5.1: Steam generation processes

Woodchip-fuelled plant generation has been added. The data for the individual steam generation processes are shown in Chapter 4. The processes linked to wheat ethanol are:

- NG boiler (Table 63)
- NG CHP (Table 64)
- lignite CHP (Table 66)
- woodchip–fuelled CHP (Table 68)

Step 6: Transportation of ethanol to the blending depot

The same transport mix used in 'rapeseed to biodiesel' has been added but excluding pipeline transport as it is unlikely that ethanol would be transported in this manner.

Table 94 Transportation of ethanol summary table to the blending depot

Share	**Transporter**	**Notes**	**Distance (km one way)**
13.2 %	Truck	Payload 40 t	305
31.6 %	Product tanker	Payload: 15 000 t	1 118
50.8 %	Inland ship/barge	Payload 1 200t	153
4.4 %	Train		381

Table 95 Transport of ethanol to depot via 40 t truck over a distance of 305 km (one way)

	I/O	**Unit**	**Amount**
Distance	Input	$\text{tkm/MJ}_{\text{ethanol}}$	0.0123
Ethanol	Input	$\text{MJ/MJ}_{\text{ethanol}}$	1.0000
Ethanol	Output	MJ	1.0000

Comments

- For the fuel consumption of a 40 t truck, see Table 70.
- LHV (ethanol) = 26.8 MJ/kg.

Table 96 Maritime transport of ethanol over a distance of 1 118 km (one way)

	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{ethanol}$	0.0417
Ethanol	Input	$MJ/MJ_{ethanol}$	1.0000
Ethanol	Output	MJ	1.0000

Comment

- For the fuel consumption of the product tanker (payload: 15,000 t), see Table 78.

Table 97 Transport of ethanol over a distance of 153 km via inland ship (one way)

	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{ethanol}$	0.0057
Ethanol	Input	$MJ/MJ_{ethanol}$	1.0000
Ethanol	Output	MJ	1.0000

Comment

- For the fuel consumption for an inland oil carrier, see Table 82.

Table 98 Transport of ethanol over a distance of 381 km via train (one way)

	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{ethanol}$	0.0142
Ethanol	Input	$MJ/MJ_{ethanol}$	1.0000
Ethanol	Output	MJ	1.0000

Comments

- For the fuel consumption of the freight train, see Table 84.

Step 7: Ethanol depot distribution inputs

Table 99 Ethanol depot

	I/O	Unit	Amount
Ethanol	Input	$MJ/MJ_{ethanol}$	1.00000
Electricity	Input	$MJ/MJ_{ethanol}$	0.00084
Ethanol	Output	MJ	1.00000

Table 100 Transport of ethanol to filling station via 40 t truck over a distance of 150 km (one way)

	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{ethanol}$	0.0060
Ethanol	Input	$MJ/MJ_{ethanol}$	1.0000
Ethanol	Output	MJ	1.0000

Table 101 Ethanol filling station

	I/O	Unit	Amount
Ethanol	Input	$MJ/MJ_{ethanol}$	1.0000
Electricity	Input	$MJ/MJ_{ethanol}$	0.0034
Ethanol	Output	MJ	1.0000

Comment

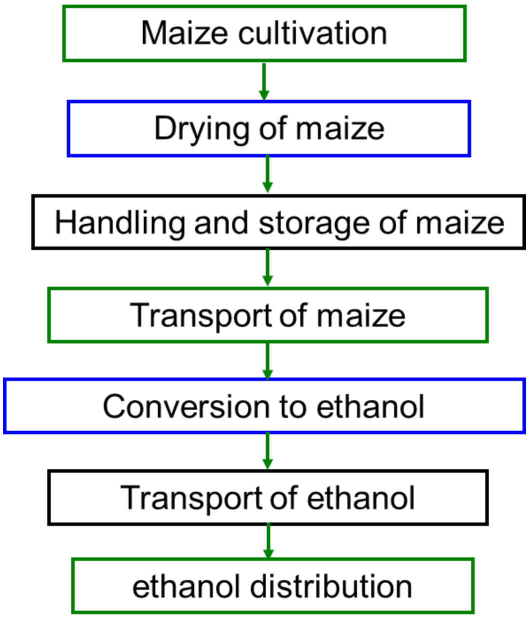
- Distribution is assumed to be same as for fossil diesel and gasoline.

Source

1 Dautrebande, 2002.

6.2 Maize to ethanol

Description of pathway



The following processes are included in the 'maize to ethanol' pathway.

The data for each process of the 'maize to ethanol' pathway are shown below, and significant updates are described in more detail with relevant references.

Step 1: Maize cultivation

The new data for maize cultivation are shown in Table 102. The updated data include:

- diesel and pesticide use in EU maize cultivation updated using data from CAPRI (see Section 2.5);
- $CaCO_3$ fertilizer use calculated by the JRC (see Section 3.10);
- N_2O emissions calculated by JRC using the JRC GNOC model (see Section 3.7);
- CO_2 emissions from neutralisation of other soil acidity calculated by the JRC (see Section 3.10);
- K_2O and P_2O_5 updated using the most recent data available (2013/2014);
- seeding material updated using data from Faostat, latest available year (2013).

In the following table, source numbers in **bold** represent the main data source; additional references are used to convert data to ‘per MJ of crop’.

Table 102 Cultivation of maize (average of maize used in EU)

	I/O	Unit	Amount	Source	Comment
Diesel	Input	MJ/MJ_{maize}	0.0312	3, **5**	See CAPRI data
N fertilizer	Input	kg/MJ_{maize}	0.0011	**2**, 6	See GNOC data
$CaCO_3$ fertilizer	Input	kg/MJ_{maize}	0.0013	7	See liming data
K_2O fertilizer	Input	kg/MJ_{maize}	0.0003	**4**, 6	3.8 kg K_2O/tonne moist crop
P_2O_5 fertilizer	Input	kg/MJ_{maize}	0.0003	**4**, 6	4.1 kg P_2O_5/tonne moist crop
Pesticides	Input	kg/MJ_{maize}	0.0001	3, **5**	See CAPRI data
Seeding material	Input	kg/MJ_{maize}	0.0005	1	49 kg/(ha*yr)
Maize	Output	MJ	1.0000		
Field N_2O emissions		g/MJ_{maize}	0.0423	2	See GNOC data
CO_2 from neutralisation of other soil acidity		g/MJ_{maize}	0.0000	7	See liming data

Comments

- LHV (dry crop) = 17.3 MJ/kg dry maize (Ref. 6).
- 14 % crop moisture content (Ref. 3).
- The raw input data in the table are either provided 'per tonne of moist crop' or converted from 'per-ha' using yields in tonnes of moist crop per ha. Here, the moist yields are for the traded moisture content of maize. This varies slightly by country, but on average is about 14 % in EU. However, the freshly-harvested crop has a higher average moisture content; consistent with the CAPRI estimates of the amount of water removed, the average initial moisture content must be 14 % + 6.1 % = 20.1 %.
- Fertilizers input (N, K_2O and P_2O_5) and yields are weighted averages of data for Ukraine and EU which are the two main suppliers of maize to the EU market (Eurostat data, average 2011-2014, see Table 105). Fertilizer inputs for EU are from Fertilizers Europe (2013-2014 data) (Ref. 4) while for Ukraine the inputs are from International Fertilizers Association, IFA (2010-2011 data) adjusted to the updated yield (Ref. 4). For Ukraine, in 2010/11: N fertilizer input = 116 ktonnes/yr; K_2O input = 18 ktonnes/yr; P_2O_5 input = 26 ktonnes/yr (IFA, 2013).

Sources

1 Faostat, accessed in October 2016.

2 Edwards and Koeble, 2012 (see Chapter 3).

3 CAPRI assumption on traded water content, agreeing with KTBL, 2006.

4 International Fertilizer Association (IFA), 2013 and Fertilizers Europe, received by JRC in August 2016 and Faostat, 2016 (for yield, average 2009-2014).

5 CAPRI data, 2012 converted to JRC format (see Section 2.5).

6 KTBL, 2006 checked with JRC calculation from composition.

7 JRC: Acidification and liming data (see Section 3.10).

Step 2: Drying of maize

Data on drying, derived from CAPRI (see Section 2.5), are shown in Table 103.

Table 103 Drying of maize

	I/O	Unit	Amount	Source
Light heating oil	Input	MJ/MJ_{maize}	0.0089	**1**, 2
Natural gas	Input	MJ/MJ_{maize}	0.0089	**1**, 2
Electricity	Input	MJ/MJ_{maize}	0.0015	**1**, 2
Maize	Input	MJ/MJ_{maize}	1.0000	
Maize	Output	MJ	1.0000	

Comments:

- 6.10 %: average % of water removed to reach traded water content, according to CAPRI data (see Section 2.5).
- 2.16 MJ heating oil/tonne of crop at traded water content for 0.1% drying (*).
- 2.16 MJ NG/tonne of crop at traded water content for 0.1% drying (*).
- 0.36 MJ electricity/tonne of crop at traded water content for 0.1% drying (**).

(*) UBA (Ref. 2) reports that 0.1% drying of grains needs 1.2 kWh= 4.32 MJ of heating oil per tonne of grain. Ecoinvent (Ref. 3) propose 5 MJ heating oil is needed per kg water evaporated (~0.1% in 1 tonne grain), on the basis of a survey of European literature. UBA data on total MJ heating fuel will be considered, assuming that half comes from NG and half from light heating oil, on the basis of discussions with national experts, as no EU-wide data is available. Also LPG is used, but this is an intermediate case.

(**) For electricity, UBA (Ref. 2) reports 0.1% drying of grains needs 0.1 kWh= 0.36MJ per tonne of grain. Ecoinvent (Ref. 3) reports a higher value (about 1kWh = 3.6 MJ electricity) perhaps including electricity for handling and storage. UBA data has been considered.

Sources

1	CAPRI data (M. Kempen, personal communication, October 2016).
2	UBA, 1999.
3	Nemecek and Kägi, 2007.

Step 3: Handling and storage of maize

Data on handling and storage of maize are shown in Table 104.

Table 104 Handling and storage of maize

	I/O	Unit	Amount	Source
Maize	Input	MJ/MJ_{maize}	1.0081	2
Electricity	Input	MJ/MJ_{maize}	0.0004	1
Maize	Output	MJ	1.0000	

Comment

- UBA (Ref. 3) proposes 12.6 kWh electricity per tonne of grain for ventilation during storage of rapeseed. For wheat, Kenkel (Ref. 2) reports average of 19 kWh/tonne for Oklahoma, and Kaltschmitt and Reinhardt (Ref. 1) only 1.6 kWh/tonne. Data from Ref. 1 has been used.

Sources

1 Kaltschmitt and Reinhardt, 1997.

2 Kenkel, 2009.

3 UBA, 1999.

Step 4: Transportation of maize

Table 105 Fraction of EU supplies (av 2011-2014) - Normalized to 100%

	Fraction of EU supplies Normalized to 100%
EU27	0.92
Ukraine	0.08
Fraction of total EU-supplies	1.00

Source

Data extracted from Eurostat, accessed in October 2016.

Table 106 Truck transport distance

	km	%	contribution to weighted av km
EU27	100	92%	91.66
Ukraine	100	8%	8.34
Total			100.00

Table 107 Transport of maize via a 40 t truck over a distance of 100 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{maize}$	0.0067
Maize	Input	MJ/MJ$_{maize}$	1.0100
Maize	Output	MJ	1.0000

Comment

- For the fuel consumption of a 40 t truck, see Table 70.

Table 108 Train transport distance

	km	%	contribution to weighted av km
EU27	0	92%	0.00
Ukraine	500	8%	42
Total			42

Table 109 Transport of maize via train over a distance of 42 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{corn}$	0.0028
Maize	Input	MJ/MJ$_{corn}$	1.0000
Maize	Output	MJ	1.0000

Comment

- For the fuel consumption of of the freight train run on grid electricity, see Table 84.

Step 5: Conversion of maize to ethanol

Table 110 Conversion of maize to ethanol in EU

	I/O	Unit	Amount	Source	Comment
Maize	Input	$MJ/MJ_{ethanol}$	1.64510	**1**, 5, **6**	2.55 dry tonne maize/tonne ethanol
Electricity	Input	$MJ/MJ_{ethanol}$	0.03591	**1**, 2, 5, **6**	0.21 kWh_e/(litre ethanol)
Steam	Input	$MJ/MJ_{ethanol}$	0.33021	**1**, 2, 5, **6**	7.03 MJ steam/litre ethanol
NH_3	Input	$MJ/MJ_{ethanol}$	0.00023	**2**, 3, **4**, 5, **6**	6.1 kg/tonne ethanol
NaOH	Input	$kg/MJ_{ethanol}$	0.00038	**2**, 3, **4**, 5, **6**	10. 1 kg/tonne ethanol
CaO	Input	$kg/MJ_{ethanol}$	0.00010	**2**, 3, **4**, 5, **6**	2.7 kg/tonne ethanol
H_2SO_4	Input	$kg/MJ_{ethanol}$	0.00012	**2**, 3, **4**, 5, **6**	3.3 kg/tonne ethanol
Urea	Input	$kg/MJ_{ethanol}$	0.00004	**2**, 3, **4**, 5, **6**	1.1 kg/tonne ethanol
Alpha-amylase	Input	$kg/MJ_{ethanol}$	0.00006	**2**, 3, **4**, 5, **6**	1.5 Kg/tonne ethanol
Gluco-amylase	Input	$kg/MJ_{ethanol}$	0.00009	**2**, 3, **4**, 5, **6**	2.4 Kg/tonne ethanol
Ethanol	Output	MJ	1.000		

Comments

- 799 kg moist DDGS and maize oil / tonne ethanol (see Table 111).
- LHV_{-vap} DDGS and oil = 18.13 MJ/kg (see Table 112).
- The values shown in column 'Comment' are averages of data from various sources converted to the same unit (see Table 111, 'adopted value' for additional details).

Sources

1 Pannonia Ethanol, 2015, personal communication, 21 September, 2016.

2 ADEME, 2010.

3 Hartmann, 1995.

4 MacLean and Spatari, 2009.

5 KTBL, 2006.

6 GREET, 2014 (dry-mill).

7 CA-GREET 2.0 – Tier1, 2015 (dry mill).

Table 111 Data used to calculate the 'adopted value' from various sources

	Unit	Ref. 1	Ref. 2	Ref. 6	Ref. 4	Adopted value
Ethanol	litres (assumed pure)/tonne maize @ 14% moisture	425	-	425	-	**425**
Electricity	KWh/litre ethanol	0.185	0.254	0.198	-	**0.212**
Steam	MJ/litre ethanol	5.58	7.73	7.8(*)	-	**7.03**
NH_3	kg/tonne ethanol	-	4.3	7.3	6.6	**6.1**
NaOH	kg/tonne ethanol	-	4.8	9.2	16.3	**10.1**
CaO	kg/tonne ethanol	-	0.0	4.4	3.8	**2.7**
H_2SO_4	kg/tonne ethanol	-	2.7	7.3	0	**3.3**
Urea	kg/tonne ethanol	-	3.2	0.0	0.0	**1.1**
Alpha-amylase	kg/tonne ethanol	-	1.1	1.0	2.5	**1.5**
Gluco-amylase	kg/tonne ethanol	-	1.3	2.4	3.4	**2.4**
DDGS (**)	kg moist DDGS/ tonne moist maize	276	-	-	-	
	kg moist DDGS/ tonne dry maize	319	-	287	-	
	kg **moist** DDGS/ tonne ethanol	814 @11.2% moisture	-	731 @9% moisture	-	**772** **@10% moisture**
	kg **dry** DDGS/ tonne ethanol	723	-	665	-	
Maize oil	kg maize oil/tonne moist maize @13.5% water	8.5	-	-	-	
	kg maize oil/tonne dry maize	9.8	-	11.1	-	**10**
	kg maize oil/tonne ethanol					**27**

(*) This value has been adjusted to the assumption that ALL DDGS are dried to 9% water, combining data reported by GREET 2014 on the amount of Natural Gas with data from CA-GREET 2.0 on the amount of DDGS dried at different water contents (9%, 55%, 65%).

(**) **Adopted value of dry DDGS per tonne of ethanol**: The amount of DDGS depends on the ethanol yield: the more ethanol, the less DDGS. We averaged the ethanol yield from Ref. 1 and Ref. 6 and we used the same references to calculate the amount of dry DDGS, converted to our moisture content.

The composition and hence LHV of the DDGS depends on the composition of the cereals used. To ensure consistency with the ethanol yield, we calculate the LHV of DDGS by mass and energy balance (in Table 112). This gives a figure for the LHV of all the dry matter that does not leave as ethanol, or fermented CO_2. However, this is consistently slightly less than the amount of DDGS reported by plant-owners. This implies that a small amount of organic material is lost elsewhere. This could be losses in handling, or losses in dilute waste streams that are not always evaporated to recover their solids. It could also be burning or decomposition of components during drying. Therefore, when we have a reported mass of DDGS that is consistent with the adopted ethanol yield, we combine the calculated average LHV with the reported mass of DDGS. This is the case for the maize and wheat processes. For other cereals, we assume the same % mass-losses as for the wheat-ethanol process.

Table 112 LHV of maize DDGS and maize oil by mass and energy balance

Mass balance	**Unit**	**Amount**
Dry mass IN (incl. process chemicals)	tonne/tonne ethanol	2.58
Water for hydrolysing starch (by stoichiometry)*	tonne/tonne ethanol	0.20
Ethanol OUT	tonne/tonne ethanol	1.00
OUT: CO2 from fermentation (by stoichiometry)*	tonne/tonne ethanol	0.96
Dry DDGS+oil (by difference)	tonne/tonne ethanol	0.82
Moist DDGS	tonne/tonne ethanol	0.91
Energy balance	**Unit**	**Amount**
GJ heat content in maize IN	GJ/tonne	44.11
GJ heat in ethanol OUT	GJ/tonne	26.81
GJ in dry starch thas fermented (by stoichiometry)*	GJ/tonne	27.94
GJ in dry DDGS + oil / tonne eth (by difference)	GJ/tonne	16.16
GJ in oil / tonne eth	GJ/tonne	0.99
GJ in DDGS / tonne eth	GJ/tonne	15.17
DDGS LHV (dry)	GJ/tonne	19.23
DDGS LHV (@ 10% moisture)	GJ/tonne	17.29
DDGS LHV_{-vap} @ 10% moisture	GJ/tonne	17.04
(DDGS @ 10% moisture + OIL) LHV_{-vap} **(for allocation purposes only)**	GJ/tonne	**18.13**

*** Fermentation stoichiometry**

	Starch			**Ethanol**		**Efficiency**
	$C_6H_{10}O_5$	**+ H_2O**	**->**	**2 x C_2H_6O**	**+ 2 x CO_2**	
Mass	162	18		92	88	**56.8%**
LHV kJ/kg	15.88			26.81		
Energy MJ	2572.56			2466.52		**95.9%**

Step 5.1: Steam generation processes

The data for the individual steam generation processes are shown in Chapter 4. The processes linked to maize ethanol are:

- NG boiler (Table 63)
- NG CHP (Table 64)
- Coal CHP (Table 66)
- woodchip–fuelled CHP (Table 68).

Step 6: Transportation of ethanol to the blending depot

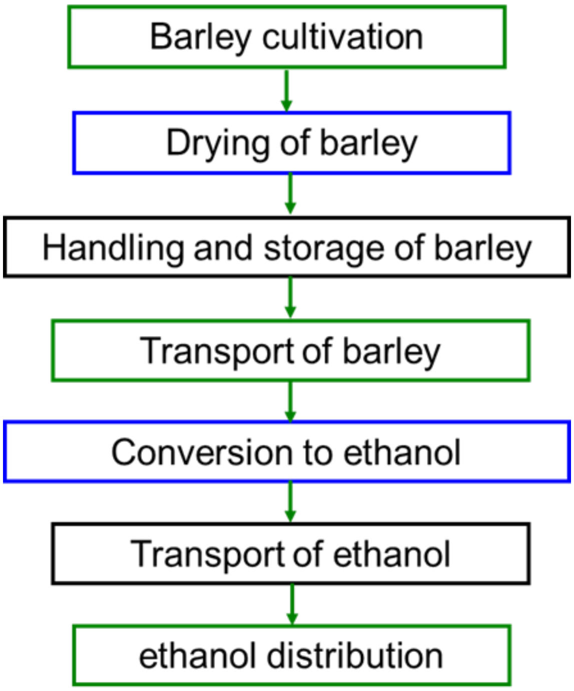
The same data are used as for wheat ethanol.

Step 7: Ethanol depot distribution inputs

The same data are used as for wheat ethanol.

6.3 Barley to ethanol

Description of pathway



The following processes are included in the 'barley to ethanol' pathway.

The data for each process are shown below; significant updates are described in more detail with relevant references.

Step 1: Barley cultivation

The new data for barley cultivation are shown in Table 113. The updated data include:

- diesel and pesticide use in barley cultivation updated using data from CAPRI (see Section 2.5);
- $CaCO_3$ fertilizer use calculated by the JRC (see Section 3.10);
- N_2O emissions calculated by JRC using the JRC GNOC model (see Section 3.7);
- CO_2 emissions from neutralisation of other soil acidity calculated by the JRC (see Section 3.10);
- K_2O and P_2O_5 updated using the most recent data available (2013/2014);
- seeding material updated using data from Faostat, latest available year (2013).

In the following table, source numbers in **bold** represent the main data source; additional references are used to convert data to ’per MJ of crop’.

Table 113 Barley cultivation

	I/O	Unit	Amount	Source	Comment
Diesel	Input	MJ/MJ_{barley}	0.04847	3, **5**	See CAPRI data
N fertilizer	Input	kg/MJ_{barley}	0.00144	2, 3	See GNOC data
$CaCO_3$ fertilizer	Input	kg/MJ_{barley}	0.00363	6	See liming data
K_2O fertilizer	Input	kg/MJ_{barley}	0.00036	3, **4**	5.3 kg K_2O/tonne moist crop
P_2O_5 fertilizer	Input	kg/MJ_{barley}	0.00036	3, **4**	5.3 kg P_2O_5/tonne moist crop
Pesticides	Input	kg/MJ_{barley}	0.00006	3, **5**	See CAPRI data
Seeding material	Input	kg/MJ_{barley}	0.00298	**1**, 3	199 kg/(ha*yr)
Barley	Output	MJ	1.0000		
Field N_2O emissions		g/MJ_{barley}	0.04350	2	See GNOC data
CO_2 from neutralisation of other soil acidity		g/MJ_{barley}	0.46644	6	See liming data

Comments

- Assumption: LHV (barley grain) = LHV (wheat grain).
- LHV (dry wheat grain) = 17.0 MJ/kg of dry substance (Ref. 3).
- 13.5 % water content (Ref. 5).
- The raw input data in the table are either provided 'per tonne of moist crop' or converted from 'per-ha' using yields in tonnes of moist crop per ha. Here, the moist yields are for the traded moisture content of barley. This varies slightly by country, but on average is about 13.5 % in EU. However, the freshly-harvested crop has a higher average moisture content; consistent with the CAPRI estimates of the amount of water removed, the average initial moisture content must be 13.5 % + 0.12 % = 13.62 %.

Sources

1 Faostat, accessed in October 2016.

2 Edwards and Koeble, 2012 (see Chapter 3).

3 Kaltschmitt and Hartmann, 2001.

4 Fertilizers Europe, received by JRC in August 2016 (2013-2014 data) and Faostat, 2016 (for yield, average 2009-2014).

5 CAPRI data, 2012, converted to JRC format (see Section 2.5).6 JRC: Acidification and liming data (Section 3.10).

Step 2: Drying of barley

Data on drying, derived from CAPRI data (see Section 2.5), are shown in Table 114.

Table 114 Drying of barley

	I/O	Unit	Amount	Source
Light heating oil	Input	MJ/MJ_{barley}	0.00017	**1**, 2
Natural gas	Input	MJ/MJ_{barley}	0.00017	**1**, 2
Electricity	Input	MJ/MJ_{barley}	0.00003	**1**, 2
Barley	Input	MJ/MJ_{barley}	1.0000	
Barley	Output	MJ	1.0000	

Comments

- 0.12 %: average % of water removed to reach traded water content, according to CAPRI data (see Section 2.5).
- 2.16 MJ heating oil/tonne of crop at traded water content for 0.1% drying (*).
- 2.16 MJ NG/tonne of crop at traded water content for 0.1% drying (*).
- 0.36 MJ electricity/tonne of crop at traded water content for 0.1% drying (**).

(*) UBA (Ref. 2) reports that 0.1% drying of grains needs 1.2 kWh= 4.32 MJ of heating oil per tonne of grain. Ecoinvent (Ref. 3) propose 5 MJ heating oil is needed per kg water evaporated (~0.1% in 1 tonne grain), on the basis of a survey of European literature. UBA data on total MJ heating fuel will be considered, assuming that half comes from NG and half from light heating oil, on the basis of discussions with national experts, as no E-wide data is available. Also LPG is used, but this is an intermediate case.

(**) For electricity, UBA (Ref. 2) reports 0.1% drying of grains needs 0.1 kWh= 0.36MJ per tonne of grain. Ecoinvent (Ref. 3) reports a higher value (about 1kWh = 3.6 MJ electricity) perhaps including electricity for handling and storage. UBA data has been considered.

Sources

1	CAPRI data (M. Kempen, personal communication, October 2016).
2	UBA, 1999.
3	Nemecek and Kägi, 2007.

Step 3: Handling and storage of barley

Data on handling and storage of barley are shown in Table 115.

Table 115 Handling and storage of barley

	I/O	Unit	Amount	Source
Barley	Input	MJ/MJ_{barley}	1.0081	2
Electricity	Input	MJ/MJ_{barley}	0.0004	1
Barley	Output	MJ	1.0000	

Comment

- UBA (Ref. 3) proposes 12.6 kWh electricity per tonne of grain for ventilation during storage of rapeseed. For wheat, Kenkel (Ref. 2) reports average of 19 kWh/tonne for Oklahoma, and Kaltschmitt and Reinhardt (Ref. 1) only 1.6kWh/tonne. Data from Ref. 1 has been used.

Sources

1 Kaltschmitt and Reinhardt, 1997.

2 Kenkel, 2009.

3 UBA, 1999.

Step 4: Transportation of barley grain

Table 116 Transport of barley grain via 40 t truck over a distance of 100 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{barley}	0.0068
Barley	Input	MJ/MJ_{barley}	1.0100
Barley	Output	MJ	1.0000

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

Step 5: Conversion of barley to ethanol

Table 117 Conversion of barley to ethanol

	I/O	Unit	Amount	Source	Comment
Barley	Input	$MJ/MJ_{ethanol}$	2.1241	1, **2**, 3	3.87 t barley grain @ 13.5 % H_2O/(t ethanol)
Electricity	Input	$MJ/MJ_{ethanol}$	0.0491	**2**, 3	1.32 GJ/(t ethanol)
Steam	Input	$MJ/MJ_{ethanol}$	0.3737	**2**, 3	10.0 GJ/(t ethanol)
NH_3	Input	$kg/MJ_{ethanol}$	0.0002	**2**, 3	1.8 kg/dry t of barley grain
NaOH	Input	$kg/MJ_{ethanol}$	0.0005	**2**, 3	4.3 kg/dry t of barley grain
H_2SO_4	Input	$kg/MJ_{ethanol}$	0.0005	**2**, 3	4.1 kg/dry t of barley grain
CaO	Input	$kg/MJ_{ethanol}$	0.0000	**2**, 3	0 kg/dry t of barley grain
alpha-amylase	Input	$kg/MJ_{ethanol}$	0.0001	**2**, 3	0.43 kg/dry t of barley grain
gluco-amylase	Input	$kg/MJ_{ethanol}$	0.0001	**2**, 3	0.59 kg/dry t of barley grain
Ethanol	Output	MJ	1.000		

Comments

- 1.657 tonnes DDGS (at 10 % water) / tonne ethanol: the same % mass-losses as for the wheat-ethanol process have been assumed compared to the value given by the mass balance calculation in Table 118 (see Table 92 in wheat to ethanol for additional explanation).
- LHV_{-vap} DDGS = 15.73 MJ/kg of wet DDGS (see Table 118).
- The values shown in column 'Comment' are averages of data from various sources converted to the same unit (see Table 92 in wheat to ethanol, 'adopted value').

Sources

1 Kaltschmitt and Hartmann, 2001.

2 Assumed proportional to wheat (see wheat to ethanol pathway) using the ratio wheat/barley of ethanol yields from (Ref. 1): 40 litres ethanol/(100 kg wheat) and 35 litres ethanol/(100 kg barley).

3 Hartmann, 1995.

Table 118 LHV of barley DDGS by mass and energy balance

Mass balance	**Unit**	**Amount**	
Barley moisture	kg/kg moist barley	13.50%	m
Dry barley	kg/kg moist barley	0.865	1-m
Ethanol yield	kg/kg moist barley	0.258	Et
Ethanol / starch by stoichiometry*	kg/kg	0.568	Em
Starch to ethanol in barley	kg/kg moist barley	0.455	St = Et/Em
Dry DDGS	kg/kg moist barley	0.410	Dd = 1-m-St
Dry DDGS including process chemicals	kg/kg raw barley	0.422	Dd + pc
DDGS @ 10% moisture	kg/kg moist barley	0.468	Dm = Dd + pc/0.9
DDGS/EtOH	kg/kg	1.814	Dr =Dm/Y
Energy balance	**Unit**	**Amount**	
Barley LHV (dry)	MJ/kg dry barley	17	Hwd
Barley LHV (@ 13.5% moisture)	MJ/kg moist barley	14.71	Hwm = Hwd *(1-m)
Ethanol LHV	MJ/kg moist barley	6.92	He = Et x 26.81
Reaction heat efficiency by stoichiometry*		95.88%	Ee
Starch energy used	MJ/kg moist barley	7.22	Hs = He/Ee
Energy in DDGS	MJ/kg moist barley	7.48	Hd = Hwm-Hs
Energy out/energy in	MJ/MJ	97.98%	(Hd + He) / Hwm
Allocation to ethanol		48.1%	He / (He + Hd)
DDGS LHV (dry)	MJ/kg	**17.75**	Hd / Dd + pc
DDGS LHV (@10% moisture)	MJ/kg	15.98	Hd / Dm
DDGS LHV$_{-vap}$ @10% moisture (for allocation purposes only)	MJ/kg	**15.73**	

*** Fermentation stoichiometry**

	Starch			**Ethanol**		**Efficiency**
	C6H10O5	**+ H2O**	**->**	**2 x C2H6O**	**+ 2 x CO2**	
Mass	162	18		92	88	56.79%
LHV kJ/kg	15.88			26.81		
Energy MJ	2572.56			2466.52		95.88%

Step 5.1: Steam generation processes

The data for the individual steam generation processes are shown in Chapter 4. The processes linked to barley ethanol are:

- NG boiler (Table 63)
- NG CHP (Table 64)
- lignite CHP (Table 66)
- woodchip-fuelled CHP (Table 68).

