DELIVERABLE FRONTPAGE

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List of abbreviations

CF:	Characterization Factor
ILCD:	International Reference Life Cycle Data System
LCA:	Life Cycle Assessment
LCIA:	Life Cycle Impact Assessment
LCI:	Life Cycle Inventory
PKO:	Palm kernel oil
PO:	Palm oil

1. Introduction: Goal and scope definition

This paper reports the life cycle assessment (LCA) case study carried out by Unilever on a tub of Rama margarine marketed in Germany in 2008 and considers the application of the novel impact categories developed as part of the EU FP7 LC-IMPACT project.

The margarine with a fat content of 70% was manufactured at two sites, one in the Netherlands (Rotterdam) and one in Germany (Pratau). The margarine was sold as a 500g unit packaged in a polypropylene tub with an aluminium/polyethylene seal and a polypropylene lid. Margarine is a water in oil emulsion, composed of edible oils, water and some minor ingredients for example emulsifiers and vitamins, which provide the desired product performance such as taste and texture. The edible oils used included rapeseed oil and maize oil from Germany, palm oil and palm kernel oil from Malaysia and sunflower oil from Argentina, Russia and the Ukraine.

The LCA covers the life cycle of the margarine, from cradle to distribution centre (i.e. excluding retail and consumption stages); the foreground system focuses on the activities that occured at Unilever production sites including the processing of the edible oils and the manufacture of the finished margarine in the Netherlands and Germany. This includes refining of all of the crude oils, fractionation of the palm oil to palm stearin and olein, and the interesterification of the palm stearin and palm kernel oil. The LCA also includes the cultivation and extraction of the oils in the different countries and relevant transport stages, production of packaging etc. as part of the background system.

In order to be able to use the novel impact categories the inventories used require a level of spatial and temporal resolution that is not commonly provided. This resolution has been added when possible as described in section 2 (inventory assessment).

1.1. Aims and Objectives

The main goal of this case study is to test the applicability and relevance of the newly derived characterisation factors for the impact categories developed in LC IMPACT. In this sense, a product containing ingredients grown in a variety of geographies was selected in order to check the usefulness of the spatial differentiation in the impact assessment methods.

In addition, the study is aimed to complement previous work on margarine (Nilsson *et al.*, 2010; Jefferies *et al.*, 2012; Milà i Canals *et al.*, in press), and to check whether any previously unidentified hotspots could be detected with the new impact categories.

1.2. Systems function and functional unit

The system under study provides a plant-based spread for human consumption, with the function of providing nutrition and other additional purposes of spreads (Nilsson *et al.*, 2010). The functional unit of this LCA is a 500 g tub of margarine i.e. margarine in a fully packaged shelf ready consumer unit. The goals of the study do not require a comparison between products, and so no further considerations on the quality or functionality of the studied margarine are required.

1.3. Type of LCA

This is an attributional LCA that considers the environmental burdens associated with the production of a 500g tub of margarine sold in Germany.

1.4. System boundary

The system boundary for the study was cradle-to-manufacturer’s distribution centre as shown in

Figure 1.1. It included the cultivation of each of the different oil crops, the extraction and refining of the oils, the additional processing of palm oil and palm kernel oil, production of packaging, manufacture of the finished product (i.e. 500g tub of margarine) and transport of the product to the primary distribution centre. The foreground system is highlighted in grey and includes the activities that occur at Unilever manufacturing sites. The composition of the margarine and source of the oils are shown in Table 2.4.

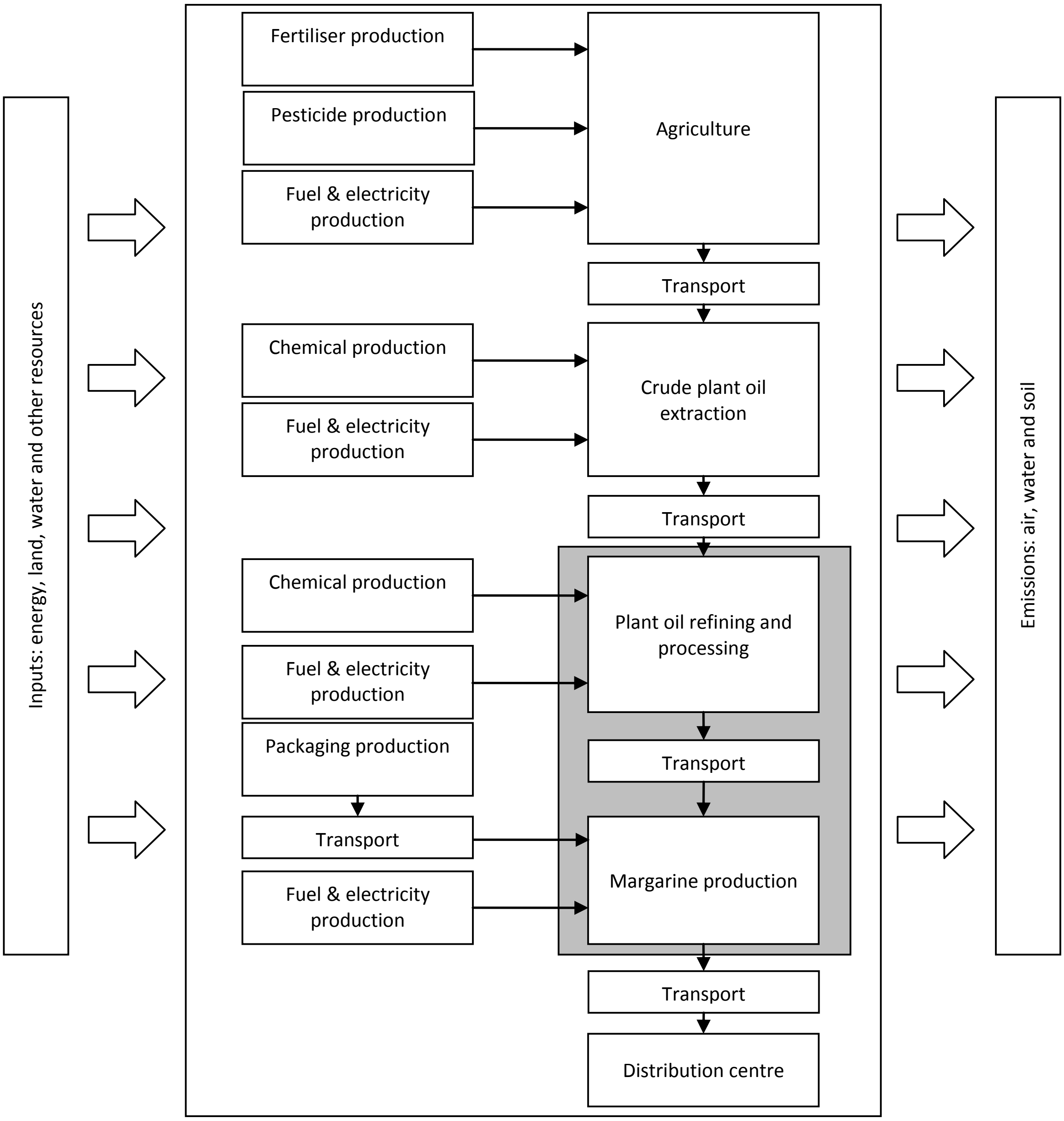

Figure 1.1: Simplified system boundary (500g tub of margarine)

1.5. Allocation

Economic allocation was used to assign impacts between different co-products in the various processes that lead to the production of margarine in this study unless otherwise stated. Economic was chosen as oil crops are harvested for their oil, without which, it would not be economic to grow them. This includes oil extraction where crude oil and oil cake/ meal are both produced but in general the oil crops are grown for the crude oil and the oil cake/ meal is a by-product used for animal feed as given in the Appendix 8.3. Further, the refining process produces both the refined oil and acid cake used for animal feed described in section 2.1.1.

1.6. Geographical, temporal and technological scope

The margarine that was studied was sold in Germany in 2008 and produced at two locations in Germany and The Netherlands. Data for the manufacturing stage were obtained from the two Unilever factories and are representative of the technology currently used in Europe. The source of the different oils by composition of the final product is shown in Table 2.4 and Table 2.5: .

1.7. Uncertainty considerations

The quality of the different processes used was considered following the ILCD guidelines. Only the uncertainty of the foreground "[v]ariability and stochastic error of the figures which describe the inputs and outputs due to e.g. measurement uncertainties, process specific variations, temporal variations, etc." has been expressed in quantitative terms (Frischnecht et al., 2007). The uncertainty around the appropriateness of the choice of datasets used was not considered nor was the background system. The overall data quality level has been indicated qualitatively in the inventory in the following sections using the Data Quality Rating (DQR) (ILCD, 2010). It is noted that the uncertainty in of both the CF and the different aspects of the inventory has not been propagated into a numerical result as the software used does not have this functionality. As all information that was used in the foreground processes came from the same sort of data source the DQR was the same for all processes.

1.8. Impact assessment

The LCA considers the application of the novel impact categories developed as part of the EU FP7 LC-IMPACT project; some existing impact categories and methods were included for comparative purposes. The impact categories considered are listed in Table 1.1.

Table 1.1: Summary of novel impact categories considered, and existing methods used to compare results.

Category	**Novel impact assessment method**	**Comparison impact assessment method**
Land use	Biodiversity Depletion Potential (BDP, de Baan *et al.* in press)	Land occupation – this is based loosely on the agricultural land occupation and urban land occupation (ReCiPe) approaches although it includes the total contribution of the different components of the product system to land occupation instead of just urban or agricultural occupation.
	Species extinction potential (de Baan *et al.*, submitted)	
Water use	Non-residential birds (Verones et al. 2013)	Not available
	Reptiles (Verones *et al.*, 2013)	Not available
	Water birds (Verones *et al.*,	Not available

	2013)	
	Water-dependent mammals(Verones *et al.*, 2013)	Not available
	Human health (Pfister *et al.*, 2009; Pfister and Hellweg, 2013)	Water stress indicator (WSI) (Pfister *et al.*, 2009; Pfister and Hellweg, 2013)
	Ecosystem quality (Pfister *et al.*, 2009; Pfister and Hellweg, 2013)	Water stress indicator (WSI) (Pfister *et al.*, 2009; Pfister and Hellweg, 2013)
	Resources (Pfister *et al.*, 2009; Pfister and Hellweg, 2013)	Water stress indicator (WSI) (Pfister *et al.*, 2009; Pfister and Hellweg, 2013)
	Fossil resource depletion (Vieira *et al.*, 2011)	Fossil depletion (ReCiPe)
Resources	Freshwater eutrophication (Azevedo, 2012)	Freshwater eutrophication (ReCiPe)
Aquatic eutrophication	Marine eutrophication (Cosme *et al.*, 2012)	Marine eutrophication (ReCiPe)
Acidification	Acidification (Azevedo *et al.*, 2012a)	Terrestrial acidification (ReCiPe)

2. Inventory and system description

The relevant information for modelling the system including the choice of datasets used and an indication of the level of uncertainty based on the requirements of the ILCD documentation is provided in the following sections. The foreground system is described in section 2.1 and includes oil refining, palm oil fractionation, interesterification and margarine production. The background system is described in section 2.2 including the cultivation of the different oil crops, oil extraction, packaging sourcing and production and transportation.

2.1. Foreground system

The foreground includes the refining of the different oils, fractionation of the refined palm oil to palm oil stearin (with the co-product palm oil olein) and the interesterification of the palm oil stearin and palm kernel oil. The manufacture of the margarine occurs at Unilever factories in Netherlands (Rotterdam) and in Germany (Pratau) whilst the other oils processing occurs only in The Netherlands. The allocation of manufacturing inputs was based on 50:50 production by mass as the finished product was considered to have the same economic value.

2.1.1. Oil refining

The refining process is considered to occur in the Netherlands and produces refined oil and the co-product acid oil cake which is used for animal feed. The production data are based on Unilever internal data for edible oil refining in the Netherlands. Economic allocation was also used to divide the burden between the refined oil and the acid oil cake, considering that the economic value of the cake is about 50% that of the refined oil. Table 2.1 specifies the main inputs and outputs to this process.

Table 2.1: Main input and output flows to the oil refining process for each plant oil per tonne of refined oil produced.

Input/ output	Palm	PKO	Maize	Rapeseed	Sunflower	Units	Overall data quality level	DQR*	Source/ proxy (generally Ecoinvent datasets)
Acid oil co-product	61.5	67.2	61.5	36.9	38	Kg	Basic	1.8	-
Activated carbon	0	0	0	2.02	5.05	Kg	Basic	1.8	GLO: charcoal, at plant [fuels]
Bleaching earth	7.5	4.3	7.5	7.1	3.0	Kg	Basic	1.8	CH: clay, at mine [additives]
Citric acid	0.54	0.54	0.54	0.01	0.01	Kg	Basic	1.8	Internal data
COD	0.054	0.054	0.054	0.25	0.25	Kg	Basic	1.8	Chemical oxygen

									demand (COD) [Analytical measures to fresh water]
Electricity	47.9	48.1	47.9	54.8	54.8	kWh	Basic	1.8	Modelled using different country Ecoinvent datasets
Diesel fuel and combustion	8.5	8.5	8.5	8.0	8.0	kg	Basic	1.8	Diesel Combustion (modified from Ecoinvent "operation, lorry 32t") and RER: diesel, at regional storage [fuels]
Cooling water	5.3	5.3	5.3	7.1	7.1	m^3	Basic	1.8	RER: water, completely softened, at plant [Appropriation]
Process water	0	0	0	0.16	0.16	m^3	Basic	1.8	RER: water, completely softened, at plant [Appropriation]
Sulphuric acid	0	0	0	10.9	11.2	Kg	Basic	1.8	RER: sulphuric acid, liquid, at plant [inorganics]
Phosphoric acid	0	0	0	1.14	0.85	Kg	Basic	1.8	RER: phosphoric acid, industrial grade, 85% in H2O, at plant [inorganics]
Nitrogen	5.3	5.3	5.3	5.0	5.0	Nm^3	Basic	1.8	RER: nitrogen,

									liquid, at plant [inorganics]
Sodium hydroxide	0	0	0	14.2	14.7	Kg	Basic	1.8	RER: sodium hydroxide, 50% in H2O, production mix, at plant [inorganics]
Crude oil lost from process	64.2	68.8	64.2	46.5	46.8	Kg	Basic	1.8	
Steam	214	215	214	266	266	Kg	Basic	1.8	RER: heat, natural gas, at boiler modulating >100kW [heating systems]
Land occupation	0.26	0.26	0.26	0.26	0.26	m^2×year	Basic	1.8	industrial area, temperate broadleaf and mixed forests
Land occupation	0.73	0.73	0.73	0.73	0.73	m^2×year	Basic	1.8	urban green area, temperate broadleaf and mixed forests

*Data Quality Rating (DQR) (ILCD, 2010)

In order to be able to assess the environmental impacts associated with land use for the industrial-based activities, the land occupation was quantified using data for Unilever's margarine manufacturing site in Germany (Milà i Canals *et al.*, in press) and classified by their biome (Koellner *et al.*, in press) to enable spatial differentiation during the life cycle impact assessment (LCIA).

2.1.2. Palm oil fractionation

Palm oil fractionation involves the fractionation of refined palm oil to palm oil stearin and palm oil olein using steam generated using gas and electricity (See Table 2.2). Note that although this activity occurs at manufacturing sites in both Germany and The Netherlands the dataset used during modelling for electricity was based on a German electricity mix. The allocation of impacts is based on the mass ratio of the two co-products produced from this process namely stearin and olein in a ratio of 20:80. Mass allocation was used for this activity because of the type of data available from the manufacturing site. It was assumed that there were no losses during palm oil fractionation.

Table 2.2: Main input flows to the palm oil fractionation process per kg of fractionated oil produced.

Input	Amount	Units	Overall data quality level	DQR*	Data used
Steam**	0.12	kg/kg	Basic	1.8	RER: heat, natural gas, at boiler modulating >100kW [heating systems]
Electricity	0.097	MJ/kg	Basic	1.8	DE: electricity, medium voltage, at grid [supply mix]

*Data Quality Rating (DQR) (ILCD, 2010)

**The amount of steam given in kg was converted to MJ using the multiplication factor of 3.228 MJ/kg – this is the total fuel burned input of steam for chemical processes (Zah & Hischier, 2007).

2.1.3. Interesterification

Interesterification of palm stearin and palm kernel oil is necessary prior to margarine production. The process involves deodorisation, bleaching and interesterification. There are two routes for interesterification, namely chemical and enzymatic. The production data used in this study was an average of the two routes and it was assumed that the process occured in both The Netherlands and Germany. Note that although this activity occurs at manufacturing sites in both Germany and The Netherlands the dataset used during modelling for electricity was based on a German electricity mix (See Table 2.3). Also, the input of enzyme into the process has been excluded.

Table 2.3: Main input and output flows to the palm oil stearin and kernel oil interesterification process per tonne of interestified oil produced.

