THÜNEN

Final report

Assessing the Environmental Eco-benefits of Organic Farming

Cooperative Research Project between Thünen Institute (TI) and National Academy of Agricultural Science (NAAS) of the Rural Development Administration (RDA) of the Republic of Korea

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Summary

The cooperative Research Project between the Thünen Institute and National Academy of Agricultural Science (NAAS) of the Rural Development Administration (RDA) of the Republic of Korea ran between 1st of July 2015 and December 31st 2016. During the cooperation multiple mutual visits of two colleagues from NAAS/RDA and from the Thünen Institute of Organic Farming (TI-OL) in Trenthorst took place. Aim of the cooperation was the adaptation of the model FARM, which is developed at TI-OL, for analyzing environmental effects in Korean paddy rice farming. This model is working on farm level, so that the results give the possibility to identify optimization potential on farm level or specific production systems. A data set of 28 organic farms and 13 non-organic farm was analyzed, which is a good basis to validate and verifying the model. The results should give examples for best-practices for producing environmental-friendly organic paddy rice with a high yield level.

Basis of the calculation were an adaptation of the guidelines for national greenhouse gas (GHG) inventories from the Intergovernmental Panel on Climate Change (IPCC) for the assessment of the product related GHG emissions on farm level as well as the USetox model and database for the calculation of midpoint characterization factors for the assessment of potential eco-toxicological effects.

The calculation of the product related GHG emissions show on average lower results compared to national averages but a high variability between the farms. Key findings are a large uncertainty of results due to the used IPCC method. Secondly, we found a possible bias against organic farming because of the general higher use of organic amendments in organic farming. However, carbon and nitrogen cycles in paddy soils are not taken into account for the calculation of GHG emissions, even though they could be different in the different farming systems.

The calculation of the eco-toxicological impact potential showed, as expected, differences between organic and non-organic farms in order(s) of magnitude in favor of organic farms. However, many of the used substances were not included in the USetox database and potential impacts had to be estimated.

Based on our results we recommend to validate the GHG emissions from organic Korean paddy rice production by measurements and to build a dynamic carbon and nitrogen flow model for paddy soil. Secondly, we recommend to avoid the use of strong chemical pesticides as much as possible and to validate the characterization factors by measurements for Korean conditions.

1 Motivation

Aim of the joint research is the analysis of environmental effects of South Korean plant production in Organic Farming. For this the material flow and life cycle assessment model FARM (Flow Analysis and Resource Management) developed at the Thünen Institute of Organic Farming is used. The results shall be used to derive compensation payments to organic farmers in South Korea.

The basis of the cooperative project is the agreement between National Academy of Agricultural Science (NAAS) of the Rural Development Administration (RDA) of the Republic of Korea and the Thünen Institute in Germany.

The kick-off meeting to the research cooperation between the National Academy of Agricultural Science (NAAS) of South Korea and the Thünen Institute (Germany) was on the 27th of April 2015. On this date the Director of the Organic Agricultural Division of Rural Development Administration (RDA), Dr. Kim Seok-Cheol and Dr. Seung Gil Hong visited the Thünen Institute of Organic Farming in Trenthorst. In an intensive discussion process a first working plan was worked out and Dr. Hong got the first introduction into the UMBERTO-software and modelling with FARM. The first idea to compare crop rotations of organically managed farms in South Korea and Germany was discarded because the situations in both countries are too different. In the further discussion between the project partners during the stay of the German researchers in South Korea it was decided to focus on the situation in South Korea and there in particular on paddy rice production in Organic Farming.