Step 6: Transportation of ethanol to the blending depot

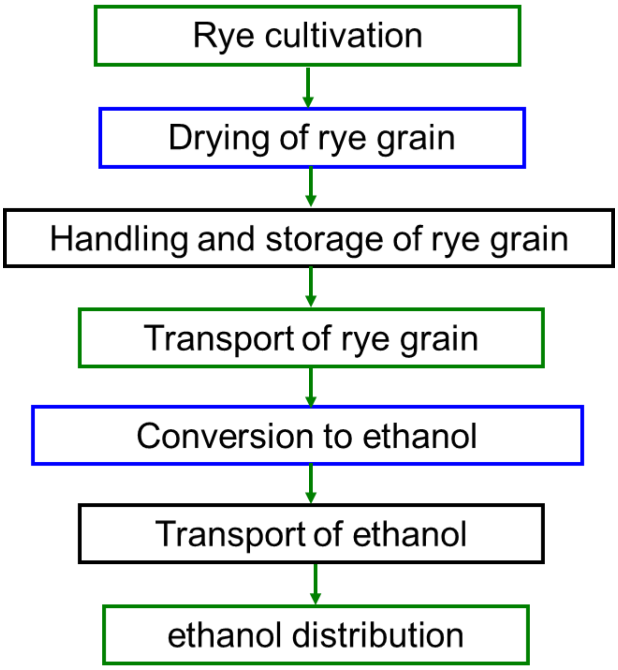
The same data are used as for wheat ethanol.

Step 7: Ethanol depot distribution inputs

The same data are used as for wheat ethanol.

6.4 Rye to ethanol

Description of pathway



The following processes are included in the 'rye to ethanol' pathway:

The data for each process are shown below; significant updates are described in more detail with relevant references.

Step 1: Rye cultivation

The new data for rye cultivation are shown in Table 119. The updated data include:

- diesel and pesticide use in rye cultivation updated using data from CAPRI (see Section 2.5);
- $CaCO_3$ fertilizer use calculated by the JRC (see Section 3.10);
- N_2O emissions calculated by JRC using the JRC GNOC model (see Section 3.7);
- CO_2 emissions from neutralisation of other soil acidity calculated by the JRC (see Section 3.10);
- K_2O and P_2O_5 updated using the most recent data available (2013/2014);
- seeding material updated using data from Faostat, latest available year (2013).

In the following table, source numbers in **bold** represent the main data source; additional references are used to convert data to ’per MJ of crop’.

Table 119 Rye cultivation

	I/O	Unit	Amount	Source	Comment
Diesel	Input	MJ/MJ_{rye}	0.05658	3, **5**	See CAPRI data
N fertilizer	Input	kg/MJ_{rye}	0.00122	**2**, 3	See GNOC data
$CaCO_3$ fertilizer	Input	kg/MJ_{rye}	0.00627	6	See liming data
K_2O fertilizer	Input	kg/MJ_{rye}	0.00032	3, **4**	4.7 kg K_2O/tonne moist crop
P_2O_5 fertilizer	Input	kg/MJ_{rye}	0.00030	3, **4**	4.4 kg P_2O_5/tonne moist crop
Pesticides	Input	kg/MJ_{rye}	0.00003	3, **5**	See CAPRI data
Seeding material	Input	kg/MJ_{rye}	0.00335	**1**, 3	178 kg/(ha*yr)
Rye grain	Output	MJ	1.0000		
Field N_2O emissions		g/MJ_{rye}	0.03679	2	See GNOC data
CO_2 from neutralisation of other soil acidity		g/MJ_{rye}	1.65073	6	See liming data

Comments

- LHV (dry crop) = 17.1 MJ/kg dry rye (Ref. 3).
- 14 % water content (Ref. 5 and 7).
- The raw input data in the table are either provided 'per tonne of moist crop' or converted from 'per-ha' using yields in tonnes of moist crop per ha. Here, the moist yields are for the traded moisture content of rye. This varies slightly by country, but on average is about 14 % in EU. However, the freshly-harvested crop has a higher average moisture content; consistent with the CAPRI estimates of the amount of water removed, the average initial moisture content must be 14 % + 0.23 % = 14.23 %.

Sources

1 Faostat, accessed in October 2016.

2 Edwards and Koeble, 2012 (see Chapter 3).

3 Kaltschmitt and Hartmann, 2001.

4 Fertilizers Europe, received by JRC in August 2016 (2013-2014 data) and Faostat, 2016 (for yield, average 2009-2014).

5 CAPRI data, 2012, converted to JRC format (see Section 2.5).

6 JRC: Acidification and liming data (Section 3.10).

7 KTBL, 2006.

Step 2: Drying of rye grain

Data on drying, derived from CAPRI data (see Section 2.5), are shown in Table 120.

Table 120 Drying of rye grain

	I/O	Unit	Amount	Source
Light heating oil	Input	MJ/MJ_{rye}	0.00034	**1**, 2
Natural Gas	Input	MJ/MJ_{rye}	0.00034	**1**, 2
Electricity	Input	MJ/MJ_{rye}	0.00006	**1**, 2
Rye	Input	MJ/MJ_{rye}	1.0000	
Rye	Output	MJ	1.0000	

Comments

- 0.23 %: average % of water removed to reach traded water content, according to CAPRI data (see Section 2.5).
- 2.16 MJ heating oil/tonne of crop at traded water content for 0.1% drying (*).
- 2.16 MJ NG/tonne of crop at traded water content for 0.1% drying (*).
- 0.36 MJ electricity/tonne of crop at traded water content for 0.1% drying (**).

(*) UBA (Ref. 2) reports that 0.1% drying of grains needs 1.2 kWh= 4.32 MJ of heating oil per tonne of grain. Ecoinvent (Ref. 3) propose 5 MJ heating oil is needed per kg water evaporated (~0.1% in 1 tonne grain), on the basis of a survey of European literature. UBA data on total MJ heating fuel will be considered, assuming that half comes from NG and half from light heating oil, on the basis of discussions with national experts, as no-EU wide data is available. Also LPG is used, but this is an intermediate case.

(**) For electricity, UBA (Ref. 2) reports 0.1% drying of grains needs 0.1 kWh= 0.36MJ per tonne of grain. Ecoinvent (Ref. 3) reports a higher value (about 1kWh = 3.6 MJ electricity) perhaps including electricity for handling and storage. UBA data has been considered.

Sources

1 CAPRI data (M. Kempen, personal communication, October 2016).

2 UBA, 1999.

3 Nemecek and Kägi, 2007.

Step 3: Handling and storage of rye grain

Data on handling and storage of barley are shown in Table 121.

Table 121 Handling and storage of rye grain

	I/O	Unit	Amount	Source
Rye	Input	MJ/MJ_{rye}	1.0081	2
Electricity	Input	MJ/MJ_{rye}	0.0004	1
Rye	Output	MJ	1.0000	

Comment

- UBA (Ref. 3) proposes 12.6 kWh electricity per tonne of grain for ventilation during storage of rapeseed. For wheat, Kenkel (Ref. 2) reports average of 19 kWh/tonne for Oklahoma, and Kaltschmitt and Reinhardt (Ref. 1) only 1.6kWh/tonne. Data from Ref. 1 has been used.

Sources

1 Kaltschmitt and Reinhardt, 1997.

2 Kenkel, 2009.

3 UBA, 1999.

Step 4: Transportation of rye grain

Table 122 Transport of rye grain via 40 t (payload 27 t) truck over a distance of 100 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{rye}	0.0068
Rye grain	Input	MJ/MJ_{rye}	1.0100
Rye grain	Output	MJ	1.0000

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

Step 5: Conversion of rye grain to ethanol

Table 123 Conversion of rye grain to ethanol

	I/O	Unit	Amount	Source	Comment
Rye grain	Input	$MJ/MJ_{ethanol}$	2.0368	1, **2**, 3	3.71 t rye grain @ 13.5 % H_2O/(t ethanol)
Electricity	Input	$MJ/MJ_{ethanol}$	0.0491	**2**, 3	1.32 GJ/(t ethanol)
Steam	Input	$MJ/MJ_{ethanol}$	0.3737	**2**, 3	10.0 GJ/(t ethanol)
NH_3	Input	$kg/MJ_{ethanol}$	0.0002	**2**, 3	1.8 kg/dry t of rye grain
NaOH	Input	$kg/MJ_{ethanol}$	0.0005	**2**, 3	4.3 kg/dry t of rye grain
H_2SO_4	Input	$kg/MJ_{ethanol}$	0.0005	**2**, 3	4.1 kg/dry t of rye grain
CaO	Input	$kg/MJ_{ethanol}$	0.0000	**2**, 3	0 kg/dry t of rye grain
alpha-amylase	Input	$kg/MJ_{ethanol}$	0.0001	**2**, 3	0.43 kg/dry t of rye grain
gluco-amylase	Input	$kg/MJ_{ethanol}$	0.0001	**2**, 3	0.59 kg/dry t of rye grain
Ethanol	Output	MJ	1.0000		

Comments

- 1.516 tonnes DDGS (at 10 % water) / tonne ethanol: the same % mass-losses as for the wheat-ethanol process have been assumed compared to the value given by the mass balance calculation in Table 124 (see Table 92 in wheat to ethanol for additional explanation).
- LHV_{-vap} DDGS = 15.81 MJ/kg of wet DDGS (see Table 124).
- The values shown in column 'Comment' are averages of data from different sources converted to the same unit of measure (see Table 92 in wheat to ethanol, 'adopted value').
- As we are applying data on wheat-ethanol process to rye, we use the wheat moisture content (13.5 % moisture).

Sources

1 Kaltschmitt and Hartmann, 2001.

2 Assumed proportional to wheat (see wheat to ethanol pathway) using the ratio wheat/rye of ethanol yields from (Ref. 1): 40 litres ethanol/(100 kg wheat) and 36-37 litres ethanol/(100 kg rye).

3 Hartmann, 1995.

Table 124 LHV of rye DDGS by mass and energy balance

Mass balance	**Unit**	**Amount**	
Rye moisture	kg/kg moist rye	13.50%	m
Dry rye	kg/kg moist rye	0.865	1-m
Ethanol yield	kg/kg moist rye	0.269	Et
Ethanol / starch by stoichiometry*	kg/kg	0.568	Em
Starch to ethanol in rye	kg/kg moist rye	0.474	St = Et/Em
Dry DDGS	kg/kg moist rye	0.391	Dd = 1-m-St
Dry DDGS including process chemicals	kg/kg raw wheat	0.402	Dd + pc
DDGS @ 10% moisture	kg/kg moist rye	0.447	Dm = Dd + pc/0.9
DDGS/EtOH	kg/kg	1.659	Dr =Dm/Y
Energy balance	**Unit**	**Amount**	
Rye LHV (dry)	MJ/kg dry rye	17	Hwd
Rye LHV (@ 13.5% moisture)	MJ/kg moist rye	14.71	Hwm = Hwd *(1-m)
Ethanol LHV	MJ/kg moist rye	7.22	He = Et x 26.81
Reaction heat efficiency by stoichiometry*		95.88%	Ee
Starch energy used	MJ/kg moist rye	7.53	Hs = He/Ee
Energy in DDGS	MJ/kg moist rye	7.18	Hd = Hwm-Hs
Energy out/energy in	MJ/MJ	97.89%	(Hd + He) / Hwm
Allocation to ethanol		50.2%	He / (He + Hd)
DDGS LHV (dry)	MJ/kg	**17.84**	Hd / Dd + pc
DDGS LHV (@10% moisture)	MJ/kg	16.06	Hd / Dm
DDGS LHV-vap @10% moisture (for allocation purposes only)	MJ/kg	**15.81**	

*** Fermentation stoichiometry**

	Starch			**Ethanol**		**Efficiency**
	$C_6H_{10}O_5$	**+ H_2O**	**->**	**2 x C_2H_6O**	**+ 2 x CO_2**	
Mass	162	18		92	88	56.79%
LHV kJ/kg	15.88			26.81		
Energy MJ	2572.56			2466.52		95.88%

Step 5.1: Steam generation processes

The data for the individual steam generation processes are shown in Chapter 4. The processes linked to rye ethanol are:

- NG boiler (Table 63)
- NG CHP (Table 64)
- lignite CHP (Table 66)
- woodchip-fuelled CHP (Table 68).

Step 6: Transportation of ethanol to the blending depot

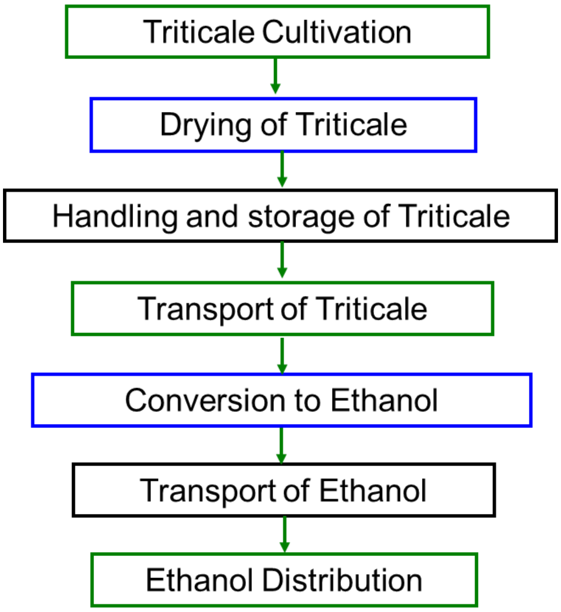
The same data are used as for wheat ethanol.

Step 7: Ethanol depot distribution inputs

The same data are used as for wheat ethanol.

6.5 Triticale to ethanol

Description of pathway



The following processes are included in the 'triticale to ethanol' pathway:

The data for each process are shown below; significant updates are described in more detail with relevant references.

Step 1: Triticale cultivation

The new data for triticale cultivation are shown in Table 125. The updated data include:

- $CaCO_3$ fertilizer use calculated by the JRC (see Section 3.10);
- N_2O emissions calculated by JRC using the JRC GNOC model (see Section 3.7);
- CO_2 emissions from neutralisation of other soil acidity calculated by the JRC (see Section 3.10).
- K_2O and P_2O_5 updated using the most recent data available (2013/2014);
- Seeding material updated using data from Faostat, latest available year (2013).

In the following table, source numbers in **bold** represent the main data source; additional references are used to convert data to ’per MJ of crop’.

Table 125 Triticale cultivation

	I/O	Unit	Amount	Source	Comment
Diesel	Input	$MJ/MJ_{triticale}$	0.0475	8	Average of the yield-adjusted CAPRI data for feed-wheat and rye
N fertilizer	Input	$kg/MJ_{triticale}$	0.0014	**2**, 3	See GNOC data
$CaCO_3$ fertilizer	Input	$kg/MJ_{triticale}$	0.0041	6	See liming data
K_2O fertilizer	Input	$kg/MJ_{triticale}$	0.0003	8	Average of Fertilizers Europe data for feed-wheat and rye (Ref. 4)
P_2O_5 fertilizer	Input	$kg/MJ_{triticale}$	0.0003	8	Average of Fertilizers Europe data for feed-wheat and rye (Ref. 4)
Pesticides	Input	$kg/MJ_{triticale}$	0.0001	8	Average of the yield-adjusted CAPRI data for feed-wheat and rye
Seeding material	Input	$kg/MJ_{triticale}$	0.0027	**1**, 3	162 kg/(ha*yr)
Triticale	Output	MJ	1.0000		
Field N_2O emissions		$g/MJ_{triticale}$	0.0403	2	See GNOC data
CO_2 from neutralisation of other soil acidity		$g/MJ_{triticale}$	0.5956	6	See liming data

Comment

- LHV (dry crop) = 16.9 MJ/kg dry triticale (Ref. 3).
- Water content: 14 %. It is assumed to be equal to rye traded moisture content, which is given by Ref. 5, agreeing with Ref. 7.
- The raw input data in the table are either provided 'per tonne of moist crop' or converted from 'per-ha' using yields in tonnes of moist crop per ha. Here, the moist yields are for the traded moisture content of triticale. This varies slightly by country, but on average is about 14 % in EU. However, the freshly-harvested crop has a higher average moisture content; consistent with the CAPRI estimates of the amount of water removed, the average initial moisture content must be 14 % + 0.21 % = 14.21 %.

Sources

1 Faostat, accessed in October 2016.

2 Edwards and Koeble, 2012 (see Chapter 3).

3 Kaltschmitt and Hartmann, 2001.

4 Fertilizers Europe, received by JRC in August 2016 (2013-2014 data) and Faostat, 2016 (for yield, average 2009-2014).

5 CAPRI data, 2012, converted to JRC format (see Section 2.5).

6 JRC: Acidification and liming data (Section 3.10).

7 KTBL, 2006.

8 See wheat to ethanol and rye to ethanol pathways.

Step 2: Drying of triticale

Data on drying of triticale are assumed to be the average of wheat and rye drying. The data are shown in Table 126.

Table 126 Drying of triticale grain

	I/O	Unit	Amount	Source
Light heating oil	Input	$MJ/MJ_{triticale}$	0.00032	**1**, 2
Natural Gas	Input	$MJ/MJ_{triticale}$	0.00032	**1**, 2
Electricity	Input	$MJ/MJ_{triticale}$	0.00005	**1**, 2
Triticale	Input	$MJ/MJ_{triticale}$	1.0000	
Triticale	Output	MJ	1.0000	

Comments:

- 0.21 %: average % of water removed to reach traded water content, according to CAPRI data (see Section 2.5).
- 2.16 MJ heating oil/tonne of crop at traded water content for 0.1% drying (*).
- 2.16 MJ NG/tonne of crop at traded water content for 0.1% drying (*).
- 0.36 MJ electricity/tonne of crop at traded water content for 0.1% drying (**).

(*) UBA (Ref. 2) reports that 0.1% drying of grains needs 1.2 kWh= 4.32 MJ of heating oil per tonne of grain. Ecoinvent (Ref. 3) propose 5 MJ heating oil is needed per kg water evaporated (~0.1% in 1 tonne grain), on the basis of a survey of European literature. UBA data on total MJ heating fuel will be considered, assuming that half comes from NG and half from light heating oil, on the basis of discussions with national experts, as no EU-wide data is available. Also LPG is used, but this is an intermediate case.

(**) For electricity, UBA (Ref. 2) reports 0.1% drying of grains needs 0.1 kWh= 0.36MJ per tonne of grain. Ecoinvent (Ref. 3) reports a higher value (about 1kWh = 3.6 MJ electricity) perhaps including electricity for handling and storage. UBA data has been considered.

Sources

1 CAPRI data (M. Kempen, personal communication, October 2016).

2 UBA, 1999.

3 Nemecek and Kägi, 2007.

Step 3: Handling and storage of triticale

Data on handling and storage of barley are shown in Table 127.

Table 127 Handling and storage of triticale

	I/O	Unit	Amount	Source
Triticale	Input	MJ/MJ$_{triticale}$	1.0081	2
Electricity	Input	MJ/MJ$_{triticale}$	0.0003	1
Triticale	Output	MJ	1.0000	

Comment

- UBA (Ref. 3) proposes 12.6 kWh electricity per tonne of grain for ventilation during storage of rapeseed. For wheat, Kenkel (Ref. 2) reports average of 19 kWh/tonne for Oklahoma, and Kaltschmitt and Reinhardt (Ref. 1) only 1.6kWh/tonne. Data from Ref. 1 has been used.

Sources

1 Kaltschmitt and Reinhardt, 1997.

2 Kenkel, 2009.

3 UBA, 1999.

Step 4: Transport of triticale

Table 128 Transport of triticale via 40 t (payload 27 t) truck over a distance of 100 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{triticale}$	0.0069
Triticale	Input	MJ/MJ$_{triticale}$	1.0100
Triticale	Output	MJ	1.0000

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

Step 5: Conversion of triticale to ethanol

Table 129 Conversion of triticale to ethanol

	I/O	Unit	Amount	Source	Comment
Triticale	Input	$MJ/MJ_{ethanol}$	1.90627	1, **2** ,3	3.48 t triticale @ 13.5 % H_2O/(t ethanol)
Electricity	Input	$MJ/MJ_{ethanol}$	0.04907	**2**, 3	1.3 GJ/(t ethanol)
Steam	Input	$MJ/MJ_{ethanol}$	0.37374	**2**, 3	10.0 GJ/(t ethanol)
NH_3	Input	$kg/MJ_{ethanol}$	0.00021	**2**, 3	1.8 kg/dry t of triticale
NaOH	Input	$kg/MJ_{ethanol}$	0.00048	**2**, 3	4.3 kg/dry t of triticale
H_2SO_4	Input	$kg/MJ_{ethanol}$	0.00046	**2**, 3	4.1 kg/dry t of triticale
CaO	Input	$kg/MJ_{ethanol}$	0.00000	**2**, 3	0.0 kg/dry t of triticale
alpha-amylase	Input	$kg/MJ_{ethanol}$	0.00005	**2**, 3	0.4 kg/dry t of triticale
gluco-amylase	Input	$kg/MJ_{ethanol}$	0.00007	**2**, 3	0.6 kg/dry t of triticale
Ethanol	Output	MJ	1.0000		

Comments

- 1.304 tonnes DDGS (at 10 % water) / tonne ethanol: the same % mass-losses as for the wheat-ethanol process have been assumed compared to the value given by the mass balance calculation in Table 130 (see Table 92 in wheat to ethanol for additional explanation).
- LHV_{-vap} DDGS = 15.97 MJ/kg of wet DDGS (see Table 130).
- The values shown in column 'Comment' are averages of data from various sources converted to the same unit (see Table 92 in wheat to ethanol, 'adopted value').
- As we are applying data on wheat-ethanol process to triticale, we use the wheat moisture content (13.5 % moisture).

Sources

1 Kaltschmitt and Hartmann, 2001.

2 Assumed proportional to wheat (see wheat to ethanol pathway) using the ratio wheat/barley of ethanol yields from (Ref. 1): 40 litres ethanol/(100 kg wheat) and 39-40 litres ethanol/(100 kg triticale).

3 Hartmann, 1995.

Table 130 LHV of DDGS by mass and energy balance

Mass balance	**Unit**	**Amount**	
Triticale moisture	kg/kg moist triticale	13.50%	m
Dry triticale	kg/kg moist triticale	0.865	1-m
Ethanol yield	kg/kg moist wheat	0.288	Et
Ethanol / starch by stoichiometry *	kg/kg	0.568	Em
Starch to ethanol in triticale	kg/kg moist triticale	0.507	St = Et/Em
Dry DDGS	kg/kg moist triticale	0.358	Dd = 1-m-St
Dry DDGS including process chemicals	kg/kg raw wheat	0.370	Dd + pc
DDGS @ 10% moisture	kg/kg moist triticale	0.411	Dm = Dd + pc/0.9
DDGS/EtOH	kg/kg	**1.427**	Dr =Dm/Y
Energy balance	**Unit**	**Amount**	
Triticale LHV (dry)	MJ/kg dry triticale	17	Hwd
Triticale LHV (@13.5% moisture)	MJ/kg moist triticale	14.71	Hwm = Hwd *(1-m)
Ethanol LHV	MJ/kg moist triticale	7.7140	He = Et x 26.81
Reaction heat efficiency by stoichiometry *		95.9%	Ee
Starch energy used	MJ/kg moist triticale	8.05	Hs = He/Ee
Energy in DDGS	MJ/kg moist triticale	6.66	Hd = Hwm-Hs
Energy out/energy in	MJ/MJ	97.74%	(Hd + He) / Hwm
Allocation to ethanol		53.7%	He / (He + Hd)
DDGS LHV (dry)	MJ/kg	**18.02**	Hd / Dd + pc
DDGS LHV (@10% water)	MJ/kg	16.21	Hd / Dm
DDGS LHV$_{\text{-vap}}$ @10% water **for allocation purposes only)**	MJ/kg	**15.97**	

*** Fermentation stoichiometry**

	Starch			Ethanol		Efficiency
	$C_6H_{10}O_5$	**+ H_2O**	**->**	**2 x C_2H_6O**	**+ 2 x CO_2**	
Mass	162	18		92	88	56.79%
LHV kJ/kg	15.88			26.81		
Energy MJ	2572.56			2466.52		95.88%

Step 5.1: Steam generation processes

The data for the individual steam generation processes are shown in Chapter 4. The processes linked to triticale ethanol are:

- NG boiler (Table 63)
- NG CHP (Table 64)
- lignite CHP (Table 66)
- woodchip-fuelled CHP (Table 68).

Step 6: Transportation of ethanol to the blending depot

The same data are used as for wheat ethanol.

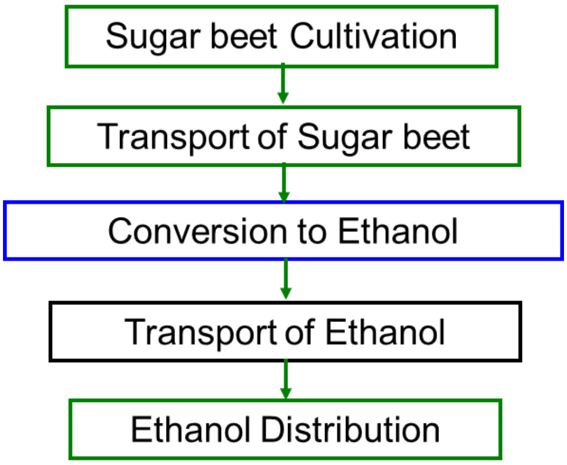
Step 7: Ethanol depot distribution inputs

The same data are used as for wheat ethanol.

6.6 Sugar beet to ethanol

Description of pathway

The following processes are included in the 'sugar beet to ethanol' pathway:



The data for each process are shown below; significant updates are described in more detail with relevant references.

Step 1: Sugar beet cultivation

The new data for sugar beet cultivation are shown in Table 131. The updated data include:

- diesel and pesticide use in sugar beet cultivation updated using data from CAPRI (see Section 2.5);
- $CaCO_3$ fertilizer use calculated by the JRC (see Section 3.10);
- N_2O emissions calculated by JRC using the JRC GNOC model (see Section 3.7);
- CO_2 from neutralisation of other soil acidity, calculated by the JRC (see Section 3.10).
- K_2O and P_2O_5 updated using the most recent data available (2013/2014).
- Sugar beet seed figure and average equivalent yield at nominal 16% sugar updated using new available data.

In the following table, source numbers in **bold** represent the main data source, additional references are used to convert data to ’per MJ of crop’.

Table 131 Sugar beet cultivation

	I/O	Unit	Amount	Source	Comment
Diesel	Input	MJ/MJ$_{\text{sugar beet}}$	0.01050	1, **4**	See CAPRI DATA
N fertilizer	Input	kg/MJ$_{\text{sugar beet}}$	0.00035	2	See GNOC data
$CaCO_3$ fertilizer	Input	kg/MJ$_{\text{sugar beet}}$	0.00108	7	See liming data
K_2O fertilizer	Input	kg/MJ$_{\text{sugar beet}}$	0.00026	1, **3**	1.1 kg K_2O/tonne wet sugar beet
P_2O_5 fertilizer	Input	kg/MJ$_{\text{sugar beet}}$	0.00015	1, **3**	0.6 kg P_2O_5/tonne wet sugar beet
Pesticides	Input	kg/MJ$_{\text{sugar beet}}$	0.00005	1, **4**	See CAPRI data
Seeding material	Input	kg/MJ$_{\text{sugar beet}}$	0.00001	**10, 11**	3.6 kg/(ha*yr)
Sugar beet	Output	MJ	1.0000		
Field N_2O emissions		g/MJ$_{\text{sugar beet}}$	0.01257	2	See GNOC data
CO_2 from neutralisation of other soil acidity		g/MJ$_{\text{sugar beet}}$	0.00000	7	See liming data

Comments

- LHV (dry crop) = 16.3 MJ/kg dry sugar beet (Ref. 1).
- Water content = 75 % (Ref. 4) and a sugar content of 16 %.
- 80.76 t/ha average yield in sugar beet ethanol EU countries, at nominal 16% sugar, excluding tops and soil (Refs. 8, 9).

Sources

1 Dreier et al., 1998.

2 Edwards and Koeble, 2012 (see Chapter 3).

3 Fertilizers Europe, received by JRC in August 2016 (2013-2014 data).

4 CAPRI data 2012, converted to JRC format (see Section 2.5).

7 JRC: Acidification and liming data (Section 3.10).

8 European Sugar Industry Association, 2013.

9 CGB and CIBE, 2013. French Confederation of Sugar Beet producers and Confederation Internationale des Betteravies Europeans, response to Commission stakeholder meeting in Brussel, May 2013, received by JRC in June 2013.

10 Rudelsheim et al., 2012.

11 British Beet Research Organisation, 2011.

ADDITIONAL COMMENTS AND COMPARISON WITH LITERATURE:

Sugar beet **seed** figure changed to 3.6 kg/hectare. Figures describe coated seeds, and are based on information from Rudelsheim and Smets (2012), and the British Beet Research Organisation (Spring 2011 bulletin).

Average EU sugar beet **yield** data from FAO was 69.21 tonnes per hectare. However, there is no trade in sugar beet, so it must practically always be grown in the same country as the ethanol factory. Therefore it is appropriate to consider only the yields where it is used for ethanol production. Furthermore, as our processing data is for sugar beet with nominal 16% sugar, we need the average equivalent yield at nominal 16% sugar for countries making sugar beet ethanol. The data used was sourced from Confederation Internationale des Betteravies Europeans (CIBE, 2013). Yield includes sugar beet tops, not normally used in the sugar production process, which are typically used in the ethanol production process. Yields are an average of the 5 years from 2007 to 2012.