	Amount	Units	Overall data quality level	DQR*	Data used
Steam	146	kg/tonne	Basic	1.8	RER: heat, natural gas, at boiler modulating >100kW [heating systems]
Electricity	26.3	kWh/tonne	Basic	1.8	DE: electricity, medium voltage, at grid [supply mix]
Natural gas**	6	Nm^3/tonne	Basic	1.8	RER: heat, natural gas, at boiler modulating >100kW [heating systems]
Bleaching earth	2	kg/tonne	Basic	1.8	DE: bentonite, at processing [additives]
Palm kernel oil	35	%	Basic	1.8	-

Oil loss	14.6	kg/tonne	Basic	1.8	-

*Data Quality Rating (DQR) (ILCD, 2010)

**The energy content of natural gas is 36.3 MJ/Nm^3.

2.1.4. Margarine product (ingredients and packaging)

The Rama margarine marketed in Germany is produced at two sites, one in Germany (Pratau) and one in The Netherlands (Rotterdam) in equal amounts. The plant oil composition of the margarine and the sourcing of those plant oils are given in Table 2.4 and Table 2.5 respectively. The utilities data given below in Table 2.6 are an average of the two sites as the 50% of the production was considered to occur at each site and the finished margarine has the same economic value.

Table 2.4: Composition of the studied margarine

Ingredient	% of mass	Source country
Palm oil & palm kernel oil (processed)	26.4	Malaysia
Maize oil	3.5	Germany
Rapeseed oil	36.2	Germany
Sunflower	3.5	Argentina, Russia and Ukraine
Water	29.1	-
Total*	98.7	-

*A cut-off of 0.5% by mass was chosen in the LCA and the mass of ingredients accounted for in the LCA was 98.7%. The remaining 1.3% of the margarine is made up of minor ingredients.

Table 2.5: Sourcing countries of crude plant oils

Crude oils	Source country	Amount (%)	Data used
Palm oil	Malaysia	100	Modelled agricultural, extraction, refining and Interesterification
Palm kernel oil	Malaysia	100	Modelled agricultural, extraction, refining and Interesterification
Maize oil	Germany	100	CH: grain maize IP, at farm [plant production], modelled extraction and refining
Rapeseed oil	Germany	100	Modelled agricultural, extraction and refining
Sunflower oil	Argentina	53	Modelled agricultural, extraction and refining
Sunflower oil	Russia	16	Modelled agricultural, extraction and refining
Sunflower oil	Ukraine	31	Modelled agricultural, extraction and refining

Table 2.6: Utilities at Unilever margarine factories

		Units	Overall data quality level	DQR*	Data used
Process water	20.4	L/kg margarine	Basic	1.8	RER: tap water, at user [Appropriation]
Electricity from	0.37	MJ/kg	Basic	1.8	DE: electricity, medium voltage, at

grid		margarine			grid [supply mix]
Gas	0.63	MJ/kg margarine	Basic	1.8	RER: heat, natural gas, at boiler modulating >100kW [heating systems]
Fuel oil	0.006	MJ/kg margarine	Basic	1.8	RER: heat, light fuel oil, at industrial furnace 1MW [heating systems]
Effluent** sent to municipal sewage treatment plant	20.36	L/kg margarine	Basic	1.8	CH: treatment, sewage, to wastewater treatment, class 3 [wastewater treatment]
Land occupation	0.26	m^2×year	Basic	1.8	artificial areas, industrial area, temperate broadleaf and mixed forests [Occupation (LU)]
Land occupation	0.73	m^2×year	Basic	1.8	artificial areas, urban, green areas, temperate broadleaf and mixed forests [Occupation (LU)]

*Data Quality Rating (DQR) (ILCD, 2010)

** This is based on the average amount of process water used in the two factories and is likely to be an overestimate.

In order to be able to assess the environmental impacts associated with land use for the industrial-based activities, the land occupation was quantified using data for Unilever's margarine manufacturing site in Germany (Milà i Canals *et al.*, in press) and classified by their biome (Koellner *et al.*, in press) to enable spatial differentiation during the life cycle impact assessment (LCIA).

The margarine is packed in a polypropylene tub with lid and a seal under the lid to protect the product. The packaging is brought into the manufacturing site in secondary packaging and the finished product is distributed in secondary packaging too. Packaging materials used are given in Table 2.7.

Table 2.7: Packaging materials used per 500g tub of margarine (unless otherwise stated).

Item	Raw material	Amount	Units	**Overall data quality level**	**DQR***	Data used (Ecoinvent database)
Tub	Polypropylene	11.1	g	Basic	1.8	RER: polypropylene, granulate, at plant [polymers] and RER: injection moulding [processing]
Lid	Polypropylene	5	g	Basic	1.8	RER: polypropylene, granulate, at plant [polymers] and RER:

						injection moulding [processing]
Secondary packaging tubs	Cardboard	135	g/kg tub	Basic	1.8	RER: corrugated board, recycling fibre, double wall, at plant [cardboard & corrugated board]
Secondary packaging lids	Cardboard	148	g/kg lid	Basic	1.8	RER: corrugated board, recycling fibre, double wall, at plant [cardboard & corrugated board]
Seal	Aluminium	1.14	g	Basic	1.8	RER: aluminium, production mix, at plant [Benefication]
	Polyethylene	0.24	g	Basic	1.8	RER: packaging film, LDPE, at plant [processing]
Distribution packaging	Cardboard	19	g	Basic	1.8	RER: corrugated board, recycling fibre, double wall, at plant [cardboard & corrugated board]
Secondary packaging finished product	Cardboard	19	g	Basic	1.8	RER: corrugated board, recycling fibre, double wall, at plant [cardboard & corrugated board]
Secondary packaging finished product	Polyethylene	0.24	g	Basic	1.8	RER: packaging film, LDPE, at plant [processing]

*Data Quality Rating (DQR) (ILCD, 2010)

2.2. Background system

2.2.1. Cultivation of oils

The edible oils that Unilever use in margarine are bought and sold in large volumes and the actual source mix for agricultural production is not readily available. In this study the spatial resolution for agricultural production for individual oils was therefore given as one or more source countries which were selected as being representative of where Unilever source its oils.

It is recognised that there is a large degree of variation spatially and temporally in impacts from agricultural production (Shonfield, 2008). This is due to differences in agricultural practices between different farms driven by local conditions such as climate, soil type, fertility, indigenous pests and the availability of technologies such as mechanisation, the use of fertilisers and pesticides etc. (Shonfield, 2008). Nevertheless, data for agricultural production for the majority of the different types of oils were based on single farms and data gaps were completed with published data. It is accepted that oil sourced from different locations even within the same country would likely show a large degree of variation in impacts compared to those represented in this inventory.

The agricultural production of rapeseed, sunflower, palm and palm kernel was modelled in Unilever's Agricultural LCA Model as detailed in Appendix 8.1 using GaBi 4. The data inputs into the agricultural model are given in this report (Appendix 8.3) relative to a hectare of crop production. No by-products from the crop production are considered, and as such all flows are allocated to the crop. On the other hand, maize was considered by using the Ecoinvent dataset CH: grain maize IP, at farm [plant production]. This was compared to the unaggregated CH: grain maize IP, at farm [plant production] to identify relevant inputs and emissions that occur on farm compared to those occurring off farm. Where necessary existing flows were corrected or additional ones were added. The full list of Ecoinvent datasets used in the agricultural model is captured in the screenshots from GaBi in appendix 8.2.

3. Modification of inventory flows to use new characterization factors

In order to use the new impact categories many flows in the inventory either needed to be replaced or additional flows added in order to be able to perform the LCIA using the new characterisation factors in the LCA software. In many cases this meant identifying flows and quantities in Ecoinvent datasets that occur at a country level compared to those occurring at an unknown level which were considered to be global. This meant manipulating datasets based on broad assumptions. This section refers to the relevant changes to flows in the datasets that are required for using the new impact categories.

3.1. Field emissions from crop production

The agricultural model considers emissions to air and water from the use of fertiliser modelled using the Bouwman model (Bouwman *et al.*, 2002, 2002a and Van Drecht *et al.*, 2003). Those emissions were corrected as given in the appendix **Error! Reference source not found.** in order to be able to use the newly developed characterisation factors.

The maize production was considered using the Ecoinvent dataset CH: grain maize IP, at farm [plant production]. This was compared to the unaggregated CH: grain maize IP, at farm [plant production] to identify relevant emissions that occur on farm compared to those occurring off farm. Existing flows were corrected and additional flows were added as given in the appendix 8.4, Table 8.7. Note that NMVOC emissions were not corrected.

3.2. Production of energy vectors

3.2.1. Light fuel oil used in manufacture

The use of light fuel oil during margarine manufacture was considered using the Ecoinvent dataset RER: heat, light fuel oil, at industrial furnace 1MW [heating systems]. This was compared to the unaggregated RER: light fuel oil, burned in industrial furnace 1MW, non-modulating [heating systems] dataset to identify relevant emissions that occur on site in the foreground system compared to those occurring in the background system. Existing flows were corrected and additional flows were added as given in the appendix 8.4, Table 8.8 for 1 MJ of light fuel oil burned.

3.2.2. Steam production from natural gas

The production of steam from natural gas during oil refining, palm oil fractionation, interesterification and margarine production was modelled using the Ecoinvent aggregated dataset RER: heat, natural gas, at boiler modulating >100kW [heating systems]. This was compared to the unaggregated RER: natural gas, burned in boiler modulating >100kW [heating systems] dataset to identify relevant emissions that occur on site in the foreground system compared to those occurring in the background system. Existing flows were corrected and additional flows were added as given in the appendix 8.4, Table 8.9 for 1 MJ of heat and parameterised in the model to be able to distinguish between the oil refining and processing that occurs in the Netherlands and margarine production that occurs in both the Netherlands and Germany. When the production occurs in both the Netherlands and Germany the values given for the respective flows are halved.

3.2.3. Diesel Combustion

The combustion of diesel during cultivation (e.g. operation tractor), during oil extraction and during oil refining was modelled using two Ecoinvent datasets: the aggregated dataset RER: diesel, at regional storage [fuels] and the unaggregated RER: operation, lorry 32t [Street]. The latter dataset was altered to be able to consider the input of diesel rather than tkm as this is how data was presented on cultivation, oil extraction and oil refining. Also, 49 additional flows have been added to be able to consider the new characterisation factors as given in the appendix 8.4, Table 8.10. All of these flows were parameterised in the model to be able to distinguish between them.

3.3. Other inventory flow changes related to specific impact areas

3.3.1. Land use - Land occupation and land transformation

The biodiversity damage potential method and characterisation factors provided by de Baan et al. (in press) were used to consider land use and land use change impacts at a WWF biome level (the appendix **Error! Reference source not found.**, Table 8.11 to Table 8.14). The identification and quantification of land occupation flows and transformation flows linked to the classification system (Koellner *et al.*, in press b) was determined using the method described by Milà i Canals et al. (in press). The biomes were determined by expert judgement using the biome map by Olson *et al.* (2001). It was assumed that the crop used the land for the whole of the year.

The new regional scale biodiversity method and characterisation factors provided by de Baan et al. (submitted) considers land use and land use change impacts at a WWF ecoregion level. As such refined level of spatial differentiation was not known for the studied crops, world average characterisation factors and country average factors were provided by de Baan (2013) as shown in the appendix 8.4, Table 8.15 and Table 8.16.

3.3.2. Water use

The amount of ground water and surface water that was consumed during irrigation of the crop was estimated using the country average blue water footprint for relevant countries taken from

Mekonnen and Hoekstra (2010) and the proportion of area actually irrigated taken from Siebert *et al.* (2010). The blue water flows and amount of water used is given in the appendix 8.4, Table 8.17

Background water flows in Ecoinvent datasets were not always clearly identified in GaBi software as ground water or surface water. The following assumptions were made when classifying these flows are given in Table 3.1.

Table 3.1: Blue water flows for background data.

Water flow	Water classification
Water	Surface
Water (ground water)	Ground
Water (lake water)	Surface
Water (river water)	Surface
Water (sea water)	n/a
Water (well water)	Ground
Water,turbine use, unspecified natural origin	Surface

3.3.3. Fossil resource depletion

The characterisation factors for fossil resource depletion were provided for different types of crude oil, natural gas and coal. Those CF were given as surplus cost in US dollars using different societal perspectives although only hierarchist was chosen for this study (Vieira *et al.*, 2011). The CF used in this study are given in Table 3.2.

Table 3.2: Characterisation factors for fossil resources data.

Flow	Unit	CF classification used*	Endpoint - Hierarchist (US$2008/unit)
Crude oil	Kg	Crude oil, light (>31.1 degree API)	0.11
Crude oil ecoinvent	Kg	Crude oil, light (>31.1 degree API)	0.11
Hard coal	Kg	Coal, coking (HHV >24 MJ/kg)	0.00085
Hard coal ecoinvent	Kg	Coal, coking (HHV >24 MJ/kg)	0.00085
Lignite	Kg	Coal, lignite (HHV <20 MJ/kg)**	0.00033
Lignite ecoinvent	Kg	Coal, lignite (HHV <20 MJ/kg)**	0.00033
Natural gas	Kg	Natural gas, medium energy (HHV 35-40 MJ/m3)	0.064
Natural gas ecoinvent	Nm^3	Natural gas, medium energy (HHV 35-40 MJ/m3)	0.051
Pit gas ecoinvent	Nm^3	Natural gas, medium energy (HHV 35-40 MJ/m3)	0.051

* default value chosen unless stated.

** lignite CF chosen.

3.3.4. Freshwater eutrophication

The characterisation factors provided for freshwater eutrophication were given as total-P and the individual P chemical species in the inventory. Therefore a number of new characterisation factors needed to be calculated. The proportion of P by weight in the different chemical species based on stoichiometry were used as the multiplication factors to convert the total-P characterisation factors into P chemical species characterisation factors as given in Table 3.3.

The characterisation factors were provided at a country level and global average (world default) to freshwater. Where emissions were to agricultural soil or industrial soil it was assumed that only 10% reaches the freshwater compartment. Characterisation factors for these emissions were corrected to consider that only 10% reaches freshwater.

The endpoint characterisation factors were provided for autotrophs and heterotrophs in lakes and streams. These were averaged before applying to the inventory.

Table 3.3: Factors used to calculate characterisation factors for different P chemical-species

Flow	Factor
Phosphorous	1
Phosphate	0.33
Phosphorous pentoxide	0.11

3.3.5. Marine eutrophication

The characterisation factors provided for marine eutrophication are given as total-N and not as the individual N chemical species in the inventory. Therefore a number of new characterisation factors needed to be calculated. The proportion of N by weight in the different chemical species based on stoichiometry were used as the multiplication factors to convert the total-N characterisation factors into N chemical species characterisation factors as given in Table 3.4. The characterisation factors are given at a country level to air, freshwater, groundwater and marine water. A global average (world default) was also provided.

Table 3.4: Factors used to calculate characterisation factors for different N containing chemical-species

Flow	Factor
Nitrogen (N)	1
Ammonia	0.82
Ammonium / ammonia	0.78
Ammonium carbonate	0.29
Nitrate	0.23
Nitrite	0.30
Nitrogen dioxide	0.30
Nitrogen oxides[3]	0.39

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[3] Average of nitrogen monoxide and nitrogen dioxide.

There were no N-flows to ground water in the inventories although many of the Ecoinvent background datasets accessed through the Ecoinvent website do contain such flows. This appears to be something to do with how the GaBi software interprets and clusters flows.

3.3.6. Acidification

The characterisation factors provided for acidification are given as sulphur dioxide, nitrogen oxides and ammonia at a country level only. These were taken directly without further manipulation and multiplied by the relevant emissions during the impact assessment stage. As no global average factors were provided they were calculated by taking an average of all of the countries.

4. Impact assessment results

The results of the impact assessment are presented by the components (descriptors) including the production of the different plant oils and other processes of the margarine life cycle shown in Table 4.1 together with a description of the activities included.

Table 4.1: Processes considered within each product life cycle component.

Component	Activities included
Maize oil	Cultivation of crop, oil extraction, oil refining and relevant transport
Rapeseed oil	
Sunflower oil	
Palm kernel oil (PKO)	
Palm oil (PO)	
PO & PKO processing	Fractionation of palm oil and interesterification of palm oil (PO) and palm kernel oil (PKO)
Packaging	Production of packaging and relevant transport
Production	Production of the margarine at the two Unilever sites
Distribution	Transport of finished product from factory to distribution centre

4.1. Land use impacts

4.1.1. Biodiversity damage potential

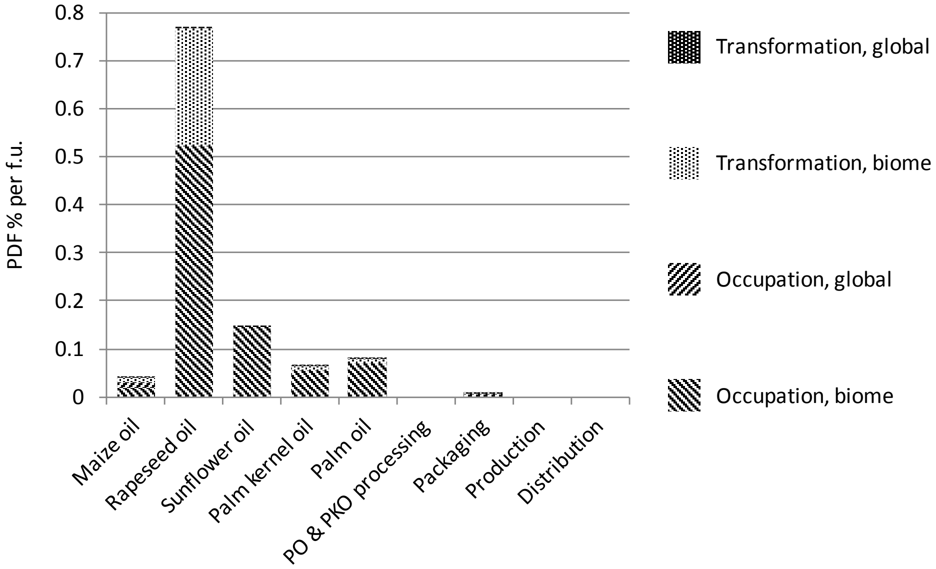


Figure 4.1: Contribution of different components of the product system to Biodiversity Potential calculated with the new CF (Units: PDF m^2 a/functional unit).