The background is another South Korean project, where about 70 farm situations of paddy rice production are recorded by using the data from farmer’s diary entries of paddy rice production. So, the real situation of organic rice production can be used for modelling material flows. That is the best way to get valid results of environmental effects of the rice cultivation process by using the FARM model. Additional data of conventional managed paddy rice fields were recorded, so that both systems – organic and conventional – can be assessed and compared. With the help of these results it is possible to identify the best practice of paddy rice production under South Korean conditions with low environmental effects (CH_4 and N_2O emissions, nitrate leaching etc.) but high outputs (yield). Otherwise it is possible to identify situations of paddy rice production with a possibility of optimization. Another issue was the implementation of eco-toxicity in the FARM model getting a more comprehensive assessment of the paddy rice production in both systems.

A very important issue is the understanding of the Organic Farming systems in each of the both countries. So, the two researchers from South Korea take the opportunity visiting organically managed farms for obtaining an insight into Organic Farming in Germany, otherwise the South Korean colleagues gave the German researchers a very impressive and comprehensive occasion to visit Korean farms and to learn a lot about the situation of Organic Farming and the organic paddy rice production in South Korea. This understanding is very important for a good and effective cooperation between the partners and as well for having good and valid modelling results.

2 Principal investigators and participants

Principal investigators are Maximilian Schüler and Dr. Herwart Böhm from the Thünen Institute of Organic Farming in Germany.

Maximilian Schüler is an Environmental Engineer (Dipl.-FH) with a major research interest in environmental management. Since 2011 he works as a scientist at the Thünen Institute for Organic Farming in Trenthorst, Germany. As the main developer of the FARM model (Flow Analysis and Resource Management Model) he has analyzed greenhouse gas emissions, energy use and nutrient flows on multiple dairy farms in Germany and Norway. Maximilian gained further work experience as a freelancing consultant for environmental management and environmental product declarations in the construction sector throughout Europe.

Dr. Herwart Böhm studied Agriculture Sciences at the Justus-Liebig-University Giessen with the focus on plant production. After he was manager of an organic farm for two years he went back to the University of Giessen for his PhD-thesis. Dr. Böhm finished his PhD study "Influence of different soil cultivation methods on the microbial activity with regard to the N-metabolisms" in 1993. From 1992 – 2001 he was scientist and lecturer in Organic Farming at the Christian-Albrechts-University of Kiel, Institute of Crop Science and Plant Breeding – Organic Farming. At that time he worked on potato production and his research included variety, fertilization and tillage studies with special emphasis on nutrient management, yield and quality. Since 2002 Dr. Böhm is senior researcher at the Thünen Institute of Organic Farming and the leader of the working group "Plant and Fodder Production". His main research topic is the grain legume production in Organic Farming and the optimization of mixed cropping systems with regard to yield stability, weed suppression, nutrient cycling, crop rotation, tillage, and feed quality.

Participants of the project are Dr. Seung Gil Hong and Dr. Seok Cheol Kim from Organic Agricultural Division of RDA/NAAS of South Korea.

3 Methods and materials

3.1 Data acquisition

Data from the farms has been collected by our Korean colleague Dr. Seung Gil Hong. During the project we had multiple iterations of plausibility control for farm basis data based on preliminary calculation results. The basis data from the analyzed farms is shown in Table 1.