Comparison with Ademe (2010) on ethanol yield (see Table 133 and Table 134)

JRC figures: 0.0777t ethanol is produced per tonne sugar beet at 16% sugar content. JRC data says 0.486 tonnes of ethanol are produced from one tonne of sugar. Therefore JRC's figure of 80.76t sugar beet/ha (at nominal 16% sugar and excluding tops) produces 6.28 t ethanol/ha. This agrees roughly with the figure from CIBE (2013), who say the ethanol yield is 6.27 t/ha. Of course, we are using their yield data, but this confirms our data on the sugar-to-ethanol process.

In comparison, ADEME (2010) found a higher ethanol production figure per ha, 6.5 t ethanol/ha (median between 6.2 and 6.8 t/ha). It is likely the difference between ADEME, and the JRC/CIBE results are due to ADEME starting off from a relatively high fermentable sugar figure per ha of 15.6 t/ha. According to the CIBE (2013) ratio for conversion of sugar to ethanol, the correct figure for Europe for fermentable sugar yield from sugar beet is 12.9 t/ha.

CONCLUSION

JRC uses yields from CIBE, and JRC sugar-ethanol plant (from Kaltschmitt 1997) has almost the same ethanol/sugar yield as given by CIBE. At the ethanol plant, ADEME has lower ethanol/sugar yield than JRC or CIBE. The ADEME ethanol plant produces less ethanol from a given amount of sugar than JRC or CIBE figures. ADEME has higher yield of sugar beet and higher sugar content than CIBE. That is because (1) France has better yields than CIBE average, confirmed by FAO, and (2) probably, averages may have been for different years, as ADEME yield (if corrected from actual 18% sugar to effective yield at nominal 16% sugar content) corresponds to average FAO yield for 2008-2009, but yields in previous years were considerably lower.

DETAILS

ADEME-DIREM 2010 Sugar beet ethanol data, p.111

"~80 tonnes/ha wet beet yield without tops

"Beet is 18% sugar". Therefore at 16% nominal sugar this corresponds to 90t/ha. Corresponds to average of 2008 and 2009 yields for France in FAO, but is more than the average until then.

suger in beet is thus 14.4 tonnes/ha

"+ 13.5 t/ha tops

containing 1.2 tonnes/ha sugar"

(farmers are not paid for tops).

So total fermentable sugar (with bonus from tops) is 15.6 tonnes/ha

tops add 1.2/14.4 = 8.33% extra sugar

"Ethanol between 6200 and 6800 kg/ha"

Average ethanol per ha = 6.5 tonnes/ha

So 1 tonne ethanol needs 2.4 tonnes fermentable sugar in beet+tops

...Of which sugar, 2.23 tonnes comes from paid-for beet (minus 7.7% for tops)

If we don't count any tops, JRC's existing plant would need 2.06 tonnes sugar per tonne ethanol, as calculated from the sugar in the declared beet input.

If we would add 7.7% sugar from tops, the JRC sugar-in-beet requirement per tonne ethanol would go up to 2.23 tonnes sugar/tonne ethanol, which is closer to ADEME, but still more efficient. So it looks like the JRC plant definitely includes "bonus sugar' from tops which are not counted as part of the beet going in.

The ADEME figure of 0.18 kg (humid) pulp per kg beet is much higher than JRC for pulp@10%moisture. Other sources agree with JRC. The ADEME figure is either before drying (water content not specified) or wrong.

CGB say 1 kg sucrose makes 0.4498 kg ethanol, or 2.22 tonnes sucrose/tonne ethanol. But if tops are considered as a free bonus, it works out about 1/.496 = 2.016 tonnes of sucrose-in-beet per tonne of ethanol. JRC process has 2.059, which is close, and shows that the tops are already included as "free sucrose" in the JRC plant (including the sugar-from-tops, that makes the total sugar in up to 2.23 tonnes sugar per tonne ethanol in JRC.. Not including tops, CGB say 1 tonne sugar beet @16% sugar makes 100 liters (79.4kg) dry ethanol.

Step 2: Transportation of sugar beet

Table 132 Transport of sugar beet via 40 t truck over a distance of 30 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{\text{sugar beet}}$	0.0074
Sugar beet	Input	MJ/MJ$_{\text{sugar beet}}$	1.0000
Sugar beet	Output	MJ	1.0000

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

Sources

1 Kaltschmitt and Hartmann, 2001.

2 Fahrzeugbau Langendorf GmbH & Co. KG; Waltop, personal communication, 2001.

3 Dreier et al., 1998.

Step 3: Conversion to ethanol

The data for the conversion of sugar beet to ethanol with no biogas from slops are shown in Table 133.

Table 133 Conversion to ethanol with no biogas from slops

	I/O	Unit	Amount	Source	Comment
Sugar beet	Input	$MJ/MJ_{ethanol}$	1.8388	1, **2**, 3	0.0777 t ethanol/(t sugar beet @ 76.5 % H_2O)
Electricity	Input	$MJ/MJ_{ethanol}$	0.0345	1, 3	
Steam	Input	$MJ/MJ_{ethanol}$	**0.2806**	1, 3	
Ethanol	Output	MJ	1.000		

Comment

- The ethanol yield includes ethanol from tops, which are not part of the 'official' beet yield paid to farmers.
- 0.058 t beet pulp/(t sugar beet at 76.5 % water).

The data for the conversion of sugar beet to ethanol with biogas from slops are shown in Table 134.

Table 134 Conversion to ethanol with biogas from slops

	I/O	Unit	Amount	Source	Comment
Sugar beet	Input	$MJ/MJ_{ethanol}$	1.8388	1	0.0777 t ethanol/(t sugar beet @ 76.5 % H_2O)
Electricity	Input	$MJ/MJ_{ethanol}$	0.0398	1	
Steam	Input	$MJ/MJ_{ethanol}$	**0.1043**	1	
Ethanol	Output	MJ	1.000		

Comment

- 0.058 t beet pulp/(t sugar beet at 76.5 % water).
- LHV_{-vap} (sugar beet pulp) = 14.4 MJ/kg of wet pulp (Refs 1, 3).
- 9 % water content of sugar beet pulp (Ref. 1).

Sources

1 Kaltschmitt and Reinhardt, 1997.
2 Dreier et al., 1998.
3 Hartmann, 1995.

CONCLUSIONS OF COMPARISON WITH ADEME, 2010 (Ref. 1) and Mortimer et al., 2004 (Ref. 2) ON CONVERSION INPUTS

- The ***steam*** input shown in Table 133 is much lower than in Mortimer et al., 2004 (Ref. 2). ADEME, 2010 (Ref. 1) also has higher total steam requirements, although a smaller fraction is allocated to distillation. However, we cannot compare the ADEME process on a more detailed level, as it does not include pulp drying, and mixes 3 different ways to make ethanol.

- By contrast, ***electricity*** is much higher in Table 133 than in Mortimer et al., 2004 (Ref. 2), but less than in ADEME, 2010 (Ref. 1).

- However, electricity has a much smaller contribution to overall emissions than steam.

- Ignoring ***process chemicals*** has negligible influence on total emissions, compared to data variations elsewhere.

DETAILS

Data from Mortimer et al., 2004 (Ref. 2), converted to MJ/MJ ethanol:

Ref. 2 allocates: 0.000488 MJ electricity to each MJ ethanol

Ref. 2 allocates: 0.465924 MJ steam to each MJethanol

Data from ADEME, 2010 (Ref. 1), in MJ/MJ ethanol:

	Electricity (MJ/MJ eth)	Heat (MJ/MJ eth)
Pressing	0.032	0.174
Fermentation	0.006	0.008
MIN distillation+dehydration	0.002	0.153
MAX distillation+dehydration	0.005	0.206
Total AT LEAST	**0.041**	**0.361**

(because some pressing heat allocated to SBP)

JRC figures for Fermentation: electricity = 0.003 MJ/MJ eth; heat = 0.000 MJ/MJ eth

JRC figure for Distillation: electricity = 0.0054 MJ/MJ eth; heat = 0.2201 MJ/MJ eth

Sources:

1 ADEME, 2010, Life Cycle Assessments Applied to First Generation Biofuels Used in France, Final report, February, 2010 and Appendix to final report, December 2009.

2 Mortimert et al., 2004, 'Energy and Greenhouse Gas Emissions for Bioethanol Production from Wheat Grain and Sugar Beet', Final Report for British Sugar plc, Report No. 23/1, January 2004.

Step 3.1: Steam generation processes

The data for the individual steam generation processes are shown in Chapter 4. The processes linked to sugar beet ethanol are:

- NG boiler (Table 63).
- NG CHP (Table 64).
- lignite CHP (Table 66).

Step 4: Transportation of ethanol to the blending depot

The same data are used as for wheat ethanol.

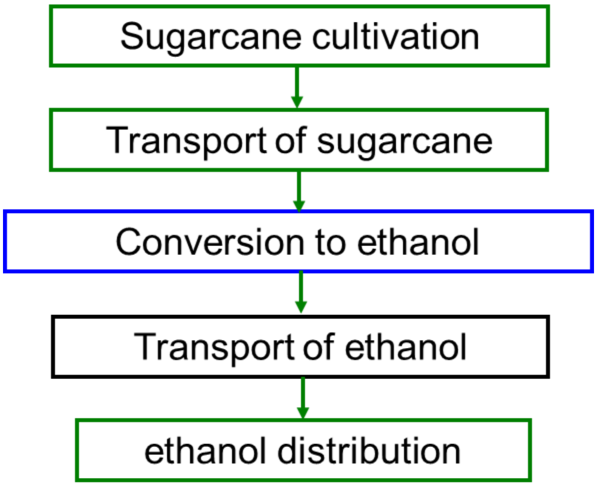
Step 5: Ethanol depot distribution inputs

The same data are used as for wheat ethanol.

6.7 Sugar cane to ethanol

Description of pathway

The following processes are included in the sugar cane-to-ethanol pathway:



The data for each process are shown below; significant updates are described in more detail with relevant references.

Step 1: Sugar cane cultivation

The new data for sugar cane cultivation are shown in Table 135. The updated data include:

- $CaCO_3$ fertilizer use calculated by the JRC (see Section 3.10);
- N_2O emissions calculated by JRC using the JRC GNOC model (see Section 3.7);
- CO_2 emissions from neutralisation of other soil acidity, calculated by the JRC (see Section 3.10).
- K_2O and P_2O_5 updated using the most recent data available.
- Sugar cane yield updated using new available data.

In the following table, source numbers in **bold** represent the main data source; additional references are used to convert data to 'per MJ of crop'.

Table 135 Sugar cane cultivation

	I/O	Unit	Amount	Source	Comments
Diesel	Input	$MJ/MJ_{\text{sugar cane}}$	0.00888	1, 2, **3**, 4	1.355 l diesel/(t sugar cane @ 72.5 % H_2O)
N fertilizer	Input	$kg/MJ_{\text{sugar cane}}$	0.00017	1, 2, **7**	See GNOC data
$CaCO_3$ fertilizer	Input	$kg/MJ_{\text{sugar cane}}$	0.00108	8	See liming data
Filter mud cake	Input	$kg/MJ_{\text{sugar cane}}$	0.00176	1, 2, **3**, **4**	720 kg/(ha*harvest)
K_2O fertilizer	Input	$kg/MJ_{\text{sugar cane}}$	0.00019	1, 2, **5**, 6	1.02 kg/tonne cane
P_2O_5 fertilizer	Input	$kg/MJ_{\text{sugar cane}}$	0.00006	1, 2, **5**, 6	0.32 kg/tonne cane
Pesticides	Input	$kg/MJ_{\text{sugar cane}}$	0.00001	1, 2, **3**	2.36 kg/(ha*yr)
Seeding material	Input	$kg/MJ_{\text{sugar cane}}$	0.00616	1, 2, **3**	2 525 kg/(ha*harvest)
Vinasse	Input	$kg/MJ_{\text{sugar cane}}$	0.21052	1, 2, **3**	86 240 kg/(ha*harvest)
Sugar cane	Output	MJ	1.0000		
Field N_2O emissions		$g/MJ_{\text{sugar cane}}$	0.00707	3, **7**	Including trash burning
CO_2 from neutralisation of other soil acidity		$g/MJ_{\text{sugar cane}}$	0.31653	8	See liming data

Comments

- LHV sugar cane (dry) = 19.6 MJ/kg of dry substance (Ref. 1).
- Water content = 72.5% (Ref. 2).
- 76.0 t sugar cane / (ha*yr), average of 6 years (2009-2014) (Ref. 6). Sugar cane is assumed to be replanted each 6 years. One year is spent preparing the ground (including possible use of a green-manure crop that is not harvested), so there are 5 harvests. Therefore, the yields used to calculate pesticides are reduced by a factor of 5/6. On the other hand, seeding material, vignasse and filter mud cake are already per harvested year.

Sources

1 Dreier, 2000.
2 Kaltschmitt and Hartmann, 2001.
3 Macedo et al., 2008.
4 Macedo et al., 2004.
5 International Fertilizer Association (IFA), 2013 (2010-2011 data).
6 Faostat, accessed in October 2016.
7 Edwards and Koeble, 2012 (see Chapter 3).
8 JRC: Acidification and liming data (Section 3.10).

Step 2: Transportation

Table 136 Transportation of sugar cane (summary table)

Commodity	Transporter
Transport of mud cake	Truck MB2213
Transport of seeding material	Truck MB2318
Transport of sugar cane	Truck (40 t) average

Table 137 Transport of mud cake via dumpster truck MB2213 over a distance of 8 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/kg	0.008
Filter mud cake	Input	kg/kg	1.00
Filter mud cake	Output	kg	1.00

Comment

- For the fuel consumption of the MB2213 truck, see Table 72.

Table 138 Transport of seeding material via MB2318 truck over a distance of 20 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/kg	0.020
Seeding material	Input	kg/kg	1.00
Seeding material	Output	kg	1.00

Comment

- For the fuel consumption of the MB2318 truck, see Table 73.

Table 139 Transport of sugar cane via 40 t truck over a distance of 20 km (one way)

	I/O	Unit	Amount
Distance	Input	$\text{tkm/MJ}_{\text{sugar cane}}$	0.0037
Sugar cane	Input	$\text{MJ/MJ}_{\text{sugar cane}}$	1.0000
Sugar cane	Output	MJ	1.0000

Comment

- For the fuel consumption of 40 t truck weighted average for sugar cane, see Table 71.

Table 140 Transport of vinasse summary table

Share of the vinasse	Transporter
4.6 %	Truck MB2318
23.6 %	Tanker truck with water cannons
71.8 %	Water channels

Table 141 Transport of vinasse via a tanker truck MB2318 over a distance of 7 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/kg	0.007
Vinasse	Input	kg/kg	1.00
Vinasse	Output	kg	1.00

Comment

- For the fuel consumption of the MB2318 tanker truck, see MB2318 Tanker truck for vinasse see Table 74.

Source

1 Macedo et al., 2004.

Table 142 Transport of vinasse via a tanker truck with water cannons over a distance of 14 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/kg	0.014
Vinasse	Input	kg/kg	1.00
Vinasse	Output	kg	1.00

Comment

- For the fuel consumption, see Table 70.

Table 143 Transport of vinasse via water channels

	I/O	Unit	Amount
Diesel	Input	MJ/kg	0.005
Vinasse	Input	kg/kg	1.00
Vinasse	Output	kg	1.00

Step 3: Conversion of sugar cane to ethanol

Table 144 Conversion of sugar cane to ethanol

	I/O	Unit	Amount	Source	Comment
Sugar cane	Input	$MJ/MJ_{ethanol}$	3.11436	1, 2, **3**	81.3 l ethanol/(t sugar cane, 72.5 % H_2O)
CaO	Input	$kg/MJ_{ethanol}$	0.00054	**3**, 4	0.93 kg/(t sugar cane, 72.5 % H_2O)
Cyclohexane	Input	$kg/MJ_{ethanol}$	0.00003	**4**	0.6 kg/(m^3 ethanol) [3]
H_2SO_4	Input	$kg/MJ_{ethanol}$	0.00043	**4**	0.00905 kg/(l ethanol) [3]
Lubricants	Input	$kg/MJ_{ethanol}$	0.00001	**3**, 4	0.01337 kg/(t sugar cane, 72.5 % H_2O) [3]
Ethanol	Output	MJ	1.000		

Comments

- The processing data we use (from Ref. 3), assumed a sugar content (TSR) of 142.2 kg sugar/tonne cane. However, the actual average sugar content from 2012 to 2016 was lower: 134.0 kg-sugar/tonne cane (Ref. 1), because more cane trash is now included in the cane harvest figures (mechanical harvesting). To account for the change, the ethanol yield of the plant has been reduced proportionally.
- According to the methodology set in Annex V, Directive (EU) 2018/2001, there is no allocation of any emissions to residues like straw or bagasse. Therefore, all the emissions from sugar cane production and processing are allocated to ethanol, whether or not bagasse or straw are used to co-generate export electricity. Conversely, the electricity exported is free of emissions from bagasse or straw provision.
- However, as there are slight emissions of CH_4 (0.003 g/MJ of ethanol) and N_2O (0.0015 g/MJ of ethanol) during combustion, these need to be allocated by exergy between exported electricity and ethanol. The fraction of bagasse-burning emissions allocated to electricity export is 0.92%. It is calculated from the total electricity export reported in 2015 (Ref. 6) and the export from the "model" plant we are considering (Ref. 5).

Sources

1	UNICA, 2016a.
2	Kaltschmitt and Hartmann, 2001.
3	Macedo et al., 2008.
4	Macedo et al., 2004.
5	Seabra and Macedo, 2011.
6	UNICA, 2016b.

Step 4: Transport of ethanol to blending depot

After the ethanol arrives in EU, transportation of is the same as for wheat ethanol.

Transportation **to** EU is calculated using the following data.

Table 145 Summary transport table of sugar cane ethanol

Transporter	**Distance (km one-way)**
Truck (40 t, payload 27 t)	700
Ocean bulk carrier	10 186

Table 146 Transport of ethanol via a 40 t truck a distance of 700 km (one way)

	I/O	**Unit**	**Amount**
Distance	Input	$tkm/MJ_{ethanol}$	0.028
Ethanol	Input	$MJ/MJ_{ethanol}$	1.000
Ethanol	Output	MJ	1.000

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

Table 147 Maritime transport of ethanol over a distance of 10 186 km (one way)

	I/O	**Unit**	**Amount**
Distance	Input	$tkm/MJ_{ethanol}$	0.380
Ethanol	Input	$MJ/MJ_{ethanol}$	1.000
Ethanol	Output	MJ	1.000

Comment

- For the fuel consumption of the the product tanker, see Table 77.

Sources

1 IMO, 2009.

2 JRC estimate based on sea distances between intermediate ports, following discussion in Ref. 1.

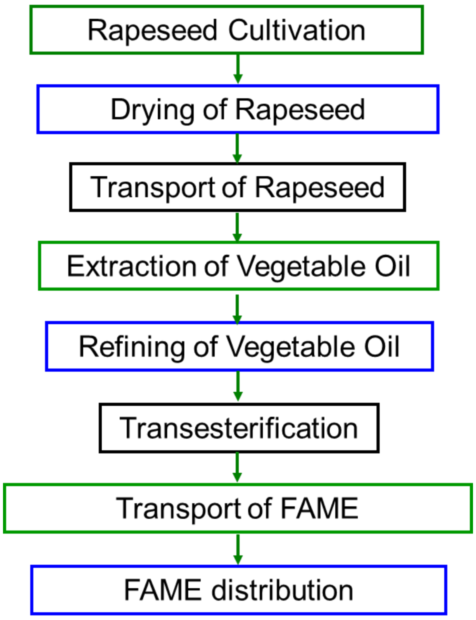
Step 5: Ethanol depot distribution inputs

The same data are used as for wheat ethanol.

6.8 Rapeseed to biodiesel

Description of pathway

The following processes are included in the 'rapeseed to biodiesel' pathway.



The data for each process are shown below; significant updates are described in more detail with relevant references.

Step 1: Rapeseed cultivation

The new data for rapeseed cultivation are shown in Table 148. The updated data include:

- diesel and pesticide use in rapeseed cultivation updated using data from CAPRI (see Section 2.5);
- $CaCO_3$ fertilizer use calculated by the JRC (see Section 3.10);
- N_2O emissions calculated by JRC using the JRC GNOC model (see Section 3.7);
- CO_2 emissions from neutralisation of other soil acidity calculated by the JRC (see Section 3.10);
- K_2O and P_2O_5 updated using the most recent data available (2013/2014);
- seeding material updated using data from Faostat, latest available year (2013).

In the following table, source numbers in **bold** represent the main data source; additional references are used to convert data to ’per MJ of crop’.

Table 148 Rapeseed cultivation

	I/O	Unit	Amount	Source	Comment
Diesel	Input	$MJ/MJ_{rapeseed}$	0.03864	2, **5**, 7	See CAPRI DATA
N fertilizer	Input	$kg/MJ_{rapeseed}$	0.00184	2, **3**, 7	See GNOC data
$CaCO_3$ fertilizer	Input	$kg/MJ_{rapeseed}$	0.00405	6	See liming data
K_2O fertilizer	Input	$kg/MJ_{rapeseed}$	0.00056	2, **4**, 7	13.7 kg K_2O/tonne moist crop
P_2O_5 fertilizer	Input	$kg/MJ_{rapeseed}$	0.00041	2, **4**, 7	10.2 kg P_2O_5/tonne moist crop
Pesticides	Input	$kg/MJ_{rapeseed}$	0.00009	2, **5**, 7	See CAPRI data
Seeding material	Input	$kg/MJ_{rapeseed}$	0.00036	**1**, 2, 7	28 kg/(ha*yr)
Rapeseed	Output	MJ	1.0000		
Field N_2O emissions		$g/MJ_{rapeseed}$	0.05720	4	See GNOC data
CO_2 from neutralisation ofother soil acidity		$g/MJ_{rapeseed}$	0.0000	6	See liming data

Comments

- 9 % is the traded water content (Ref. 2). The input data refer to a tonne of rapeseed at this water content, even if the fresh harvest has higher water content.
- LHV rapeseed (dry) = 27.0 MJ/kg dry rapeseed (JRC calculation using the oil content reported by Diester 2008, Ref. 7, see Table 156).

Sources

1 Faostat, accessed in October 2016.

2 Rous, J-F, PROLEA, personal communication, 27 July 2009.

3 Edwards and Koeble, 2012 (see Chapter 3).

4 Fertilizers Europe, received by JRC in August 2016 (2013-2014 data) and Faostat, 2016 (for yield, average 2009-2014).

5 CAPRI data, 2012 converted to JRC format (see Section 2.5).

6 JRC: Acidification and liming data (see Section 3.10).

7 JRC calculation derived from composition supplied by J-F. Rous, Diester/PROLEA 'bilan vapeur', personal communication, 2008.

Step 2: Rapeseed drying and storage

Table 149 Rapeseed drying and storage

	I/O	Unit	Amount	Source
Light heating oil	Input	$MJ/MJ_{rapeseed}$	0.0062	1
NG	Input	$MJ/MJ_{rapeseed}$	0.0062	1
Electricity	Input	$MJ/MJ_{rapeseed}$	0.0030	1
Rapeseed	Input	$MJ/MJ_{rapeseed}$	1.000	
Rapeseed	Output	MJ	1.000	

Comments

- The initial water content is 15 %; the final water content is 9 %. Ref. 1 says 0.1% drying needs 4.32 MJ fuel per tonne grain (see discussion in wheat drying). The assumption is that fuel for drying is half heating oil and half NG. LPG is in-between.
- 1kg (~0.1% in 1tonne) water removal needs 0.1kWh (=6kW/tonne) + 12.6 kWh/tonne fixed (ventilation) (Ref. 1).
- CAPRI does not report drying emissions for oil seeds; therefore, we kept the original values.

Sources

1 UBA, 1999.

2 Dreier et al., 1998.

Step 3: Transportation of rapeseed

Table 150 Transportation of rapeseed summary table

Share	Transporter	Type	Distance (km)
73.70 %	40 tonne truck	Payload 27 t	163
4.40 %	Handymax	Payload 37 000 t	5 000
6.10 %	Inland barge	Payload 8 800 t	376
15.80 %	Train		309

Table 151 Transport of rapeseed over a distance of 163 km via 40 tonne truck (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{rapeseed}$	0.0066
Biomass	Input	MJ/MJ$_{rapeseed}$	1.0100
Biomass	Output	MJ	1.0000

Comment

- For the fuel consumption for a 40 t truck, see Table 70.

Table 152 Maritime transport of rapeseed over a distance of 5 000 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{rapeseed}$	0.2037
Biomass	Input	MJ/MJ$_{rapeseed}$	1.0000
Biomass	Output	MJ	1.0000

Comment

- For the fuel consumption of Handymax for transport of oilseed, see Table 76.

Table 153 Transport of rapeseed over a distance of 376 km via inland ship (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{rapeseed}$	0.0153
Biomass	Input	MJ/MJ$_{rapeseed}$	1.0000
Biomass	Output	MJ	1.0000

Comment

- For the fuel consumption of a bulk carrier for inland navigation, see Table 81.

Table 154 Transport of rapeseed over a distance of 309 km via train (one way)

	I/O	Unit	Amount
Distance	Input	tkm/$MJ_{rapeseed}$	0.0126
Biomass	Input	MJ/$MJ_{rapeseed}$	1.0000
Biomass	Output	MJ	1.0000

Comment

- For the fuel consumption of the freight train run on grid electricity, see Table 84.

Sources

1 Kaltschmitt and Hartmann, 2001.

2 Fahrzeugbau Langendorf GmbH & Co. KG; Waltop, personal communication, 2001.

3 Dreier et al., 1998.

4 European Biodiesel Board (EBB), 2009.

Step 4: Oil mill: extraction of vegetable oil from rapeseed

Table 155 Oil mill: extraction of vegetable oil from rapeseed

	I/O	Unit	Amount	Source	Comments
Electricity	Input	MJ/MJ_{oil}	0.00972	**1**, 2	359.60 MJ/(t plant oil)
n-hexane	Input	MJ/MJ_{oil}	0.002280	**1**, 2	1.87 kg/(t plant oil)
Rapeseed	Input	MJ/MJ_{oil}	1.57965	**1**, 2	0.420 kg oil/(kg rapeseed @ 9 % H_2O)
Steam	Input	MJ/MJ_{oil}	0.04326	**1**, 2	1 600.6 MJ/(t plant oil)
Crude vegetable oil	Output	MJ	1.00000		

Comments

- LHV vegetable oil = 37 MJ/(kg of oil) (Ref. 2).
- 1.338 kg cake/(kg plant oil) (Ref. 1).
- LHV rapeseed cake (dry) = 18.38 MJ/(kg dry cake) (see Table 157).
- 10.5 %: ref. 6 says 11% in USA; Ref. 8 says less than 11% in EU and in the case of rapeseed cake the typical water content is about half a % less than the limit.
- 2.3 % excess water in cake which is evaporated to reach 10.5 %. Mass difference of input and output indicates meal released as water vapor.

LHV of rapeseed

This varies according to the composition of the rapeseed. The oil content was provided by the European Biodiesel Board (EBB), and the water content of rapeseed used - by PROLEA. We filled out the remaining composition in proportion to that found in *Nutrient Requirements of Dairy Cattle: Seventh Revised Edition*, 2001 (ed. National Academy of Sciences) and then calculated the LHV from the LHV of the components.

Table 156 LHV of rapeseed (dry)

EBB/DIESTER rapeseed	**Wet basis**	**Dry matter basis**	**LHV components MJ/kg (Ref. 3)**	**Contributions MJ/kg dry matter**	**Component**
Rapeseed Diester spec.		0.91			Dry matter
	42.6 %	46.8 %	37	17.32	Oil
		18.3 %	24.5	4.49	Protein
		19.0 %	15.88	3.01	Carbohydrate
		11.8 %	18.27 (*)	2.16	Fibre
		4.1 %	0	0.00	Ash
		100 %		**26.976**	SUM

(*) Same as wood.

Comments

- Dry-matter composition from Ref. 6, except that oil content is raised to that reported in Ref. 7.
- Other dry-mass components are reduced in proportion.
- Water content of (9 %) from Ref. 8.

Calculation of consistent LHV of dry rapeseed cake

Table 157 LHV of dry rapeseed cake

0.420	kg extracted/kg$_{\text{rapeseed, moist}}$
0.462	kg/kg$_{\text{rapeseed, dry}}$
0.538	kg$_{\text{cake, dry}}$/kg$_{\text{rapeseed, dry}}$
17.077	MJ bound in the extracted oil
9.90	MJ bound in the cake
18.38	MJ/kg$_{\text{cake, dry}}$

Sources

1 European Biodiesel Board (EBB), 2009.
2 Mehta and Anand, 2009.
3 ECN Phyllis database of biomaterials properties.
4 Hartmann, 1995.
5 Rous, J-F, PROLEA, personal communication, 27 July 2009.
6 NRC, 2001.
7 M. Rous (Diester), personal communication, 18 September 2008.
8 Bunge 2012: specifications of oilseed cakes: http://www.bunge.hu/english/ind2_31.htm acessed Sept 2012.

Step 5: Refining of vegetable oil

Table 158 Refining of vegetable oil

	Unit	Amount	Source	Comment
Electricity	MJ/MJ_{oil}	0.0009	**1**, 2	34.38 MJ/(t oil)
H_3PO_4	kg/MJ_{oil}	0.000032	**1**, 2	1.19 kg/(t oil)
NaOH	kg/MJ_{oil}	0.000088	**1**, 2	3.26 kg/(t oil)
Crude vegetable oil	MJ/MJ_{oil}	1.0246	**1**	
Steam	MJ/MJ_{oil}	0.0040	**1**, 2	149.19 MJ/(t oil)
Plant oil	MJ	1.0000		37 MJ/kg of oil

Sources

1 European Biodiesel Board (EBB), 2009.

2 Mehta and Anand, 2009.

Step 6: Transesterification

Table 159 Transesterification

	I/O	Unit	Amount	Source	Comment
Electricity	Input	MJ/MJ_{FAME}	0.00405	**1**, 2, 4	150.5 MJ/(t FAME)
Sodium methylate ($Na(CH_3O)$)	Input	kg/MJ_{FAME}	0.0001145	2, **4**, **5**, **6**	14.2 kg of 30% solution/(t FAME)
HCl	Input	kg/MJ_{FAME}	0.000097	**1**, 2, 4	3.61 kg/(t FAME)
Methanol	Input	MJ/MJ_{FAME}	0.05110	**1**, 2, 4	95.29 kg/(t FAME)
Plant oil	Input	MJ/MJ_{FAME}	1.00063	**1**, 2, 4	
Steam	Input	MJ/MJ_{FAME}	0.0330	**1**, 2, 3, 4	1 229 MJ/(t FAME)
FAME	Output	MJ	1.0000		

Comments

- LHV (FAME) = 37.2 MJ/(kg FAME) (Ref. 2).
- LHV (glycerol) = 16 MJ / (kg glycerol) (Ref. 4).
- 101.87 kg glycerol / (t FAME).