Figure 4.1 shows the contribution of the different components of the product system to biodiversity damage potential calculated with the new CF. The occupation and transformation flows were either given at a biome level or at a global level and the impact from land use on biodiversity damage potential was calculated with the respective CF for those flows. The different oil crops dominate the results mainly from cultivation and to a much lesser extent the processing of those oils with rapeseed being the biggest contributor due to it being the largest ingredient in the margarine (see Table 2.4). The sunflower and maize contributions are greater and the palm and palm kernels contributions are smaller than might be expected from their respective ingredient levels in the margarine. This can be explained by the differing crop yields of the oils (e.g. palm oil has a higher yield per unit area of land compared to sunflower and maize).

4.1.2. Species extinction potential

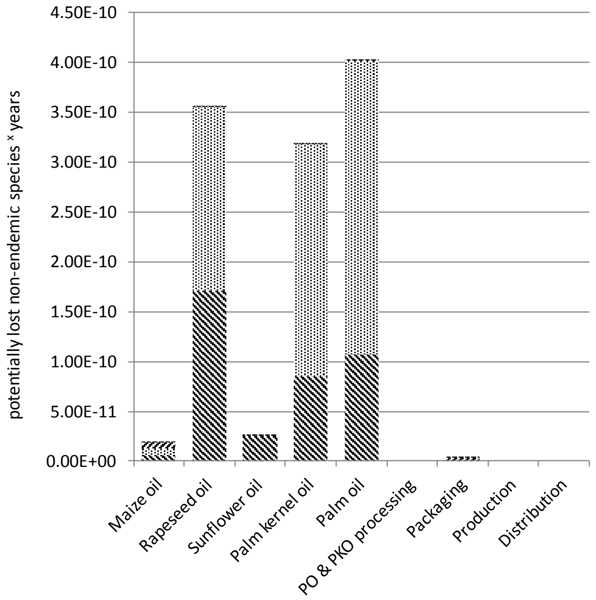


Figure 4.2: Contribution of land occupation and transformation to species extinction (Units: potentially lost NON-endemic species · years/functional unit).

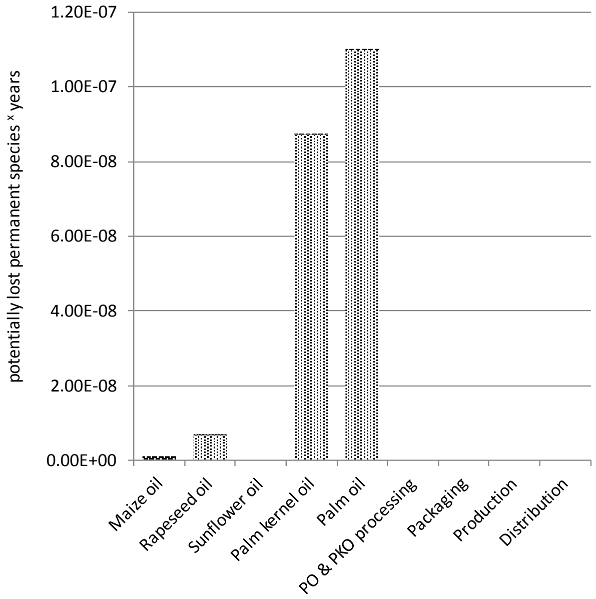


Figure 4.3: Contribution of land occupation and transformation to permanent species extinction (Units: potentially lost endemic species · years/functional unit).

▦ Transformation background ▨ Occupation background ░ Transformation cultivation ▧ Occupation cultivation

Figure 4.2 and Figure 4.3 show the contribution of the different components of the product system to non-endemic species extinction potential and permanent species extinction potential calculated with the new CF. The occupation and transformation flows were either given at a country level or at a global level based on ecoregion and the impact from land use was calculated with the respective CF for those flows. As was expected, the impacts were dominated by the cultivation stage, with minor contributions from occupation and transformation flows in the background system.

As opposed to Figure 4.1, the palm oil and palm kernel oil have a larger contribution to potential species extinction than rapeseed oil, which is the main ingredient in the margarine product. This is especially true for potential permanent extinctions (Figure 4.3), due to the higher occurrence of endemic species (and higher species number) in the country ecoregions where palm oil is grown. In this sense, using an absolute (Figure 4.2, Figure 4.3) vs. a relative (Figure 4.1) indicator provides a new dimension of information to the LCA results. Transformation flows dominate the results for absolute species extinction potential as opposed to the relative biodiversity damage potential, which is dominated by occupation flows (Figure 4.1, Milà i Canals *et al.*, in press).

4.1.3. Land occupation

The land occupation was based on the ReCiPe approach although includes the total contribution of different components of the product system to land occupation instead of just urban or agricultural occupation. The contribution to land occupation for all of the different components of the product system is shown in Figure 4.4.

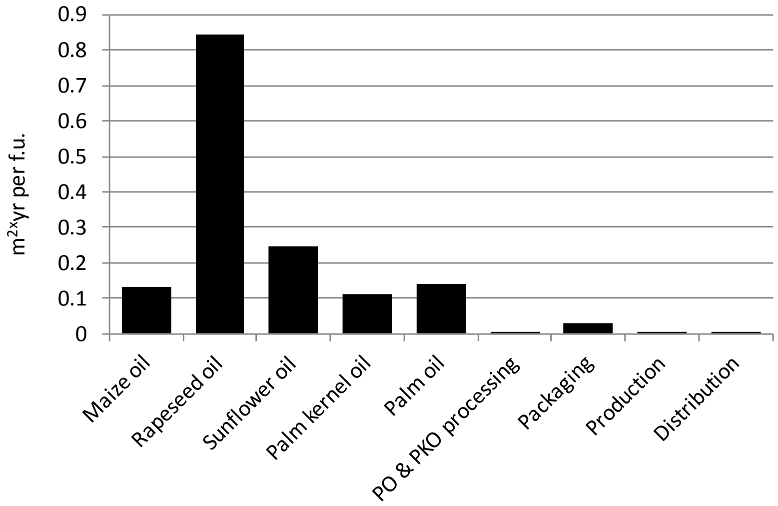


Figure 4.4: Contribution of different components of the product system to land occupation (Milà i Canals et al. in press).

As highlighted in Milà i Canals et al. (in press) using an inventory indicator for land occupation loosely based on the ReCiPe methodology (Figure 4.4) offers a very close proxy for the relative impacts on Biodiversity Damage Potential (Figure 4.1). However, the new method developed in LC IMPACT, which considers the potential absolute species extinctions at regional (Figure 4.2) and global (Figure 4.3) levels, provides completely different results: transformation, rather than occupation flows, comes to dominate the results, and the hotspots shift to the cultivation of crops in biodiversity-rich regions (e.g. palm oil in South East Asia).

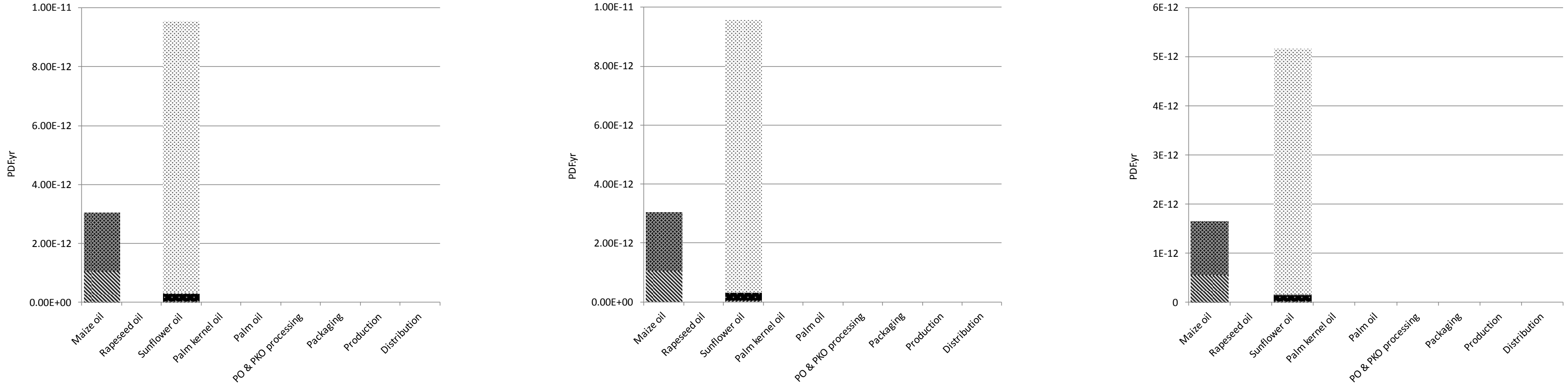
4.2. Consumptive water use impacts

The impacts associated with consumptive water use were considered using the water use impacts on wetlands biodiversity impacts categories and compared with the water stress indicator (WSI), human health, ecosystem quality and resources impact categories. Note that only water consumption associated with irrigation during cultivation was considered although the different components of the product system have been included in the legend of the results.

4.2.1. Water use impacts on wetlands biodiversity

The impact categories due to loss of non-residential birds, reptiles, water birds, water-dependent mammals and amphibians were considered (Verones *et al.*, submitted).

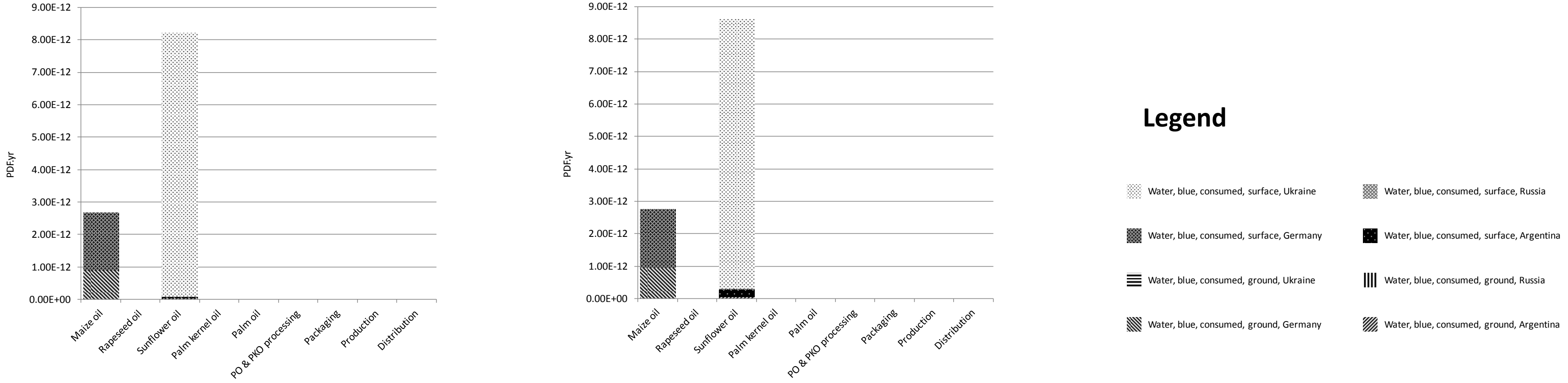
The consumptive water use flows were added for cultivation but only abstracted water flows were available for the background data and so no impacts from processes other than crop irrigation have been included here. The assessment of consumptive water use in crop cultivation as shown in Figure 4.5 and only sunflower and maize growing have such flows, as these were the only two irrigated crops. Sunflower cultivation is dominated by “water, blue, consumed, surface Ukraine” and the Ukraine has the highest water consumption compared to the other sourcing countries (Argentina and Russia). Furthermore in the Ukraine all the irrigation water used is considered to be abstracted from surface water whereas in Argentina and Russia it is a mix of surface and ground water. In addition the CF for consumed surface water is greatest for the Ukraine.



a. **Water consumption and non-residential birds .**

c. **Water consumption and water birds.**

e. **Water consumption and amphibians.**



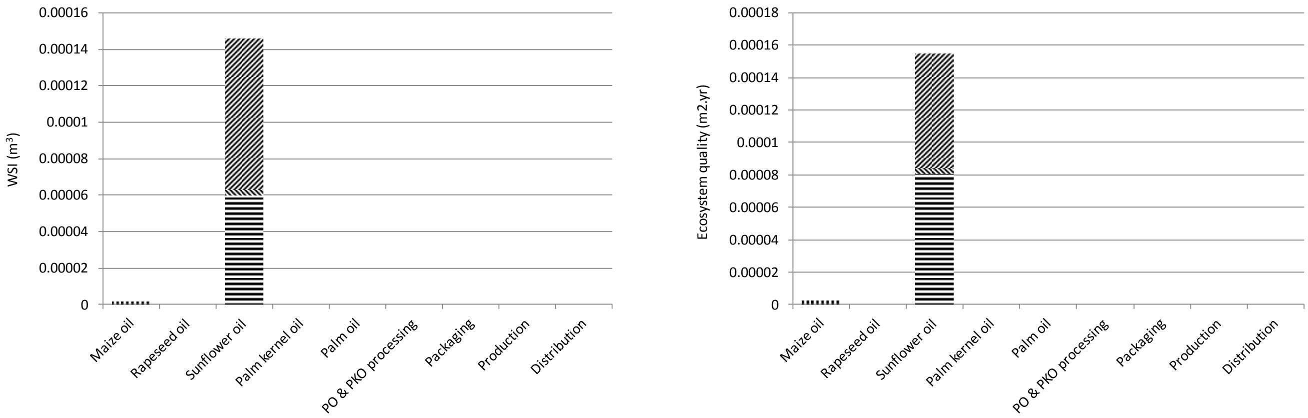
b. **Water consumption and reptiles.**

d. **Water consumption and water-dependent mammals.**

Figure 4.5: Water use impacts on wetlands biodiversity (non-residential birds, reptiles, water birds, water-dependent mammals and amphibians) across whole product life cycle including water consumed only during irrigation of the crops.

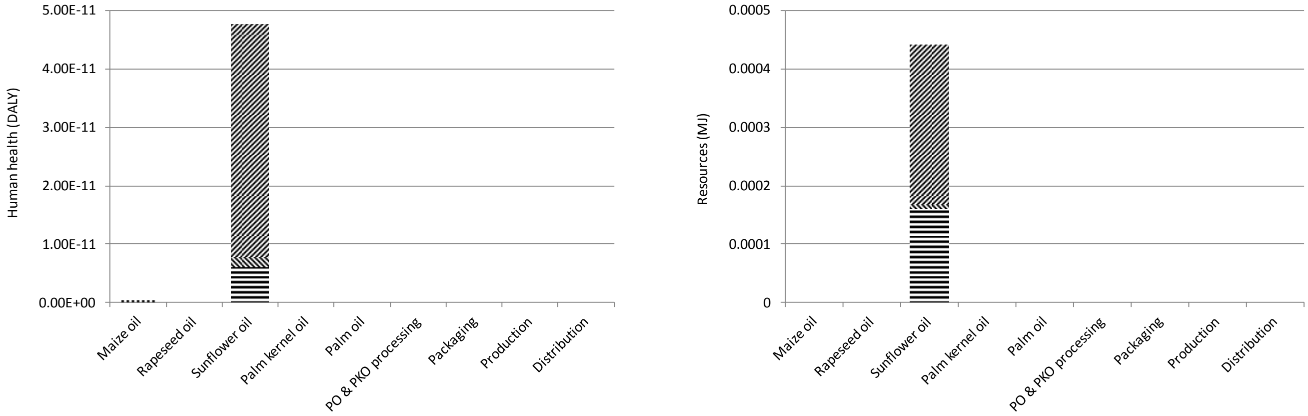
4.2.2. Water stress indicator (WSI), human health, ecosystem quality and resources

Additional impact categories associated with water use (midpoint water stress indicator (WSI), endpoint human health, endpoint ecosystem quality and endpoint resources) were assessed following the methods suggested by Pfister (Pfister et al. 2009; Pfister and Hellweg 2013). Results are provided in Figure 4.6. The methods suggest considering only the consumptive water use flows, which were only added for cultivation (see section 3.3.2) and are spatially resolved. It can be seen in Figure 4.6 that only sunflower and maize production have such flows, because these are the only irrigated crops. Sunflower cropping is dominated by “water, blue, consumed, surface Ukraine” and “water, blue, consumed, surface Argentina”. Sunflower grown in Ukraine has the highest water consumption per tonne compared to other sourcing countries (Argentina and Russia), although the CF for consumed surface water in Argentina is greater than Ukraine which is greater than for Russia.



a) Water stress indicator (WSI).

c) Ecosystem quality.



b) Human health.

d) Resources

Legend

▨ Water, blue, consumed, surface, Ukraine

▧ Water, blue, consumed, surface, Russia

▥ Water, blue, consumed, surface, Germany

▤ Water, blue, consumed, surface, Argentina

Figure 4.6: Impacts derived from water consumption.