Table 1: Collected basis data of the farms for paddy rice production

FARM ID	Location	Area (ha)	Diesel plou-ghing (l/ha)	Oil cake (kg/10a)	Cow manure compost (kg/10a)	Mineral fertilizer (kg/10a)	Total N (kg/10a)	Total P (kg/10 a)	Aerat ions	Yield (t/ha)
ORG 1	JinCheon_1	0.9094	80.0	37	2000*		6.07	0.37		5.75
ORG 2	JinCheon_2	0.9094	80.0	84			9.24	0.84		7.69
ORG 3	Cherwon_1	0.3756	7.0	200			10.00	2.00		6.39
ORG 4	Cherwon_2	0.4044	28.0	200			10.00	2.00		4.62
ORG 5	Cherwon_3	0.3970	28.0	200			10.00	2.00		3.85
ORG 6	GunSan_1	0.4232	22.4	95			3.80	1.9.	1	5.91
ORG 7	AnSeong_1	0.8147	144.0	182			7.28	3.64	1	7.41
ORG 8	HongSeong_1	0.393	85.5		3050		12.51	17.08		6.36
ORG 9	HongSeong_2	0.2902	79.2		3100		17.86	18.39	1	6.89
ORG 10	HongSeong_3	0.3759	39.0		0		0.00	0.00		5.32
ORG 11	HongSeong_4	0.3260	14.0		307		15.35	3.07		6.44
ORG 12	YangPyeong_1	0.2067	45.5	1026			47.034	18.00		7.89
ORG 13	YangPyeong_4	0.1922	91.0	832			34.94	14.98		8.53
ORG 14	BuAn	0.5375	45.0	149			7.45	1.49		5.58
ORG 15	HongCheon	0.2902	20.8	359			12.45	6.89		5.51
ORG 16	YeongCheon	0.2042	25.8	392			17.64	5.88		4.90
ORG 17	JeongEup	0.4298	39.0	149			7.45	1.49		2.99
ORG 18	SangJu	0.4146	60.0	314			12.56	6.28		4.82
ORG 19	SangJu	0.6155	28.0	2481			127.71	24.81		6.05
ORG 20	WonJu	0.2351	49.5	298			14.90	0.00		5.32
ORG 21	YeoJu	0.2197	48.0	2730			114.66	49.14	1	6.37
ORG 22	PyeongTaek_1	0.2076	42.0	2000			80.00	40.00	1	8.30
ORG 23	PyeongTaek_2	0.2076	42.0	2000			80.00	40.00	1	7.66
ORG 24	YangPyeong_1	0.1498	28.0	1746			69.84	34.92		7.09
ORG 25	YangPyeong_4	0.3484	28.0	1900			76.00	38.00		8.53
ORG 26	GimHae_1	0.4797	0.0	0			0.00	0.00		7.14
ORG 27	Asan_1	0.2595	0.0	462			23.10	4.62		5.70
ORG 28	HongSeong_5	0.0498	22.8		3100		12.71	17.36		5.10
CON 1	Gunsan_1	0.3416	28.0			9.45	9.45	3.90		7.51
CON 2	Gunsan_2	0.2691	28.0			9.45	9.45	3.90		7.42
CON 3	HongSeong_1	0.2418	79.2			14.05	14.05	7.15		5.53
CON 4	YeongJu	0.6942	30.0			12.81	12.81	4.27	1	6.00
CON 5	Asan	0.4978	11.9			1.44	1.44	0.00		5.02
CON 6	HongCheon	0.1055	15.9			12.90	12.90	8.60		5.69
CON 7	SangJu	0.2071	77.6			8.53	8.53	5.97		5.80
CON 8	YeoJu	0.2563	99.0			16.66	16.66	4.50		6.42
CON 9	GimHae	0.2007	90.0			0.00	25.00	9.80		5.84
CON 10	Goseong	0.0753	31.8			13.00	13.00	6.80		5.04
CON 11	Namhae	0.2582	75.0			0.00	143.30	11.62		7.68

* Swine manure digestate

3.2 FARM model

For the modelling of the organic paddy rice production the software Umberto NXT Universal (ifu Hamburg GmbH) in the version 7.1 was used. Included in the software are the ecoinvent databases version 2.2 (Hischier et al. 2010) and 3.1 (Weidema et al. 2013). The software is specialized in quantitative assessments of material and energy flows for the use in environmental life cycle assessment (LCA), material flow cost accounting (MFCA) and related fields.

The FARM-Model (Flow Analysis and Resource Management Model) is an assessment tool to analyze product and area related energy and mass flows of agricultural production and resulting predicted environmental impacts. With integration of supply-chain operations, means of production and infrastructure the FARM model offers a complete life cycle assessment (LCA) from "cradle-to-farm gate". The FARM model links farm data (parameterized process data) with emission prediction models (e.g. direct nitrogen emissions, methane from enteric fermentation, etc.) and ensures mass balances for nitrogen, phosphorous, and potassium. Interfaces on process level allow direct embedding of further (sub-) models. The parameterized input data can be varied automatically thus allowing scenario analyses (e.g. effectiveness of emission abatement measures) and uncertainty analyses (e.g. Monte Carlo simulation).

