AC0410 ANNEX 2: LCA AND BIOENERGY PROCESSING METHODOLOGY AND RESULTS

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The life cycle is subdivided into discreet models that can be connected in order to cover the whole life cycle of anaerobic digestion and bioenergy chains. The agricultural production of feedstocks and the application of digestate are modelled by the University of Bangor while the anaerobic digestion and the production of biofuels are modelled by the Thünen Institute of Agricultural Technology. This Annex is subdivided into two main parts: Biogas and liquid biofuels. The focus of this study is on biogas production from agricultural products and residues.

Part 1: Biogas

The report is structured following the four step approach of LCA (goal and scope, Inventory, Environmental impact assessment and Interpretation) according to ISO 14040.

Goal and scope

An attributional LCA approach is used for this study. The goal of the study is to estimate the energy i.e. produced heat and electricity and selected environmental impacts from various feedstock, namely maize, rye, grass, food-waste as well as pig and dairy slurry. Additionally the amount of nutrients in the digestate is estimated based on the feedstock composition and emission reduction measures.

The system boundary is from cradle-to-gate and the functional unit is 1 t or m^3 of feedstock. The life cycle will be completed by the University of Bangor, which models the feedstock production at the farm level and the use of the digestate using MANNER-NPK. The downstream emissions from food-waste, pig-and dairy slurry are assumed to be zero.

Inventory

The composition of the feedstock and the parameters for the biogas plant including CHP at two different scales (small and large scale CHP) are taken from various sources[1] (Amon et al. 2007, Möller et al. 2010, Poeschl et al.2012, Scholwin et al. 2006, Thomson et al. 2013 , Stinner et al. 2008, Moset et al. 2012, Braun et al. 2010, Voigt 2008). Typical feedstock composition and biogas yield from biogas plant running at full scale in Germany are shown in Table 1.

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[1] http://www.lfl-design3.bayern.de/iab/duengung/39709/
http://www.lwk-niedersachsen.de/index.cfm/portal/betriebumwelt/nav/360/article/17878.html
http://www.lfu.bayern.de/abfall/biogashandbuch/index.htm
http://www.landwirtschaft.sachsen.de/landwirtschaft/7147.htm
http://daten.ktbl.de/biogas/startseite.do;jsessionid=82E6458BDBA842A8B67F3946A5CB4D13
http://www.lfu.bayern.de/abfall/biogashandbuch/index.htm
http://www.lwk-niedersachsen.de/index.cfm/portal/betriebumwelt/nav/360/article/17878.html
http://www.cropgen.soton.ac.uk/deliverables.htm

Table 1: Composition of various feedstocks for biogas production

Feedstock		DM	ODM	N	NH$_4$	P$_2$O$_5$	K$_2$O	Biogas	Methane
		(%)	(% DM)	(% DM)	(% DM)	(% DM)	(% DM)	yield	yield
								(Nm^3/t	(Nm^3/t
								substrate)	substrate)
Maize silage	Δ	28-35	85-98	2.3-3.3		1.5-1.9	4.2-7.8	170-220	89-120
	Ø	33	95	2.8		1.8	4.3	200	106
Grass silage	Δ	25-50	70-95	3.5-6.9		1.8-3.7	6.9-19.8	170-200	93-109
	Ø	35	90	4		2.2	8.9	180	98
Manure (dairy/cattle	Δ	6-11	75-82	2.6-6.7	1-4	0.5-3.3	5.5-10	20-30	11-19
	Ø	10	80	3.5		1.7	6.3	25	14
Manure (pig)	Δ	4-7	75-86	6-18	3-17	2-10	3-7.5	20-35	12-21
	Ø	6	80	3.6		2.5	2.4	28	17
Green rye silage	Δ								
	Ø	25	90					150	79
Cereal silager	Δ	30-35	92-98	4		3.25		170-220	90-120
	Ø	33	95	4.4		2.8	6.9	190	105
Food waste	Δ	14-30	75-96.5	0.74-2.8	0.04	0.03-0.1	2.5-4.5	640-760	57
	Ø							680 Nm3/t ODM	

The values used for this study are provided by the University of Bangor based on Farm-Adapt outputs and UK-specific values where available (Table 2).