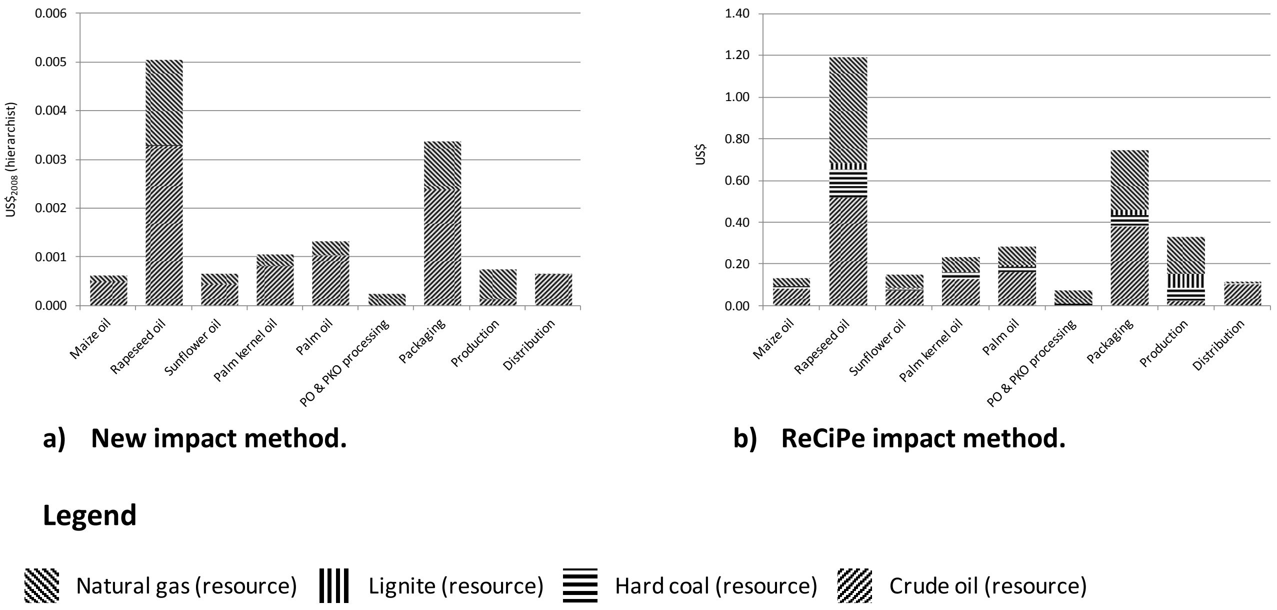
The results shown above for several impact categories derived from water consumption follow a similar pattern to the potential impacts on wetlands biodiversity. However, maize oil growing (in Germany) has an almost negligible contribution to the impacts described in this section, which suggests that CF for impacts on wetlands in Germany are higher than the impacts modelled with the WSI. Note that the contribution from processes other than crop irrigation have not been quantified due to the limitations in the inventory information. Such contribution is likely to be greater than zero, but probably negligible when compared to irrigation.

4.3. Fossil resource depletion

The impact results for fossil resource depletion are given in Figure 4.7 for both a) the new impact method and b) ReCiPe impact method.

The new impact method results are dominated by the use of natural gas and crude oil, which is in part due to their CF being greater than for the coal (coking and lignite) but mainly due to these being the dominant inputs. The contribution from the different oils is relative to their inclusion as ingredients in the product but also in part due to their yields. The life cycle stage with the greatest contribution to the different oils is cultivation, which includes diesel use on farm and the production of the different fertilisers. The contribution from packaging is from the fossil resource embodied in the material but also from the energy use to produce the material.

Comparing the new impact method to ReCiPe the contribution from the different life cycle elements is similar other than for ReCiPe where the margarine production has a greater contribution. This is due to the CF for coal (coking and lignite) being within the same scale as those for crude oil and natural gas.



a) New impact method.

b) ReCiPe impact method.

Legend

▨ Natural gas (resource) ||| Lignite (resource) ≡ Hard coal (resource) ▨ Crude oil (resource)

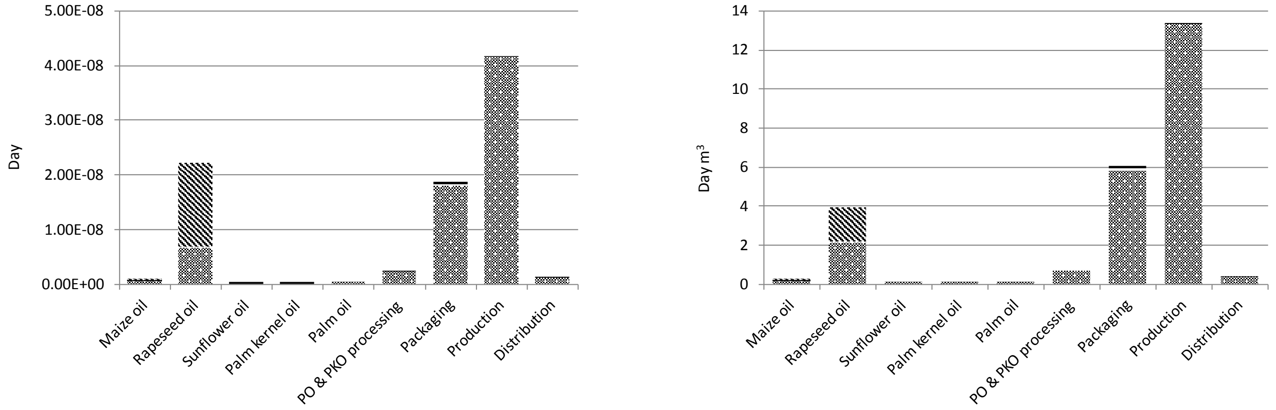
Figure 4.7: Endpoint fossil resource depletion.

Other resources are likely to be relevant in the life cycle of margarine, e.g. mineral resources such as phosphate rock for fertilisers. However, no new CF were provided in LC IMPACT for such resources, and so were excluded from the analysis.

4.4. Freshwater eutrophication

As shown in Figure 4.8, the emissions of phosphate linked to the production of the margarine dominate the results for freshwater eutrophication. These are emissions from waste water treatment using the Ecoinvent dataset “CH: treatment, sewage, to wastewater treatment, class 3” where the emission flows are considered at a global scale for spatial resolution. The flows in the Ecoinvent inventory for wastewater treatment were not modified to provide the spatial resolution that is required to use the new characterization factors due to time constraints during the project. The CF for the global emission compared to Germany for phosphate is four and eleven times greater at the mid point and end point level respectively suggesting the result from this phosphate emission is an overestimate.

The emission of phosphorous from rapeseed production in Germany is also large compared to Maize production due to the rapeseed being a significant ingredient. No P containing fertiliser was used on the sunflower and the amount used on palm and palm kernel oil was outweighed by P uptake by the crop.



a) Mid point

b) End point

Legend

▧ Phosphorus, Germany

▥ Phosphorus Pentoxide (P2O5)

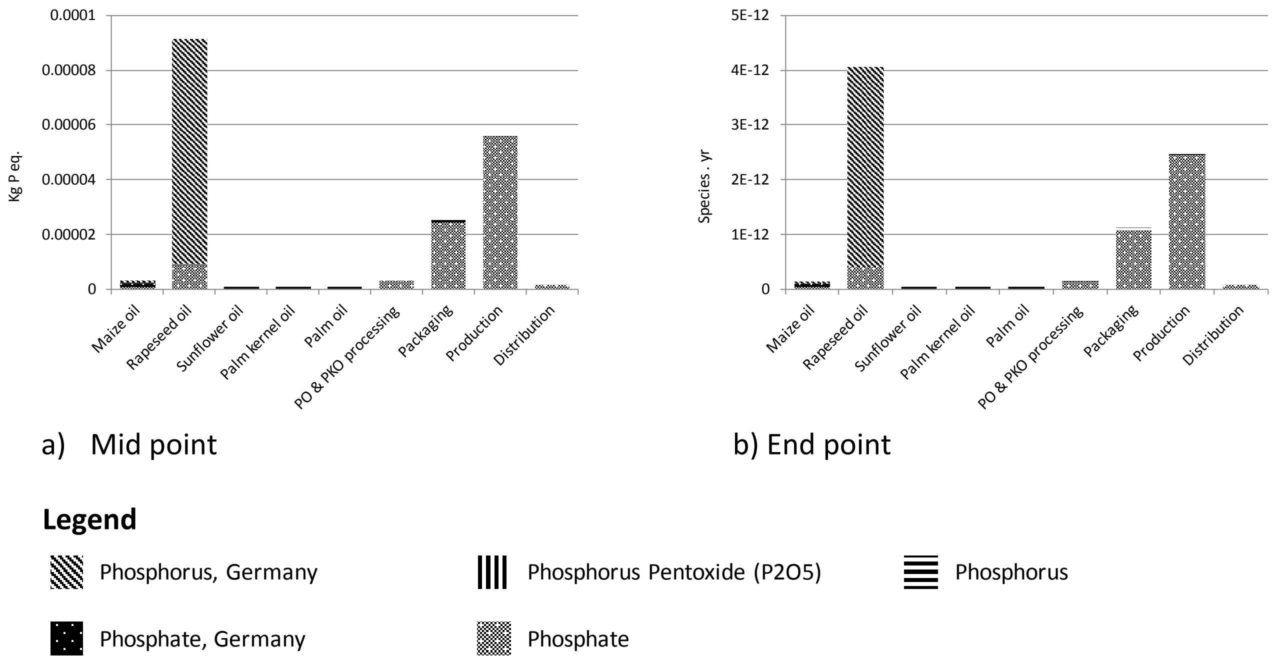
▤ Phosphorus

■ Phosphate, Germany

▩ Phosphate

Figure 4.8: New impact method freshwater eutrophication.

Comparing the results from the new method to ReCiPe in Figure 4.9 the same general pattern is seen with the exception of the phosphorus emission from rapeseed production in Germany which now dominates the margarine profile.



a) Mid point

b) End point

Figure 4.9: ReCiPe impact method freshwater eutrophication.

4.5. Marine eutrophication

Section 4.5.1 and 4.5.2 describe the results for the new method and ReCiPe method for assessing marine eutrophication respectively.

4.5.1. New method

Figure 4.10 shows the results for marine eutrophication potential following application of the new CF for the different N-species to air, freshwater and marine water described in section 3.3.5. These CF were generated in the LC IMPACT project, and are described in Cosme *et al.* (2012). The global CF value for “N to marine water” was calculated by taking an average of all country CF values for “N to marine water” as they were given as n/a in the information provided.

As shown in Figure 4.10, emissions linked to rapeseed cultivation dominate the results because this is a significant ingredient with relatively high nitrate and ammonia emissions. In addition, the new CF for emissions in Germany are very high compared to the other countries considered, with the exception of Ukraine for ammonia to air and Russia for nitrate to freshwater (although only sunflower is sourced from these countries and is used in smaller amounts). Palm and palm kernel oil have small contributions due to their high yields per hectare, as well as relatively lower emissions and CF for Malaysia.

Emissions of nitrate to freshwater (horizontal stripes) and to a lesser extent ammonia to air (dots) during cultivation (rapeseed but also other crops: palm and palm kernel; sunflower; maize) dominate the results. As spatial differentiation was introduced for this stage the new CF at the country level have been used along with global CF when spatial differentiation was not possible.

The spatially differentiated emissions dominate this impact, essentially because the cultivation stage is the biggest hotspot for eutrophying emissions.

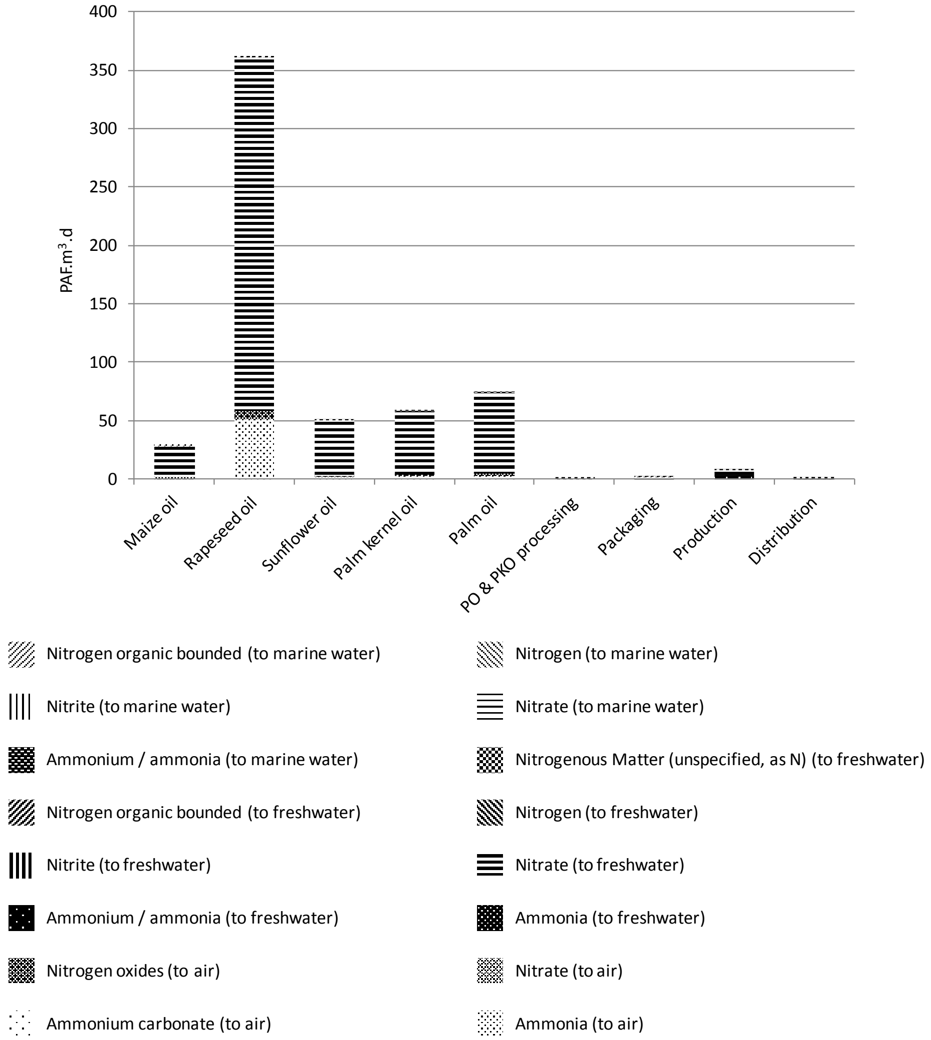


Figure 4.10:Contribution of different chemical species to Marine Eutrophication Potential calculated with the new CF (Units: PAF ·m^3·d/functional unit) for the different components of the product system.

4.5.2. ReCiPe

In comparison, Figure 4.11 shows the results for marine eutrophication as calculated by the ReCiPe method (Goedkoop *et al.*, 2008). As can be seen, even though the CF in ReCiPe do not have the level of spatial detail provided at a country level, the overall results look similar to those shown in Figure 4.10. The results are also dominated by nitrate to freshwater emissions; with a smaller contribution from ammonia to air and nitrogen oxides to air (the latter grow in relative contribution when using ReCiPe).

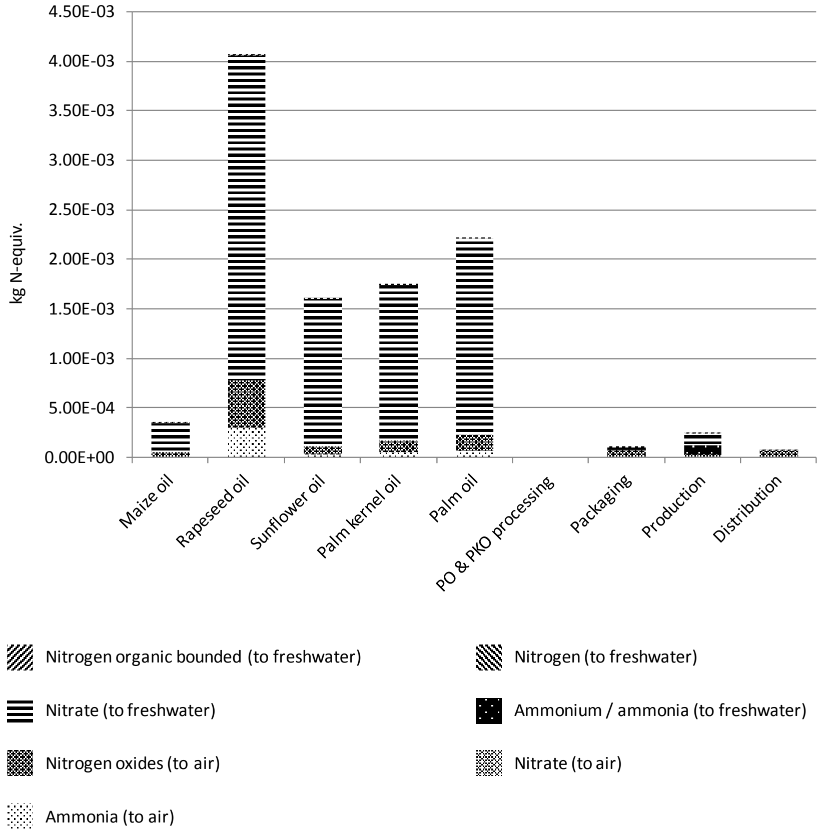


Figure 4.11:Contribution of different chemical species to Marine Eutrophication Potential calculated using ReCiPe (Units: kg N-equiv./functional unit) for the different components of the product system.