3.3 Framework for assessment of greenhouse gas emissions

The general method for the calculation of greenhouse gas (GHG) emissions is based on the methodology of life cycle assessment (LCA, ISO 2006, ISO 2009). For an LCA, four stages have to be performed: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation of results. The execution of these stages is performed iteratively, that means that e.g. the goal and scope is refined if available data quality is different than expected. In the following goal and scope are defined. The other phases are seamlessly incorporated into this report.

The goal of this study is described in section 1 of this report. The scope of this study is cradle-to-farm gate. This means that all processes from the extraction of raw materials until the harvest of rice are included into the study. Processing of rice, use of rice (consumption) and disposal of residues is not included in this study. The functional unit used for comparison is 1 kg FM rice harvested. Allocation is performed based on cut-off as defined in the ecoinvent 3 methodological report (Weidema 2013) throughout the entire model.

Currently, no general framework exists for the calculation of GHG emissions of paddy rice on farm level. However, LCA of rice production has been done e.g. in Italy (Blengini and Busto 2009) where organic production was calculated as an improvement scenario. Another study performed an LCA for conventional rice in Taihu region, China (Wang 2010). Both of these studies use the guidelines for national inventory reporting from the IPCC (2006a) for the calculation of direct GHG emissions. Consequently, the IPCC guidelines are applied in this study as well.

3.3.1 Description of IPCC guidelines for direct emissions of GHG from paddy rice

From previous studies we know that direct methane emissions from the flooded paddy fields are the most significant contributor to the impact category GWP (e.g. Blengini and Busto 2009).

The IPCC guidelines for the calculation for national GHG inventories (IPCC 2006a) give a formula for the calculation of methane from paddy rice cultivation based on a daily emission factor, cultivation period and harvested area.

Equation (1): Calculation of annual methane emissions from paddy fields

$$CH_{4\,Rice} = \sum_{i,j,k} (EF_{i,j,k} \times t_{i,j,k} \times A_{i,j,k} \times 10^{-6})$$

Where:

$CH_{4\,Rice}$ = annual methane emissions from rice cultivation, Gg CH_4 yr^{-1}

EF_{ijk} = a daily emission factor for *i*, *j*, and *k* conditions, kg CH_4 ha^{-1} day^{-1}

t_{ijk} = cultivation period of rice for *i*, *j*, and *k* conditions, day

A_{ijk} = annual harvested area of rice for *i*, *j*, and *k* conditions, ha yr^{-1}

i, *j*, and *k* = represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary

As both the cultivation period and the harvested area are available for each individual farm, this equation can be used to calculate the farm specific CH_4 emission. The daily emission factor EF_{ijk} depends on multiple scaling factors that influence the methane production in a paddy field. This is expressed by equation (2).

Equation (2): Adjusted daily emission factor

$$EF_i = EF_c \times SF_w \times SF_p \times SF_o \times SF_{s,r}$$

Where:

EF_i = Adjusted daily emission factor for a particular harvested area

EF_c = baseline emission factor for continuously flooded fields without organic amendments

SF_w = Scaling factor to account for the differences in water regime during the cultivation period (from Table 5.12)

SF_p = Scaling factor to account for the differences in water regime in the pre-season before the cultivation period (from Table 5.13)

SF_o = Scaling factor should vary for both type and amount of organic amendment applied (from Equation 5.3 and Table 5.14)

$SF_{s,r}$ = Scaling factor for soil type, rice cultivar, etc., if available

In the following we present each scaling factor for the adjusted daily emission factor.