Table 2: Feedstock characteristics used in this study based on Farm-Adapt outputs and UK-specific values (default biogas yields shown)

	Dry matter	Total N	NH$_4$-N	P$_2$O$_5$	K$_2$O	Biogas
	%	kg/m^3 fm	kg/m^3 fm	kg/m^3 fm	kg/m^3 fm	m^3/t fm
Dairy slurry	10	4.21	2.31	1.8	4	24
Pig slurry	4	3.9	2.7	1.80	2.41	21.6
Maize silage	30	4.23	0.63	1.9	4.5	187.5
Grass silage	25	5.37	0.81	2.0	6.25	160
Food waste	26	7.1	0.04	1.3	3.3	160

Feedstock compositions vary widely depending on the crop variety, soil, climate conditions, pre-treatment, storage, etc. Moreover, the performance of the biogas plant depends on a number of additional factors, such as appropriate process control, additives, fermenter insulation, etc. In order to reflect the range of produced energy and associated environmental burdens, three main scenarios and two sub-scenarios are defined. The main scenarios are:

1. Best case scenario: It is assumed the emissions from the operation are limited to the unavoidable emissions, the biogas yield is high. This scenario reflects the optimal case upon which it is almost impossible to improve.
2. Default scenario (average management practise): Average figures are assumed for the pre-treatment, fermentation process and emissions from fermentation, the CHP plant and the digestate storage. The calculated values represent typical values for biogas plants and associated CHP units.
3. Worst case scenario: High losses during pre-treatment, low biogas yield and high emissions from the fermentation, CHP and digestate storage are assumed. This scenario represents a very poor management performance having several events of fault. However major accidents are not considered here.

The sub-scenarios reflect the influence of the operator of the biogas plant based on the default scenario. Emissions and yield are inter-connected; in these default scenarios only the emissions are varied whilst energy output remains constant. The sub-scenarios are:

2a. Good default: Emissions from the fermentation and the digestate storage are half or a quarter lower than for the default scenario. The emission reduction compared to the default scenario can be attributed to various causes: e.g. improved fermentation, early detection of leakages and immediate repair, maintenance of the CHP-burner, etc. This scenario reflects good management of the biogas plant and the CHP unit.

2b. Poor default: Emissions from fermentation and digestate storage are 50% higher than in the default scenario due to leakages, release during feeding operation, reduced process efficiency, etc. The operator is unskilled and dysfunctions occur from time to time. This scenario reflects poor management of the biogas plant and CHP.

Several assumptions and simplifications had to be made. Table 2 and Table 3 show some of these assumptions for the smaller and larger maize AD modules (biogas yields and CH_4 content, and digestate NH_4 content, vary with feedstock). Maize, rye and grass are ensilaged before fed into the fermenter. The average mass loss during ensilaging is assumed to be 10%; this value is frequently used in LCA studies and also within the ECOINVENT database. However, it is reported that unavoidable losses are 3-6% but can range to 30% if poorly performed (Voigt, 2008). In the latter case emissions would occur which are not considered here. For the best case scenario 5%, for the default 10% and for the worst case 25% are assumed. The feedstock is immediately transferred to the biogas plant and no emissions occur due to storage. However, this is offset by a long average storage time for the digestate of 180 days, with methane emissions ranging from 0 to 10% and ammonia emissions ranging from 0 to 82% of ammonium in the digestate.

Table 3. AD module parameters for maize feedstock in a small (<500 kWe) AD unit

Variable parameter	**Best case**	**Good default**	**Default**	**Poor default**	**Worst case**
Biogas yield [Nm^3/ t silage]	200	188	188	188	175
Storage loss CH_4 [%]	0	2.5	5	7.5	10
CH_4 loss in CHP [%]	0.1	0.5	0.5	0.5	1
Storage loss NH_3 [% NH_4 in digestate]	0.0	2.0	10.0	16.0	52.0
Mass loss during ensilage [%]	5	10	10	10	25
Fixed parameter					
Fermenter electricity demand*	0.78 MJ per produced Nm^3 biogas				
Fermenter heat demand*	1.64 MJ per produced Nm^3 biogas				
CH4 content biogas [%]	53	53	53	53	53
Heat efficiency CHP [%]	43	43	43	43	43
Electricity efficiency CHP [%]	37.5	37.5	37.5	37.5	37.5
*Represents 10% electricity output and 20% heat output in default scenario					

Table Error! No text of specified style in document.**.1. AD module parameters for maize feedstock in a large (>500 kWe) AD unit**