Sources

1 European Biodiesel Board (EBB), 2009.

2 ECN Phyllis database of biomaterials properties.

3 Rous, personal communication, 23 September 2008.

4 Edwards, JRC, 2003: chemical thermodynamic calculation with HSC for windows.

5 European Biodiesel Board, J. Coignac, Comments to Commission's May 2013 stakeholder consultation, received 13 June 2013.

6 European Biodiesel Board, D. Buttle, personal communication, 2013.

Step 6.1: Steam generation processes

The data for the individual steam generation processes are shown in Chapter 4. The process linked to extraction, refining of rapeseed oil and transesterification is steam generation from NG boiler (Table 63).

Step 7: Transportation of FAME to the blending depot

Table 160 Transportation of FAME summary table to the blending depot

Share	Transporter	Notes	Distance (km one way)
11.4 %	Truck	Payload 40 t	305
27.2 %	Product tanker	Payload: 15 000 t	1 118
43.8 %	Inland ship/barge	Payload 1 200t	153
3.8 %	Train		381
13.8 %	Pipeline		5

Comment

- Transport of FAME via pipeline is assumed to be the same as for gasoline. (The number has been supplied by TotalFinaElf without indicating the distance). See Table 85.

Source

1 European Biodiesel Board (EBB), personal communication.

Table 161 Transport of FAME via 40 t truck over a distance of 305 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{FAME}	0.0088
FAME	Input	MJ/MJ_{FAME}	1.0000
FAME	Output	MJ	1.0000

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

Table 162 Maritime transport of FAME over a distance of 1 118 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{FAME}$	0.0301
FAME	Input	MJ/MJ$_{FAME}$	1.0000
FAME	Output	MJ	1.0000

Comment

- For the fuel consumption of the product tanker (payload: 15,000 t), see Table 79.

Table 163 Transport of FAME over a distance of 153 km via inland ship (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{FAME}$	0.0041
FAME	Input	MJ/MJ$_{FAME}$	1.0000
FAME	Output	MJ	1.0000

Comment

- For the fuel consumption for an inland oil carrier, see Table 82.

Table 164 Transport of FAME over a distance of 381 km via train (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{FAME}$	0.0102
FAME	Input	MJ/MJ$_{FAME}$	1.0000
FAME	Output	MJ	1.0000

Comments

- For the fuel consumption of the freight train, see Table 84.

Step 8: FAME depot distribution inputs

Table 165 FAME depot

	I/O	Unit	Amount
FAME	Input	MJ/MJ$_{FAME}$	1.00000
Electricity	Input	MJ/MJ$_{FAME}$	0.00084
FAME	Output	MJ	1.00000

Table 166 Transport of FAME to filling station via 40 t truck over a distance of 305 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{FAME}$	0.0043
FAME	Input	MJ/MJ$_{FAME}$	1.0000
FAME	Output	MJ	1.0000

Table 167 FAME filling station

	I/O	Unit	Amount
FAME	Input	MJ/MJ$_{FAME}$	1.0000
Electricity	Input	MJ/MJ$_{FAME}$	0.0034
FAME	Output	MJ	1.0000

Comment

- Distribution is assumed to be same as for fossil diesel and gasoline.

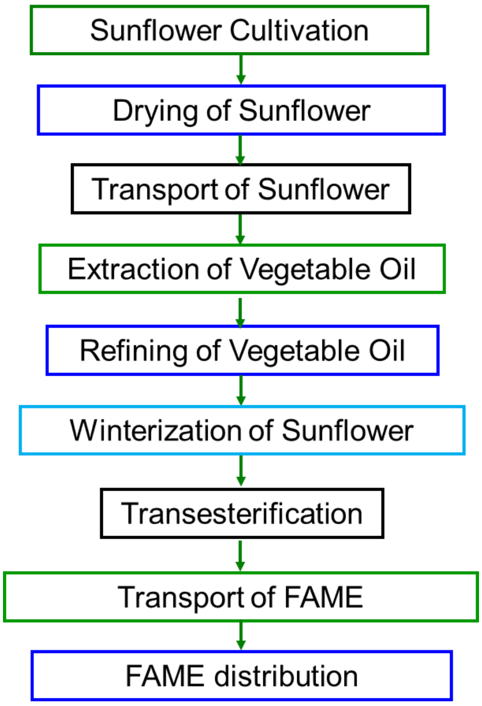
Source

1 Dautrebande, 2002.

6.9 Sunflower to biodiesel

Description of pathway

The following processes are included in the 'sunflower to biodiesel' pathway.



The data for each process are shown below; significant updates are described in more detail with relevant references.

Step 1: Sunflower cultivation

The new data for sunflower cultivation are shown in Table 168. The updated data include:

- diesel and pesticide use in sunflower cultivation updated using data from CAPRI (see Section 2.5);
- $CaCO_3$ fertilizer use calculated by the JRC (see Section 3.10);
- N_2O emissions calculated by JRC using the JRC GNOC model (see Section 3.7);
- CO_2 emissions from neutralisation of other soil acidity, calculated by the JRC (see Section 3.10).
- seeding material updated using data from Faostat, latest available year (2013).

In the following table, source numbers in bold represent the main data source; additional references are used to convert data to ’per MJ of crop’.

Table 168 Sunflower cultivation

	I/O	Unit	Amount	Source	Comment
Diesel	Input	$MJ/MJ_{sunflower\ seed}$	0.06937	2, **5**, 7	See CAPRI data
N fertilizer	Input	$kg/MJ_{sunflower\ seed}$	0.00103	**2**, 3, 7	See GNOC data
$CaCO_3$	Input	$kg/MJ_{sunflower\ seed}$	0.00220	6	See liming data
K_2O fertilizer	Input	$kg/MJ_{sunflower\ seed}$	0.00046	2, **4**, 7	22 kg K_2O/(ha*yr) (*)
P_2O_5 fertilizer	Input	$kg/MJ_{sunflower\ seed}$	0.00061	2, **4**, 7	29 kg P_2O_5/(ha*yr) (*)
Pesticides	Input	$kg/MJ_{sunflower\ seed}$	0.00005	2, **5**, 7	See CAPRI data
Seeding material	Input	$kg/MJ_{sunflower\ seed}$	0.00035	**1**, 2, 7	17 kg/(ha*yr)
Sunflower seed	Output	MJ	1.0000		
Field N_2O emissions		$g/MJ_{sunflower\ seed}$	0.03949	2	See GNOC data
CO2 from neutralisation of other soil acidity		$g/MJ_{sunflower\ seed}$	0.00000	6	See liming data

(*) Data from Fertilizers Europe are not used because in the Fertilizers Europe per-crop data, sunflower is mixed with other oilseeds.

Comments

- 9.0 % traded water content of sunflower seed (Refs 4 and 2).
- LHV sunflower (dry) = 27.2 MJ/kg dry sunflower seed (Ref. 7).

Sources

1 Faostat, accessed in October 2016.

2 Rous, J-F, PROLEA, personal communication, 27 July 2009.

3 Edwards and Koeble, 2012 (see Chapter 3).

4 ADEME, 2010 and Faostat, 2016 (for yield, average 2009-2014).

5 CAPRI data, 2012 converted to JRC format (see Section 2.5).

6 JRC: Acidification and liming data (see Section 3.10).

7 JRC calculation derived from composition supplied by J-F. Rous, Diester/PROLEA 'bilan vapeur', personal communication, 2008.

Step 2: Sunflower drying and storage

Table 169 Sunflower drying and storage

	I/O	Unit	Amount	Source
Light heating oil	Input	$MJ/MJ_{sunflower\ seed}$	0.0061	1
NG	Input	$MJ/MJ_{sunflower\ seed}$	0.0061	1
Electricity	Input	$MJ/MJ_{sunflower\ seed}$	0.00298	1
Sunflower seed	Input	$MJ/MJ_{sunflower\ seed}$	1.000	
Sunflower seed	Output	MJ	1.000	

Comments

- The initial water content is 15 %; the final water content is 9 %. Ref. 1 says 0.1% drying needs 4.32 MJ fuel per tonne grain (see discussion in wheat drying). The assumption is that fuel for drying is half heating oil and half NG. LPG is in-between.
- 1kg (~0.1% in 1tonne) water removal needs 0.1kWh (=6kW/tonne) + 12.6 kWh/tonne fixed (ventilation) (Ref. 1).
- CAPRI does not report drying emissions for oil seeds; therefore, we kept the original values.

Sources

1 UBA, 1999.

2 Dreier et al., 1998.

Step 3: Transportation of sunflower seed

Table 170 Transportation of sunflower seed summary table

Share	Transporter	Notes	Distance (km one way)
68.60 %	40 t truck	Payload 27 t	292
31.40 %	Electric train		450

Table 171 Transport of sunflower seed over a distance of 292 km via truck (one way)

	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{sunflower\ seed}$	0.0118
Biomass	Input	$MJ/MJ_{sunflower\ seed}$	1.0100
Biomass	Output	MJ	1.0000

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

Table 172 Transport of sunflower seed over a distance of 450 km via train (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{\text{sunflower seed}}$	0.0182
Biomass	Input	MJ/MJ$_{\text{sunflower seed}}$	1.0000
Biomass	Output	MJ	1.0000

Comment

- For the fuel consumption of the electric train, see Table 84.

Sources

1 European Biodiesel Board (EBB), 2009.

2 Dreieret al., 1998.

Step 4: Oil mill: extraction of vegetable oil from sunflower seed

Table 173 Oil mill: extraction of vegetable oil from sunflower seed

	I/O	Unit	Amount	Source	Comments
Electricity	Input	MJ/MJ$_{\text{oil}}$	0.01123	**1**, 2	415.50 MJ/(t plant oil)
n-hexane	Input	MJ/MJ$_{\text{oil}}$	0.002889	**1**, 2	2.37 kg/(t plant oil)
Sunflower seed	Input	MJ/MJ$_{\text{oil}}$	1.5264	**1**, 2	0.439 kg oil/(kg seed)
Steam	Input	MJ/MJ$_{\text{oil}}$	0.03388	**1**, 2	1 253.4 MJ/(t plant oil)
Crude vegetable oil	Output	MJ	1.0000		

Comments

- LHV vegetable oil = 37 MJ/(kg of oil) (Ref. 2).
- 1.237 kg cake/kg plant oil (Ref. 1).
- 18.15 MJ/(kg dry cake).
- Water content (cake): 11.5%; Ref. 8 says less than 12%; Ref. 5 says 11.5+/-0.5% for safe handling and storage.
- 2 % excess water which would be in the cake if it were not evaporated in the pre-cooking stage of the crush process. The steam input to the crushing includes the energy to do this drying (Ref. 5).

LHV of sunflower seed

Table 174 LHV of sunflower (dry)

EBB/DIESTER sunflower seed	**Wet basis**	**Dry matter basis**	**LHV components MJ/kg (Ref. 3)**	**Contributions MJ/kg dry matter**	**Component**
Sunflower seed Diester		0.91			Dry matter
	44.0 %	48.4 %	37	17.89	Oil
		17.1 %	24.5	4.18	Protein
		13.2 %	15.88	2.10	Carbohydrate
		16.8 %	18.27 (*)	3.07	Fibre
		4.5 %	0	0.00	Ash
		100 %		**27.24**	SUM

(*) Same as wood.

Comments

- Dry-matter composition from Ref. 6, except that oil content is raised to that reported in Ref. 7.
- Other dry-mass components are reduced in proportion.

Calculation of consistent LHV of dry sunflower cake

Table 175 LHV of dry sunflower cake

0.439	kg extracted/kg$_{seed, moist}$
0.482	kg/kg$_{seed, dry}$
0.518	kg$_{cake, dry}$/kg$_{seed, dry}$
17.85	MJ bound in the extracted oil
9.40	MJ bound in the cake
18.15	**MJ/kg$_{cake, dry}$**

Sources

1 European Biodiesel Board (EBB), 2009.

2 Mehta and Anand, 2009.

3 ECN Phyllis database of biomaterials properties.

4 Hartmann, 1995.

5 Rous, J-F, PROLEA, personal communication, 27 July 2009.

6 NRC, 2001.

7 Rous, M., (Diester), personal communication, 18 September 2008.

8 Bunge 2012: specifications of oilseed cakes: http://www.bunge.hu/english/ind2_31.htm accessed Sept 2012.

Step 5: Refining of vegetable oil

Table 176 Refining of vegetable oil

	I/O	Unit	Amount	Source	Comment
Electricity	Input	MJ/MJ_{oil}	0.00231	**1**, 2	85.3 MJ/(t oil)
H_3PO_4	Input	kg/MJ_{oil}	0.000012	**1**, 2	0.45 kg/(t oil)
NaOH	Input	kg/MJ_{oil}	0.000069	**1**, 2	2.55 kg/(t oil)
Crude vegetable oil	Input	MJ/MJ_{oil}	1.0256	1	
Steam	Input	MJ/MJ_{oil}	0.0058	**1**, 2	215.4 MJ/(t oil)
Plant oil	Output	MJ	1.0000		37 MJ/kg of oil

Sources

1 European Biodiesel Board (EBB), 2009.

2 Mehta and Anand, 2009.

Step 6: Winterisation of sunflower

Table 177 Winterisation of sunflower

	I/O	Unit	Amount
Crude vegetable oil	Input	MJ/MJ_{oil}	1.0101
Plant oil	Output	MJ	1.0000

Source

1 European Biodiesel Board (EBB), 2009.

Step 7: Transesterification

Same input data used as for rapeseed.

Step 8: Transport of FAME to the blending depot

Same input data used as for rapeseed.

Step 9: FAME depot distribution inputs

Same input data used as for rapeseed.

6.10 Soybean to biodiesel

Description of pathway

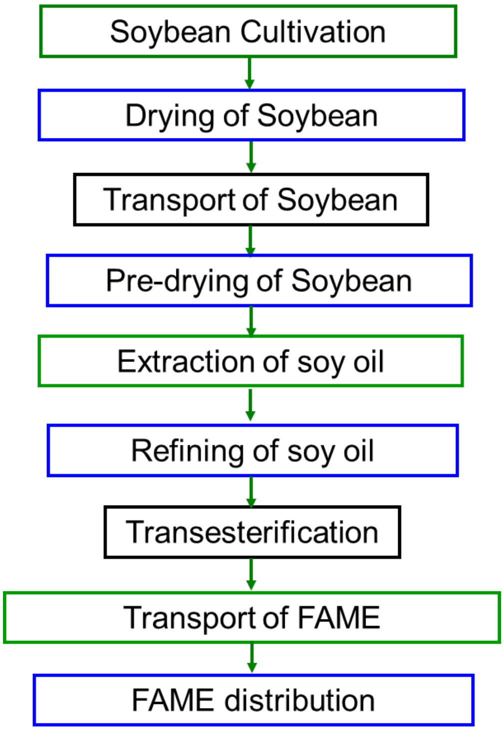
The 'soybean import mix to biodiesel' pathway shown in this section includes data on the weighted mix of soybeans/soy oil produced in EU and imported from Argentina, Brazil and the United States to the EU.

The pathway is derived from national data for:

- EU
- Brazil
- Argentina
- United States.

which are shown in the national soy data (Section 6.10.1). Table 178 shows the contributions of each country (calculated in terms of soy oil equivalent) calculated from Eurostat data (between 2011 and 2014).

The following processes are included in the pathway.



Transportation of soybean to Europe

We assume that feedstock is transported to EU in solid form (as soybeans).

Table 178 Data on EU production and imports (2011-2014)

	Units	soybean (av 2011-2014)	soy oil eqivalent	soy oil (average 2011-2014)	TOT (tonnes)	% (not all countries)
EU27	Production (1000 t)	1 236	238		237 603	
	Export (100 kg)	410 314	78 903		7 890	
	Prod - export (tonnes)				229 713	10%
Argentina /Paraguay	Import (100 kg)	18 971 856	3 648 288	1 183 949	483 224	20%
Brazil	Import (100 kg)	54 203 411	10 423 316	521 432	1 094 475	46%
USA	Import (100 kg)	29 108 820	5 597 626	72 639	567 026	24%
				TOTAL	2 374 438	100%

Source

Data extracted from Eurostat (accessed in October 2016).

Step 1: Soybean Cultivation

Table 179 Soybean cultivation (weighted average of exporters to EU and EU, by oil+oil-equivalent seeds)

	I/O	Unit	Amount	Source	Comment
Diesel	Input	$MJ/MJ_{soybeans}$	0.03148	1	
N fertilizer	Input	$kg/MJ_{soybeans}$	0.00008	2	See GNOC data
Ca fertilizer as $CaCO_3$	Input	$kg/MJ_{soybeans}$	0.00742	3	See liming data
K_2O fertilizer	Input	$kgMJ_{soybeans}$	0.00069	1	13.7 kg K_2O/(tonne moist soya)
P_2O_5 fertilizer	Input	$kg/MJ_{soybeans}$	0.00071	1	14.3 kg P_2O_5/(tonne moist soya)
Pesticides	Input	$kg/MJ_{soybeans}$	0.00006	1	
Seeding material	Input	$kg/MJ_{soybeans}$	0.00133	1	
Soybeans	Output	MJ	1.0000		
Field N_2O emissions		$g/MJ_{soybeans}$	0.0428	2	See GNOC data
CO_2 from neutralisation of other soil acidity		$g/MJ_{soybeans}$	3.09385	3	See liming data

Comments

- LHV soybean (dry) = 23 MJ/kg of dry soybeans (Ref. 5).
- 13 % traded water content (Ref. 6), ideal for transport and storage (Ref. 4).

Sources

1	Derived from national data from EU, Argentina, Brazil and the United States (Section 6.10.1) and weighted on the basis of each country contribution shown in Table 178).
2	Edwards and Koeble, 2012 (see Chapter 3).
3	JRC: Acidification and liming data in this report (Section 3.10).
4	EMBRAPA, 2004.
5	Jungbluth et al., 2007.
6	Beuerlein, 2012.

Step 2: Drying

The values are derived from national average data (Section 6.10.1).

Table 180 Drying to 13 % water content

	LPG MJ/MJ soybean weighted	NG MJ/MJ soybean weighted	Heating oil and diesel MJ/MJ soybean weighted	Electricity MJ/MJ soybean weighted
EU	0.00007	0.00022	0.00000	0.00009
Argentina	0.00015	0.00022	0.00003	0.00000
Brazil	0.00000	0.00000	0.00096	0.00007
United States	0.00020	0.00060	0.00000	0.00025
Total	**0.00042**	**0.00104**	**0.00100**	**0.00042**

Step 3: Transportation of soybeans

Transport of soybeans via truck (see Table 181) is derived from national average data (Table 182).

Table 181 Transport of soybeans via 40 t truck over a distance of 517 km (one way)

	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{soybeans}$	0.0258
Soybeans	Input	$MJ/MJ_{soybeans}$	1.0100
Soybeans	Output	MJ	1.0000

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

Table 182 Regional truck transport distances

	Km	%	Contribution to weighted average km
EU	126	10	12
Argentina	350	20	71
Brazil	900	46	415
United States	80	24	19
Total			**517**

Transport of soybeans via train (Table 183) is derived from national average data (see Table 184).

Table 183 Transport of soybeans via diesel train over a distance of 179 km (one way)

	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{soybeans}$	0.0089
Soybeans	Input	$MJ/MJ_{soybeans}$	1.0100
Soybeans	Output	MJ	1.0000

Comment

- For the fuel consumption for a freight train run on diesel fuel, see Table 83.

Table 184 Regional train transport distances

	Km	%	Contribution to weighted average km
EU	51	10	5
Argentina	0	20	0
Brazil	377	46	174
United States	0	24	0
Total			**179**

Transport of soybeans via ship and barge (see Table 185 and Table 186) are derived from national average data (Table 187).

Table 185 Transport of soybeans via inland ship over a distance of 615 km (one way)

	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{soybeans}$	0.0307
Soy oil	Input	$MJ/MJ_{soybeans}$	1.0000
Soy oil	Output	MJ	1.0000

Comment

- For the fuel consumption for an oil carrier for inland navigation, see Table 81.

Table 186 Maritime transport of soybeans over a distance of 9 381 km (one way)

	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{soybeans}$	0.4688
Soy oil	Input	$MJ/MJ_{soybeans}$	1.0000
Soy oil	Output	MJ	1.0000

Comment

- For the fuel consumption of Handymax for transport of oilseeds, see Table 76.

Table 187 Regional shipping and barge distances for soybeans

	Nautical sea miles	km sea	km barge	%	Contribution to weighted average km (sea)	Contribution to weighted average km (barge)
EU			24	10	0	2
Argentina (Rosario)	6 584	12 194	0	20	2 482	0
Brazil (Mix)	5 565	10 306	209	46	4 751	96
United States (New Orleans)	4 860	9 000	2 161	24	2 149	516
Total					**9 381**	**615**

Source

1 Website: Searates.com.

Step 4: Pre-drying soybeans at oil mill

This is Argentine data, but is used for all oil mills because they are all fed with soybeans at 11 % moisture instead of the traded moisture content of 13 %. Although drying to 13 % is optimal for transport and storage of beans, an extra drying step is often needed to reach 11 % moisture before crushing (as reported in the mill data), because otherwise the meal ends up with too much moisture for storage and transport.

Table 188 Pre-drying at oil mill

	Unit	Amount	Source
NG	$MJ/MJ_{soybeans}$	0.00293	1
Soybeans	$MJ/MJ_{soybeans}$	1.0000	
Soybeans	MJ	1.0000	

Comments

- Ref. 1 says 758 Gkcal to dry 75 % of 40.5 Mtonnes beans at mills.

Source

1 de Tower and Bartosik, 2012.

Step 5: Extraction of vegetable oil from soybeans

The following data have been updated using new information from FEDIOL, 2013 and replacing the data from Jungbluth et al., 2007 (Ecoinvent report).

Table 189 Oil mill

	I/O	Unit	Amount	Source	Comment
Electricity	Input	MJ/MJ_{oil}	0.014595	**6**, 2	150 kWh/(t soybeans) [6]
n-hexane	Input	MJ/MJ_{oil}	0.003657	**6**, 2	3 kg/(t soybeans) [6]
Soybeans	Input	MJ/MJ_{oil}	2.87698	**6**, 2	192.3 kg oil/(t soybeans) [6]
Steam	Input	MJ/MJ_{oil}	0.081865	**6**, 2	3 029 MJ/(t soy oil) [6]
Vegetable oil	Output	MJ	1.0000		37 MJ/(kg vegetable oil) [2]

Comments

- 20.5 MJ/kg: LHV soybeans @ 11 % moisture (Ref 1).
- 794 kg moist cake/(t soybeans) (Ref. 5).
- 11 %: water content of beans input (Ref 5).

Calculation of consistent LHV of dry soybean cake

- 0.192 kg oil extracted/kg seed, moist.
- 0.216 kg oil/kg seed, dry.
- 0.784 kg cake, dry/kg seed, dry (by dry mass balance).
- 7.994 MJ bound in the extracted oil.

- 15.01 MJ bound in the cake.
- **19.14** MJ/kg dry cake.

Consistent water content of cake by mass-balance

- 110 kg water entering per tonne beans.
- 986 total kg out for 1 tonne beans.
- 14 lost mass = kg evaporated water.
- 96 kg water in cake.
- 12.13 % water content of cake.
- 16.52 MJ/kg = LHV-vap

Comments

- This data comes from FEDIOL, 2013 and replaces data from Jungbluth et al., 2007 (Ecoinvent report).
- We also have INTA data from Hilbert, 2010 for Argentina, but it is unclear which data is per tonne of oil and which per tonne of beans.

  Pradhan, 2011 gives data for one modern US soy-oil-mill but clearly states this does NOT represent the national average.

Comments on water content of cake

- The moisture content of the oilseed cake was back-calculated by mass-balance from:
  - the traded water content of beans
  - the reported process yields of oil and cake process yields.

Sources

1 UBA, 1999.

2 Mehta and Anand, 2009.

3 Bunge, 2012.

4 Hartmann, 1995.

5 Jungbluth et al., 2007 (Ecoinvent report).

6 FEDIOL, 2013.

Step 6: Refining of vegetable oil from soybean

Table 190 Refining of vegetable oil

	I/O	Unit	Amount	Source	Comment
Electricity	Input	MJ/MJ_{oil}	0.0023	**1**, 2	85.3 MJ/(t oil) [1]
H_3PO_4	Input	kg/MJ_{oil}	0.000012	**1**, 2	0.45 kg/(t oil) [1]
NaOH	Input	kg/MJ_{oil}	0.000069	**1**, 2	2.55 kg/(t oil) [1]
Crude vegetable oil	Input	MJ/MJ_{oil}	1.0256	1	
Steam	Input	MJ/MJ_{oil}	0.0058	**1**, 2	215.4 MJ/(t oil) [1]
Vegetable oil	Output	MJ	1.0000		37 MJ/kg of oil [2]

Sources

1 European Biodiesel Board (EBB), 2009.

2 Mehta and Anand, 2009.

No winterisation is required for soy oil.

Step 7: Trasesterification

Same input data used as for rapeseed.

Step 8: Transportation of FAME to the blending depot

Same input data used as for rapeseed.

Step 9: FAME depot distribution inputs

Same input data used as for rapeseed.

6.10.1 National soy data

The following pages contain the country-specific input data used to derive the soy pathway described above.

EU soya

Table 191 Soybean cultivation in EU

	I/O	Unit	Amount	Source	Comment
Diesel	Input	$MJ/MJ_{soybeans}$	0.05802	2, **5**	See CAPRI data
N fertilizer	Input	$kg/MJ_{soybeans}$	0.00004	**3**	See GNOC data
Ca fertilizer as $CaCO_3$	Input	$kg/MJ_{soybeans}$	0.00166	6	See liming data
K_2O fertilizer	Input	$kgMJ_{soybeans}$	0.00057	2, **4**	11.3 kg K_2O/(tonne moist soya)
P_2O_5 fertilizer	Input	$kg/MJ_{soybeans}$	0.00040	2, **4**	8.1 kg P_2O_5/(tonne moist soya)
Pesticides	Input	$kg/MJ_{soybeans}$	0.00014	2, **5**, 7	See CAPRI data
Seeding material	Input	$kg/MJ_{soybeans}$	0.00173	**1**, 2, 7	95 kg/(ha*yr)
Soybeans	Output	MJ	1.0000		
Field N_2O emissions		$g/MJ_{soybeans}$		3	GNOC calculates EU import weighted av.
CO_2 from neutralisation of other soil acidity		$g/MJ_{soybeans}$	0.44534	6	See liming data

Comments

- **23.0** MJ/(kg dry soybean) (Ref. 7);
- **13 %**: taded water content (Ref. 2).

Sources

1 Faostat, accessed in October 2016.

2 Liebster, 1988.

3 Edwards and Koeble, 2012 (see Chapter 3).

4 International Fertilizer Association (IFA), 2013 (2010-2011 data) and Faostat, 2016 (for yield, average 2009-2014).

5 CAPRI data, converted to JRC format (see Section 2.5).

6 JRC: Acidification and liming (see Section 3.10).

7 Jungbluth et al., 2007 (Ecoinvent report).

Drying of soybeans

Table 192 Soybean drying (same as US)

	Unit	Amount
LPG	$MJ/MJ_{soybean}$	0.00076
NG	$MJ/MJ_{soybean}$	0.00232
Electricity	$MJ/MJ_{soybean}$	0.00098
Soybeans	$MJ/MJ_{soybean}$	1.000
Soybeans	MJ	1.000

Comment

- See drying in 'United States soya'.

Transport of soybeans

Table 193 Transportation of EU soybean summary table (assumed to be the same as rapeseed, without the 4.4% which comes in by sea)

Share	Transporter	Type	Distance (km)
77.1 %	40 tonne truck	Payload 27 t	163
6.4 %	Inland barge	Payload 8 800 t	376
16.5 %	Train		309

Table 194 Transport of soybean over a distance of 163 km via 40 tonne truck (one way)

	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{rapeseed}$	0.0081
Biomass	Input	$MJ/MJ_{rapeseed}$	1.0100
Biomass	Output	MJ	1.0000

Comment

- For the fuel consumption for a 40 t truck, see Table 70.

Table 195 Transport of soybean over a distance of 376 km via inland ship (one way)

	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{rapeseed}$	0.0188
Biomass	Input	$MJ/MJ_{rapeseed}$	1.0000
Biomass	Output	MJ	1.0000

Comment

- For the fuel consumption of a bulk carrier for inland navigation, see Table 81.

Table 196 Transport of soybean over a distance of 309 km via train (one way)

	I/O	Unit	Amount
Distance	Input	$tkm/MJ_{rapeseed}$	0.0154
Biomass	Input	$MJ/MJ_{rapeseed}$	1.0000
Biomass	Output	MJ	1.0000

Comment

- For the fuel consumption of the freight train run on grid electricity, see Table 84.