Note also in Figure 4.11 that the palm and palm kernel and sunflower have much greater impacts relative to the rapeseed oil when compared to the results in Figure 4.10. This suggests that, even if the overall conclusions are not changed in this specific case (where the oil used in the highest proportion is also related to the highest CF), the new CF suggest a clearer dominance by one of the sources of eutrophying substances: nitrate emissions from Germany. The absolute results are also different due to the fact that different units are used.

4.6. Acidification

Figure 4.12 shows the results for acidificaton potential calculated with the new CF generated in this project, and described in Azevedo *et al.*, (2012a). Global CF values were calculated as the average of all countries, and were used to characterise the flows for which no spatial information was available. These results were then compared to the ReCiPe midpoint category Terrestrial acidification, see Figure 4.13.

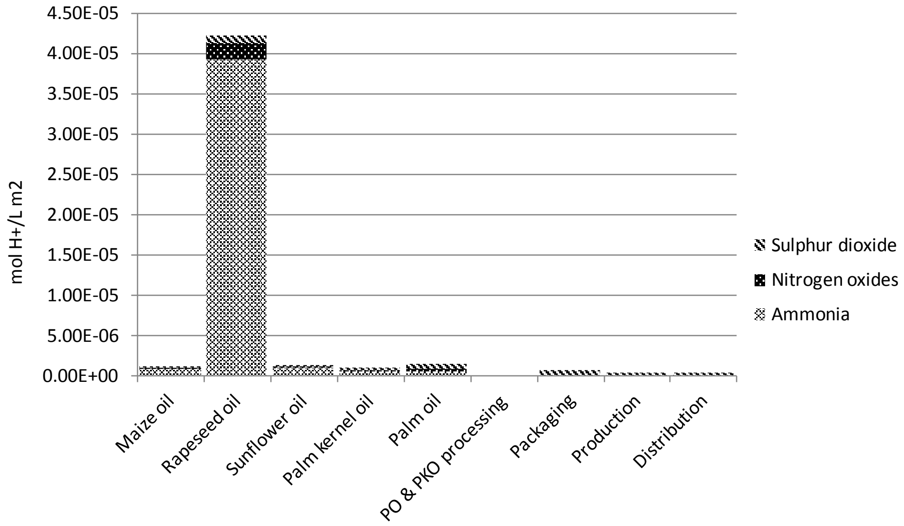


Figure 4.12:Contribution of different chemical species to Acidification Potential calculated

As seen in Figure 4.12, ammonia to air emissions related to rapeseed oil production (cultivation, oil extraction and refining stages) dominate the results with rapeseed cultivation making up close to 100% of this emission. Rapeseed is high because it is a significant ingredient with relatively high emissions and the characterisation factors for Germany are very large compared to other countries considered. Palm and palm kernel are smaller than might be expected due to high yields and smaller relative emissions and characterisation factors for Malaysia compared to other countries considered.

The spatial resolution provided in this project (e.g. for the ammonia emissions, at a country level) introduces significant differences to previous non-spatially-resolved methods (see Figure 4.13, calculated with ReCiPe).

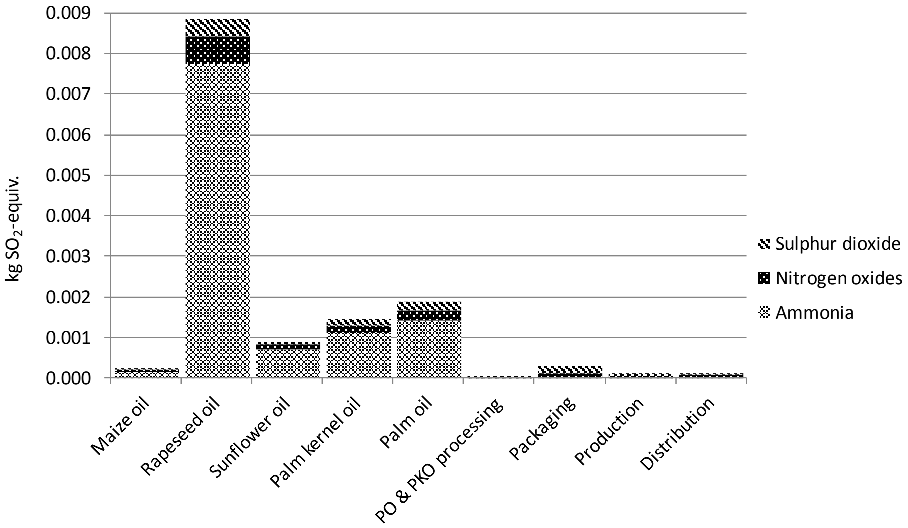


Figure 4.13:Contribution of different chemical species to Acidification Potential calculated using ReCiPe (Units: kg SO_2-equiv./functional unit) for the different components of the product system.

Difference between these results and the spatially resolved methodology (Figure 4.12) suggest that palm, palm kernel and sunflower are not as big an issue as perhaps suggested in the ReCiPe methodology, once regional sensitivity to acidification has been taken into account.

5. Interpretation

5.1. Applicability and relevance of the new models

A few of the impact categories results change significantly when the new methods are used as compared to the most relevant existing models (e.g. considering impacts on biodiversity damage potential at a local scale vs. considering regional and global extinction potential). However, in some other impact categories, the refinement brought by the increased level of spatial differentiation does not introduce a significant change in the results (e.g. eutrophication; acidification) for this specific case study. The differences introduced tend to further concentrate the hotspots on fewer locations / processes, which in this case study simplifies the interpretation and suggestion of improvement opportunities.

The newly developed methods often bring in a detailed uncertainty analysis related to the different levels of spatial differentiation considered (e.g. higher uncertainty related to the global or biome-level characterisation factors for biodiversity than to those expressed at the ecoregion level, de Baan *et al.* submitted). This is a great contribution to understanding the consequences of not having enough refinement in the supply chain information. However, current LCA software is not prepared to incorporate this level of uncertainty information (quantitative uncertainty related to both LCI parameters / flows and LCIA CF), and so it has not been considered in this study.

5.1.1. Data availability

It must be noted too that in some cases the level of spatial refinement allowed by the LCIA methods could not be implemented with the LCI information available to date, and so the full magnitude of the changes proposed by the new methodological developments could not be tested.In this sense, it is arguable whether LCI databases and knowledge within product supply chains (particularly in global supply chains) are ready to incorporate the latest developments facilitated by increasing inventory flow definition and/or geographical differentiation. E.g. most of the background processes used in this study do not differentiate between total abstracted water and water consumed (e.g. evaporated). While there are ways to overcome this limitation by approximating the % of water consumed in different processes (e.g. Milà i Canals et al. 2010; Muñoz et al.; Jefferies et al. 2012), these are impractical to implement in globally distributed, large product systems like the one studied. This is not to say that such developments in LCIA are not relevant, but they indicate that the current LCI information is still inadequate. Also LCA practitioners will often be confronted by lack of traceability across supply chains particularly for commodities and this results in less spatial refinement in the results than required for some of the LCIA methods. In this sense, the new LCIA methods for land and water use impact assessment are refined to the level of eco-regions or even grid cell; however, current inventory information for global supply chains, particularly for commodity crops, can barely point to the likely country of origin.

5.2. New learnings on margarine impacts

Some new impact areas, particularly related to resource use, have been studied in this project that had not been considered in previous studies on margarine (Nilsson et al. 2010; Jefferies et al.

2012; Milà i Canals et al. in press). In addition, a new level of spatial refinement and/or modelling sophistication has been applied for many of the existing impact categories, such as impacts on biodiversity (from relative effects on local biodiversity to absolute potential extinctions at regional or global scales), water use, acidification and eutrophication.

In terms of biodiversity, perhaps the most unexpected results appear when potential impacts on biodiversity are estimated at an absolute level, rather than at a relative impact level for potential natural vegetation as is commonly done in LCA (de Baan et al. in press). With the new methods developed in LC IMPACT (de Baan et al. submitted), those crops grown in biodiversity-rich environments (in this case study: palm oil) show a much higher potential impact.

For impacts related to water use, a similar trend as found by Jefferies *et al.* (2012) for the same margarine has been confirmed by applying a broader range of water impact pathways (section 0): the impacts are clearly dominated by those crops which are irrigated (sunflower and maize, in this case). So in the case of water derived impacts no new knowledge on hotspots has been obtained with the new methods.

6. Challenges and needs for further research

- Identifying the spatial resolution of flows within background datasets in LCA software e.g. Ecoinvent datasets in GaBi, is difficult and open to interpretation. This is clearly a need for further refinement that database developers will need to incorporate. The methods developed in this project suggest the relevant differentiation required, at spatial and/or archetypical (e.g. urban/rural) level.
- GaBi software interpretation of Ecoinvent water flows means that the source of water i.e. ground or surface, is not clear.
- Water flows in Ecoinvent are given as abstracted and not consumed and therefore current water flows in background datasets cannot be used directly.
- The source of commodity type products e.g. sunflower oil, is often not known within a country and therefore specific CF at a regional basis are compromised. However, current efforts by many manufacturing companies to use sustainably sourced and traceable raw materials may help overcoming this limitation. This is not likely to be achieved at a large scale within the next decade, though.
- GIS type maps of crop production are not readily available; linked to the point above, enhanced traceability will progressively improve the availability of knowledge, although the practical implementation and conversion of spatially explicit information into LCA will remain technically challenging.
- There are potential issues with modelling and interpretation of life cycle databases in different LCA software, for example there were no N chemical species-flows to ground water in the inventory although many of the Ecoinvent background datasets accessed through the Ecoinvent website do contain such flows. This appears to be something to do with how GaBi interprets and clusters flows. Characterisation factors for marine eutrophication exist for ground water and the fact that such N-flows appear to be emitted to freshwater in GaBi means that there is an overestimation of impacts.

The additional value and insights revealed by the new methods requires further validation through more case studies. However, to optimise the added value, closer collaboration between method developers and practitioners will be required to ensure that the increased sophistication in the modelling can be matched by the required extra information demands. In other words, we need theory and practice of LCA working “in perfect harmony” (Baitz *et al.*, 2013).

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(D3.7: Recommended assessment framework, method and characterisation and normalisation factors for ecosystem impacts of eutrophying emissions (phase 3))

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8. Appendix

8.1. Agricultural model

8.1.1. Aspects considered in the agricultural model

The aspects that are considered in the agricultural model are given in Figure 8.1.

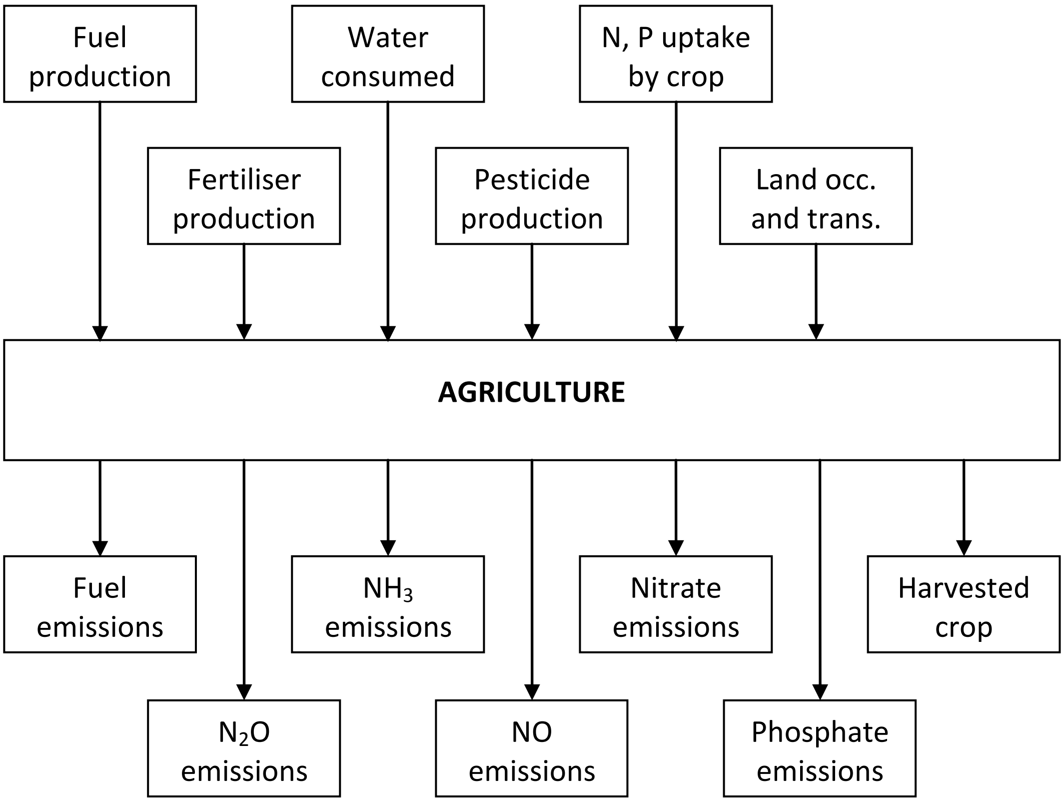

Figure 8.1: Aspects considered in the agricultural model

Mechanical operations, fuel consumption

The impacts associated with mechanical operations on the farm are assessed based on fuel consumed by these processes only e.g. mechanical processing on the farm accounts for fuel use but not maintenance of the tractor. Fuel use is included for fertiliser application, plant protection, soil preparation, seeding, harvesting and irrigation. The impacts from production and maintenance of infrastructure are only included in background datasets when using Ecoinvent database.

Fertiliser production

The impacts associated with the production of the fertilisers used are considered in the model using the fertiliser datasets taken from the Ecoinvent database. The impacts from the transport of the fertilisers from the point of production to farm are not included as detailed data was not available and the relative contribution was considered small in the context of the overall results.

Pesticide production

The impacts associated with the production of the pesticides used are considered in the model using the pesticide datasets taken from the Ecoinvent database. The impacts from the transport of the pesticides from the point of production to farm are not included as detailed data was not available and the relative contribution was considered small in the context of the overall results.

Consumed water

The water consumed directly during the irrigation of the crops is from ground water and or surface water. This is captured as the input flows “water consumed, ground [Water]” and “water consumed, surface [Water]”.

Land occupation and land transformation

The land occupation (m^2/yr) and land transformation (m^2) are captured according to type of farming and biome for example the input flow “Occ, agri, arable, intensive, temperate grasslands, savannas & shrub [Occupation (LU)]” or “Tran, from agri, arable, tropical and subtropical moist broadleaf forests [Transformation (LUC)]”.

8.1.2. Nitrogen cycle

The gaseous emissions of ammonia (NH3), nitric oxide (NO) and nitrous oxides (N2O) are calculated using the nitrogen cycle modelled using the Bouwman model (Bouwman *et al.*, 2002, 2002a and Van Drecht *et al.*, 2003). The factors used in the Bouwman model are given in table 1 and the equations used for calculating NH3, NO and N2O are given in Equation 8.1, Equation 8.2 and Equation 8.3, respectively. The nitrate emissions to water are based on a mass balance assuming nitrogen equilibrium in soil using Equation 8.4.