Variable parameter	**Best case**	**Good default**	**Default**	**Poor default**	**Worst case**
Biogas yield [Nm^3/ t silage]	200	188	188	188	175
Storage loss CH_4 [%]	0	1.25	2.5	3.75	5
CH_4 loss in CHP [%]	0	0.1	0.1	0.1	0.5
Storage loss NH_3 [% NH_4 in digestate]	0	1.25	2.5	5	10
Mass loss during ensilage [%]	5	10	10	10	25
Fixed parameter					
Fermenter electricity demand*	0.78 MJ per produced Nm^3 biogas				
Fermenter heat demand*	1.64 MJ per produced Nm^3 biogas				
CH4 content biogas [%]	53	53	53	53	53
Heat efficiency CHP [%]	43	43	43	43	43
Electricity efficiency CHP [%]	41	41	41	41	41
*Represents 10% electricity output and 20% heat output in default scenario					

The ammonium content is modelled assuming a conversion rate of 22% of the total N-content for maize, grass and rye based on the original N-content. Data for food waste digestate (e.g. as considered in MANNER-NPK) indicate high NH_4-N contents and thus high conversion rates for organic N during digestion. A corresponding food waste-digestate NH_4-N content of 80% of total N was applied. Pig and dairy slurry contain already a considerable content of ammonium. For pig slurry an increase of 10% from the organic-bound nitrogen is assumed and for dairy slurry a 20% increase. Due to the ammonium-ammonia equilibrium in aqueous solution part of the ammonium is lost as ammonia in the biogas, oxidised to nitrogen oxide in the CHP unit and released to the environment. The ammonium-ammonia equilibrium in aqueous solution depends mainly on temperature and pH. The ammonia content is modelled and shown in Fig. 1.

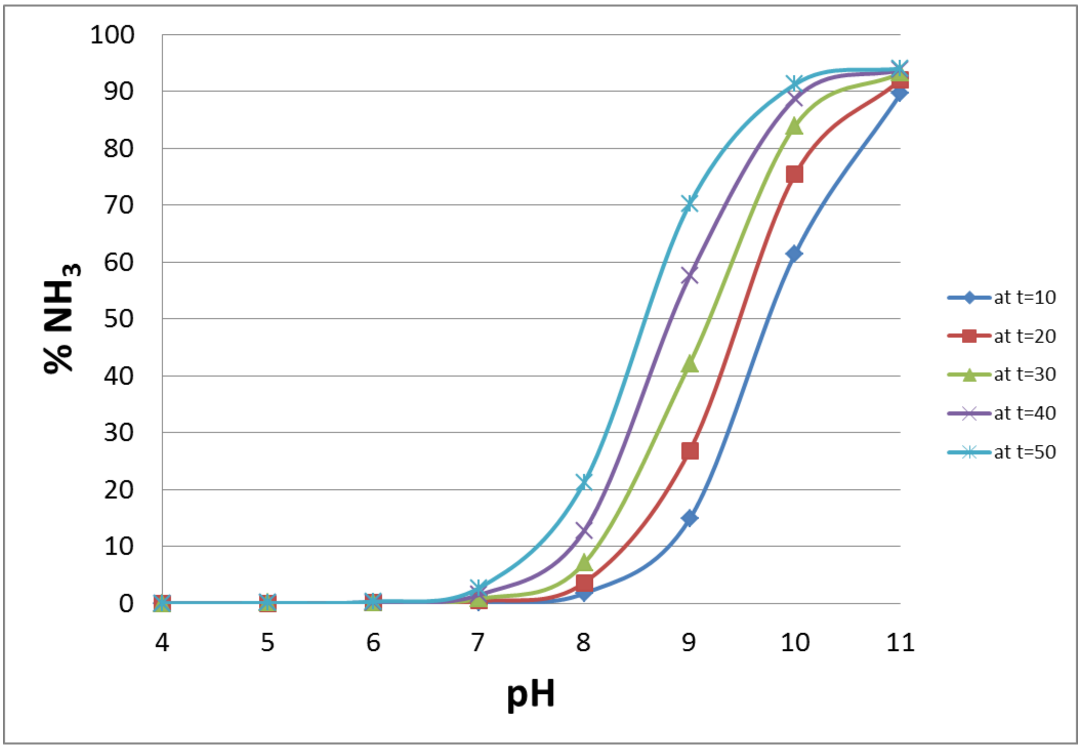

Fig.1: NH_3 depending on pH and temperature in aqueous systems

The temperature of mesophilic fermentation is around 38° at pH 8, hence an ammonia loss of 10% of the ammonium present in the fermenter is assumed. The remaining ammonium and the organic-bound nitrogen remain in the digestate as well as the original amount of potassium and phosphate. A static model is used to calculate the ammonia emissions form the digestate, ignoring that there might be also a dynamic equilibrium between ammonium and organic-bound nitrogen organic-bound nitrogen is converted to ammonium.