Brazil soya

Soybean cultivation

Table 197 Soybean cultivation in Brazil

	I/O	Unit	Amount	Source	Comment
Diesel	Input	$MJ/MJ_{soybeans}$	0.02810	1, 2, 5, **6**	
N fertilizer	Input	$kg/MJ_{soybeans}$	0.00009	4, 5, **8**	
Ca fertilizer as $CaCO_3$	Input	$kg/MJ_{soybeans}$	0.01000	12	See liming data
K_2O fertilizer	Input	$kgMJ_{soybeans}$	0.00117	4, 5, **8**	23 kg K_2O/(tonne moist soya)
P_2O_5 fertilizer	Input	$kg/MJ_{soybeans}$	0.00122	4, 5, **8**	24 kg P_2O_5/(tonne moist soya)
Pesticides	Input	$kg/MJ_{soybeans}$	0.00003	4, 5, 6	
Seeding material	Input	$kg/MJ_{soybeans}$	0.00122	4, 6, 7	
Soybeans	Output	MJ	1.0000		
Field N_2O emissions		$g/MJ_{soybeans}$		9	GNOC calculates EU import weighted av.
CO_2 from neutralisation of other soil acidity		$g/MJ_{soybeans}$	4.30911	10	See liming data

Comments

- **23.0** MJ/(kg dry soybean) (Ref. 4):
- Diesel use: **1 606** MJ/(ha*yr). No data specific to Brazil was found. This is the value for the United States, derived from Ref. 6.
- N fertilizer: **0.00171** kg N/(kg moist soya) calculated in Ref. 11 from data in Ref. 9.
- Pesticides (etc.) use: **1.6** kg/(ha*yr):
  - Pradhan et al., 2011: United States 2006 = 1.6 kg/ha
  - Jungbluth et al., 2007 (Ecoinvent report): Brazil 2001 = 0.0579 kg/t (=0.2 kg/ha)
  - Cederberg, 2001: United States 2004= 0.0476 kg/t (=0.14 kg/ha) (USDA, 2004).
- Seeding material: **70** kg/(ha*yr):
  - USA data: 68.9 kg/ha (Ref. 6)
  - AG data: 70-80 kg/ha (Ref. 7)
  - United States and BR: 70 kg/ha (Ref. 4).
- 13 % ideal water content for transport and storage (Ref. 5) EMBRAPA, 2004: 'soybeans are harvested at 18 % humidity', but yields are usually reported at traded water content, which is 13 %.

Sources

1 CENBIO, 2009.

2 Ministério da Agricultura, Pecuária e Abastecimento, 2007.

3 Da Silva et al., 2010.

4 Jungbluth et al., 2007 (Ecoinvent report).

5 EMBRAPA, 2004.

6 Pradhan et al., 2011.

7 Panichelli et al., 2009.

8 International Fertilizer Association (IFA), 2013 (2010-2011 data) and Faostat, 2016 (for yield, average 2009-2014).

9 Edwards and Koeble, 2012 (see Chapter 3).

10 JRC: Acidification and liming (see Section 3.10).

Drying of soybeans

Table 198 Soybean drying

	Unit	Amount	Sources
Diesel	$MJ/MJ_{soybean}$	0.002091	1, 2
Electricity	$MJ/MJ_{soybean}$	0.000161	1, 2
Soybeans	$MJ/MJ_{soybean}$	1.000	
Soybeans	MJ	1.000	

Comment

- 13 % final humidity rate after drying (Ref. 3).

Sources

1 Da Silva et al., 2010.

2 Marques, 2006.

3 EMBRAPA, 2004.

Transport of soybeans

Table 199 Weighted average of transport of soybeans from central-west and south to Brazilian seaport

34[1]	km	Truck to drying places
865.8[2]	km	Truck from drying place to Brazilian port
899.8[2]	km	Total truck distance
377.4[3]	km	Railway
208.9[4]	km	Inland waterway

Comments

- 1) 20 km in south Brazil states (weight 0.3) and 40 km in central-west states (weight 0.7).
- 2) Da Silva, 2010: central-west (weighting 0.7): 1101 km; south (weighting 0.3): 317 km.
- 3) Da Silva, 2010: central-west (weight 0.7): 393 km; south (weight 0.3): 341 km.
- 4) Da Silva, 2010: central-west (weight 0.7): 289 km; south (weight 0.3): 22 km.

Table 200 Transportation by truck

	Unit	Amount
Distance	$\text{tkm/MJ}_{\text{soybean}}$	0.0450
Soybean	$\text{MJ/MJ}_{\text{soybean}}$	1.0100
Soybean	MJ	1.0000

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

Table 201 Transportation by train

	Unit	Amount
Distance	$\text{tkm/MJ}_{\text{soybean}}$	0.0189
Soybean	$\text{MJ/MJ}_{\text{soybean}}$	1.0100
Soybean	MJ	1.0000

Comment

- For the fuel consumption for a freight train run on diesel fuel, see Table 83.

Table 202 Transportation by inland waterway

	Unit	Amount
Distance	$tkm/MJ_{soybean}$	0.0104
Soybean	$MJ/MJ_{soybean}$	1.0100
Soybean	MJ	1.0000

Comment

- For the fuel consumption of a bulk carrier for inland navigation, see Table 81.

Source

1 Da Silva et al., 2010.

Table 203 Shipping distances to Rotterdam

	Nautical miles sea	km sea
Brazil (Santos)	5 501	10 188
Brazil (Paranagua)	5 629	10 425
Average	5 565	10 306

Sources

1 Reuters, 2012.

2 Salin, 2009.

3 Flaskerud, 2003.

Argentina soya

Soybean cultivation

Table 204 Soybean cultivation in Argentina

	I/O	Unit	Amount	Source	Comment
Diesel	Input	$MJ/MJ_{soybeans}$	0.031300	**1**, 2, 4	
N fertilizer	Input	$kg/MJ_{soybeans}$	0.000128	3	
Ca fertilizer as $CaCO_3$	Input	$kg/MJ_{soybeans}$	0.007706	6	See liming data
K_2O fertilizer	Input	$kgMJ_{soybeans}$	0.000003	3	0.07 kg K_2O/(tonne moist soya)
P_2O_5 fertilizer	Input	$kg/MJ_{soybeans}$	0.000316	3	6.33 kg P_2O_5/(tonne moist soya)
Pesticides	Input	$kg/MJ_{soybeans}$	0.000116	1	5.77 kg/ha soybeans
Seeding material	Input	$kg/MJ_{soybeans}$	0.001569	**7**, 8	
Soybeans	Output	MJ	1.0000		
Field N_2O emissions		$g/MJ_{soybeans}$		5	GNOC calculates EU import weighted av.
CO_2 from neutralisation of other soil acidity		$g/MJ_{soybeans}$	3.398113	6	See liming data

Comments

- 23 MJ/kg of dry soybeans (Ref 5).
- 13% water content.
- Diesel use: **1560** MJ/(ha*yr) (Refs 1, 2):
  - 1660 MJ/ha includes 30km transport to store, and drying, according to Ref. 2 quoted in Ref. 1. In the context, we suppose that assumes all drying inputs are diesel. Therefore we subtract the drying energy per ha derived from our drying data.
- N fertilizer: **0.00257** kg N/(kg moist soya) .

Sources

1 Muzio et al., 2009.

2 SAGPyA, 2008.

3 International Fertilizer Association (IFA), 2013 (2010-2011 data) and Faostat, 2016 (for yield, average 2009-2014).

4 Jungbluth et al., 2007 (Ecoinvent report).

5 Edwards and Koeble, 2012 (see Chapter 3).

6 JRC: Acidification and liming (see Section 3.10).

7 Hilbert et al., 2010 (with updated yield, 2009-2014).

8 Faostat, accessed in October 2016.

Drying

Table 205 Soybean drying

	Unit	Amount	Sources
LPG	MJ/MJ$_{soybeans}$	0.00074	1
NG	MJ/MJ$_{soybeans}$	0.00110	1
Diesel	MJ/MJ$_{soybeans}$	0.000160	
Soybeans	MJ/MJ$_{soybeans}$	1.000	
Soybeans	MJ	1.000	

Source

1 De Tower and Bartosik, 2012.

Transport of soybeans

Truck transport	**Distance km**
Argentina	350

Table 206 Truck transport of soybeans

	Unit	Amount
Distance	tkm/MJ$_{soybean}$	**0.0175**
Soybean	MJ/MJ$_{soybean}$	**1.0100**
Soybean	MJ	**1.0000**

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

Table 207 Shipping and barge distances to Rotterdam

	Nautical miles sea	km sea
Argentina (Rosario)	6 584	12 194

Source

1 Website: Searates.com

United States soya

Soybean cultivation

Table 208 Soybean cultivation in the United States

	I/O	Unit	Amount	Source	Comment
Diesel	Input	MJ/MJ$_{soybeans}$	0.02742	5	
N fertilizer	Input	kg/MJ$_{soybeans}$	0.00005	4	
Ca fertilizer as $CaCO_3$	Input	kg/MJ$_{soybeans}$	0.00453	7	See liming data
K_2O fertilizer	Input	kgMJ$_{soybeans}$	0.00039	**1**, 2	7.77 kg K_2O/(tonne moist soya)
P_2O_5 fertilizer	Input	kg/MJ$_{soybeans}$	0.00021	**1**, 2	4.12 kg P_2O_5/(tonne moist soya)
Pesticides	Input	kg/MJ$_{soybeans}$	0.00003	5	1.60 kg/(ha *yr)
Seeding material	Input	kg/MJ$_{soybeans}$	0.00118	**5**, 2	68.9 kg/(ha *yr)
Soybeans	Output	MJ	1.0000		
Field N_2O emissions		g/MJ$_{soybeans}$		4	GNOC calculates EU import weighted av.
CO_2 from neutralisation of other soil acidity		g/MJ$_{soybeans}$	1.56184	7	See liming data

Comments

- LHV soybean (dry) = 23 MJ/kg of dry substance (Ref. 4).
- 13.0 % traded moisture content of SB in the United States (Ref. 7).
- Diesel use: **1 606** MJ/(ha*yr):
  - 33.3 li diesel+12.8 gasoline per ha. Possibly some of this is used for drying rather than cultivation.
- N fertilizer: **0.00106** kg N/(kg moist soya).

Sources

1	International Fertilizer Association (IFA), 2013 (2010-2011 data).
2	Faostat data for yield (average 2009-2014).
3	Jungbluth et al., 2007 (Ecoinvent report).
4	Edwards and Koeble, 2012 (see Chapter 3).
5	Pradhan, et al., 2011.
6	Beuerlein, 2012.
7	JRC: Acidification and liming (see Section 3.10).

Drying

Table 209 Soybean drying

	Unit	**Amount**	**Sources**
LPG	$MJ/MJ_{soybeans}$	0.00084	1, 2
NG	$MJ/MJ_{soybeans}$	0.00256	1
Electricity	$MJ/MJ_{soybeans}$	0.00108	1
Soybeans	$MJ/MJ_{soybeans}$	1.000	
Soybeans	MJ	1.000	

Comments

- Hypothesis: drying consumes the part of the reported American-soy fuel-for-cultivation which is not diesel or gasoline.
- 2 litres/ha of LPG. Possibly some of the diesel or gasoline from cultivation is also used for drying, but if so, it would only come off the cultivation emissions.
- NG: 4.1 m^3/ha.
- Electricity: 17.1 kWh/ha.

Sources

1 Beuerlein, 2012.

2 Metrology Centre, 2012.

Transport of soybeans

Table 210 Transport of soybeans via 40 t truck over a distance of 80 km (one way)

	Unit	Amount
Distance	$tkm/MJ_{soybean}$	0.0040
Soybean	$MJ/MJ_{soybean}$	1.0100
Soybean	MJ	1.0000

Comments

- American soybeans board says 300 miles (480 km) for transport of fertilizers to farm.
- For the fuel consumption of the 40 t truck, see Table 70.

Shipping and barge transport distances

Omni Tech International (2010) assumes transport of soybeans from Arkansas via rail to eastern seaboard ports.

However, the U.S. Soybean Export Council (USSEC) (2011) says: 'The U.S. Atlantic Coast was once quite important to U.S. soybean exports. But the role of the Atlantic diminished when rail freight rates were deregulated. Under deregulation, railroads serving the Gulf faced severe competition from barges and water movement, but railroads serving the U.S. East Coast had no competition. That has kept rail rates high going east, so that the geographic freight advantage of a shorter voyage to European destinations is generally eaten up by the higher internal transportation costs. Except for local soybean production, all supplies must be railed in from the central United States, and eastern processors usually absorb the local soybean production to supply the region�given huge poultry industry with soy meal and the populous East Coast with soybean oil.

Like PNW ports, the Atlantic Coast export volume tends to grow when ocean freight rates are relatively high, and the freight advantage to Europe from the Atlantic compared to the Gulf grows large enough to compensate for the cost of railing in Midwestern soybeans.'

The USDA Agricultural Marketing Service, in its 'Brazil Soybean Transportation 2008/9' and several other reports of soybean export transport costs, use Davenport, Iowa as its typical source for American soybean exports, exporting via the Mississippi. Some 60 % of American soybean exports are said to tranship in the New Orleans region.

Therefore, we chose the Mississippi export route via the New Orleans area, which carries 60 % of American soybean exports, according to the USSEC report.

Table 211 Transport of soybeans seed via inland ship over a distance of 2 161 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{soybeans}$	0.1080
Soybeans	Input	MJ/MJ$_{soybeans}$	1.0100
Soybeans	Output	MJ	1.0000

Comments

- Davenport, Iowa to New Orleans (Ref. 1).
- For the fuel consumption of a bulk carrier for inland navigation, see Table 81.

Source

1 USDA Agricultural Marketing Service, Brazil Soybean Transportation, October 28, 2010, example for United States soybeans export.

2 Omni Tech International, 2010.

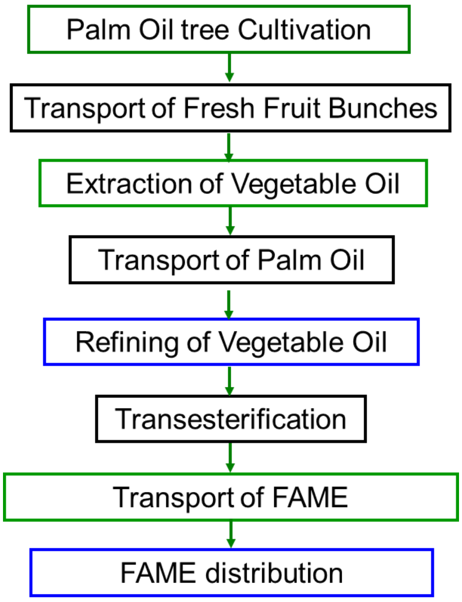
Table 212 Shipping and barge distances to Rotterdam

	Nautical miles sea	km sea
New Orleans	4 860	8 979

6.11 Palm oil to biodiesel

Description of pathway

The following processes are included in the 'palm oil to biodiesel' pathway.



The data for each process are shown below; significant updates are described in more detail with relevant references.

Planted area on peat in 2008: calculation from data in Miettinen et al., 2012 (Ref. 1)

According to data reported in Miettinen et al., 2012 for the two largest palm oil producing countries in the world, Indonesia and Malaysia[39], in 2007, there was 957 kha of oil palm on peat in Indonesia and 624 in Malaysia[40]; a total of 1 581 kha. In 2011, the figures were 1 311 and 844 kha respectively; a total of 2 155 kha (Ref. 1). Interpolating linearly, we estimate a total of **1 810 kha on peat in 2008**.

Planted area on peat in 2008: calculation from data in Gunarso et al., 2013 (Ref. 3)

Gunarso et al., 2013 (Ref. 3) reports planted area on peat in 2005 and 2010. In 2005, Indonesia and Malaysia totalled 1 370 kha of oil palm on peat, and in 2010 this had grown to 2 250 kha. By linear interpolation, we estimate **in 2008** the **planted area of oil palm on peat** was **1 900 kha**.

---

[39] According to USDA data, in 2014, Indonesia and Malaysia accounted for around 86 percent of total global palm oil production.

[40] This is consistent with MPOB data from (Wahid et al. 2010), who reported that oil palm planted on peat were 313 kha and 666 kha in 2002/2003 and 2009/2010 respectively.

Total Harvested area now

The most recent data on total palm oil harvested area, for December 2015, comes from MPOB, 2016 (Ref. 4) for Malaysia and from USDA, 2016 (Ref. 5) for Indonesia.
The **total harvested areas in 2015** are given as 4 859 and 8 965 kha respectively; a total of **13 824 kha**.

Present harvested area on mineral soil - using Miettinen's data (Refs. 1, 2)

To find the harvested area on mineral soil, it is necessary to subtract, from the total harvested area in December 2015, the harvested area on peat in 2015. However, the literature shows data only for planted area on peat. But it is known that plants become harvestable after 3 years, so we subtract the part of the area on peat that was planted before 2012, and that is the planted area on peat in 2012. Miettinen et al., 2012 (Ref. 1) report the total planted area on peat in 2010 that was 2 155 kha; and that increased to 3 106 kha in 2015 according to Miettinen et al., 2016 (Ref. 2). Linear interpolation indicates the planted area on peat was 2 535 kha in 2012.

Therefore, according to Miettinen's data, the **harvested area on mineral soil in 2015** is: 13 824 – 2 535 = **11 289 kha**.

Present harvested area on mineral soil, using Gunarso's data (Ref. 3)

As mentioned above, Gunarso et al., 2013 (Ref. 3) reported that Indonesia and Malaysia totalled 1 370 kh of oil palm on peat 2005, and in 2010 this had grown to 2 250 kha. By linear extrapolation, the 2012 planted area of oil palm on peat was 2 602 kha.

Therefore, according to Gunarso's data, the harvested area on mineral soil in 2015 is:
13 824 – 2 602 = **11 222 kha**.

CONCLUSION

Using Miettinen's data for palm-on-peat, the fraction of RED-eligible harvestable area that is on peat is:

1810/ (1810 + 11 289) = **13.8%**

Using Gunarso's data for palm-on-peat, the fraction of RED-eligible harvestable area that is on peat is:

1900/ (1900 + 11 222) = **14.5%**

We shall assume the fraction of RED-eligible harvestable area that is on peat is **14%**.

Sources

1 Miettinen et al., 2012.

2 Miettinen et al., 2016.

3 Gunarso et al., 2013, report by the Working Group of Roundtable on Sustainable Palm Oil (RSPO).

4 Malaysia Palm Oil Board (MPOB), 2016.

5 USDA, 2016.

Step 1: Cultivation of oil palm tree

The new data for palm oil tree cultivation are shown in Table 213. The updated data include:

- diesel and pesticide use in palm oil tree cultivation;
- $CaCO_3$ fertilizer use updated according to the Malaysian Palm Oil Board comments received in 2013;
- N_2O emissions calculated by JRC using the JRC GNOC model (see Section 3.7);
- K_2O and P_2O_5 updated using the most recent data available;
- CO_2 emissions from neutralisation of other soil acidity, calculated by the JRC (see Section 3.10).
- Extra methane emissions from Empty Fruit Bunch (EFB) decomposition (see text box below).

In the following table, source numbers in bold represent the main data source; additional references are used to convert data to 'per MJ of crop'.

Table 213 Cultivation of oil palm tree

	I/O	Unit	Amount	Source	Comment
Diesel	Input	MJ/MJ_{FFB}	0.00537	6	2.37 litres/(t moist FFB)
K_2O	Input	kg/MJ_{FFB}	0.00058	**2**, 3	9.18 kg/(t moist FFB)
N fertilizer	Input	kg/MJ_{FFB}	0.00032	4	See GNOC data
$CaCO_3$ fertilizer	Input	kg/MJ_{FFB}	0.00000	7	
P_2O_5 fertilizer	Input	kg/MJ_{FFB}	0.00010	**2**, 3	1.66 kg/(t moist FFB)
EFB compost	Input	kg/MJ_{FFB}	0.01420	1	225 kg/(t moist FFB)
Pesticides	Input	kg/MJ_{FFB}	0.00005	6	0.744 kg/(t moist FFB)
Fresh fruit bunches (FFBs)	Output	MJ	1.0000		
Field N_2O emissions	-	g/MJ_{FFB}	0.02981	4	See GNOC data
CO_2 from neutralisation of other soil acidity		g/MJ_{FFB}	0.00000	5	

Comments

- LHV Fresh Fruit Bunches (FFB) (dry) = 24 MJ/kg dry substance.
- 34 % moisture in FFB (Ref. 8). Fertilizers input (N, K_2O and P_2O_5) and yields are weighted averages of data for Malaysia and Indonesia which are the two main suppliers of palm oil to the EU market (Eurostat data, average 2011-2014). Fertilizer inputs for Malaysia and Indonesia are from the International Fertilizer Association, IFA (2010-2011 data) (Ref. 2) adjusted to the updated yield (av 2009-2014).

Sources

1 Schmidt, 2007.

2 International Fertilizer Association (IFA), 2013 and Faostat, 2016 (for yield, average 2009-2014).

3 Eurostat, accessed in October 2016.

4 Edwards and Koeble, 2012 (see Chapter 3).

5 As no aglime is used on oil-palm according to Ref. 8, there are no aglime emissions and no excess-over-fertilizer-acidification aglime emissions (explained in Ref. 4).

6 Choo et al., 2011.

7 Comments received from the Malaysian Palm Oil Board (MBOP), 14th June to Commission stakeholder meeting in May 2013.

Extra Methane Emissions from EFB Decomposition

Some additional direct emissions from palm oil production have been uncovered. It was recently noticed that there are Clean Development Mechanism (CDM) projects (including in Indonesia and Malaysia) that receive credits for avoiding methane emissions from EFB disposition [1, 2]. The methane arises because EFB decomposition in the usual practice is in fact partly anaerobic (the CDM projects avoid the methane emissions from EFB by either aerobically composting it, or treating it and burning it for electricity). The methane emissions have been attributed to the cultivation step, because the typical disposition of them is as a mulch on the plantation[1].

Calculation Method

The UN's CDM administration issued detailed methodologies to estimate the avoided methane emissions from EFB decomposition (drawing on IPCC guidelines), and the one that applies to the usual disposition of EFBs is included in [2]; it is correctly used by the projects for avoiding EFB decomposition. Using this tool, and bearing in mind the allocation of part of the cultivation emissions to by-products, and the yields of the conversion processes, we calculated the emissions.

In [1] Annex 3, the baseline emissions from EFB decay are shown.

17% is assumed to decay in one year.

In the first year, 117,000 tonnes EFB produce 18,438 tonne CO2e. The **total methane potential of that EFB** is thus 18,438/0.17 = **108,459 tCO2e**, (or 108,459/117,000 = **0.927 tCO2e/tonne EFB**)

The mill has a 120,000 t/y capacity, with an operational load average of 85% = an output of 102,000 tonnes/y Crude Palm Oil (CPO) [1].

Per tonne of CPO, total methane potential is 18,438/102,000 = **0.18 tonnes CO2e/tCPO**

There is a conservatism factor CDM introduce in their model that decreases emissions by 10%. However, in the present calculation, it is anti-conservative, so it is removed. That makes the best estimate 108,459/0.9 = 120,510 tCO2E per year, or 0.2008 tonnes CO2e/tCPO.

The Global Warming Potential (GWP) assumed in [1] is 21 for methane, but in RED calculations 25 is used. This brings the emissions up to 143,464 tonnes CO2e per year, or 0.2391 tonnes CO2e/tCPO, or **6.46 g/MJ CPO @37 MJ/kg.**

There's no procedure to consider N2O emissions from EFB decomposition in the CDM guidelines. This would be an additional source of emissions which can be considered in future iterations of this work. However, it is not likely to be significant.

Comparison with CDM project on EFB composting in Indonesia [2]

In Oct-Dec 2010 (i.e. year 1), the project composts 21,100 tonnes EFB.

It saves baseline emissions of 3,325 tonnes CO2e from the avoided methane emission from "usual" EFB disposition. That makes 0.1575 tCO2e/tonne EFB in those 3 months.

The CDM methodology AM0025 [2] is the same as for the Malaysian project [1], and assumes 17% decomposition per year.

So total methane potential is 0.1575/0.17 = **0.926 tCO2e/tonne EFB**, which is the same as [1] within rounding errors.

[1] EFB is typically used as a mulch, which produces methane during decomposition. From [1]: '*EFB has been used as a fertiliser, but it is still at the development stage and costly, thus these are producing facilities...registered as CDM projects. Also, fertilisers are produced only in small scale mills and never in large quantities. The project site would process 120 tonnes that would be beyond the capacity of any fertilizer. The only remaining realistic and credible alternative scenario for the disposal of EFB would be …the biomass residues are dumped or left to decay under clearly anaerobic conditions*'.

It is true that there has been an increase in the number of CDM projects composting EFBs, but in 2016 these only accounted for 17% of EFBs in Malaysia (and probably less in Indonesia). Furthermore, these projects are already receiving CDM credits for the avoided methane emissions.

Sources:

1 CDM Malaysia ACM0006 Version 06.2 and ACM0014 Version 02.1, February 20, 2009. http://gec.jp/gec/jp/Activities/cdm-fs/2008/200811SmartEnergy_jMalaysia_pdd.pdf\

2 CDM Indonesia. Version: 01. Completed on: 06 April 2010. https://cdm.unfccc.int/UserManagement/FileStorage/JQWMFDE6C3IX074L5YPNHAS9T8VK1O.

Step 2: Transportation of fresh fruit bunches (FFBs)

Table 214 Transport of fresh fruit bunches via 12 t truck (payload 7t) over a distance of 50 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ$_{FFB}$	0.0032
FFBs	Input	MJ/MJ$_{FFB}$	1.0000
FFBs	Output	MJ	1.0000

Comment

- For the fuel consumption of the 12 t truck, see Table 75.

Sources

1 Lastauto Omnibus Katalog, 2010; ETM EuroTransportMedia Verlags- und Veranstaltungs-GmbH, Stand August 2009.

2 Choo et al., 2011.

Step 3: Storage of fresh fruit bunches

Table 215 Storage of fresh fruit bunches

	I/O	Unit	Amount
FFBs	Input	MJ/MJ_{FFB}	1.0000
FFBs	Output	MJ	1.0000

Source

1 Malaysian Palm Oil Board (MPOB) personal communication at data review meeting, Ispra, November 2011.

Step 4: Oil mill: plant oil extraction from fresh fruit bunches

Table 216 Plant oil extraction from fresh fruit bunches (FFB)

	I/O	Unit	Amount	Source
FFB	Input	MJ/MJ_{oil}	2.1427	
Grid electricity	Input	MJ/MJ_{oil}	0.000078	5
Diesel	Input	MJ/MJ_{oil}	0.00445	5
Emission/open POME pond	Emission	gCH_4/MJ_{oil}	0.9844	5
Emission/closed POME pond	Emission	gCH_4/MJ_{oil}	0.1477	5
CH_4 from shells and fibre combustion	Emission	gCH_4/MJ_{oil}	0.0007	
N_2O from shells and fibre combustion	Emission	gN_2O/MJ_{oil}	0.000996	
Crude palm oil (CPO)	Output	MJ	1.0000	

Comments

- Grid electricity:
  - 1.76 MJe/tonne CPO, after Ref. 5 allocated 1/1.64 of the inputs to oil by mass
- Diesel:
  - 100.33 MJ/tonne CPO, after Ref. 5 allocated 1/1.64 of the inputs to oil by mass
- Emission/open POME (Palm Oil Mill Effluent) pond: 22.21 kg/tonne CPO, after Ref. 5 allocated 1/1.64 of the inputs to oil by mass.
- Emission/closed POME pond: 85 % of methane emissions assumed captured by methane capture technology (Ref. 5).
- 0.36 tonne of solid fuel/tonne CPO, after Ref. 5 allocated 1/1.64 of the inputs to oil by mass; 0.003 g CH4/MJ of solid biofuel and 0.004 g N2O/MJ of solid biofuel (Ref. 7).

Emissions from palm oil mill

We took the emissions from the palm oil mill from the recent publication by MPOB staff (Ref. 5). The inputs and emissions reported in that paper are those allocated to 1 t of crude palm oil by mass allocation. According to this paper, making 1 t palm oil produces 0.64 t of useful by-products, so to find the unallocated emissions per tonne palm oil, we have to multiply the figures by 1.64.

Most of the heat and power for the mill (a composite of 12 representative mills) comes from burning all the pressed mesocarp fibre and some nutshells in a CHP generator. However, a little grid electricity and diesel are also in the mix. There is a surplus of nutshells, which is exported, according to Ref. 5, as a low-cost fuel.

We calculate emissions for palm oil specifically instead of a combination of palm oil and palm kernel oil. Palm kernel oil is as yet rarely used for biofuel as it has higher-value uses for soap making, etc., competing with tallow.

That means allocating part of the mill emissions to palm kernels. As we do not have an LHV for palm kernels, we calculated our energy-based allocation by calculating separately for the two components of the kernels: palm kernel meal and palm kernel oil.

The main emission from the mill is methane released from the anaerobic effluent pond. Following the MPOB (Ref. 5), without methane capture, 11.94 kg methane per tonne of effluent is emitted, whereas with methane capture, this is reduced by 85 %.

Calculation of LHV of palm oil

Table 217 LHV of palm oil

Component	**Weight fraction of FFB**	**Source**	**LHV$_{\text{-vap}}$ (MJ/kg)**	**Source**	**Moisture**	**Output in allocat. def. LHV$_{\text{-vap}}$**	**LHV of dry part of moist biomass (MJ/kg)**
Palm oil	0.200	1	37	6	0 %	7.393	37.0
Palm kernel meal	0.029	2, 3	16.4	2	10 %	0.481	16.7
Palm kernel oil	0.024	1	37	6	0 %	0.888	37
Excess nutshells	0.074	5	**0 (*)**	4	10 %	0.000	17.3
Allocation to crude palm oil	**84 %**				**Total**	**8.762**	

(*)Directive (EU) 2018/2001in Annex V defines nutshells as a residue. Therefore they should not be allocated any emissions.

Sources

1 Schmidt, 2007.

2 Calculated from composition by JRC 'LHV calculator' using composition in Ref. 4.

3 Chin, 1991.

4 Panapanaan and Helin, 2009.

5 Choo et al., 2011.

6 Mehta and Anand, 2009.

7 IPCC, 2006.

Step 5: Transport of palm oil

Table 218 Transport of palm oil summary table

Transporter	Notes	Distance (km one-way)
Truck	Payload 27 t	120
Product tanker	Payload 22,560 t	16,287

Comment

- Shipping distance: palm oil Kuching (Borneo, between peninsula Malaysia and Indonesia) to Rotterdam.

Source

1 Website: Searates.com

Table 219 Transport of palm oil via a 40 t truck over a distance of 120 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{oil}	0.0035
Vegetable oil	Input	MJ/MJ_{oil}	1.0000
Vegetable oil	Output	MJ	1.0000

Comment

- For the fuel consumption of a 40 t truck, see Table 70.