Table 8.1: Factors classes and factor class values for modelling the emission of ammonia, nitrous and nitric oxide used in the Bouwman model

Factor, factor class	Factor value NH3–model	 N2O–model	 NO–model
Fixed factor (f_{fix})		0.411	-1.527
Crop type (f_{crop})			
Grass	-0.158	-1.268	
Grass-clover		-1.242	
Legume	-0.046	-0.023	
Other upland crops	-0.047	0.000	
Wetland rice	0.000	-2.536	
Fertiliser type (f_{fert}) (a)			
Ammonium sulfate	0.429	0.0051	0.0056
Urea	0.666	0.0051	0.0061
Ammonium nitrate	-0.350	0.0061	0.004
Calcium ammonium nitrate	-1.064	0.0037	0.0062
Calcium nitrate	-1.585	0.0034	0.0054
Anhydrous ammonia	-1.151	0.0056	0.0051
Other ammon. based fertilisers		0.0051	0.0056
Other nitrate based fertilisers		0.0034	0.0054
Urea ammonium nitrate solution	0.000	0.0053	0.0004
Other N solutions	-0.748		
Monoammonium phosphate	-0.622	0.0039	0.0055
Diammonium phophate	0.182	0.0039	0.0055
Other compound NP and NPK	0.014	0.0039	0.0055
Compound NK	-1.585		
Ammonium bicarbonate	0.387	0.0051	0.0056
Animal manure	0.995	0.0021	0.0016
Animal manure plus synthetic N		0.0042	0.0055
Urine	0.747	0.0051	0.0061
Grazing	-0.378		
Application mode (f_{mode})			
Broadcast	-1.305		
Incorporate	-1.895		
Apply in solution	-1.292		
Broadcast or incorporate, then flood	-1.844		
Broadcast to floodwater at panicle initiation	-2.465		
Soil texture (f_{tex}) (b)			
Coarse		-0.008	
Medium		-0.472	
Fine		0.000	
Soil organic carbon content (%) (f_{SOC})			
SOC ≤ 1.0		0.000	0.000
1.0 < SOC ≤ 3.0		0.140	0.000

3.0 < SOC ≤ 6.0		0.580	2.571
SOC > 6.0		1.045	2.571
Soil pH (f_{pH})			
pH ≤ 5.5	-1.072	0.000	
5.5 < pH ≤ 7.3	-0.933	0.109	
7.3 < pH ≤ 8.5	-0.608	-0.352	
pH > 8.5	0.000	-0.352	
Soil cation exchange capacity (cmol kg-1) (f_{CEC})			
CEC ≤ 16	0.088		
16 < CEC ≤ 24	0.012		
24 < CEC ≤ 32	0.163		
CEC > 32	0.000		
Soil drainage (f_{drain})			
Poor		0.000	0.000
Good		-0.42	0.946
Climate (f_{clim}) (c)			
Temperate	-0.402	0.000	
Tropical	0.000	0.824	

(a) Multiply with N application rate for N2O and NO model.

(b) "Coarse" includes sand, loamy sand, sandy loam, loam, silt loam and silt; "Medium" includes sandy clay loam, clay loam and silty clay loam; "Fine" includes sandy clay, silty clay and clay.

(c) For NH3: "Temperate" = temperatures <20°C, "Tropical" = ≥20°C. For N_2O and NO: "Temperate" = temperate oceanic and continental, cool tropical, boreal and polar/alpine; "Tropical" = (sub-) tropical, subtropics winter/summer rains, tropics, warm humid, tropics warm seasonal dry.

The emissions are calculated using the following equations, where mass is kg of N applied and exponential is e^x.

Equation 8.1: Ammonia emissions

NH_3 (kg-N) from applying fertiliser = mass x exponential ($f_{crop} + f_{fert} + f_{mode} + f_{pH} + f_{CEC} + f_{clim}$)

Equation 8.2: Nitrous oxide emissions

N2O (kg-N) from applying fertiliser = exponential ($f_{fix} + f_{crop} + (\text{mass x } f_{fert}) + f_{tex} + f_{SOC} + f_{pH} + f_{drain} + f_{clim}$)

Equation 8.3: Nitric oxide emissions

NO (kg-N) from applying fertiliser = exponential ($f_{fix} + (\text{mass} * f_{fert}) + f_{SOC} + f_{drain}$)

Equation 8.4: Nitrate emissions

Nitrate = N input from fertiliser – N losses to atmosphere – N uptake by crop

8.1.3. Phosphorous cycle

Phosphate emissions to water are based on a mass balance assuming phosphorous equilibrium in soil using Equation 8.5.

Equation 8.5: Phosphate emissions

Phosphate = P input from fertiliser – P uptake by crop

8.1.4. Aspects not included in the agricultural model

Pesticide emissions and residues

The emission of pesticides to the environment and pesticide residues in the harvested crop are not included in the model. This due to the complexity on estimating the level of specific pesticide emissions and residues that require detailed information such as time of application and mode of application that is not readily available in the public domain.

Carbon cycle in soil

The carbon balance in the soil, which includes carbon uptake and carbon emissions in the form of carbon dioxide and methane, is not included in the model.

8.1.5. References

Bouwman AF, Boumans LJ M and Batjes NH (2002) Estimation of global NH_3 volatilization loss from synthetic fertilizers and animal manure applied to arable lands and grasslands, Global Biogeochemical Cycles, 16 (2)

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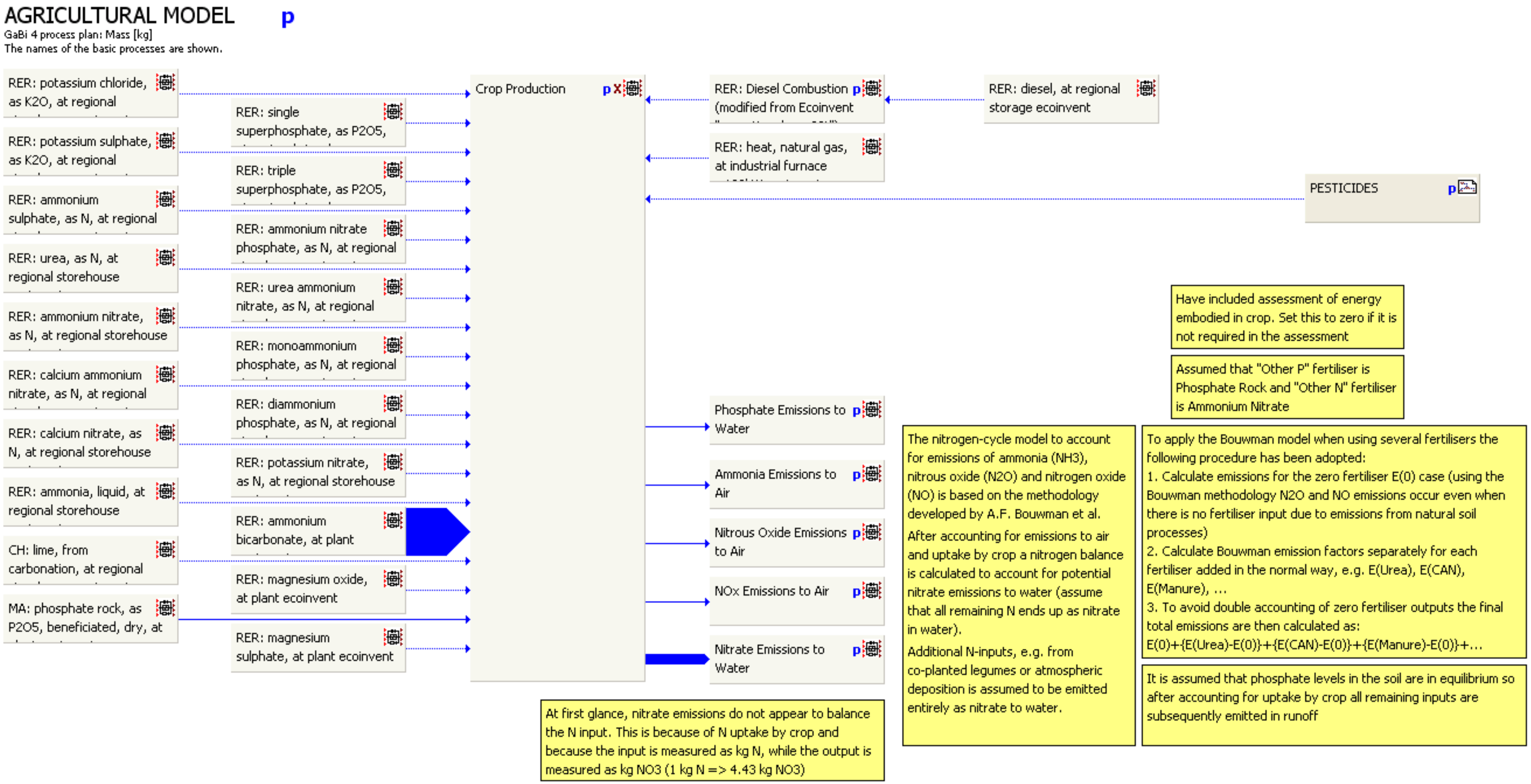
8.2. Agricultural model screenshot – Ecoinvent datasets used



Have included assessment of energy embodied in crop. Set this to zero if it is not required in the assessment

Assumed that "Other P" fertiliser is Phosphate Rock and "Other N" fertiliser is Ammonium Nitrate

The nitrogen-cycle model to account for emissions of ammonia (NH3), nitrous oxide (N2O) and nitrogen oxide (NO) is based on the methodology developed by A.F. Bouwman et al.

After accounting for emissions to air and uptake by crop a nitrogen balance is calculated to account for potential nitrate emissions to water (assume that all remaining N ends up as nitrate in water).

Additional N-inputs, e.g. from co-planted legumes or atmospheric deposition is assumed to be emitted entirely as nitrate to water.

To apply the Bouwman model when using several fertilisers the following procedure has been adopted:

1. Calculate emissions for the zero fertiliser E(0) case (using the Bouwman methodology N2O and NO emissions occur even when there is no fertiliser input due to emissions from natural soil processes)
2. Calculate Bouwman emission factors separately for each fertiliser added in the normal way, e.g. E(Urea), E(CAN), E(Manure), ...
3. To avoid double accounting of zero fertiliser outputs the final total emissions are then calculated as: E(0)+{E(Urea)-E(0)}+{E(CAN)-E(0)}+{E(Manure)-E(0)}+...

It is assumed that phosphate levels in the soil are in equilibrium so after accounting for uptake by crop all remaining inputs are subsequently emitted in runoff

At first glance, nitrate emissions do not appear to balance the N input. This is because of N uptake by crop and because the input is measured as kg N, while the output is measured as kg NO3 (1 kg N => 4.43 kg NO3)

Figure 8.2: Agricultural model – top level plan.

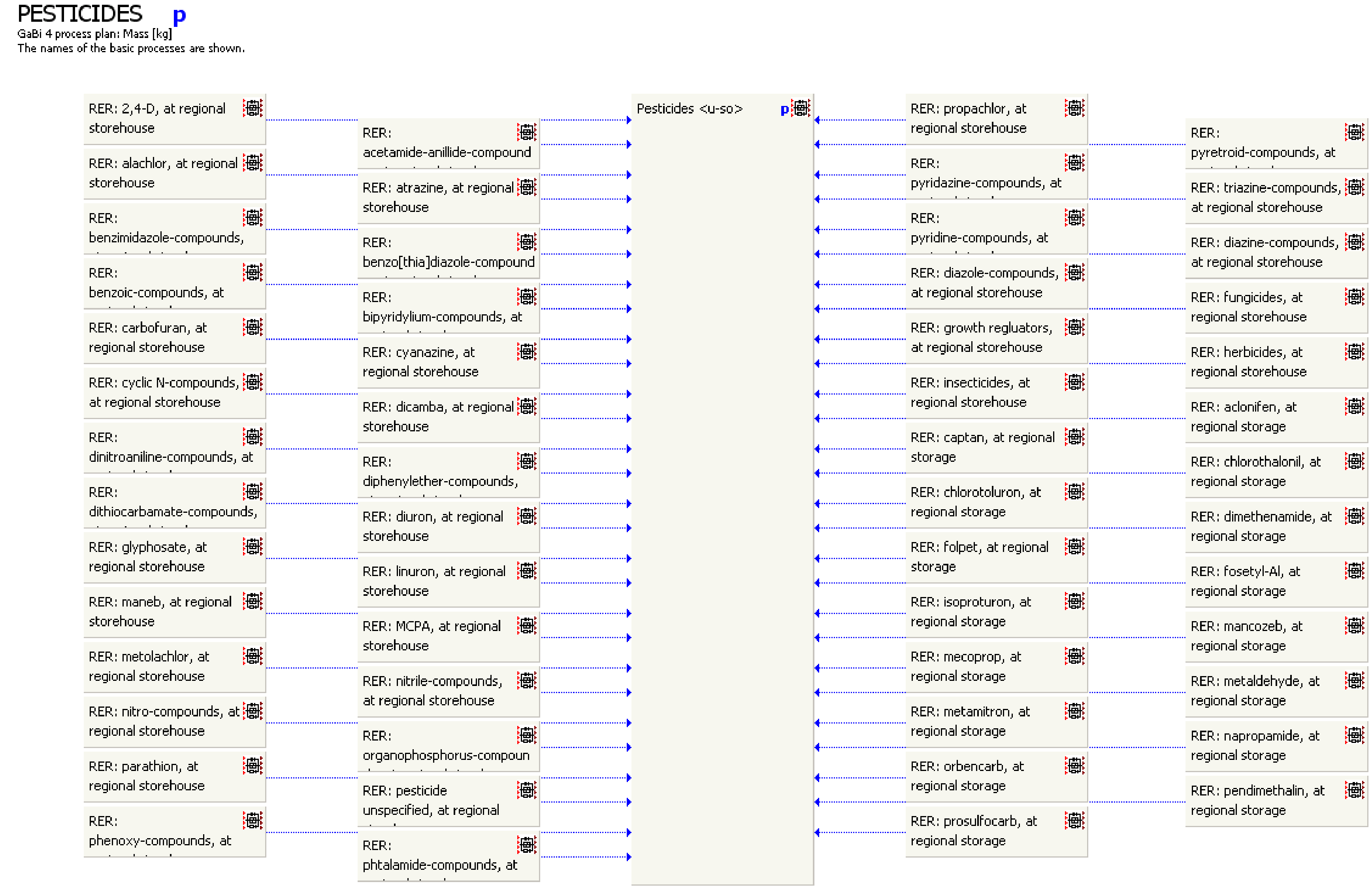


Figure 8.3: Agricultural model – Pesticide plan.

8.3. Inventory of vegetable oils (PO, PKO, Rapeseed oil & Sunflower oil)

The inventory of cultivation and oil extraction for the different vegetable oils: palm oil, palm kernel oil, rapeseed oil and sunflower oil modeled in the agricultural model are given in Table 8.2: Palm oil cultivation and extraction.Table 8.2 to
Table 8.5 respectively.

Table 8.2: Palm oil cultivation and extraction.

Description	Value	Reference	Comment
Crop production			
General			
[kg/ha/yr] Mass of harvested crop	25000	2	
[kg/ha/yr] Diesel fuel consumed	168.1	2, 3	
[kg/ha/yr] Pesticide active ingredient applied	10.6	2	
[kg-N/ha/yr] Applied nitrogen fertiliser taken up by harvested crop	50.1	2, 9	
[kg-P/ha/yr] Applied phosphorus fertiliser taken up by harvested crop	13.63	2, 9	
Fertilisers			
[kg-N/ha/yr] Amount of Ammonium Sulphate fertiliser applied	22	2, 3	Ammonium sulphate used as substitute for ammonium chloride
[kg-K2O/ha/yr] Amount of Potassium Chloride fertiliser applied	170	2, 3	
[kg-P2O5/ha/yr] Amount of Phosphate Rock fertiliser applied	20.1	2, 3	
[kg-N/ha/yr] Amount of nitrogen obtained from other sources	26.36	2, 3	Based on input from leguminous cover crops, palm oil mill effluent and empty fruit bunches
[kg-P2O5/ha/yr] Amount of phosphorus obtained from other sources		2, 3	Based on input from leguminous cover crops, palm oil mill effluent and empty fruit bunches
Bouwman model factors			
Fertiliser application mode	Broadcast	2, 3	
Climate	Tropical	6	Average for Jenangau and Rengam regions
Crop type	Other upland crop		
Soil drainage	Good	6	Average for Jenangau and Rengam regions
[pH] Soil pH	4.5	6	Average for Jenangau and Rengam regions
[cmol/kg] Soil exchange capacity (SEC)	26.4	6, 7	Average for Jenangau and Rengam regions

[%] Soil organic carbon (SOC) content	0.87	6	Average for Jenangau and Rengam regions
Soil texture	Fine	6	Average for Jenangau and Rengam regions
Oil extraction			
[%] Impacts allocated to oil	85.2	1	Economic allocation
[kg] Crop input to crushing mill	4545	8	
[kg] Crude oil production	1000	8	
[kg] Palm kernel production	227	8	Contains 50% PKO
[kg] Shell produced during oil extraction process	3318	8	
[kg] Water	2500	8	
Transport			
[km] Distance from farm to crushing mill (road)	10	4	
[km] Distance from refinery to factory (road)	50	4	
[km] Distance from crushing mill to refinery (road)	150	4	
[km] Distance from crushing mill to refinery (sea)	14800	5	

References	**Number**
Economic data (oil versus meal) provided by Gerrit den-Dekker, X (private communication)	1
The Oil Palm 4th Edition, R.H.V. Corley & P.B. Tinker, Blackwell Publishing	2
Confidential data from Malaysian plantation (2001, provided by Gail Smith, X)	3
Google Maps - http://maps.google.co.uk/maps	4
World Ports Distances http://www.portworld.com/map/	5
Food and Agriculture Organisation of the United Nations http://www.fao.org/docrep/field/003/T5057E/T5057E02.htm	6
Helling et al. (1964), Soil Sci Soc Amer Proc 28, 517--520	7
Life Cycle Analysis: Rama und Biskin, Barmentlo, et al, X Report, 1992	8
Nutrient uptake data from IFA at http://www.fertilizer.org/ifa/publicat/html/pubman/namtype.htm	9
X internal data - for edible oil refinery in NL	10

Table 8.3: Palm kernel oil cultivation and extraction.