During biogas conversion in the CHP plant methane emissions occur, which range from 0.1 to 1% in small CHP units and from 0 to 0.5% in large CHP units, because the latter is usually equipped with an oxidation catalyst. The conversion efficiency for the small CHP unit is 37.5% for electricity and 43% for heat, while in the large unit the efficiency for electricity rises to 41% (Voigt 2008, FNR 2010).

The parasitic energy consumption of the fermenter and utilities is calculated using maize biogas plans in Germany from which extensive data are available. Average figures are that 10% of the produced electricity and 20% of the produced heat from the biogas is used within the plant. Due to varying dry matter content of feedstock, the energy consumption is calculated based on the amount of biogas produced. The default scenario for biogas from maize with a large scale CHP-unit is used as a baseline where 1290 MJ electricity and 1350 MJ heat is produced from 165 Nm^3 biogas (1 t maize), if 10% of the electricity is needed for the fermenter and 20% of the heat then that results in 0.78 MJ electricity /Nm^3 and 1.643 MJ heat/Nm^3 biogas produced. These values are used to calculate the heat and electricity demand for the fermenter of each feedstock.

Fig. 2 shows the model for the biogas system from maize from gate-to-gate.

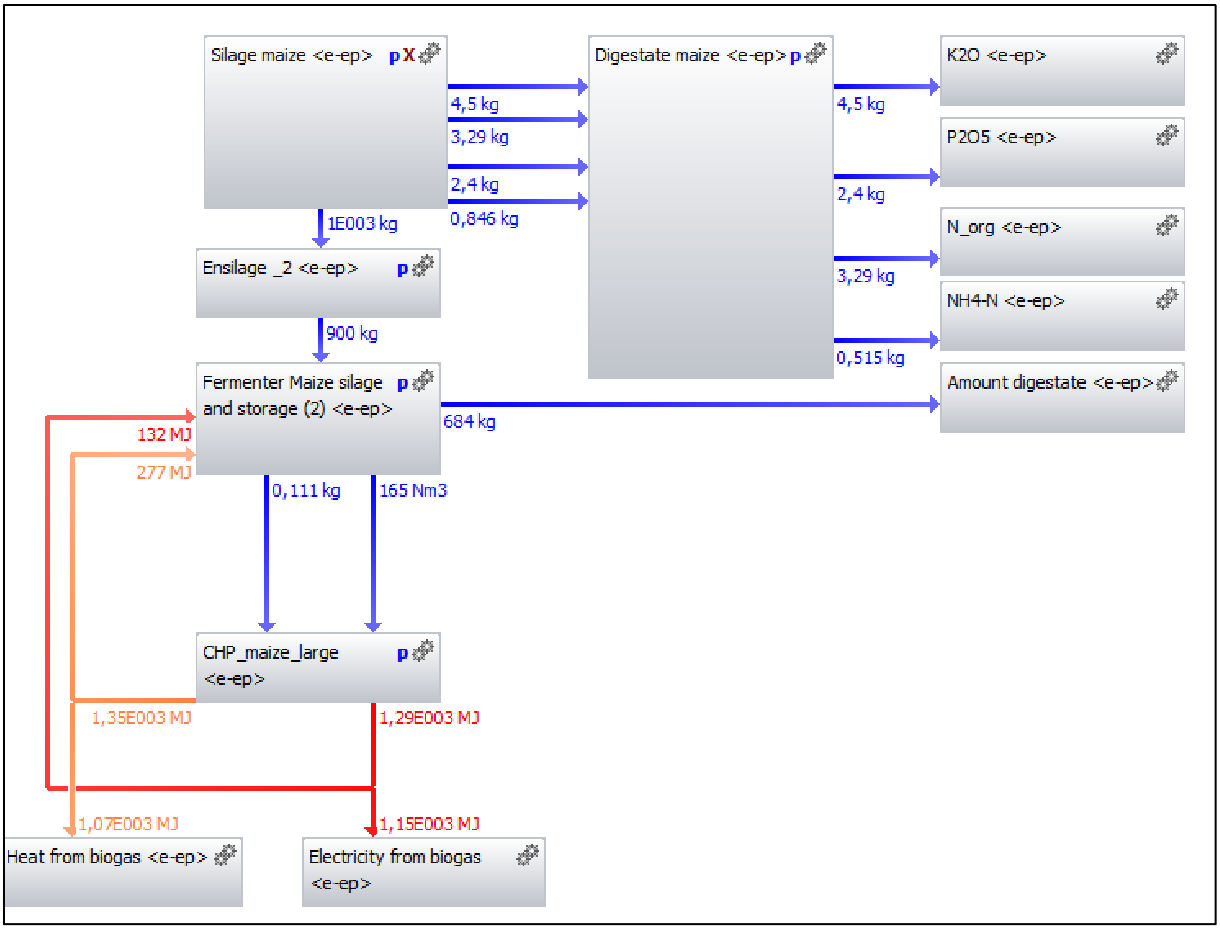

Fig.2: Model for biogas from maize (default scenario)

Environmental impact assessment