Table 220 Depot for palm oil

	I/O	Unit	Amount
Vegetable oil	Input	MJ/MJ_{oil}	1.0000
Electricity	Input	MJ/MJ_{oil}	0.00084
Vegetable oil	Output	MJ	1.0000

Comment

- One depot at export and one depot at input terminal

Source

1 Dautrebande, 2002.

Table 221 Maritime transport of palm oil over a distance of 16 287 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{oil}	0.4402
Vegetable oil	Input	MJ/MJ_{oil}	1.0000
Vegetable oil	Output	MJ	1.0000

Comment

- For the fuel consumption of the product tanker (payload 22,560 t), see Table 80.

Step 6: Refining of vegetable oil from oil palm

Table 222 Refining of vegetable oil from oil palm (70% of palm oil imports) assumed to be the same as for rapeseed

	I/O	Unit	Amount	Source	Comment
Electricity	Input	MJ/MJ_{oil}	0.00093	**1**, 2	34.38 MJ/(t oil)
H_3PO_4	Input	kg/MJ_{oil}	0.00003	**1**, 2	1.19 kg/(t oil)
NaOH	Input	kg/MJ_{oil}	0.00009	**1**, 2	3.26 kg/(t oil)
Crude vegetable oil	Input	MJ/MJ_{oil}	1.02459	1	
Steam	Input	MJ/MJ_{oil}	0.00403	**1**, 2	149.2 MJ/(t oil)
Plant oil	Output	MJ	1.0000		37 MJ/kg of oil (Ref. 2)

Comment

- This process applies to 70% of palm oil imports which is the % of not refined palm oil coming from Malaysia and Indonesia (Ref. 3).

Sources

1 European Biodiesel Board (EBB), 2009.

2 Edwards, JRC, 2012, based on ECN Phyllis database of biomaterials properties.

3 FEDIOL, personal communication, November 2016.

Table 223 Physical refining of vegetable oil from oil palm used in Malaysia (30% of palm oil imports)

	I/O	Unit	Amount	Source	Comment
Electricity	Input	MJ/MJ_{oil}	0.00116	**1**, 2	42.98 MJ/(t oil)
H_3PO_4	Input	kg/MJ_{oil}	0.00002	**1**, 2	0.59 kg/(t oil)
Bleaching earth	Input	kg/MJ_{oil}	0.00025	**1**, 2	9.11 kg/(t oil)
Crude vegetable oil	Input	MJ/MJ_{oil}	1.00198	1	0.002 fraction of oil lost in spent bleaching earth
Steam (generated at 90% eff. from heating oil)	Input	MJ/MJ_{oil}	0.01160	**1**, 2	429.26 MJ/(t oil)
Plant oil + palm fatty acid	Output	MJ	1.0000		37 MJ/kg of oil (Ref. 2)

Comment

- This process applies to 30% of palm oil imports which is the share of refined palm oil coming from Malaysia and Indonesia (Ref. 3).
- Allocation by LHV to palm oil fatty acid co-product results in same value per MJ of refined palm oil, as it has almost the same LHV as palm oil.

Sources

1 Choo et al., 2011.

2 Edwards, JRC, 2012, based on ECN Phyllis database of biomaterials properties.

3 FEDIOL, personal communication, November 2016.

Step 7: Transesterification

Table 224 Transesterification

	I/O	Unit	Amount	Source	Comment
Electricity	Input	MJ/MJ_{FAME}	0.00405	**1**, 2, 4	150.5 MJ/(t FAME)
Sodium methylate (Na(CH$_3$O))	Input	kg/MJ_{FAME}	0.00037	2, **4**, **5**, **6**, **7**	45.5 kg of 30% solution/(t FAME)
HCl	Input	kg/MJ_{FAME}	0.00010	**1**, 2, 4	3.61 kg/(t FAME)
Methanol	Input	MJ/MJ_{FAME}	0.05110	**1**, 2, 4	95.29 kg/(t FAME)
Plant oil	Input	MJ/MJ_{FAME}	1.00063	**1**, 2, 4	
Steam	Input	MJ/MJ_{FAME}	0.03303	**1**, 2, 3, 4	1 229 MJ/(t FAME)
FAME	Output	MJ	1.00000		

Comments

- LHV (FAME) = 37.2 MJ/(kg FAME) (Ref. 2).
- 16 MJ / (kg glycerol) (Ref. 4).
- 101.87 kg glycerol/(t FAME).

Sources

1 European Biodiesel Board (EBB), 2009.

2 ECN Phyllis database of biomaterials properties.

3 Rous, personal communication, 23 September 2008.

4 Edwards, JRC, 2003: chemical thermodynamic calculation with HSC for windows.

5 European Biodiesel Board, J. Coignac, Comments to Commission's May 2013 stakeholder consultation, received 13 June 2013.

6 European Biodiesel Board, D. Buttle, personal communication, 2013.

7 ADEME, 2010.

Step 7.1: Steam generation processes

The data for the individual steam generation processes are shown in Chapter 4. The process linked to refining (in Table 222) and transesterification is steam generation from NG boiler (Table 63).

Step 8: Transportation of FAME to the blending depot

The same transport mix used in ‘rapeseed to biodiesel’ has been added, but excluding pipeline transport as it is unlikely that this product would be transported in this manner.

Table 225 Transportation of FAME to the blending depot (summary table)

Share	Transporter	Notes	Distance (km one way)
13.2 %	Truck	Payload 40 t	305
31.6 %	Product tanker	Payload: 15 000 t	1 118
50.8 %	Inland ship/barge	Payload 1 200t	153
4.4 %	Train		381

Table 226 Transport of FAME via 40 t truck over a distance of 305 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{FAME}	0.0088
FAME	Input	MJ/MJ_{FAME}	1.0000
FAME	Output	MJ	1.0000

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

Table 227 Maritime transport of FAME over a distance of 1 118 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{FAME}	0.0301
FAME	Input	MJ/MJ_{FAME}	1.0000
FAME	Output	MJ	1.0000

Comment

- For the fuel consumption of the product tanker (payload: 15,000 t), see Table 79.

Table 228 Transport of FAME over a distance of 153 km via inland ship (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{FAME}	0.0041
FAME	Input	MJ/MJ_{FAME}	1.0000
FAME	Output	MJ	1.0000

Comment

- For the fuel consumption for an inland oil carrier, see Table 82.

Table 229 Transport of FAME over a distance of 381 km via train (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{FAME}	0.0102
FAME	Input	MJ/MJ_{FAME}	1.0000
FAME	Output	MJ	1.0000

Comments

- For the fuel consumption of the freight train, see Table 84.

Step 9: FAME depot distribution inputs

Same input data are used as for rapeseed.

6.12 Waste cooking oil

Waste cooking oil (used cooking oil, UCO) is defined as a waste in accordance with the definition of waste in the Waste Framework Directive 2008/98/EC and, therefore, is attributed zero GHG emissions at its point of collection in accordance with RED. However, used cooking oil is being brought into the EU from considerable distances. The major world exporter is USA, and if its use in the EU continues to increase (as it can be expected that it will continue increasing also in future), it could supply a large part of the EU used cooking oil.

Transport of waste cooking oil

We assumed that 20% of UCO currently used for biodiesel comes from overseas (Ref. 1).

Table 230 Transport of waste oil via 40 t truck over a distance of 100 km

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{oil}	0.0029
Vegetable oil	Input	MJ/MJ_{oil}	1.0000
Vegetable oil	Output	MJ	1.0000

Comment

- For the fuel consumption for the 40 t truck, see Table 70.

Table 231 Maritime transport of waste cooking oil over a distance of 7 000 km (Ref. 1)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{oil}	0.1892
Vegetable oil	Input	MJ/MJ_{oil}	1.0000
Vegetable oil	Output	MJ	1.0000

Comments

- LHV waste cooking oil = 37 MJ/kg.
- For the fuel consumption of the product tanker (payload 22 560 t), see Table 80.

Sources

1 European Waste-to-Advanced Biofuels Association & Mittelstandverband abfallbasierter Kraftstoffe, 2014.

Transesterification of used cooking oil to FAME

Table 232 Transesterification and pretreatment of used cooking oil and animal fat to FAME (before allocation)

	I/O	Unit	Amount	Source
Electricity	Input	MJ/MJ_{FAME}	0.00676	1, 2
H_3PO_4	Input	kg/MJ_{FAME}	0.00005	1, 2
KOH	Input	kg/MJ_{FAME}	0.00043	1, 2
Sulphuric acid	Input	kg/MJ_{FAME}	0.00029	1, 2
Methanol	Input	MJ/MJ_{FAME}	0.05643	1, 2
Oil or fat	Input	MJ/MJ_{FAME}	1.03627	2
NG	Input	MJ/MJ_{FAME}	0.04710	1, 2
FAME	Output	MJ	1.0000	

Comments

- 37.0 MJ/kg oil or fat.
- 37.2 MJ/kg FAME.
- The transesterification process includes pre-treatment inputs. Weighted averages for the industry (EWABA and BDI, see ref 1 and 2) were used to calculate electricity, natural gas (or NG equivalent), methanol and sulphuric acid inputs. Weighted averages for companies using the same inputs as BDI were used to calculate the smaller inputs i.e., KOH and H3PO4.
- The by-products considered for allocation were heavy phase, glycerol, and bio-oil from distillation.
- The allocation factor to biodiesel = 0.937. It is a weighted average of the average BDI allocation factor (0.930) (Ref. 2) and the EWABA average allocation factor (0.941) (Ref. 1) weighted on the basis of their production. The by-products considered for allocation were heavy phase, glycerol, and bio-oil from distillation.
- The estimated BDI Used Cooking Oil Methyl Ester (UCOME) production is 250,000 tonnes (Ref. 2, 3). We estimated that around 60% of total production of 'waste' oils and fats in Europe is UCOME (Greenea, 2016). BDI plants in Europe which process UCO and tallow have a production capacity of 548 kt. If 60% of this produces UCOME (329 kt), and these factories run at an estimated 75% capacity, it results in a UCOME supply of ~ 250 kt.
- EWABA UCOME production in EU equals around 460 ktonnes (Ref. 1).

Sources

1	European Waste to Advanced Biofuels Association (EWABA), industry data provided to JRC, July 2017. Inputs used are weighted averages, calculated using individual inputs weighted per factory's annual UCOME production.
2	BDI (Bioenergy International, Austria), plant input data and plant sites and capacities, provided to JRC, July 2017. Input data represents average of typical production inputs used in BDI plants in the EU.
3	Greenea, 2016.

For transport of FAME and distribution, same input data are used as for palm oil.

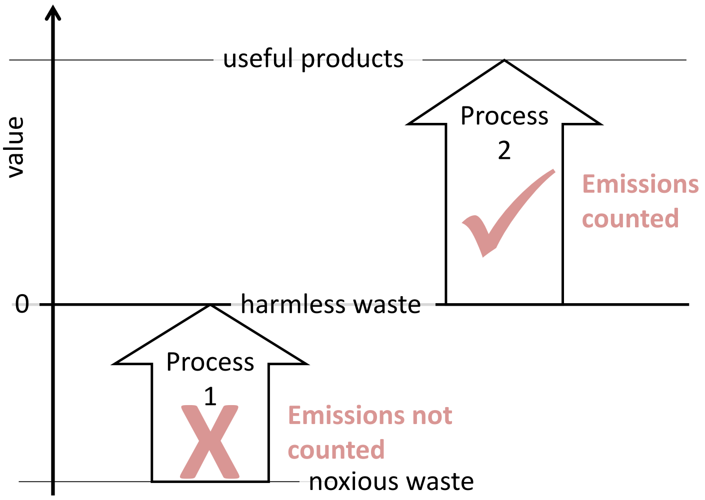
6.13 Animal fat

In accordance with the RED methodology, wastes and residues have zero life-cycle GHG emissions up to the process of collection of those materials. However, emissions from *processing* of waste needs to be taken into account unless the product still qualifies as a waste or residue.

As a thought experiment, consider the case where there are two separate processes:

- Process 1, a hygenizing process which converts noxious waste with a negative value[41] into a harmless but useless material
- Process 2, which separates the harmless material into useful and valuable products.

Under RED, the "harmless waste" would qualify as a waste if it fullfills the definition in Article 3(1) of the "waste directive" Directive 2008/98/EC[42], because it is useless and would be disposed of, if it was not for process 2.



Under the RED, the emissions from process 1 are not counted, because its product is still a waste, whose emissions are not counted. However the emissions from process 2 would contribute to the emissions attributed to the useful products.

If an economic operator were to put their system boundary to include both process 1 and process 2 as a single process, the calculation of emissions should not change. Therefore we only count the emissions from the overall process that turns the waste into a product. If the process intrinsically combines both process 1 and process 2, we multiply the overall process emissions by the fraction of the process' total added value that goes from zero to the value of the useful products. For the rendering process, we estimate that 63% of the emissions do not count, so we attribute only 37% of rendering emissions to the products (Table 233).

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[41] i.e. the plant has received a gate fee to process the waste into something less noxious.

[42] The waste directive says *"A "waste" is any substance or object which the holder discards or intends to discard or is required to discard"*

Rendering of animal carcass co-produces different grades of fat (loosely called tallow) and a by-product: meat-and-bone meal. According to the Fat Processors and Renderers Association (EFPRA) (Ref. 1), meat-and-bone meal is sold as a co-product, even though its use is still restricted by regulations in the wake of the BSE crisis. In some previous years it has been a waste which required a gate fee for incineration. If meat-and-bone meal is considered a product, then it should be allocated part of the emissions from the rendering process, on the basis of LHV. On the other hand, if national regulations categorize it as a 'waste', all the emissions attributed to products should be allocated to the fat.

For the purpose of the calculation of the default emissions meat-and-bone meal was considered as a co-product. Therefore, of the 37% of rendering emissions attributed to products, less than half (47%) are allocated to fat (Table 234), on the basis of lower heat content (“wet”-definition), and the rest to the meat-and-bone meal by-product.

Table 233 Fraction of rendering process attributed to products

	Amount	**Unit**	**Source**
Gate fee for wet animal carcass (negative value)	-100	Euro/tonne wet carcass	
	-716	Euro/tonne net fat produced	
Approx. price Cat 1 meat and bone meal	10	Euro/tonne	1
	25.6	Euro/tonne gross fat produced	
	27	Euro/tonne net fat produced	
NWE Price of cat. 1 tallow	375	Euro/tonne	1
	375	Euro/tonne gross fat produced	
	390	Euro/tonne net fat produced	
Ratio net/gross fat	0.96		
Fraction of the rendering process which is considered to be adding positive value (rather than bring waste up to zero value)	**36.7%**		

Source

1 European Fat Processors and Renderers Association (EFPRA), 2015, personal communication: approximate material prices for the EU.

Table 234 Allocation of emissions of rendering between fat and meat-and bone meal for the case that meat-and bone meal is not considered a waste

	kg/kgfat	Fraction moisture	LHV dry	Ref	LHV-vap	Heat content of products (per kg fat out)
Dry carcass	3.45					
Wet meat-and-bone meal	2.56	3.8%	18.0	7,8	17.2	44.05
Net fat production	1.00	1.2%	38.8	7	38.3	38.31
Fraction of animal fat in total LHV of products						**46.5%**
Fraction of rendering emissions attributable to animal fat, IF meat and bone meal is NOT considered a waste						**17.1%**

Ref. 6 gives CO_2 emitted (per million pounds of animal waste) from burning NG, and some of the animal fat. These CO_2 emissions are converted back into tonnes of NG (and GJ of NG) per tonne of fat (Table 235). Thus most of their fuel used in rendering is NG; we have not accounted for other (more CO_2-intensive) fossil fuels burnt in EU plants which are not on the NG grid, which are also more likely to burn Cat 1 fat[43].

We note that cat. 1 animal fat is now generally more expensive than fuel oil or NG. Therefore, the few renderers who formerly burnt Cat. 1 animal fat are now likely to burn fossil fuel. That fat is most likely to be replaced by fuel oil, because the burner for fat does not need to be modified to burn fuel oil, and because the factories may not be on the NG grid. Accordingly, we have added ~10% of fuel oil to the fuel mix in rendering, to replace the equivalent amount of animal fat.

Table 235 NG per tonne of fat

PER MILLION POUNDS ANIMAL WASTE			454 tonnes animal waste	
Reported emissions:	**t CO2**	**t Carbon**	**tonnes fuel**	**GJ**
Fat burnt in rendering	6.77	1.85	2.46	
NG	49.9	13.61	18.1	0.36
LHV NG GJ/tonne (WTW)	50			
PER TONNE OF MOIST FAT (including fat which is burnt)				**GJ NG/tonne fat**
Fat burnt in rendering	0.103	0.028	0.037	
NG	0.758	0.207	0.276	0.0055

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[43] 'Cat 1' refers to a category of animal by-product (ABP). ABPs are categorised according to their risk using the basic principles in Regulation (EC) 1069/2009.

No emissions are attributed to transport from slaughterhouse to rendering plant, as the material is a waste at this stage.

Step 1: Animal fat processing from carcass (biodiesel)

Table 236 Animal fat processing from carcass (biodiesel) (per kg produced fat)

Rendering	I/O	Unit	Amount	Source
Carcass	Input	dry kg carcass/kg fat	3.45	4
Electricity	Input	MJ/kg_{tallow}	0.65	4
Natural gas	Input	MJ/kg_{tallow}	11.68	4,6
Fuel oil	Input	MJ/kg_{tallow}	1.43	6

Comments

- LHV animal fat @ 1.2% moisture = 38.3 MJ/kg.
- Water content of carcass: 50%.

Table 237 Rendering (per MJ produced fat)

	I/O	Unit	Amount	Source
Fat in carcass	Input	$MJ/MJ_{tallow\ (part\ of\ carcass)}$	1.0000	4
Electricity	Input	MJ/MJ_{tallow}	0.01704	4, 6
Natural gas	Input	MJ/MJ_{tallow}	0.3047	6
Fuel oil	Input	MJ/MJ_{tallow}	0.0374	
Tallow	Output	MJ	1.0000	

Sources

1	Ecoinvent, LCI of tallow production.
2	Notarnicola et al., 2007.
3	Raggi et al., 2007.
4	De Camillis et al., 2010.
5	LCA report from BIODIEPRO project. See http://www.argentenergy.com/articles/article_8.shtml online.
6	US National Renderers Association website: see http://nationalrenderers.org online.
7	ECN database Phyllis 2 accessed 2014.
8	Laraia et al., 2001.

Step 2: Tansport of tallow to the plant

Table 238 Transport of tallow via 40 t truck over a distance of 150 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{FAME}	0.00435
FAME	Input	MJ/MJ_{FAME}	1.0000
FAME	Output	MJ	1.0000

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

We assume the rest of the processing is the same as for waste cooking oil.

6.14 Hydrotreated Vegetable Oil (HVO)

This process applies to hydrotreating of Rapeseed oil (ROHY), Sunflower oil (SOHY), Soy oil (SYHY), Palm oil (POHY): NExBTL^{TM} deep hydrogenation process and distribution.

For input data on supply of the vegetable oils, please refer to the equivalent FAME pathway (e.g. rapeseed to biodiesel, sunflower to biodiesel, palm oil to biodiesel, etc.).

Diesel-fuel is produced along with small amounts of bio-gasoline (0.44/44 GJ/GJ of diesel, Larivé, J-F., CONCAWE, personal communication, May 2013). The bio-gasoline is taken into account by allocation by energy. The steam reformer which produces H2 for the process from natural gas has been included in the system boundary. This is not valid for HVO from UCO and tallow which are assumed to have different amounts of co-products (see Table 241).

Table 239 Hydrotreating of vegetable oil (except palm oil, UCO and tallow) via NExBTL process including H2 generation (generation of a diesel-like fuel)

	I/O	Unit	Amount
NG	Input	MJ/MJ_{fuel}	0.10981
Vegetable oil	Input	MJ/MJ_{fuel}	1.02385
H_3PO_4	Input	kg/MJ_{fuel}	0.00002
NaOH	Input	kg/MJ_{fuel}	0.00003
N_2	Input	kg/MJ_{fuel}	0.000001
Electricity	Input	MJ/MJ_{fuel}	0.00155
Diesel-like fuel	Output	MJ	1.0000

Source

1 Reinhardt et al., 2006.

Table 240 Hydrotreating of palm oil via NExBTL process including H2 generation (generation of a diesel-like fuel)

	I/O	Unit	Amount	Source
NG	Input	MJ/MJ_{fuel}	0.085762	1, 2
Vegetable oil	Input	MJ/MJ_{fuel}	1.023852	1
H_3PO_4	Input	kg/MJ_{fuel}	0.000017	1
NaOH	Input	kg/MJ_{fuel}	0.000027	1
N_2	Input	kg/MJ_{fuel}	0.000005	1, 2
Electricity	Input	MJ/MJ_{fuel}	0.000864	1, 2
Diesel-like fuel	Output	MJ	1.0000	

Sources

1 Reinhardt et al., 2006.

2 ConocoPhillips, personal communication 25 October 2007.

Table 241 Hydrotreating of UCO and tallow via NExBTL process and other producer, including H2 generation (generation of a diesel-like fuel)

	I/O	Unit	Amount	Source
NG	Input	MJ/MJ_{fuel}	0.13372	1, 2
UCO/animal fat	Input	MJ/MJ_{fuel}	0.96255	1, 2
H_3PO_4	Input	kg/MJ_{fuel}	0.00003	1, 2
NaOH	Input	kg/MJ_{fuel}	0.00003	3
N_2	Input	kg/MJ_{fuel}	0.00001	3
Electricity	Input	MJ/MJ_{fuel}	0.00896	1, 2
Diesel-like fuel	Output	MJ	1.0000	

Comments

- Weighted averages of Neste (Ref. 1) and REG (Ref. 2) were used to calculate UCO requirement, natural gas equivalent, electricity input and phosphoric acid. The weighting factor is estimated on the basis of production capacities of the two companies. Neste has a EU production capacity of 1.5 million tonnes of HVO per year, while REG has a capacity of 250 thousand tonnes (Ref. 4). Individual input data for the two companies are shown in Table 242.
- Allocation factors: according to the Neste literature (Ref. 1), along with 1 MJ of BTL-like fuel, 0.00516 MJ of naphtha and 0.0528 MJ of propane-rich off gas is typically produced. A further output of propane-rich off-gas (0.01004 MJ/MJ BTL) is

used within the process to generate steam. According to REG data (Ref. 2), along with 1MJ of BTL-like fuel, 0.0526 MJ of naphtha and 0.0406 MJ of LPG type fuel are produced.

Table 242 Some input data for Neste and REG

Input	Neste	REG	Unit	Source
UCO requirement	1.018	1.061	MJ/MJ_{fuel}	1, 2
Natural gas equivalent	0.136 (*)	0.178 (**)	MJ/MJ_{fuel}	1, 2
Electricity requirement	0.009	0.015	MJ/MJ_{fuel}	1, 2
H_3PO_4	0.000031	0.00003	kg/MJ_{fuel}	1, 2

(*) Assuming that 1.315 kWh of natural gas is required to make 1 MJ of hydrogen. The hydrogen requirement is 0.104 MJ/MJ_{fuel} (Ref. 1).

(**) It includes hydrogen and natural gas consumption, and factor for producing hydrogen from NG elaborated from original REG data.

Sources

1 Neste, NExBTL Renewable Diesel Singapore Plant, 2015. Mixed used cooking oil pathway description public. Method 2B Application Neste Singapore Pte Ltd Method 2B Application of Global Mixed UCO to Renewable Diesel (NExBTL).

2 REG (Renewable Energy Group), 2017, HVO producer using multi-feedstocks. Processing information presented to JRC during a meeting at Ispra, September 27th 2017.

3 Reinhardt et al., 2006.

4 Greenea, 2017.

Transportation of diesel-like fuel to the blending depot

Table 243 Transportation of diesel-like fuel to the blending depot (summary table)

Share	Transporter	notes	Distance (km one way)
11.4 %	Truck	Payload 40 t	305
27.2 %	Product tanker	Payload: 15 000 t	1 118
43.8 %	Inland ship/barge	Payload 1 200t	153
3.8 %	Train		381
13.8 %	Pipeline		5

Table 244 Transport of diesel-like fuel via 40 t truck over a distance of 305 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{fuel}	0.0075
Diesel-like fuel	Input	MJ/MJ_{fuel}	1.0000
Diesel-like fuel	Output	MJ	1.0000

Comment

- For the fuel consumption of the 40 t truck, see Table 70.

Table 245 Maritime transport of diesel-like fuel over a distance of 1 118 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{fuel}	0.0254
Diesel-like fuel	Input	MJ/MJ_{fuel}	1.0000
Diesel-like fuel	Output	MJ	1.0000

Comment

- For the fuel consumption of the product tanker (payload: 15,000 t), see Table 79.

Table 246 Transport of diesel-like fuel over a distance of 153 km via inland ship (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{fuel}	0.0035
Diesel-like fuel	Input	MJ/MJ_{fuel}	1.0000
Diesel-like fuel	Output	MJ	1.0000

Comment

- For the fuel consumption for an inland oil carrier, see Table 82.

Table 247 Transport of diesel-like fuel over a distance of 381 km via train (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{fuel}	0.0087
Diesel-like fuel	Input	MJ/MJ_{fuel}	1.0000
Diesel-like fuel	Output	MJ	1.0000

Comments

- For the fuel consumption of the freight train, see Table 84.

Table 248 Transport of diesel-like fuel over a distance of 5 km via pipeline

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{fuel}	0.0002
Diesel-like fuel	Input	MJ/MJ_{fuel}	1.0000
Diesel-like fuel	Output	MJ	1.0000

Comments

- Assumed to be the same as for gasoline.

Table 249 Diesel-like fuel depot

	I/O	Unit	Amount
Diesel-like fuel	Input	MJ/MJ_{fuel}	1.00000
Electricity	Input	MJ/MJ_{fuel}	0.00084
Diesel-like fuel	Output	MJ	1.00000

Source

1 Dautrebande, 2002.

Table 250 Transport of diesel-like fuel via 40 t truck over a distance of 150 km (one way)

	I/O	Unit	Amount
Distance	Input	tkm/MJ_{fuel}	0.0043
Diesel-like fuel	Input	MJ/MJ_{fuel}	1.0000
Diesel-like fuel	Output	MJ	1.0000

Table 251 Diesel-like fuel filling station

	I/O	Unit	Amount
Diesel-like fuel	Input	MJ/MJ_{fuel}	1.0000
Electricity	Input	MJ/MJ_{fuel}	0.0034
Diesel-like fuel	Output	MJ	1.0000

Source

1 Dautrebande, 2002.

6.15 Black liquor

This covers 3 processes for making different transport fuels made in pulp mills by gasifying black liquor, including DME, methanol, and FT liquids.

When calculated using the RED methodology, the results do not differ significantly between the fuels; therefore they are combined to a single process.

For data on roundwood harvest and forestry residues collection, refers to the input data for solid and gaseous bioenergy pathways (JRC, 2017).

Table 252 Liquid fuels via gasification of black liquor (methanol, DME, FT liquids)

	I/O	**Unit**	**Amount**
Dry roundwood	Input	$MJ/MJ_{biofuel}$	1.50
Dry forest residues	Input	$MJ/MJ_{biofuel}$	0.44
Liquid fuels	Output	MJ	1.00

Detailed calculations per fuel

1. Black liquor gasification to methanol

Alternatively, some or all of the black liquor can be gasified instead of burnt in the recovery boiler. Various fuels (methanol, DME or Fischer–Tropsch products mix (naphtha, gasoline, diesel) can be made from the gas. Here we used data on the CHEMREC oxygen-blown BL gasification process. Gasification produces less heat and electricity than burning the black liquor in the reference pulp plant. Therefore, extra biomass (in the form of forest residues) is required to make the plant self-sufficient for heat and electricity. In the modelled plant, the tall oil is gasified along with the black liquor.

Table 253 Black liquor gasification to methanol

	I/O	Unit	Amount	Source
Roundwood	Input	GJ/dry t pulp	39.0	1, 3
Shortfall in electricity	Input	GJ/dry t pulp	2.42	4
Forest residues for electricity	Input	GJ/dry t pulp	6.05	4
Forest residues for pulp	Input	GJ/dry t pulp	5.56	4
Total forest residues	Input	GJ/dry t pulp	11.61	
Pulp	Output	GJ/dry t pulp	14.05	2
Methanol	Output	GJ/dry t pulp	11.78	4
Total outputs	Output	GJ/dry t pulp	25.83	

Comments:

- Roundwood requirement for pulp mill: 2.05 dry tonnes / dry tonne pulp.
- LHV wood (dry) = 19 MJ / kg dry wood.
- Moisture (wood) = 50%.
- LHV (pulp - cellulose dry) = 15.9 MJ/kg dry.
- Moisture (pulp) = 10%.
- LHV (MeOH) = 19.9 MJ/kg.
- GJ dry roundwood per GJ output = 1.51
- GJ dry forest residues per GJ output = 0.45

For transport and distribution of methanol, see 'wood to methanol pathway'.

2. Black liquor gasification to DME

Table 254 Black liquor gasification to DME

	I/O	Unit	Amount	Source
Roundwood	Input	GJ/dry t pulp	39.0	1, 3
Shortfall in electricity	Input	GJ/dry t pulp	2.39	4
Forest residues for electricity	Input	GJ/dry t pulp	5.98	4
Forest residues for pulp	Input	GJ/dry t pulp	5.38	4
Total forest residues	Input	GJ/dry t pulp	11.36	
Pulp	Output	GJ/dry t pulp	14.05	2
DME	Output	GJ/dry t pulp	11.87	4
Total outputs	Output	GJ/dry t pulp	25.92	

Comments

- Roundwood requirement for pulp mill: 2.05 dry tonnes / dry tonne pulp
- LHV wood (dry)= 19 MJ / kg dry wood
- Moisture (wood) = 50%
- LHV (pulp – cellulose dry) = 15.9 MJ/kg dry
- Moisture (pulp) = 10%
- LHV (DME) = 28.4 MJ/kg
- GJ dry roundwood per GJ output = 1.50
- GJ dry forest residues per GJ output = 0.44

For transport and distribution of DME, see 'wood to DME pathway'.