Description	Value	Reference	Comment
Crop production			
General			
[kg/ha/yr] Mass of harvested crop	25000	2	
[kg/ha/yr] Diesel fuel consumed	168.1	2, 3	
[kg/ha/yr] Pesticide active ingredient applied	10.6	2	
[kg-N/ha/yr] Applied nitrogen fertiliser taken up by harvested crop	50.1	2, 9	
[kg-P/ha/yr] Applied phosphorus fertiliser taken up by harvested crop	13.63	2, 9	
Fertilisers			
[kg-N/ha/yr] Amount of Ammonium Sulphate fertiliser applied	22	2, 3	Ammonium sulphate used as substitute for ammonium chloride
[kg-K2O/ha/yr] Amount of Potassium Chloride fertiliser applied	170	2, 3	
[kg-P2O5/ha/yr] Amount of Phosphate Rock fertiliser applied	20.1	2, 3	
[kg-N/ha/yr] Amount of nitrogen obtained from other sources	26.36	2, 3	Based on input from leguminous cover crops, palm oil mill effluent and empty fruit bunches
[kg-P2O5/ha/yr] Amount of phosphorus obtained from other sources	5.5	2, 3	Based on input from leguminous cover crops, palm oil mill effluent and empty fruit bunches
Bouwman model factors			
Fertiliser application mode	Broadcast	2, 3	
Climate	Tropical	6	Average for Jenangau and Rengam regions
Crop type	Other upland crop		
Soil drainage	Good	6	Average for Jenangau and Rengam regions

[pH] Soil pH	4.5	6	Average for Jenangau and Rengam regions
[cmol/kg] Soil exchange capacity (SEC)	26.4	6, 7	Average for Jenangau and Rengam regions
[%] Soil organic carbon (SOC) content	0.87	6	Average for Jenangau and Rengam regions
Soil texture	Fine	6	Average for Jenangau and Rengam regions
Oil extraction			
[%] Impacts allocated to oil	14.2	1	Economic allocation
[kg] Crop input to crushing mill	4545	8	
[kg] Crude oil production	113.5	8	
[kg] Palm oil production	1000	8	PO is the major co-product
[kg] Shell production	3318	8	
[kg] Hexane	2	8	
[kg] Water	2500		
Transport		4	
[km] Distance from farm to crushing mill (barge)	0	4	
[km] Distance from farm to crushing mill (road)	10	4	
[km] Distance from farm to crushing mill (sea)	0	5	
[km] Distance from refinery to factory (road)	50	11	
[km] Distance from crushing mill to refinery (sea)	0	11	
[km] Distance from crushing mill to refinery (road)	150	11	
[km] Distance from crushing mill to refinery (sea)	14800	12	

References	**Number**
Economic data (oil versus meal) provided by Gerrit den-Dekker, X (private communication)	1
The Oil Palm 4th Edition, R.H.V. Corley & P.B. Tinker, Blackwell Publishing	2
Confidential data from Malaysian plantation (2001, provided by Gail Smith, X)	3

Google Maps - http://maps.google.co.uk/maps	4
World Ports Distances http://www.portworld.com/map/	5
Food and Agriculture Organisation of the United Nations http://www.fao.org/docrep/field/003/T5057E/T5057E02.htm	6
Helling et al. (1964), Soil Sci Soc Amer Proc 28, 517--520	7
Life Cycle Analysis: Rama und Biskin, Barmentlo, et al, X Report, 1992	8
Nutrient uptake data from IFA at http://www.fertilizer.org/ifa/publicat/html/pubman/namtype.htm	9
X internal data - for edible oil refinery in NL	10
Google Maps - http://maps.google.co.uk/maps	11
World Ports Distances http://www.portworld.com/map/	12

Table 8.4: Rapeseed oil cultivation and extraction.

Description	Value	Reference	Comment
Crop production			
General			
[kg/ha/yr] Mass of harvested crop	4250	2	
[kg/ha/yr] Diesel fuel consumed	59.5	2	
[kg/ha/yr] Pesticide active ingredient applied	0.535	2	
[kg-N/ha/yr] Applied nitrogen fertiliser taken up by harvested crop	135	3	
[kg-P/ha/yr] Applied phosphorus fertiliser taken up by harvested crop	25	3	
Fertilisers			
[kg-N/ha/yr] Amount of Ammonium Sulphate fertiliser applied	72	2	
[kg-CaO/ha/yr] Amount of Lime fertiliser applied	400	2	
[kg-K2O/ha/yr] Amount of Potassium Chloride fertiliser applied	241	2	
[kg-N/ha/yr] Amount of Urea fertiliser applied	136	2	
[kg-P2O5/ha/yr] Amount of Triple Superphosphate fertiliser applied	59.5	2	
Bouwman model factors			
Fertiliser application mode	In solution	2	
Climate	Temperate	2	
Crop type	Other upland crop	2	
Soil drainage	Good	2	
[pH] Soil pH	6.75	2	
[cmol/kg] Soil exchange capacity (SEC)	25.2	2	
[%] Soil organic carbon (SOC) content	1.5	2	
Soil texture	Coarse	2	

Oil extraction

[%] Impacts allocated to oil	76.9	1	Economic allocation
[kg] Crop input to crushing mill	2500	5	
[kg] Crude oil production	1000	5	
[kg] Meal production	1500	5	
[MJ] Electricity	500	5	
[kg] Hexane	2	5	
[MJ] Steam	1680	5	

Transport

[km] Distance from farm to crushing mill (road)	65	4
[km] Distance from refinery to factory (road)	50	4
[km] Distance from crushing mill to refinery (road)	650	4

References	**Number**
Economic data (oil versus meal) provided by Gerrit den-Dekker, X (private communication)	1
Data supplied by Christof Walter (X agronomist)	2
Nutrient uptake data from IFA at http://www.fertilizer.org/ifa/publicat/html/pubman/namtype.htm	3
Google Maps - http://maps.google.co.uk/maps	4
Life Cycle Analysis: Rama und Biskin, Barmentlo, et al, X Report, 1992	5
X internal data - for edible oil refinery in NL	6

Table 8.5: Sunflower oil cultivation and extraction.

Description	Value	Reference	Comment
Crop production			
General			
[kg/ha/yr] Mass of harvested crop	1500	1	
[kg/ha/yr] Diesel fuel consumed	38.9	1	
[kg/ha/yr] Pesticide active ingredient applied	1.03	1	
[kg-N/ha/yr] Applied nitrogen fertiliser taken up by harvested crop	27.5	6	
[kg-P/ha/yr] Applied phosphorus fertiliser taken up by harvested crop	6.2	6	
Fertilisers			
[kg-K2O/ha/yr] Amount of Potassium Chloride fertiliser applied	7.5	1	
[kg-N/ha/yr] Amount of other NP or NPK fertiliser applied (assumed to Monoammonium Phosphate)	45	1	
[kg-P2O5/ha/yr] Amount of Phosphate Rock fertiliser applied	14.2	1	
[kg-N/ha/yr] Amount of Urea fertiliser applied	55	1	
Bouwman model factors			
Fertiliser application mode	Incorporate	1	
Climate	Tropical	1	
Crop type	Other upland crop	1	
Soil drainage	Good	1	
[pH] Soil pH	6.07	1	
[cmol/kg] Soil exchange capacity (SEC)	13.7	1	
[%] Soil organic carbon (SOC) content	1.5	1	
Soil texture	Medium	1	
Oil extraction			

[%] Impacts allocated to oil	82.4	7	Economic allocation
[kg] Crop input to crushing mill	2500	2	
[kg] Crude oil production	1000	2	
[kg] Meal production	1500	2	
[MJ] Electricity	500	2	
[kg] Hexane	2	2	
[MJ] Steam	1680	2	

Transport

[km] Distance from farm to crushing mill (road)	100	4
[km] Distance from refinery to factory (road)	50	4
[km] Distance from crushing mill to refinery (sea)	800	5
[km] Distance from crushing mill to refinery (road)	20	4
[km] Distance from crushing mill to refinery (sea)	11500	5

References	**Number**
Site specific data supplied by Peter Carroll	1
Life Cycle Analysis: Rama und Biskin, Barmentlo, et al, X Report, 1992	2
X internal data - for edible oil refinery in NL	3
Google Maps - http://maps.google.co.uk/maps	4
World Ports Distances http://www.portworld.com/map/	5
Nutrient uptake data from IFA at http://www.fertilizer.org/ifa/publicat/html/pubman/namtype.htm	6
Economic data (oil versus meal) provided by Gerrit den-Dekker, X (private communication)	10

8.4. Modification of inventory flows to use new characterization factors.

Table 8.6: Changes to emission flows from the use of fertiliser

Existing flow	**Additional flow**
Ammonia [Inorganic emissions to air]	Ammonia, Germany, rural, ground [Inorganic emissions to air]
	Ammonia, Russia, rural, ground [Inorganic emissions to air]
	Ammonia, Argentina, rural, ground [Inorganic emissions to air]
	Ammonia, Ukraine, rural, ground [Inorganic emissions to air]
	Ammonia, Malaysia, remote, ground [Inorganic emissions to air]
Nitrogen oxides [Inorganic emissions to air]	Nitrogen oxides, Germany, rural, ground [Inorganic emissions to air]
	Nitrogen oxides, Russia, rural, ground [Inorganic emissions to air]
	Nitrogen oxides, Argentina, rural, ground [Inorganic emissions to air]
	Nitrogen oxides, Ukraine, rural, ground [Inorganic emissions to air]
	Nitrogen oxides, Malaysia, remote, ground [Inorganic emissions to air]
Nitrate [Inorganic emissions to fresh water]	Nitrate, Germany [Inorganic emissions to fresh water]
	Nitrate, Ukraine [Inorganic emissions to fresh water]
	Nitrate, Russia [Inorganic emissions to fresh water]
	Nitrate, Argentina [Inorganic emissions to fresh water]
	Nitrate, Malaysia [Inorganic emissions to fresh water]
Phosphorus [Inorganic emissions to fresh water]	Phosphorus, Argentina [Inorganic emissions to fresh water]
	Phosphorus, Germany [Inorganic emissions to fresh water]
	Phosphorus, Russia [Inorganic emissions to fresh water]
	Phosphorus, Ukraine [Inorganic emissions to fresh water]
	Phosphorus, Malaysia [Inorganic emissions to fresh water]

Table 8.7: Changes to emission flows in Maize production

Existing flow	Amount (kg)	Additional flow	Amount (kg)
Ammonia [Inorganic emissions to air]	5.87E-05	Ammonia, Germany, rural, ground [Inorganic emissions to air]	2.02E-03
Ammonium / ammonia [ecoinvent long-term]	1.11E-08	Ammonium / ammonia, Germany [ecoinvent long-term]	4.41E-09

Ammonium / ammonia [Inorganic emissions to fresh water]	6.78E-06	Ammonium / ammonia, Germany [Inorganic emissions to fresh water]	2.41E-06
Ammonium / ammonia [Inorganic emissions to sea water]	7.43E-08	Ammonium / ammonia, Germany [Inorganic emissions to sea water]	3.37E-08
Dust (PM2,5 - PM10) [Particles to air]	1.48E-05	Dust (PM2,5 - PM10), rural, ground [Particles to air]	1.97E-05
Dust (PM2.5) [Particles to air]	2.32E-05	Dust (PM2.5), rural, ground [Particles to air]	7.46E-05
Nitrate [ecoinvent long-term]	1.10E-05	Nitrate, Germany [ecoinvent long-term]	7.74E-06
Nitrate [Inorganic emissions to sea water]	1.85E-07	Nitrate, Germany [Inorganic emissions to sea water]	7.50E-08
Nitrate [Inorganic emissions to air]	4.76E-09	Nitrate, Germany [Inorganic emissions to air]	1.70E-09
Nitrate [Inorganic emissions to fresh water]	3.91E-04	Nitrate, Germany [Inorganic emissions to fresh water]	4.65E-02
Nitrogen [Inorganic emissions to sea water]	2.63E-09	Nitrogen, Germany [Inorganic emissions to sea water]	1.20E-09
Nitrogen [Inorganic emissions to fresh water]	3.24E-06	Nitrogen, Germany [Inorganic emissions to fresh water]	1.25E-06
Nitrogen organic bounded [Inorganic emissions to fresh water]	1.64E-07	Nitrogen organic bounded, Germany [Inorganic emissions to fresh water]	1.48E-07
Nitrogen organic bounded [Inorganic emissions to sea water]	9.11E-08	Nitrogen organic bounded, Germany [Inorganic emissions to sea water]	4.00E-08
Nitrogen organic bounded [ecoinvent long-term]	1.82E-08	Nitrogen organic bounded, Germany [ecoinvent long-term]	7.20E-09
Nitrogen oxides [Inorganic emissions to air]	2.94E-04	Nitrogen oxides, Germany, rural, ground [Inorganic emissions to air]	8.96E-04

Nitrous oxide (laughing gas) [Inorganic emissions to air]	1.34E-04	Nitrous oxide (laughing gas), Germany [Inorganic emissions to air]	9.18E-04
Phosphate [Inorganic emissions to fresh water]	1.60E-05	Phosphate, Germany [Inorganic emissions to fresh water]	1.19E-04
Phosphate [Inorganic emissions to sea water]	9.53E-05	Phosphate, Germany [Inorganic emissions to sea water]	4.29E-07
Phosphate [ecoinvent long-term]	3.96E-05	Phosphate, Germany [ecoinvent long-term]	3.24E-05
Phosphorus [Inorganic emissions to air]	1.39E-08	Phosphorus, Germany [Inorganic emissions to air]	1.73E-09
Phosphorus [Inorganic emissions to sea water]	4.78E-09	Phosphorus, Germany [Inorganic emissions to sea water]	2.12E-09
Phosphorus [Inorganic emissions to agricultural soil]	4.94E-09	Phosphorus, Germany [Inorganic emissions to agricultural soil]	1.88E-09
Phosphorus [Inorganic emissions to fresh water]	6.67E-07	Phosphorus, Germany [Inorganic emissions to fresh water]	2.87E-05
Phosphorus [Inorganic emissions to industrial soil]	4.69E-08	Phosphorus, Germany [Inorganic emissions to industrial soil]	2.22E-08
Sulphur dioxide [Inorganic emissions to air]	3.10E-04	Sulphur dioxide, Germany, rural, ground [Inorganic emissions to air]	1.17E-04

Table 8.8: Changes to emission flows in heat, light fuel oil process

Existing flow	Amount (kg)	Additional flow	Amount (kg)
Ammonia [Inorganic emissions to air]	1.97E-07	Ammonia, Germany, urban, high-stack [Inorganic emissions to air]	7.88E-08
		Ammonia, Netherlands, urban, high-stack [Inorganic emissions to air]	7.88E-08
Dust (PM2.5) [Particles to air]	4.40E-06	Dust (PM2.5), urban, high-stack [Particles to air]	1.05E-07
Nitrogen oxides [Inorganic	4.46E-05	Nitrogen oxides, Germany, urban,	2.63E-05

emissions to air]		high-stack [Inorganic emissions to air]	
		Nitrogen oxides, Netherlands, urban, high-stack [Inorganic emissions to air]	2.63E-05
Nitrous oxide (laughing gas) [Inorganic emissions to air]	2.32E-07	Nitrous oxide (laughing gas), Germany [Inorganic emissions to air]	3.15E-07
		Nitrous oxide (laughing gas), Netherlands [Inorganic emissions to air]	3.15E-07
Sulphur dioxide [Inorganic emissions to air]	1.08E-04	Sulphur dioxide, Germany, urban, high-stack [Inorganic emissions to air]	2.46E-05
		Sulphur dioxide, Netherlands, urban, high-stack [Inorganic emissions to air]	2.46E-05

Table 8.9: Existing flows altered and additional flows added to steam production (modified from Ecoinvent "heat, natural gas, at boiler modulating >100kW")

Existing flow	Amount (kg)	Additional flow	Amount (kg)
Dust (PM2.5) [Particles to air]	8.94E-07	Dust (PM2.5), urban, high-stack [Particles to air]	1.04E-07
Nitrogen oxides [Inorganic emissions to air]	2.52E-05	Nitrogen oxides, Netherlands, urban, high-stack [Inorganic emissions to air]	1.63E-05
		Nitrogen oxides, Germany, urban, high-stack [Inorganic emissions to air]	1.63E-05
Nitrous oxide (laughing gas) [Inorganic emissions to air]	1.35E-07	Nitrous oxide (laughing gas), Netherlands [Inorganic emissions to air]	5.20E-07
		Nitrous oxide (laughing gas), Germany [Inorganic emissions to air]	5.20E-07
Sulphur dioxide [Inorganic emissions to air]	2.56E-05	Sulphur dioxide, Netherlands, urban, high-stack [Inorganic emissions to air]	5.72E-07
		Sulphur dioxide, Germany, urban, high-stack [Inorganic emissions to air]	5.72E-07