Five impact categories from the CML Nov. 2010 method have been selected for the analysis. The impact categories used are “Abiotic resource depletion” (both, fossil and elements) as well as “Acidification”, “Eutrophication” and “Global Warming Potential”. While the former are quantifying the depletion of resources the latter are the most relevant environmental impacts of agricultural systems.

Interpretation

The interpretation of results can only be done under consideration of the growing stage and the digestate application. Both are conducted by the University of Bangor. Hence, the interpretation will be done in the final report.

Part 2: Liquid biofuels

Goal and scope

The goal of the study is to estimate the GHG savings and environmental burdens of liquid biofuels production and use as transport fuel. Baseline data from the BIOGRACE tool version 4c[2] for production system using natural gas as energy source are used as inventory data. An attributional LCA approach is used for this study in order be in incompliance with the Renewable Energy Directive[3]; consequently allocation is conducted based on the energy content of the products. The system boundary is from cradle-to-grave and the functional unit is 1 t of feedstock.

Fig. 3 shows the model for biodiesel from rapeseeds and Fig. 4 the figures after allocation has been performed.

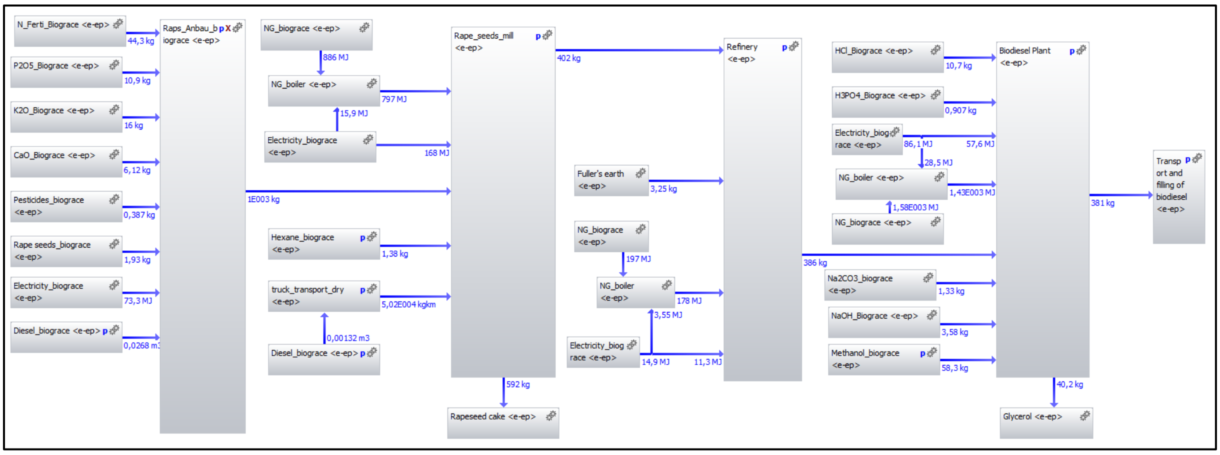

Fig. 3: Model and material flows for biodiesel from rapeseeds (unallocated results)