3. Black liquor gasification to FT liquids

Table 255 Black liquor gasification to FT liquids

	I/O	Unit	Amount	Source
Roundwood	Input	GJ/dry t pulp	39.0	1, 3
Shortfall in electricity	Input	GJ/dry t pulp	3.59	4
Forest residues for electricity	Input	GJ/dry t pulp	8.98	4
Forest residues for pulp	Input	GJ/dry t pulp	1.11	4
Total forest residues	Input	GJ/dry t pulp	10.09	
Pulp	Output	GJ/dry t pulp	14.05	2
FT liquids	Output	GJ/dry t pulp	10.55	4
Total outputs	Output	GJ/dry t pulp	24.60	

Comments:

- Roundwood requirement for pulp mill: 2.05 dry tonnes / dry tonne pulp
- LHV wood (dry) = 19 MJ / kg dry wood
- Moisture (wood) = 50 %
- LHV (pulp - cellulose (dry) = 15.9 MJ/kg dry
- Moisture (pulp) = 10 %
- LHV (FT liquid) = 44 MJ/kg
- GJ dry roundwood per GJ output = 1.58
- GJ dry forest residues per GJ output = 0.41

Sources

1 Berglin et al., 1999.
2 ECN Phyllis database (value for cellulose).
3 Landälv, 2007.
4 Ekbom et al., 2005.

For transport and distribution of FT liquids, see 'wood to liquid hydrocarbons pathway.

6.16 Wood to Liquid Hydrocarbons

For the feedstock supply, data from “woodchips from SRF poplar 500-2500 km” or “woodchips from forest residues 500-2000 km” pathways (as appropriate) should be considered in the solid and gaseous bioenergy pathways (JRC, 2017).

BTL plant

Table 256 BTL plant

	I/O	**Unit**	**Amount**	Source
Biomass	Input	$MJ/MJ_{FT\ diesel}$	2.1288	1, 2, 3
Dolomite	Input	$MJ/MJ_{FT\ diesel}$	0.0052	1
NaOH	Input	$MJ/MJ_{FT\ diesel}$	0.000009	1
FT diesel	Output	MJ	1.000	

Comments

- LHV wood (dry) = 19 MJ/ kg dry wood.
- Moisture (wood chips) = 30 %.
- LHV (FT diesel) = 44 MJ/kg dry.
- Yield = 114.5 kg FT diesel / t wood (@ 30%).
- There is an excess electricity production of 0.239 MJ / MJ FT diesel. The above table represents inputs post-allocation to excess electricity. The electricity was assigned an exergy factor of 1.

Sources

1 Hamelinck, 2004.

2 Tijemsen et al., 2002.

3 Paisley et al., 2001.

4 Woods ad Bauen, 2003.

Transportation of FT diesel to the blending depot

The same transport mix used in ‘wheat to ethanol’ has been considered and the results were corrected by LHV.

6.17 Wood to methanol

For feedstock emissions, please refer to data in "woodchips from SRF poplar 500-2500 km" or "woodchips from forest residues 500-2000 km", as appropriate, in solid and gaseous bioenergy pathways (JRC, 2017).

Methanol plant

Table 257 Methanol production (gasification, synthesis)

	I/O	Unit	Amount	Source
Biomass	Input	$MJ/MJ_{Methanol}$	1.960	1, 2, 3, 4
Methanol	Output	MJ	1.000	

Comments

- LHV wood (dry) = 19 MJ/ kg dry wood.
- Moisture (wood chips) = 30 %.
- LHV (Methanol) = 19.9 MJ/kg
- Biomass input is an average of two systems; BCL's gasifier which requires 1.747 MJ woodchip input, and the Värnamo gasifier requiring 2.174 MJ woodchip input (BCL input includes extra 0.045 MJ wood used by the plant to produce its own electricity).

Sources

1 Katofsky, 1993.

2 Dreier et al., 1998.

3 Paisley et al., 2001.

4 Atrax, 1999.

Transportation of methanol to the blending depot

The same transport mix used in 'wheat to ethanol' has been considered and the results were corrected by LHV.

6.18 Wood to DME

For feedstock emissions, please refer to data in "woodchips from SRF poplar 500-2500 km" or "woodchips from forest residues 500-2000 km", as appropriate, in solid and gaseous bioenergy pathways (JRC, 2017).

DME plant

Table 258 DME production (gasification, synthesis)

	I/O	Unit	Amount	Source
Biomass	Input	MJ/MJ_{DME}	1.960	1, 2, 3
DME	Output	MJ	1.000	

Comments

- LHV wood (dry) = 19 MJ/ kg dry wood.
- Moisture (wood chips) = 30 %.
- LHV (DME) = 28.4 MJ/kg
- Yield = 392.7 kg / t wood (@ 30%).
- Output = 4.15 MWel produced by the gasification plant itself (extra wood input included in the calculation.

Sources

1 Katofsky, 1993.

2 Dreier et al., 1998.

3 Paisley et al., 2001.

Transportation of DME to the blending depot

The same transport mix used in 'wheat to ethanol' has been considered and the results were corrected by LHV.

6.19 Straw to ethanol

For the supply of straw, the straw baling processes upstream of the agricultural residues and straw pellet pathways should be considered from the solid and gaseous bioenergy pathways report (JRC, 2017).

Table 259 Conversion of wheat straw to ethanol via hydrolysis and fermentation with biomass by-product used for process heat and electricity (which is also exported)

	I/O	Unit	Amount	Source	Comment
Straw bales	Input	MJ/MJ$_{\text{ethanol}}$	3.52853	**1**, 3	5.5 t$_{\text{straw (dry)}}$/ t$_{\text{ethanol}}$
Ammonium sulphate	Input	kg/MJ$_{\text{ethanol}}$	0.00016	**2**, 3	0.004 t$_{\text{input}}$ / t$_{\text{ethanol}}$
Ammonia	Input	kg/MJ$_{\text{ethanol}}$	0.00042	**2**, 3	0.011 t$_{\text{input}}$ / t$_{\text{ethanol}}$
Monopotassium phosphate	Input	kg/MJ$_{\text{ethanol}}$	0.00023	**2**, 3	0.006 t$_{\text{input}}$ / t$_{\text{ethanol}}$
Magnesium sulphate	Input	kg/MJ$_{\text{ethanol}}$	0.00003	**2**, 3	0.001 t$_{\text{input}}$ / t$_{\text{ethanol}}$
Calcium chloride	Input	kg/MJ$_{\text{ethanol}}$	0.00005	**2**, 3	0.001 t$_{\text{input}}$ / t$_{\text{ethanol}}$
Sodium chloride	Input	kg/MJ$_{\text{ethanol}}$	0.00035	**2**, 3	0.009 t t$_{\text{input}}$ / t$_{\text{ethanol}}$
Antifoam	Input	kg/MJ$_{\text{ethanol}}$	0.00070	**2**, 3	0.019 t$_{\text{input}}$ / t$_{\text{ethanol}}$
SO2	Input	kg/MJ$_{\text{ethanol}}$	0.00005	**2**, 3	0.001 t$_{\text{input}}$ / t$_{\text{ethanol}}$
DAP	Input	kg/MJ$_{\text{ethanol}}$	0.00031	**2**, 3	0.008 t$_{\text{input}}$ / t$_{\text{ethanol}}$
NaOH	Input	kg/MJ$_{\text{ethanol}}$	0.00485	**2**, 3	0.130 t$_{\text{input}}$ / t$_{\text{ethanol}}$
CaO	Input	kg/MJ$_{\text{ethanol}}$	0.00193	**2**, 3	0.052 t$_{\text{input}}$ / t$_{\text{ethanol}}$
Ethanol	Output	MJ	1.0000		
Electricity export	Output	MJ/MJ$_{\text{ethanol}}$	0.398	1	2 MJ lignin used to power CHP; electrical efficiency 26.7%.

Comments

- Enzymes (cellulose) production is assumed to be ‘integrated’ into the ethanol plant. This means that the same pre-treated cellulosic feedstock is used for both cellulase and ethanol. This would save 20% of costs (Ref. 2).
- LHV straw (dry) = 17. 2 MJ/ kg of dry straw (Ref. 4).
- Moisture (straw) = 13.5 %.

Sources

1 Biochemtex, 2015 and Biochemtex 2016 stakeholder workshop (September 2016).

2 Johnson, 2016.

3 Kaltschmitt and Hartmann, 2001.

4 ECN Phyllis 2 database (average data, for LHV).

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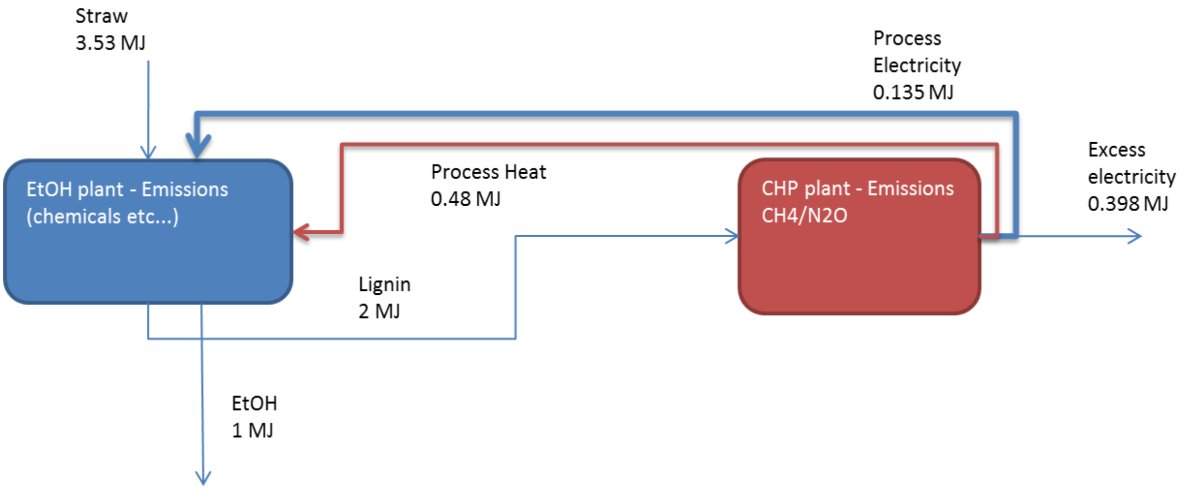
Calculation of exergy allocation for internal CHP

The use of an internal CHP in any pathway to produce process heat and electricity (and excess heat or electricity) requires emissions to be properly allocated between the heat and power produced. The methodology for this is detailed in COM (2016)767, Annex V part C.

The exergy allocation requires the solution of an algebraic system of equations to calculate the emissions shared between process heat and electricity used for ethanol production, and exported electricity from the plant. The inputs and outputs considered for this calculation are shown in the schematic below:



Transportation of ethanol to the blending depot

The same data are used as for wheat ethanol.

Ethanol depot distribution inputs

The same data are used as for wheat ethanol.

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Part Three — Review process

7. Consultation with experts and stakeholders

7.1 Expert Consultation (November 2011)

In order to guarantee transparency and ensure use of the most up-to-date scientific information and data, the JRC consulted with recognised experts. They discussed and resolved methodological issues and determined the best way to assess both the input data used for calculating default GHG emissions and the processes for future updates.

This expert consultation, organised by the JRC's Institute of Energy and Transport (IET), at JRC Ispra on 22 and 23 November 2011, had the following objectives.

- To discuss input data used in the latest JRC calculations of default values for biofuel, bioliquid, biomass and biogas (to be updated in annexes of the relevant directives). The aim of these discussions was to collect the experts' input and comments on the data presented, verify the data quality and ensure that data sources were current.
- To discuss the need for standardisation activities and for harmonisation of the used conversion factors and input values for GHG calculations.

To facilitate discussion and help experts prepare, input data for all solid, gaseous and liquid biofuels prepared by the JRC and used for GHG calculations were distributed one week prior to the meeting. The presentation of the data was structured as follows.

1. General overview of input data common for all pathways: fossil fuel comparator and crude mixes, transport processes, chemicals and fertilizers. Fuel properties (e.g. lower heating value (LHV), yield and moisture content) were distributed in advance, and were not discussed again during the meeting.
2. Presentation of biogas pathway input data, resulting from the combination of two feedstocks (manure and maize), two outputs (biomethane and electricity) and two groups of upgrading technologies.
3. Presentation of biomass pathway input data: 13 pathways from several feedstocks (e.g. forest or industrial residues, short rotation forestry, roundwood, and agricultural residues) through different process chains (used for power and heat production) were discussed.
4. Presentation of new JRC methodology for calculation of global N_2O emissions from cultivation, developed in collaboration with the Climate Change Unit of the JRC's Institute for the Environment and Sustainability (IES).
5. Presentation of liquid biofuel input data. These included the update of existing input data (e.g. rapeseed, soybean, palm oil, sugar and cereal crops), and the development of new pathways.

7.1.1 Main outcomes of the discussion

General issues

The main issues raised at the workshop are described below.

- JRC values for flaring emissions are increasing in this new set of data, compared to the previous version (from the Well-to-Wheels (WTW) report, version 2 – 2008 data set), while flaring emissions are observed to have decreased in recent years.
- It was suggested that differentiated emission factors for fossil fuels be used, based on different crude oil mixes for different world regions (instead of using the common EU value), making use of, for example, the US Environmental

Protection Agency (EPA) or International Energy Agency (IEA) inventory databases.

- Shipping emissions: the JRC considered that the return journey of the means of transport was empty. It was argued that the return trip is often used to transport other goods. While this may apply to container ships, it is not the case for chemical tankers or grain carriers: these are specialist ships, which will not easily find a suitable export commodity from the EU for the return journey.
- The JRC is using the Öko Institute's (44) Globales Emissions-Modell Integrierter Systeme (GEMIS) database v. 4.5 and v. 4.6 as a source for many input data. More updated versions are now available (4.7 was released in September 2011 and 4.8 in December 2011).
- Bonn University's Common Agricultural Policy Regional Impact Analysis (CAPRI) database provides a number of relevant input data for EU cultivation processes, and particularly on diesel use, that may be useful for supplementing the JRC data set.
- It was proposed that the JRC create and make available a specific database for emissions deriving from the production of fertilizers in use (not only ammonium nitrate and urea), using International Fertilizer Association (IFA) data.
- Fertilizers: if producers can claim emissions from a specific fertilizer factory, these may have already been 'traded away' under the Emissions Trading Scheme (ETS). Nevertheless, it is permitted, according to DG Energy.
- More information on the sources of EU fertilizer imports is desirable.
- The JRC was asked to clarify **how** the LHV data for feedstocks (e.g. wood, and dried distillers' grains with solubles (DDGS)) are calculated.
- Hydrotreated vegetable oil (HVO) fuel properties were not included in the database distributed at the workshop.

Comments on calculation of global N_2O emissions

- The approach for calculating soil N_2O emissions received positive feedback, especially the transparency of the methodology and the obtained results. However, it should be stressed that the Stehfest and Bouwman (2006) statistical approach allows the calculation of soil N_2O emission for crop groups only; the individual biofuel crops have to be assigned to the corresponding group.

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(44) See http://www.oeko.de/home/dok/546.php online.

Comments on liquid biofuel pathways

Biodiesel pathways

- It was argued that emissions attributed to methanol input should consider the 40 % 'conservatism factor' in biodiesel processing emissions, since the amount of methanol is fixed stoichiometry, and will not vary from plant to plant. However, emissions associated with different processes for methanol production can vary greatly.
- A Greenpeace report analyses sources of soy biodiesel in the EU; this is useful for calculating a weighted average of EU suppliers.
- More up-to-date data on Brazilian soy-biodiesel cultivation and processing can be obtained from Centro Nacional de Referência em Biomassa (CENBIO) or Campinas University.
- Misprint in soy winterisation yield.
- **Operational** data now available for the NESTE (45) HVO process, and other Swedish HVO processes. The experts have agreed to provide the JRC with these data.
- The Institute for Energy and Environmental Research (IFEU) should be able to provide new data on biodiesel from jatropha seeds.
- The representative of NESTE OIL offered to provide data concerning a possible new pathway for biodiesel from *Camelina*.
- The EBB offered to provide data concerning soybean crushing.

Palm oil

- The MPOB noted that there was no decomposition of palm fruit before processing, as this is carried out within 24 hours in Malaysia.
- Another point for consideration is whether empty fruit bunches might form methane when used as mulch.
- There was a suggestion that palm kernel oil processing be separated from the palm oil process (this may be easily done by allocation to the kernels).
- Various palm oil data were received in paper published by MPOB staff; diesel use in particular needs to be checked.
- Methane capture from palm oil crushing effluent is only ~85 % effective; moreover, few oil mills in Malaysia are actually currently equipped with such technology.

Cottonseed oil

More data are now available, and representatives from the EBB offered to provide them to JRC.

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(45) See http://www.nesteoil.com/ online.

Animal fat

It needs to be specified whether the new default pathway applies only to Category 3 animal fats. Categories 1 and 2 should be classified as residues, according to Annex V of the RED.

Ethanol pathways

- The natural gas combined heat and power (NG CHP) process for 'steam' should refer to the 'heat' output. This needs to be checked.
- Electricity and steam use data in the ethanol process need to be checked: the latest processes may be better by 10 % to 15 %.
- A summary of comparison could be included in the JEC's Well-To-Tank (WTT) report.
- There are no straw-fired ethanol plants in the EU, but in Sweden these plants are fired by woodchips.
- Argonne National Laboratory in the United States produced an updated survey of fuel used in American maize-ethanol plants.
- We should not confuse Argonne National Laboratory's Californian 'Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation' (GREET) data with United States–average GREET data, for which there was an update in September 2011.
- There was a more detailed data in review of American dry mill ethanol production by Steffen Müller (2008)
- It was suggested that transportation of maize-ethanol to the EU is occurring by barge via the Mississippi river, rather than by train to Baltimore, as believed at the time. This needs to be checked in the JRC pathways.

  t was noted that in Brazil, limestone ($CaCO_3$) is used, not calcium oxide (CaO). There may be some confusion here: JRC's 'CaO for fertilizer' is ~85 % limestone, and only has about 10 % of the emissions of CaO as a process chemical.
- Sweet sorghum–ethanol data from Thailand can be provided by the IFEU. There are also data on cultivation trials in Spain. However, at the moment there seems to be no use of ethanol from sweet sorghum in the EU.

7.2 Stakeholder meeting (May 2013)

A second workshop was organized by the JRC's Institute of Energy and Transport (IET), in Brussel on 28 May 2013.

Representatives from industries, Member States and various stakeholders were invited to the meeting.

The objective was to present assumptions, input data and methodology used in the latest calculations for input data.

After the meeting, stakeholders had the opportunity to send comments and ask for clarifications on the draft report (2013) circulated before the meeting and the data presented during the workshop.

The comments and questions were received in June 2013. JRC took them into account for the final updates of the input data which are included in this version of the report.

7.2.1 Main updates

The main issues raised at the stakeholder meeting and the main changes compared to the draft report (2013) include:

- Fossil fuel comparators (FFC), diesel, heating oil and heavy fuel oil

- Improved N_2O calculation from GNOC

- New drying data from CAPRI

- P and K fertilizers: new updated data

- N fertilizer emissions: new updated data

- Calculation method for electricity credits for biofuel pathways (the ones using CHP in conventional ethanol and ethanol-from-straw).

- Correction of sodium methylate input data

- Updates in single pathways: updates and changes in some pathways (sugarbeet, palm oil, animal fats, etc.) are included in this report based on additional information provided by stakeholders.

- Transport of biodiesel and ethanol: made consistent in all pathways

7.3 Experts and stakeholders workshop (September 2016)

An expert and stakeholders workshops were organized by the JRC and DG ENER, in Brussel on 27 and 28 September 2016.

Experts and representatives from industries, Member States and stakeholders were invited to the meeting.

The objective was to present assumptions, input data and methodology used in the latest calculations for input data.

Before and after the workshops, experts and stakeholders had the opportunity to send comments and ask for clarifications on the draft report (2016) circulated before the meetings.

JRC took the comments into account for the final updates of the input data which are included in this version of the report.

The main changes are shown below and the lists of comments received along with the replies are included in Appendix 1 of version 1c of the report (46).

7.3.1 Main updates

The main changes compared to the draft report (August 2016 version) include:

- Fossil fuel comparator and fossil fuels supply emission factors (Section 2.1);

- Drying data (Section 2.5.2);

- Fertilizer inputs (N, K_2O and P_2O_5) updated with new data from Fertilizers Europe (2016);

- New acidification-induce emissions recommended by Fertilizers Europe;

- N_2O field emissions updated with new N fertilizer input;

- Exergy allocation between steam and electricity in CHP units and exergy allocation between exported electricity and ethanol (in the sugarcane to ethanol and straw to ethanol pathways);

- Various updates in single pathways with additional information received from stakeholders and recent data (Chapter 6).

7.4 Final version 1d compared to version 1c

This final version of the report updates and replaces the previous report (version 1c) published in July 2017 after the publication of the Commission proposal COM(2016)767.

The updated input data are based on additional information provided by companies for some pathwyas and additional research carried out by the JRC. The pathways affected by these final updates are mainly: palm oil, waste cooking oil, animal fat and HVO.

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(46) Edwards R., Padella M., Giuntoli J., Koeble R., O'Connell A., Bulgheroni C., Marelli L., 2017. 'Appendix 1- Outcomes of stakeholders conusltations - Definition of input data to assess GHG default emissions from biofuels in EU leglisaltion, version 1c - July 2017', JRC Science for Policy Report, EUR 28349EN.

Appendix 1. Fuel/feedstock properties

	Reference				
	Feedstocks				
	By-products				

Liquid biofuels (Et-OH)

Fuel	Property	Value	Unit	Reference	Comment
Gasoline	LHV (mass)	43.2	MJ/kg	WTT App. 1, V4a	
	LHV (volume)	32.2	MJ/l	WTT App. 1, V4a	
	Density	0.745	kg/l	WTT App. 1, V4a	
Diesel	LHV (mass)	43.1	MJ/kg	WTT App. 1, V4a	
	LHV (volume)	35.9	MJ/l	WTT App.1, V4a	
	Density	0.832	kg/l	WTT App.1, V4a	
Crude	LHV (mass)	42.0	MJ/kg	WTT App.1, V4a	
	LHV (volume)	34.4	MJ/l	WTT App.1, V4a	
	Density	0.820	kg/l	WTT App.1, V4a	
FT - diesel	LHV (mass)	44	MJ/kg	WTT App. 1, V4a	
	LHV (volume)	34.3	MJ/l	WTT App.1, V4a	
	Density	0.780	kg/l	WTT App.1, V4a	
Ethanol	LHV (mass)	26.8	MJ/kg	WTT App.1, V4a	
	LHV (volume)	21.3	MJ/l	WTT App.1, V4a	
	Density	0.794	kg/l	WTT App.1, V4a	
Methanol	LHV (mass)	19.9	MJ/kg	WTT App.1, V4a	

	LHV (volume)	15.8	MJ/l	WTT App.1, V4a	
	Density	0.793	kg/l	WTT App.1, V4a	
DME	LHV (mass)	28.4	MJ/kg	WTT App.1, V4a	
	LHV (volume)	19.0	MJ/l	WTT App.1, V4a	
	Density	0.670	kg/l	WTT App.1, V4a	
Sugarbeet	LHV dry	16.3	MJ/kg dry	Dreier et al., 1998	
	Moisture	75 %	kg water/kg total	CAPRI data	
	LHV-vap	2.2	MJ/kg wet		Calculated
Sugar beet pulp	LHV dry	16.1	MJ/kg dry	Kaltschmitt and Reinhardt, 1997	
	Moisture	9 %	kg water/kg total		
	LHV-vap	14.4	MJ/kg wet		Calculated
Wheat (grain)	LHV dry	17	MJ/kg dry	Kaltschmitt and Hartmann, 2001	
	Moisture	13.5 %	kg water/kg total	CAPRI data	
	LHV-vap	14.4	MJ/kg wet		Calculated
Wheat (straw)	LHV dry	17.2	MJ/kg dry	WTT App.1, V4a	
	Moisture	13.5 %	kg water/kg total	WTT App.1, V4a	
	LHV-vap	14.5	MJ/kg wet		Calculated
DDGS (wheat)	LHV dry	18.09	MJ/kg dry		Calculated
	Moisture	10 %	kg water/kg total		

	LHV-vap	16.0	MJ/kg wet		Calculated
Barley (grain)	LHV dry	17.0	MJ/kg dry	Kaltschmitt and Hartmann, 2001	
	Moisture	13.5 %	kg water/kg total		
	LHV-vap	14.4	MJ/kg wet		Calculated
DDGS (barley)	LHV dry	17.8	MJ/kg dry		Calculated
	Moisture	10 %	kg water/kg total		
	LHV-vap	15.7	MJ/kg wet		Calculated
Sugar cane	LHV dry	19.6	MJ/kg dry	Dreier, T., 2000	
	Moisture	72.5 %	kg water/kg total	Kaltschmitt, 2001	
	LHV-vap	3.6	MJ/kg wet		Calculated
Maize (grain)	LHV dry	17.3	MJ/kg dry	KTBL, 2006	
	Moisture	14 %	kg water/kg total	KTBL, 2006	
	LHV-vap	14.5	MJ/kg wet		Calculated
DDGS (maize)	LHV dry	19.2	MJ/kg dry		Calculated
	Moisture	10 %	kg water/kg total		
	LHV-vap	17.3	MJ/kg wet		Calculated
Triticale (grain)	LHV dry	16.9	MJ/kg dry	Kaltschmitt and Hartmann, 2001	
	Moisture	14 %	kg water/kg total		Assumed to be the same a rye
	LHV-vap	14.2	MJ/kg wet		Calculated

DDGS (triticale)	LHV dry	18.0	MJ/kg dry		Calculated
	Moisture	10 %	kg water/kg total		
	LHV-vap	16.0	MJ/kg wet		
Rye (grain)	LHV dry	17.1	MJ/kg dry	Kaltschmitt and Hartmann, 2001	
	Moisture	14 %	kg water/kg total	CAPRI data	
	LHV-vap	14.4	MJ/kg wet		
DDGS (rye)	LHV dry	17.8	MJ/kg dry		Calculated
	Moisture	10 %	kg water/kg total		
	LHV-vap	15.8	MJ/kg wet		

	Feedstocks				
	By-products				
	Oil				

Liquid biofuels (biodiesel)

Fuel	Property	Value	Unit	Reference	Comment
Crude and refined vegetable oil	LHV (mass)	37.0	MJ/kg	WTT App.1, V4a	
	LHV (volume)	34.0	MJ/l		
	Density	0.920	kg/l		
Biodiesel (methyl ester)	LHV (mass)	37.2	MJ/kg	WTT App.1, V4a	
	LHV (volume)	33.1	MJ/l		
	Density	0.890	kg/l		
Glycerol	LHV (mass)	16	MJ/kg	Edwards, JRC, 2003: chemical thermodynamic calculation with HSC for windows	
Rapeseed	LHV dry	27.0	MJ/kg dry	JRC calculation (see Section 6.8)	EU rapeseed only
	Moisture	9 %	kg water/kg total	Rous, J-F, Prolea, personal communication, 2012	
	LHV-vap	24.3	MJ/kg wet		
Rapeseed cake	LHV (dry)	18.4	MJ/kg dry	Back-calculated from rapeseed and EBB data on oil mill	
	Moisture	10.5 %	kg water/kg total		
	LHV-vap wet (RED)	16.2	MJ/kg wet		Calculated
Sunflower seed	LHV dry	27.2	MJ/kg dry	JRC calculation (see Section 6.9)	
	Moisture	9 %	kg water/kg total		

	LHV-vap	24.5	MJ/kg wet		Calculated
Sunflower cake	LHV dry	18.2	MJ/kg dry	Back-calculated from sunflower and EBB data on oil mill	
	Moisture	11.5 %	kg water/kg total		
	LHV-vap	15.8	MJ/kg wet		Calculated
Soybeans	LHV dry	23	MJ/kg dry	Jungbluth et al., 2007	
	Moisture	13 %	kg water/kg total		
	LHV-vap	19.7	MJ/kg wet		Calculated
Soybeans cake	LHV dry	19.1	MJ/kg dry		
	Moisture	12.1 %	kg water/kg total	Back-calculated from mass balance soybean cake 794 kg cake/1 000 kg moist soybean; 192 kg oil/1 000 kg moist soybean	However, Bunge report has maximum 12.5 %
	LHV-vap	16.5	MJ/kg wet		Calculated
Palm (fresh fruit bunch)	LHV dry	24.0	MJ/kg dry		
	Moisture	34 %	kg water/kg total		
	LHV-vap	15.0	MJ/kg wet		Calculated
Palm kernel meal	LHV dry	18.5	MJ/kg dry	Kaltschmitt and Reinhardt, 1997	
	Moisture	10 %	kg water/kg total		
	LHV-vap	16.4	MJ/kg wet		Calculated
Animal fat (also tallow oil)	LHV dry	38.8	MJ/kg dry	ECN database Phyllis 2	
	Moisture	1.2 %	kg water/kg total		
	LHV-vap	38.3	MJ/kg wet		Calculated

Appendix 2. Crop residue management

Table 260 Fraction of crop residues removed from the field based on JRC/PBL (2010). The residue removal for cereals (excluding maize) in the EU is an expert estimate based on recent literature.