Table 8.10: Additional flows added to Diesel Combustion (modified from Ecoinvent "operation, lorry 32t") dataset

Existing flow	Cultivation flows	Extraction flows	Refining flows
Ammonia [Inorganic	Ammonia, Argentina,	Ammonia, Argentina,	Ammonia,

emissions to air]	rural, ground [Inorganic emissions to air]	rural, low-stack [Inorganic emissions to air]	Netherlands, urban, high-stack [Inorganic emissions to air]
-	Ammonia, Germany, rural, ground [Inorganic emissions to air]	Ammonia, Germany, rural, low-stack [Inorganic emissions to air]	-
-	Ammonia, Malaysia, remote, ground [Inorganic emissions to air]	Ammonia, Malaysia, remote, low-stack [Inorganic emissions to air]	-
-	Ammonia, Russia, rural, ground [Inorganic emissions to air]	Ammonia, Russia, rural, low-stack [Inorganic emissions to air]	-
-	Ammonia, Ukraine, rural, ground [Inorganic emissions to air]	Ammonia, Ukraine, rural, low-stack [Inorganic emissions to air]	-
Dust (PM2,5 - PM10) [Particles to air]	Dust (PM2,5 - PM10), remote, ground [Particles to air]	Dust (PM2,5 - PM10), remote, low-stack [Particles to air]	Dust (PM2,5 - PM10), urban, high-stack [Particles to air]
-	Dust (PM2,5 - PM10), rural, ground [Particles to air]	Dust (PM2,5 - PM10), rural, low-stack [Particles to air]	-
Dust (PM2.5) [Particles to air]	Dust (PM2.5), remote, ground [Particles to air]	Dust (PM2.5), remote, low-stack [Particles to air]	Dust (PM2.5), urban, high-stack [Particles to air]
-	Dust (PM2.5), rural, ground [Particles to air]	Dust (PM2.5), rural, low-stack [Particles to air]	-
Nitrogen oxides [Inorganic emissions to air]	Nitrogen oxides, Argentina, rural, ground [Inorganic emissions to air]	Nitrogen oxides, Argentina, rural, low-stack [Inorganic emissions to air]	Nitrogen oxides, Netherlands, urban, high-stack [Inorganic emissions to air]
-	Nitrogen oxides, Germany, rural, ground [Inorganic emissions to air]	Nitrogen oxides, Germany, rural, low-stack [Inorganic emissions to air]	-
-	Nitrogen oxides, Malaysia, remote, ground [Inorganic emissions to air]	Nitrogen oxides, Malaysia, remote, low-stack [Inorganic emissions to air]	-
--	Nitrogen oxides, Russia, rural, ground [Inorganic emissions to air]	Nitrogen oxides, Russia, rural, low-stack [Inorganic emissions to	-

		air]	
-	Nitrogen oxides, Ukraine, rural, ground [Inorganic emissions to air]	Nitrogen oxides, Ukraine, rural, low-stack [Inorganic emissions to air]	-
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Nitrous oxide (laughing gas), Argentina [Inorganic emissions to air]	Nitrous oxide (laughing gas), Argentina [Inorganic emissions to air]	Nitrous oxide (laughing gas), Netherlands [Inorganic emissions to air]
-	Nitrous oxide (laughing gas), Germany [Inorganic emissions to air]	Nitrous oxide (laughing gas), Germany [Inorganic emissions to air]	-
-	Nitrous oxide (laughing gas), Malaysia [Inorganic emissions to air]	Nitrous oxide (laughing gas), Malaysia [Inorganic emissions to air]	-
-	Nitrous oxide (laughing gas), Russia [Inorganic emissions to air]	Nitrous oxide (laughing gas), Russia [Inorganic emissions to air]	-
-	Nitrous oxide (laughing gas), Ukraine [Inorganic emissions to air]	Nitrous oxide (laughing gas), Ukraine [Inorganic emissions to air]	-
Sulphur dioxide [Inorganic emissions to air]	Sulphur dioxide, Argentina, rural, ground [Inorganic emissions to air]	Sulphur dioxide, Argentina, rural, low-stack [Inorganic emissions to air]	Sulphur dioxide, Netherlands, urban, high-stack [Inorganic emissions to air]
-	Sulphur dioxide, Germany, rural, ground [Inorganic emissions to air]	Sulphur dioxide, Germany, rural, low-stack [Inorganic emissions to air]	-
-	Sulphur dioxide, Malaysia, remote, ground [Inorganic emissions to air]	Sulphur dioxide, Malaysia, remote, low-stack [Inorganic emissions to air]	-
-	Sulphur dioxide, Russia, rural, ground [Inorganic emissions to air]	Sulphur dioxide, Russia, rural, low-stack [Inorganic emissions to air]	-
-	Sulphur dioxide, Ukraine, rural, ground [Inorganic emissions to air]	Sulphur dioxide, Ukraine, rural, low-stack [Inorganic emissions to air]	-

Table 8.11: Land occupation and land transformation biome flows for cultivation

Country	**Land occupation and land transformation flow**

Malaysia	Occ, agri, permanent crops, extensive, tropical and subtropical moist broadleaf forests [Occupation (LU)]
Malaysia	Tran, from agri, arable, tropical and subtropical moist broadleaf forests [Transformation (LUC)]
Malaysia	Tran, from tropical and subtropical moist broadleaf forests [Transformation (LUC)]
Malaysia	Tran, to agri, permanent crops, intensive, tropical and subtropical moist broadleaf forests [Transformation (LUC)]
Germany	Occ, agri, arable, intensive, temperate broadleaf and mixed forests [Occupation (LU)]
Germany	Tran, from agriculture, permanent crops, temperate broadleaf and mixed forests [Transformation (LUC)]
Germany	Tran, from grassland, Pasture/meadow, temperate broadleaf and mixed forests [Transformation (LUC)]
Germany	Tran, to agri, arable, intensive, temperate broadleaf and mixed forests [Transformation (LUC)]
Argentina	Occ, agri, arable, intensive, temperate grasslands, savannas & shrub [Occupation (LU)]
Russia	Occ, agri, arable, intensive, boreal forests/taiga [Occupation (LU)]
Russia	Occ, agri, arable, intensive, temperate broadleaf and mixed forests [Occupation (LU)]
Ukraine	Occ, agri, arable, intensive, temperate broadleaf and mixed forests [Occupation (LU)]

Table 8.12: Land occupation and land transformation biome flows for extraction

Country	**Land occupation and land transformation flow**
Malaysia	Occ, artificial areas, industrial area, tropical and subtropical moist broadleaf forests [Occupation (LU)]
Malaysia	Occ, artificial areas, urban, green areas, tropical and subtropical moist broadleaf forests [Occupation (LU)]
Malaysia	Tran, from agri, arable, tropical and subtropical moist broadleaf forests [Transformation (LUC)]
Malaysia	Tran, from tropical and subtropical moist broadleaf forests [Transformation (LUC)]
Malaysia	Tran, to artificial areas, industrial area, tropical and subtropical moist broadleaf forests [Transformation (LUC)]
Malaysia	Tran, to artificial areas, urban, green areas, tropical and subtropical moist broadleaf forests [Transformation (LUC)]
Germany	Occ, artificial areas, industrial area, temperate broadleaf and mixed forests [Occupation (LU)]
Germany	Occ, artificial areas, urban, green areas, temperate broadleaf and mixed forests [Occupation (LU)]
Russia	Occ, artificial areas, industrial area, boreal forests/taiga [Occupation (LU)]
Russia	Occ, artificial areas, industrial area, temperate broadleaf and mixed forests [Occupation (LU)]
Ukraine	Occ, artificial areas, industrial area, temperate broadleaf and mixed forests [Occupation (LU)]
Argentina	Occ, artificial areas, industrial area, temperate grasslands, savannas & shrub [Occupation (LU)]

Russia	Occ, artificial areas, urban, green areas, boreal forests/taiga [Occupation (LU)]
Russia	Occ, artificial areas, urban, green areas, temperate broadleaf and mixed forests [Occupation (LU)]
Ukraine	Occ, artificial areas, urban, green areas, temperate broadleaf and mixed forests [Occupation (LU)]
Argentina	Occ, artificial areas, urban, green areas, temperate grasslands, savannas & shrub [Occupation (LU)]

Table 8.13: Land occupation and land transformation biome flows for refining

Country	Land occupation and land transformation flow
Germany	Occ, artificial areas, industrial area, temperate broadleaf and mixed forests [Occupation (LU)]
Germany	Occ, artificial areas, urban, green areas, temperate broadleaf and mixed forests [Occupation (LU)]
Netherlands	Occ, artificial areas, industrial area, temperate broadleaf and mixed forests [Occupation (LU)]
Netherlands	Occ, artificial areas, urban, green areas, temperate broadleaf and mixed forests [Occupation (LU)]

Table 8.14: Land occupation and land transformation biome flows for margarine production

Country	Land occupation and land transformation flow
Germany	Occ, artificial areas, industrial area, temperate broadleaf and mixed forests [Occupation (LU)]
Germany	Occ, artificial areas, urban, green areas, temperate broadleaf and mixed forests [Occupation (LU)]
Netherlands	Occ, artificial areas, industrial area, temperate broadleaf and mixed forests [Occupation (LU)]
Netherlands	Occ, artificial areas, urban, green areas, temperate broadleaf and mixed forests [Occupation (LU)]

Table 8.15: Land occupation and land transformation and characterisation factors for cultivation

Occupation/ transformation flow	Land type	Occupation	Transformation	Permanent
Occ, arable, Argentina	Agriculture	1.21E-10		
Occ, arable, Germany	Agriculture	2.04E-10		
Occ, arable, Russia	Agriculture	2.27E-11		
Occ, arable, Ukraine	Agriculture	1.20E-10		
Occ, perm crop, Malaysia	Average: Agriculture/ Managed forest	7.69E-10		
Trans, from arable, Malaysia	Agriculture		-7.40E-08	-2.64E-05
Trans, from forest, Malaysia	0		0	0
Trans, from past/meadow, Germany	Pasture		-9.12E-09	0
Trans, from permanent crop, Germany	Average: Agriculture/ Managed forest		-1.36E-08	-3.72E-07

Trans, to arable, Germany	Agriculture		2.28E-08	5.07E-07
Trans, to permanent crops, Malaysia	Average: Agriculture/ Managed forest		4.95E-08	1.84E-05

Table 8.16: Land occupation and land transformation and characterisation factors for background datasets

Occupation/ transformation flow	**Land type**	**Occupation**	**Transformation**	**Permanent**
Occupation, arable, non-irrigated	Agriculture	2.61E-10		
Occupation, construction site	Urban	1.14E-10		
Occupation, dump site	Urban	1.14E-10		
Occupation, dump site, benthos	n/a			
Occupation, forest, intensive	Managed forest	1.06E-10		
Occupation, forest, intensive, normal	Managed forest	1.06E-10		
Occupation, forest, intensive, short-cycle	Managed forest	1.06E-10		
Occupation, industrial area	Urban	1.14E-10		
Occupation, industrial area, benthos	n/a			
Occupation, industrial area, built up	Urban	1.14E-10		
Occupation, industrial area, vegetation	Urban	1.14E-10		
Occupation, mineral extraction site	Urban	1.14E-10		
Occupation, pasture and meadow, extensive	Pasture	1.47E-10		
Occupation, permanent crop, fruit, intensive	Average: Agriculture/ Managed forest	1.84E-10		
Occupation, shrub land, sclerophyllous	Pasture	1.47E-10		
Occupation, traffic area, rail embankment	Urban	1.14E-10		
Occupation, traffic area, rail network	Urban	1.14E-10		
Occupation, traffic area, road embankment	Urban	1.14E-10		
Occupation, traffic area, road network	Urban	1.14E-10		
Occupation, urban, discontinuously built	Urban	1.14E-10		
Occupation, water bodies, artificial	n/a			
Occupation, water courses, artificial	n/a			
Transformation, from arable	Agriculture		-1.69E-08	-1.48E-05
Transformation, from arable, non-irrigated	Agriculture		-1.69E-08	-1.48E-05
Transformation, from arable, non-irrigated, fallow	Agriculture		-1.69E-08	-1.48E-05
Transformation, from dump site, inert material landfill	Urban		-5.86E-09	-7.70E-06

Transformation, from dump site, residual material landfill	Urban		-5.86E-09	-7.70E-06
Transformation, from dump site, sanitary landfill	Urban		-5.86E-09	-7.70E-06
Transformation, from dump site, slag compartment	Urban		-5.86E-09	-7.70E-06
Transformation, from forest	0		0	0
Transformation, from forest, extensive	Managed forest		-6.22E-09	-6.66E-06
Transformation, from forest, intensive, clear-cutting	Managed forest		-6.22E-09	-6.66E-06
Transformation, from industrial area	Urban		-5.86E-09	-7.70E-06
Transformation, from industrial area, benthos	n/a			
Transformation, from industrial area, built up	Urban		-5.86E-09	-7.70E-06
Transformation, from industrial area, vegetation	Urban		-5.86E-09	-7.70E-06
Transformation, from mineral extraction site	Urban		-5.86E-09	-7.70E-06
Transformation, from pasture and meadow	Pasture		-8.60E-09	-1.00E-05
Transformation, from pasture and meadow, intensive	Pasture		-8.60E-09	-1.00E-05
Transformation, from sea and ocean	n/a			
Transformation, from shrub land, sclerophyllous	Pasture		-8.60E-09	-1.00E-05
Transformation, from tropical rain forest	0		0	0
Transformation, from unknown	Average: Agriculture/ Pasture/ Urban/ Managed forest		-9.39E-09	-9.78E-06
Transformation, to arable	Agriculture		1.69E-08	1.48E-05
Transformation, to arable, non-irrigated	Agriculture		1.69E-08	1.48E-05
Transformation, to arable, non-irrigated, fallow	Agriculture		1.69E-08	1.48E-05
Transformation, to dump site	Urban		5.86E-09	7.70E-06
Transformation, to dump site, benthos	n/a			
Transformation, to dump site, inert material landfill	Urban		5.86E-09	7.70E-06
Transformation, to dump site, residual material landfill	Urban		5.86E-09	7.70E-06
Transformation, to dump site, sanitary landfill	Urban		5.86E-09	7.70E-06
Transformation, to dump site, slag compartment	Urban		5.86E-09	7.70E-06

Transformation, to forest	0		0	0
Transformation, to forest, intensive	Managed forest		6.22E-09	6.66E-06
Transformation, to forest, intensive, clear-cutting	Managed forest		6.22E-09	6.66E-06
Transformation, to forest, intensive, normal	Managed forest		6.22E-09	6.66E-06
Transformation, to forest, intensive, short-cycle	Managed forest		6.22E-09	6.66E-06
Transformation, to heterogeneous, agricultural	Agriculture		1.69E-08	1.48E-05
Transformation, to industrial area	Urban		5.86E-09	7.70E-06
Transformation, to industrial area, benthos	n/a			
Transformation, to industrial area, built up	Urban		5.86E-09	7.70E-06
Transformation, to industrial area, vegetation	Urban		5.86E-09	7.70E-06
Transformation, to mineral extraction site	Urban		5.86E-09	7.70E-06
Transformation, to pasture and meadow	Pasture		8.60E-09	1.00E-05
Transformation, to permanent crop, fruit, intensive	Average: Agriculture/ Managed forest		1.15E-08	1.07E-05
Transformation, to sea and ocean	n/a			
Transformation, to shrub land, sclerophyllous	Pasture		8.60E-09	1.00E-05
Transformation, to traffic area, rail embankment	Urban		5.86E-09	7.70E-06
Transformation, to traffic area, rail network	Urban		5.86E-09	7.70E-06
Transformation, to traffic area, road embankment	Urban		5.86E-09	7.70E-06
Transformation, to traffic area, road network	Urban		5.86E-09	7.70E-06
Transformation, to unknown	Average: Agriculture/ Pasture/ Urban/ Managed forest		9.39E-09	9.78E-06
Transformation, to urban, discontinuously built	Urban		5.86E-09	7.70E-06
Transformation, to water bodies, artificial	n/a			
Transformation, to water courses, artificial	n/a			

Table 8.17: Blue water flows for crop production in the different sourcing countries.

Country	**Blue water flows**	**Amount (m^3/ha)**

Palm fruit, Malaysia	Water, blue, consumed, ground, Malaysia [Water]	0
	Water, blue, consumed, surface, Malaysia [Water]	0
Rapeseed, Germany	Water, blue, consumed, ground, Germany [Water]	0
	Water, blue, consumed, surface, Germany [Water]	0
Sunflower, Argentina	Water, blue, consumed, ground, Argentina [Water]	2.16
	Water, blue, consumed, surface, Argentina [Water]	6.88
Sunflower, Russia	Water, blue, consumed, ground, Russia [Water]	0.71
	Water, blue, consumed, surface, Russia [Water]	1.25
Sunflower, Ukraine	Water, blue, consumed, ground, Ukraine [Water]	0
	Water, blue, consumed, surface, Ukraine [Water]	11.21
Maize, Germany	Water, blue, consumed, ground, Germany [Water]	4.04
	Water, blue, consumed, surface, Germany [Water]	15.01