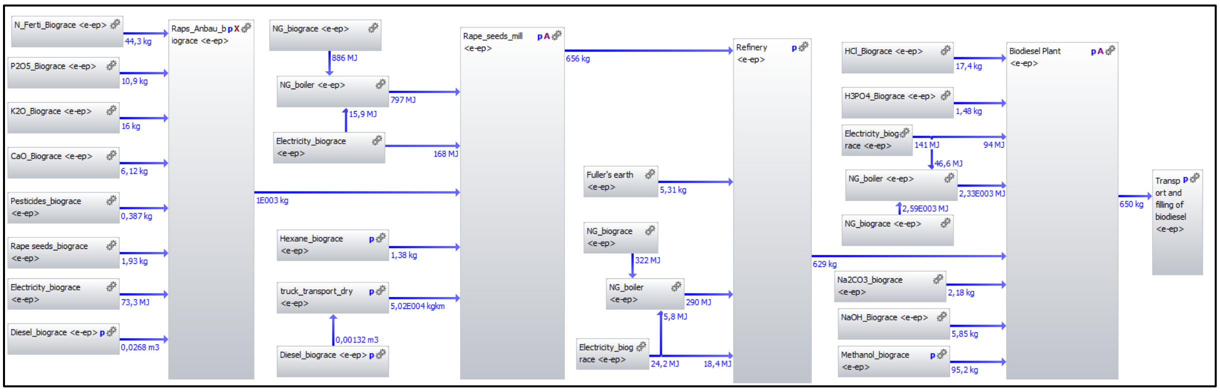

Fig. 4: Model and material flows for the biodiesel from rapeseeds (allocated)

Inventory

Inventory data were taken from BIOGRACE for rapeseeds, wheat and sugar beet. BIOGRACE considers GHG emissions only. Ecoinvent data were applied to BIOGRACE activity data to calculate other environmental impacts. Although the LCAD tool uses environmental burden data for feedstock cultivation based on baseline cultivation scenarios, agricultural production burdens were also

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[2] http://biograce.net/

[3] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:01:EN:HTML

calculated here according to BIOGRACE for comparison. The N_2O calculator of the BIOGRACE tool version 4c was used to calculate nitrous oxide, nitrate and ammonia emissions in the field from fertiliser application and crop residues. Ecoinvent datasets were used to model the system and calculate the environmental burdens, including upstream emissions from agricultural production. Moreover the emissions from diesel consumption in the field were calculated using ECOINVENT working processes for the respective crops but scaled to the total diesel consumption shown in the BIOGRACE tool for the respective crops. An example is shown in Fig. 5.

Fig. 5: Working processes for the production of rapeseeds scaled to the overall diesel consumption for rapeseeds production according to BIOGRACE Version 4c, which equals 69.6 kg diesel/ha

For biodiesel from rapeseed three systems are investigated: The biograce default values as well as systems using the same input data but two different fertilisers, CAN and $(NH_4)_2SO4$. The former has higher upstream GHG emissions and the latter lower upstream emissions than the generic N-fertiliser provided by BIOGRACE. The difference is significant for biodiesel from rapeseed as shown in the results section.

The same procedure was followed for bioethanol from sugar beet. However, differences between different N-fertiliser have a smaller effect as the contribution of N-fertilisers to GHG-emissions in the sugar beet system is significantly lower than for the rapeseed system.

For bioethanol from wheat systems, burdens were calculated with and without straw removal (i.e. changing the cultivation allocation). Straw frequently remains on the field in order to maintain the soil carbon content but can also be removed depending on the crop rotation and local conditions. Straw is part of the remaining biomass on the field that contains nitrogen, which will be released in the form of ammonia, nitrate and nitrous oxide. Ammonia and nitrate can also form nitrous oxide. IPPC (2006) Tier 1 emission factors are used in the BIOGRACE tool and also for this study. The removal of straw results in 4% higher GHG emission reduction than when it remains on the field, compared to conventional transport fuel. However, the benefit from straw for soil carbon and for the following crop is removed but not accounted for (one of the shortcomings when full crop rotation periods are not considered).

Note that cultivation emissions are calculated separately in the LCAD tool, and residue N emissions are allocated to the following crop, in order to match emissions with fertilisation value. It is assumed that two thirds of straw is harvested for winter wheat crops (see Annex 1).

Environmental impact assessment

Five impact categories from the CML Nov. 2010 method were selected to calculate environmental burdens. The impact categories used are “Abiotic resource depletion” (both, fossil and elements), “Acidification”, “Eutrophication” and “Global Warming Potential”. While the former quantify the depletion of resources the latter are the most relevant environmental impacts for agricultural systems. This approach enables the calculation of full lifecycle GHG-emission changes relative to replaced conventional fuels.

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