COUNTRY ID	COUNTRY NAME	EU27	barley	cassava	coconut	cotton	maize	oilpalm	rapeseed	rye	safflowe	sorghum	soybean	sugarbeet	sugarcane	sunflower	triticale	wheat
13	AUSTRIA	EU2	0.2				0		0	0.2			0	0		0	0.2	0.2
16	BELGIUM	EU2	0.2				0		0	0.2		0		0		0	0.2	0.2
20	BULGARIA	EU2	0.2				0		0	0.2		0	0	0		0	0.2	0.2
50	CZECH REPUBLIC	EU2	0.2				0		0	0.2			0	0		0	0.2	0.2
54	DENMARK	EU2	0.2				0		0	0.2				0		0	0.2	0.2
61	ESTONIA	EU2	0.2				0		0	0.2			0	0		0	0.2	0.2
63	FINLAND	EU2	0.2				0		0	0.2			0	0		0	0.2	0.2
66	FRANCE	EU2	0.2				0		0	0.2		0	0	0		0	0.2	0.2
51	GERMANY	EU2	0.2				0		0	0.2		0		0		0	0.2	0.2
80	GREECE	EU2	0.2				0		0	0.2			0	0		0	0.2	0.2
91	HUNGARY	EU2	0.2				0		0	0.2		0	0	0		0	0.2	0.2
95	IRELAND	EU2	0.2				0		0	0.2				0		0	0.2	0.2
10	ITALY	EU2	0.2				0		0	0.2		0	0	0		0	0.2	0.2
12	LATVIA	EU2	0.2				0		0	0.2			0	0		0	0.2	0.2
12	LITHUANIA	EU2	0.2				0		0	0.2			0	0		0	0.2	0.2
12	LUXEMBOURG	EU2	0.2				0		0	0.2				0		0	0.2	0.2
15	NETHERLANDS	EU2	0.2				0		0	0.2				0		0	0.2	0.2
16	POLAND	EU2	0.2				0		0	0.2			0	0		0	0.2	0.2
16	PORTUGAL	EU2	0.2				0		0	0.2			0	0		0	0.2	0.2
17	ROMANIA	EU2	0.2				0		0	0.2		0	0	0		0	0.2	0.2
19	SLOVAKIA	EU2	0.2				0		0	0.2			0	0		0	0.2	0.2
19	SLOVENIA	EU2	0.2				0		0	0.2		0	0	0		0	0.2	0.2
60	SPAIN	EU2	0.2				0		0	0.2		0	0	0		0	0.2	0.2
19	SWEDEN	EU2	0.2				0		0	0.2				0		0	0.2	0.2
70	UNITED KINGDOM	EU2	0.2				0		0	0.2				0		0	0.2	0.2
1	AFGHANISTAN		0.5				0.5		0.5			0.5	0.5	0.5	0.5	0.5		0.5
4	ALBANIA		0.2				0			0.2			0	0		0		0.2
56	ALGERIA		0.9				0.9		0.9			0.9		0.9		0.9	0.9	0.9
5	ANDORRA		0.2				0		0				0			0		0.2
2	ANGOLA			0.6			0.6					0.6	0.6		0.6	0.6		
8	ARGENTINA		0.2	0.2			0.2		0.2	0.2		0.2	0.2	0.2	0	0.2		0.2
9	ARMENIA		0				0						0	0		0		0
12	AUSTRALIA		0				0		0	0		0	0		0	0	0	0
14	AZERBAIJAN		0				0			0			0	0	0	0		0
19	BANGLADESH		0.3	0.3			0.3		0.3			0.3	0.3		0.3	0.3		0.3
24	BELARUS		0				1		0	0			0	0		0	0	0
25	BELIZE			0.2			0.2					0.2	0.2		0			0.2
17	BENIN			0.7			0.7					0.7	0.7		0.7			
31	BHUTAN		0.9				0.1		0.1			0.1	0.1		0			0.9
27	BOLIVIA		0.2	0.2			0.2					0.2	0.2		0	0.2		0.2
23	BOSNIA AND HERZEGOWINA		0.2				0		0	0.2			0	0		0		0.2
32	BOTSWANA			0.6			0.6					0.6	0.6		0.6	0.6		0.6
28	BRAZIL		0.2	0.2			0.2			0.2		0.2	0.2		0	0.2		0.2
30	BRUNEI DARUSSALAM			0.1														
18	BURKINA FASO			0.7			0.7					0.7	0.7		0.7			
15	BURUNDI			0.7			0.7					0.7	0.7		0.7			0.7
10	CAMBODIA			0.1			0.1					0.1	0.1		0	0.1		
39	CAMEROON			0.7			0.7					0.7	0.7		0.7			0.7
34	CANADA		0				0		0	0			0	0		0	0	0
33	CENTRAL AFRICAN REPUBLIC			0.7			0.7					0.7			0.7			
20	CHAD			0.7			0.7					0.7			0.7			
36	CHILE		0.2				0.2		0.2	0.2				0.2	0	0.2		0.2
37	CHINA		0.7	0.4			0.4		0.4	0.4		0.4	0.4	0.4	0.4	0.4	0.4	0.7
43	COLOMBIA		0.2	0.2			0.2					0.2	0.2		0			0.2
41	CONGO			0.2			0.2					0.2	0.2		0.2			
40	CONGO, THE DEMOCRATIC REPUBLIC OF T			0.2			0.2					0.2	0.2		0.2	0.2		0.2

COUNTRY ID	COUNTRY NAME	EU27	barley	cassava	coconut	cotton	maize	oilpalm	rapeseed	rye	safflowe	sorghum	soybean	sugarbeet	sugarcane	sunflower	triticale	wheat
46	COSTA RICA			0.2			0.2					0.2	0.2		0			
38	COTE D'IVOIRE			0.7			0.7					0.7	0.7		0.7			
89	CROATIA		0.2				0		0	0.2		0	0	0		0	0.2	0.2
47	CUBA			0.2			0.2								0			
55	DOMINICAN REPUBLIC			0.2			0.2					0.2			0			
57	ECUADOR		0.2	0.2			0.2					0.2	0.2		0			0.2
58	EGYPT		0.9				0.9			0.9		0.9	0.9	0.9	0.9	0.9		0.9
18	EL SALVADOR		0.2	0.2			0.2					0.2	0.2		0			0.2
79	EQUATORIAL GUINEA			0.7														
59	ERITREA		0.7				0.7					0.7			0.7			0.7
62	ETHIOPIA		0.7	0.7			0.7		0.7			0.7	0.7		0.7			0.7
84	FRENCH GUIANA			0.2											0			
69	GABON			0.7			0.7					0.7	0.7		0.7			
77	GAMBIA			0.7			0.7					0.7			0.7			
71	GEORGIA		0				0			0			0	0		0		0
73	GHANA			0.7			0.7					0.7	0.7		0.7			
83	GUATEMALA		0.2	0.2			0.2					0.2	0.2		0			0.2
75	GUINEA			0.7			0.7					0.7	0.7		0.7			
78	GUINEA-BISSAU			0.7			0.7					0.7			0.7			
86	GUYANA			0.2			0.2								0			
90	HAITI			0.2			0.2					0.2			0			
88	HONDURAS			0.2			0.2					0.2	0.2		0			0.2
87	HONG KONG						0.1											
94	INDIA		0.9	0.2			0.2		0.2			0.2	0.2		0.8	0.2		0.9
92	INDONESIA			0.1			0.1						0.1		0.1			
96	IRAN, ISLAMIC REPUBLIC OF		0.9				0.9		0.9			0.9	0.9	0.9	0.9	0.9		0.9
97	IRAQ		0.2				0.2					0.2	0.2	0.2		0.2		0.2
99	ISRAEL		0.2				0.2					0.2	0.2	0.2		0.2		0.2
10	JAMAICA			0.2			0.2								0			
10	JAPAN		0.9										0.1	0.1	0			0.9
10	JORDAN		0.2				0.2							0.2		0.2		0.2
10	KAZAKSTAN		0				0		0	0			0	0		0		0
10	KENYA		0.7	0.7			0.9		0.7			0.5	0.7		0.7	0.7		0.7
16	KOREA, DEMOCRATIC PEOPLE'S REPUBLIC		0.9	0.1			0.1			0.1		0.1	0.1			0.1		0.9
11	KOREA, REPUBLIC OF		0.9				0.1		0.1	0.1		0.1	0.1					0.9
11	KUWAIT		0.2				0.2											0.2
10	KYRGYZSTAN		0				0					0		0		0		0
11	LAO PEOPLE'S DEMOCRATIC REPUBLIC			0.1			0.1		0.1			0.1	0.1		0	0.1		0.9
11	LEBANON		0.2				0.2					0.2		0.2				0.2
12	LESOTHO		0.6				0.6			0.6		0.6	0.6			0.6		0.6
11	LIBERIA			0.7			0.7						0.7		0.7			
11	LIBYAN ARAB JAMAHIRIYA		0.9				0.9											0.9
13	MACEDONIA, THE FORMER YUGOSLAV REP		0.2				0		0	0.2			0	0		0	0.2	0.2
12	MADAGASCAR			0.7			0.7								0.7			0.7
14	MALAWI			0.7			0.7					0.7	0.7		0.7	0.7		0.7
14	MALAYSIA			0.1			0.1					0.1			0	0.1		
13	MALI			0.7			0.7					0.7			0.7			0.7
13	MAURITANIA						0.7					0.7			0.7			
13	MEXICO		0.2	0.2			0.2					0.2	0.2	0.2	0	0.2	0.2	0.2
12	MOLDOVA, REPUBLIC OF		0				0		0	0			0	0		0		0
13	MONGOLIA		0.9				0.1		0.1				0.1			0.1		0.9
12	MOROCCO		0.9				0.9		0.9			0.9		0.9	0.9	0.9		0.9
13	MOZAMBIQUE			0.7			0.7					0.7	0.7		0.7	0.7		0.7
13	MYANMAR		0.1	0.1			0.1		0.1	0.1		0.1	0.1		0.1	0.1	0.1	0.1
14	NAMIBIA			0.6			0.6					0.6				0.6		
15	NEPAL		0.9				0.1		0.1				0.1		0			0.9
15	NEW ZEALAND		0				0		0									0
15	NICARAGUA			0.2			0.2					0.2	0.2		0			0.2
14	NIGER			0.7			0.7					0.7	0.7		0.7			0.7
15	NIGERIA			0.7			0.7					0.7	0.7		0.7			0.7
15	NORWAY		0.2						0	0.2							0.2	0.2
15	OMAN											0.2						0.2
15	PAKISTAN		0.8				0.8		0.8			0.8			0.8	0.8		0.8
17	PALESTINIAN TERRITORY, OCCUPIED		0.2				0.2					0.2				0.2		0.2

COUNTRY ID	COUNTRY NAME	EU27	barley	cassava	coconut	cotton	maize	oilpalm	rapeseed	rye	safflowe	sorghum	soybean	sugarbeet	sugarcane	sunflower	triticale	wheat
16	PANAMA			0.2			0.2					0.2			0			
16	PAPUA NEW GUINEA			0.1											0			
17	PARAGUAY		0.2	0.2			0.2					0.2	0.2		0	0.2		0.2
16	PERU		0.2	0.2			0.2								0			0.2
16	PHILIPPINES			0.1			0.1						0.1		0.1			
16	PUERTO RICO			0.2			0.2								0			
17	RUSSIAN FEDERATION		0	0			0		0	0			0	0		0	0	0
17	RWANDA			0.7			0.7					0.7	0.7		0.7	0.7		0.7
17	SAUDI ARABIA		0.2				0.2					0.2						0.2
18	SENEGAL			0.7			0.7					0.7			0.7			
17	SERBIA AND MONTENEGRO		0.2				0		0	0.2			0	0		0	0.2	0.2
18	SIERRA LEONE			0.7			0.7					0.7			0.7			
18	SOMALIA		0.7	0.7			0.7					0.7			0.7			0.7
22	SOUTH AFRICA		0.6	0.6			0.6			0.6		0.6	0.6		0.6	0.6		0.6
11	SRI LANKA			0.1			0.1						0.1		0			
18	SUDAN			0.7			0.7					0.7			0.7	0.7		0.7
19	SURINAME			0.2									0.2		0			
19	SWAZILAND						0.6					0.6	0.6		0.6	0.6		0.6
35	SWITZERLAND		0.2				0		0	0.2			0	0		0	0.2	0.2
19	SYRIAN ARAB REPUBLIC		0.2				0.2					0.2	0.2	0.2		0.2		0.2
21	TAIWAN, PROVINCE OF CHINA						0.1					0.1			0			
20	TAJIKISTAN		0				0					0	0	0		0		0
21	TANZANIA, UNITED REPUBLIC OF		0.7	0.7			0.1					0.1	0.7		0.7	0.7		0.7
20	THAILAND			0.1			0.1					0.1	0.1		0.1	0.1		0.1
20	TIMOR LESTE			0.1			0.1						0.1					
20	TOGO			0.7			0.7					0.7						
20	TRINIDAD AND TOBAGO			0.2			0.2								0			
20	TUNISIA		0.9						0.9			0.9		0.9		0.9	0.9	0.9
21	TURKEY		0.2				0.2		0.2	0.2		0.2	0.2	0.2		0.2	0.2	0.2
20	TURKMENISTAN		0				0					0		0		0		0
21	UGANDA			0.7			0.7					0.7	0.7		0.7	0.7		0.7
21	UKRAINE		0				0		0	0		0	0	0		0	0	0
21	UNITED STATES		0				0		0	0		0	0	0	0	0		0
21	URUGUAY		0.2				0.2					0.2	0.2		0	0.2		0.2
21	UZBEKISTAN		0				0			0		0		0		0		0
22	VENEZUELA			0.2			0.2					0.2	0.2		0	0.2		
22	VIET NAM		0.4	0.4			0.4		0.4	0.4			0.4		0		0.4	0.4
22	YEMEN		0.2				0.2					0.2						0.2
22	ZAMBIA			0.6			0.6					0.6	0.6		0.6	0.6		0.6
23	ZIMBABWE		0.6	0.6			0.6					0.6	0.6		0.6	0.6		0.6

Table 261 Fraction of crop residues burnt in the field based on JRC/PBL (2010) and Seabra et al. (2011) for Brazilian sugarcane.

COUNTRY ID	COUNTRY NAME	EU27	barley	cassava	coconut	cotton	maize	oilpalm	rapeseed	rye	safflowe	sorghum	soybean	sugarbeet	sugarcane	sunflower	triticale	wheat
13	AUSTRIA	EU2	0.0				0.0		0.0	0.0			0.0	0.0		0.0	0.0	0.0
16	BELGIUM	EU2	0.0				0.0		0.0	0.0		0.0		0.0		0.0	0.0	0.0
20	BULGARIA	EU2	0.1				0.1		0.1	0.1		0.1	0.1	0.1		0.1	0.1	0.1
50	CZECH REPUBLIC	EU2	0.1				0.1		0.1	0.1			0.1	0.1		0.1	0.1	0.1
54	DENMARK	EU2	0.0						0.0	0.0				0.0			0.0	0.0
61	ESTONIA	EU2	0.1				0.1		0.1	0.1			0.1	0.1			0.1	0.1
63	FINLAND	EU2	0.0				0.0		0.0	0.0			0.0	0.0				0.0
66	FRANCE	EU2	0.0				0.0		0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0
51	GERMANY	EU2	0.0				0.0		0.0	0.0		0.0		0.0		0.0	0.0	0.0
80	GREECE	EU2	0.1				0.1		0.1	0.1			0.1	0.1		0.1		0.1
91	HUNGARY	EU2	0.1				0.1		0.1	0.1		0.1	0.1	0.1		0.1	0.1	0.1
95	IRELAND	EU2	0.0						0.0					0.0				0.0
10	ITALY	EU2	0.0				0.0		0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0
12	LATVIA	EU2	0.1				0.1		0.1	0.1			0.1	0.1			0.1	0.1
12	LITHUANIA	EU2	0.1				0.1		0.1	0.1			0.1	0.1		0.1	0.1	0.1
12	LUXEMBOURG	EU2	0.0				0.0		0.0	0.0				0.0			0.0	0.0
15	NETHERLANDS	EU2	0.0				0.0		0.0	0.0				0.0			0.0	0.0
16	POLAND	EU2	0.1				0.1		0.1	0.1			0.1	0.1		0.1	0.1	0.1
16	PORTUGAL	EU2	0.0				0.0		0.0	0.0			0.0	0.0		0.0	0.0	0.0
17	ROMANIA	EU2	0.1				0.1		0.1	0.1		0.1	0.1	0.1		0.1	0.1	0.1
19	SLOVAKIA	EU2	0.1				0.1		0.1	0.1			0.1	0.1		0.1	0.1	0.1
19	SLOVENIA	EU2	0.1				0.1		0.1	0.1		0.1	0.1	0.1		0.1	0.1	0.1
60	SPAIN	EU2	0.0				0.0		0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0
19	SWEDEN	EU2	0.0						0.0	0.0				0.0			0.0	0.0
70	UNITED KINGDOM	EU2	0.0						0.0	0.0				0.0			0.0	0.0
1	AFGHANISTAN		0.1				0.1		0.1			0.1	0.1	0.1	0.16	0.1		0.1
4	ALBANIA		0.1				0.1			0.1			0.1	0.1		0.1		0.1
56	ALGERIA		0.0				0.0		0.0			0.0		0.0		0.0	0.0	0.0
5	ANDORRA		0.0				0.0		0.0				0.0			0.0		0.0
2	ANGOLA			0.0			0.0					0.0	0.0		0.06	0.0		
8	ARGENTINA		0.2	0.2			0.2		0.2	0.2		0.2	0.2	0.2	0.99	0.2		0.2
9	ARMENIA		0.1				0.1						0.1	0.1		0.1		0.1
12	AUSTRALIA		0.2				0.3		0.2	0.2		0.2	0.2		0.39	0.2	0.2	0.2
14	AZERBAIJAN		0.1				0.1			0.1			0.1	0.1	0.1	0.1		0.1
19	BANGLADESH		0.1	0.1			0.1		0.1			0.1	0.1		0.11	0.1		0.1
24	BELARUS		0.1				0		0.1	0.1			0.1	0.1		0.1	0.1	0.1
25	BELIZE			0.2			0.2					0.2	0.2		0.99			0.2
17	BENIN			0.1			0.1					0.1	0.1		0.13			
31	BHUTAN		0				0.4		0.4			0.4	0.4		1			0
27	BOLIVIA		0.2	0.2			0.2					0.2	0.2		0.99	0.2		0.2
23	BOSNIA AND HERZEGOWINA		0.1				0.1		0.1	0.1			0.1	0.1		0.1		0.1
32	BOTSWANA			0.0			0.0					0.0	0.0		0.06	0.0		0.0
28	BRAZIL		0.2	0.2			0.2			0.2		0.2	0.2		0.64	0.2		0.2
30	BRUNEI DARUSSALAM			0.4														
18	BURKINA FASO			0.1			0.1					0.1	0.1		0.13			
15	BURUNDI			0.1			0.1					0.1	0.1		0.17			0.1
10	CAMBODIA			0.4			0.4					0.4	0.4		1	0.4		
39	CAMEROON			0.1			0.1					0.1	0.1		0.13			0.1
34	CANADA		0.0				0.0		0.0	0.0			0.0	0.0		0.0	0.0	0.0
33	CENTRAL AFRICAN REPUBLIC			0.1			0.1					0.1			0.13			
20	CHAD			0.1			0.1					0.1			0.13			
36	CHILE		0.2				0.2		0.2	0.2				0.2	0.99	0.2		0.2
37	CHINA		0.0	0.0			0.0		0.0	0.0		0.0	0.0	0.0	0.1	0.0	0.0	0.0
43	COLOMBIA		0.2	0.2			0.2					0.2	0.2		0.99			0.2
41	CONGO			0.2			0.1					0.2	0.2		0.28			
40	CONGO, THE DEMOCRATIC RE			0.2			0.1					0.2	0.2		0.28	0.2		0.2
46	COSTA RICA			0.2			0.2					0.2	0.2		0.99			
38	COTE D'IVOIRE			0.1			0.1					0.1	0.1		0.13			
89	CROATIA		0.1				0.1		0.1	0.1		0.1	0.1	0.1		0.1	0.1	0.1
47	CUBA			0.2			0.2								0.99			
55	DOMINICAN REPUBLIC			0.2			0.2					0.2			0.99			
57	ECUADOR		0.2	0.2			0.2					0.2	0.2		0.99			0.2

COUNTRY ID	COUNTRY NAME	EU27	barley	cassava	coconut	cotton	maize	oilpalm	rapeseed	rye	safflowe	sorghum	soybean	sugarbeet	sugarcane	sunflower	triticale	wheat
58	EGYPT		0.0				0.0			0.0		0.0	0.0	0.0	0.01	0.0		0.0
18	EL SALVADOR		0.2	0.2			0.2					0.2	0.2		0.99			0.2
79	EQUATORIAL GUINEA			0.1														
59	ERITREA		0.0				0.0					0.0			0.07			0.0
62	ETHIOPIA		0.1	0.1			0.1		0.1			0.1	0.1		0.17			0.1
84	FRENCH GUIANA			0.2											0.99			
69	GABON			0.1			0.1					0.1	0.1		0.13			
77	GAMBIA			0.1			0.1					0.1			0.13			
71	GEORGIA		0.1				0.1			0.1			0.1	0.1		0.1		0.1
73	GHANA			0.1			0.1					0.1	0.1		0.13			
83	GUATEMALA		0.2	0.2			0.2					0.2	0.2		0.99			0.2
75	GUINEA			0.1			0.1					0.1	0.1		0.13			
78	GUINEA-BISSAU			0.1			0.1					0.1			0.13			
86	GUYANA			0.2			0.2								0.99			
90	HAITI			0.2			0.2					0.2			0.99			
88	HONDURAS			0.2			0.2					0.2	0.2		0.99			0.2
87	HONG KONG						0.4											
94	INDIA		0.0	0.2			0.3		0.2			0.2	0.2		0.2	0.2		0.0
92	INDONESIA			0.7			0.7						0.7		0.73			
96	IRAN, ISLAMIC REPUBLIC OF		0				0		0			0	0	0	0	0		0
97	IRAQ		0.1				0.1					0.1	0.1	0.1		0.1		0.1
99	ISRAEL		0.1				0.1					0.1	0.1	0.1		0.1		0.1
10	JAMAICA			0.2			0.2								0.99			
10	JAPAN		0.0										0.0	0.0	0.01			0.0
10	JORDAN		0.1				0.1							0.1		0.1		0.1
10	KAZAKSTAN		0.1				0.1		0.1	0.1			0.1	0.1		0.1		0.1
10	KENYA		0.1	0.1			0		0.1			0	0.1		0.17	0.1		0.1
16	KOREA, DEMOCRATIC PEOPLE'		0	0.4			0.4			0.4		0.4	0.4			0.4		0
11	KOREA, REPUBLIC OF		0				0.4		0.4	0.4		0.4	0.4					0
11	KUWAIT		0.2				0.2											0.2
10	KYRGYZSTAN		0.1				0.1					0.1		0.1		0.1		0.1
11	LAO PEOPLE'S DEMOCRATIC R			0.4			0.4		0.4			0.4	0.4		1	0.4		0
11	LEBANON		0.1				0.1					0.1		0.1				0.1
12	LESOTHO		0.0				0.0			0.0		0.0	0.0			0.0		0.0
11	LIBERIA			0.1			0.1						0.1		0.13			
11	LIBYAN ARAB JAMAHIRIYA		0.0				0.0											0.0
13	MACEDONIA, THE FORMER YU		0.1				0.1		0.1	0.1			0.1	0.1		0.1	0.1	0.1
12	MADAGASCAR			0.0			0.0								0.07			0.0
14	MALAWI			0.1			0.1					0.1	0.1		0.17	0.1		0.1
14	MALAYSIA			0.4			0.4					0.4			1	0.4		
13	MALI			0.1			0.1					0.1			0.13			0.1
13	MAURITANIA						0.1					0.1			0.13			
13	MEXICO		0.2	0.2			0.2					0.2	0.2	0.2	0.99	0.2	0.2	0.2
12	MOLDOVA, REPUBLIC OF		0.1				0.1		0.1	0.1			0.1	0.1		0.1		0.1
13	MONGOLIA		0				0.4		0.4				0.4			0.4		0
12	MOROCCO		0.0				0.0		0.0			0.0		0.0	0.01	0.0		0.0
13	MOZAMBIQUE			0.1			0.1					0.1	0.1		0.17	0.1		0.1
13	MYANMAR		0.4	0.4			0.4		0.4	0.4		0.4	0.4		0.49	0.4	0.4	0.4
14	NAMIBIA			0.0			0.0					0.0				0.0		
15	NEPAL		0				0.4		0.4				0.4		1			0
15	NEW ZEALAND		0.5				0.5		0.5									0.5
15	NICARAGUA			0.2			0.2					0.2	0.2		0.99			0.2
14	NIGER			0.1			0.1					0.1	0.1		0.13			0.1
15	NIGERIA			0.1			0.1					0.1	0.1		0.13			0.1
15	NORWAY		0.0						0.0	0.0							0.0	0.0
15	OMAN											0.2						0.2
15	PAKISTAN		0.1				0.1		0.1			0.1			0.19	0.1		0.1
17	PALESTINIAN TERRITORY, OCC		0.2				0.2					0.2				0.2		0.2
16	PANAMA			0.2			0.2					0.2			0.99			
16	PAPUA NEW GUINEA			0.4											1			
17	PARAGUAY		0.2	0.2			0.2					0.2	0.2		0.99	0.2		0.2
16	PERU		0.2	0.2			0.2								0.99			0.2
16	PHILIPPINES			0.6			0.6						0.6		0.65			
16	PUERTO RICO			0.2			0.2								0.99			
17	RUSSIAN FEDERATION		0.1	0.1			0.1		0.1	0.1			0.1	0.1		0.1	0.1	0.1

COUNTRY ID	COUNTRY NAME	EU27	barley	cassava	coconut	cotton	maize	oilpalm	rapeseed	rye	safflowe	sorghum	soybean	sugarbeet	sugarcane	sunflower	triticale	wheat
17	RWANDA			0.1			0.1					0.1	0.1		0.17	0.1		0.1
17	SAUDI ARABIA		0.2				0.2					0.2						0.2
18	SENEGAL			0.1			0.1					0.1			0.13			
17	SERBIA AND MONTENEGRO		0.1				0.1		0.1	0.1			0.1	0.1		0.1	0.1	0.1
18	SIERRA LEONE			0.1			0.1					0.1			0.13			
18	SOMALIA		0.0	0.0			0.0					0.0			0.07			0.0
22	SOUTH AFRICA		0.0	0.0			0.0			0.0		0.0	0.0		0.06	0.0		0.0
11	SRI LANKA			0.4			0.4						0.4		1			
18	SUDAN			0.0			0.0					0.0			0.07	0.0		0.0
19	SURINAME			0.2									0.2		0.99			
19	SWAZILAND						0.0					0.0	0.0		0.06	0.0		0.0
35	SWITZERLAND		0.0				0.0		0.0	0.0			0.0	0.0		0.0	0.0	0.0
19	SYRIAN ARAB REPUBLIC		0.1				0.1					0.1	0.1	0.1		0.1		0.1
21	TAIWAN, PROVINCE OF CHINA						0.4					0.4			1			
20	TAJIKISTAN		0.1				0.1					0.1	0.1	0.1		0.1		0.1
21	TANZANIA, UNITED REPUBLIC		0.1	0.1			0.2					0.2	0.1		0.17	0.1		0.1
20	THAILAND			0.5			0.5					0.5	0.5		0.53	0.5		0.5
20	TIMOR LESTE			0.4			0.4						0.4					
20	TOGO			0.1			0.1					0.1						
20	TRINIDAD AND TOBAGO			0.2			0.2								0.99			
20	TUNISIA		0.0						0.0			0.0		0.0		0.0	0.0	0.0
21	TURKEY		0.3				0.3		0.3	0.3		0.3	0.3	0.3		0.3	0.3	0.3
20	TURKMENISTAN		0.1				0.1					0.1		0.1		0.1		0.1
21	UGANDA			0.1			0.1					0.1	0.1		0.17	0.1		0.1
21	UKRAINE		0.1				0.1		0.1	0.1		0.1	0.1	0.1		0.1	0.1	0.1
21	UNITED STATES		0.0				0.0		0.0	0.0		0.0	0.0	0.0	0.03	0.0		0.0
21	URUGUAY		0.2				0.2					0.2	0.2		0.99	0.2		0.2
21	UZBEKISTAN		0.1				0.1			0.1		0.1		0.1		0.1		0.1
22	VENEZUELA			0.2			0.2					0.2	0.2		0.99	0.2		
22	VIET NAM		0	0.4			0.4		0.4	0.4			0.4		1		0.4	0
22	YEMEN		0.2				0.2					0.2						0.2
22	ZAMBIA			0.0			0.0					0.0	0.0		0.06	0.0		0.0
23	ZIMBABWE		0.0	0.0			0.0					0.0	0.0		0.06	0.0		0.0

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List of abbreviations and definitions

AERU	Agriculture & Environment Research Unit
ALA	Agricultural Lime Association
AOAC	Association of Official Analytical Chemists
BGN	below-ground nitrogen
CA	conventional agriculture
CAPRI	Common Agricultural Policy Regional Impact
CEC	cation exchange capacity
CENBIO	Centro Nacional de Referência em Biomassa
CFB	circulating fluidised bed
CHP	combined heat and power
CRF	common reporting format
DDGS	dried distillers' grains with solubles
DG Climate Action	Directorate-General for Climate Action
DG Energy	Directorate-General for Energy
DNDC	DeNitrification DeComposition
EBB	European Biodiesel Board
EcoLab	Laboratoire écologie fonctionnelle et environnement
EDGAR	Emission Database for Global Atmospheric Research
ENSAT	Ecole Nationale Supérieure Agronomique de Toulouse
ENTSO-E	European Network of Transmission System Operators for Electricity
EPA	Environmental Protection Agency
ETS	Emissions Trading Scheme
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FFB	fresh fruit bunch
FIEs	fertilizer-induced emissions
FQD	Fuel Quality Directive (2009/30/EC)
GEMIS	Globales Emissions-Modell Integrierter Systeme (Global Emission Model of Integrated Systems)
GHG	greenhouse gas
GNOC	Global crop- and site-specific Nitrous Oxide emission Calculator
GREET	Gases, Regulated Emissions, and Energy use in Transportation
GWP	global warming potential
HV	high voltage
HVO	hydrotreated vegetable oil
IEA	International Energy Agency

IES	Institute for the Environment and Sustainability
IET	Institute of Energy and Transport
IFA	International Fertilizer Association
IFEU	Institute for Energy and Environmental Research
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
JEC	JRC-EUCAR-CONCAWE consortium
JRC	European Commission, Joint Research Centre
LBST	Ludwig-Bölkow-Systemtechnik GmbH
LCA	life cycle assessment
LHV	lower heating value
LPG	liquefied petroleum gas
LV	low voltage
MPOB	Malaysian Palm Oil Board
MV	medium voltage
NG CHP	natural gas combined heat and power
NG	natural gas
NREL	National Renewable Energy Laboratory
NUTS	Nomenclature of Territorial Units for Statistics
POME	palm oil milling effluent
RED	Renewable Energy Directive (2009/28/EC)
RFA	Renewable Fuels Agency
UCO	used cooking oil
UNICA	Brazilian Sugarcane Industry Association (A União da Indústria de Cana-de-Açúcar)
WTT	Well-To-Tank
WTW	Well-to-Wheels

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