CH_4 Emission (kg CH_4 ha^{-1} d^{-1})	Emission factor	Error range
	1.30	0.80-2.20
Source: Yan et al., 2005		

Figure (1): Default CH4 baseline emission factor.

The baseline emission is 1.30 kg CH_4 ha^{-1} d^{-1}. For a growing period of 120 days this means a default methane emission of 156 kg CH_4 per ha paddy rice production. The methane emissions from paddy fields show two distinctive peaks over a course of 120 days flooding. Consequently, single or multiple aerations can disturb the anaerobic conditions and reduce CH_4 emissions. Therefore, the baseline emission is reduced by a scaling factor depending on the existence (and number) of aerations during the cultivation period.

Water Regime		Aggregated case		Disaggregated case	
		Scaling Factor (SF_w)	Error Range	Scaling Factor (SF_w)	Error Range
Upland[a]		0	-	0	-
Irrigated[b]	Continuously flooded	0.78	0.62-0.98	1	0.79-1.26
	Intermittently flooded – single aeration			0.60	0.46-0.80
	Intermittently flooded – multiple aeration			0.52	0.41-0.66
Rainfed and deep water[c]	Regular rainfed	0.27	0.21-0.34	0.28	0.21-0.37
	Drought prone			0.25	0.18-0.36
	Deep water			0.31	ND

Figure (2): Scaling factor SFw for aerations during cultivation period.

The cultivation system under study is deemed irrigated. We can use the scaling factors for the disaggregated case, as each farm is calculated independently from each other. For no aeration the scaling factor remains 1, for a single aeration the scaling factor is 0.6. The farms in our study did not have multiple aerations.

TABLE 5.13
DEFAULT CH_4 EMISSION SCALING FACTORS FOR WATER REGIMES BEFORE THE CULTIVATION PERIOD

Water regime prior to rice cultivation		Aggregated case		Disaggregated case	
		Scaling factor (SF_p)	Error range	Scaling factor (SF_p)	Error range
Water regime prior to rice cultivation (schematic presentation showing flooded periods as shaded)		Aggregated case		Disaggregated case	
		Scaling factor (SF_p)	Error range	Scaling factor (SF_p)	Error range
Non flooded pre-season <180 d	< 180 d CROP	1.22	1.07-1.40	1	0.88-1.14
Non flooded pre-season >180 d	> 180 d CROP			0.68	0.58-0.80
Flooded pre-season (>30 d)[a,b]	> 30 d CROP			1.90	1.65-2.18

Figure (3): Scaling factor SF_p for flooding pre-season.

The farms in our study have not been flooded more than 30 days prior to cultivation. No flooding is done after cultivation so that more than 180 days prior to cultivation is non flooded. The scaling factor is therefore set to 0.68 in all farms under study.

Equation (3): Scaling factor SF_o for organic amendmends.

$$SF_o = \left(1 + \sum_i ROA_i \times CFOA_i\right)^{0.59}$$

The application rate of each organic amendment (as fresh matter, except for straw) is multiplied with its conversion factor to calculate the scaling factor for organic amendments.

Organic amendment	Conversion factor (CFOA)	Error range
Straw incorporated shortly (<30 days) before cultivation[a]	1	0.97-1.04
Straw incorporated long (>30 days) before cultivation[a]	0.29	0.20-0.40
Compost	0.05	0.01-0.08
Farm yard manure	0.14	0.07-0.20
Green manure	0.50	0.30-0.60

a: straw application means that straw is incorporated into the soil, it does not include case that straw just placed on the soil surface, nor that straw was burned on the field.

Source: Yan et al., 2005

Figure (4): Conversion factors of organic amendments for the calculation of the scaling factor SF_o

While soil type and rice cultivar have an influence on CH_4 emissions, IPCC (2006a) does not provide general applicable scaling factors. Consequently, SF_s and SF_r, as defined in equation (2) are set to 1.

Another source of relevant GHG emissions in paddy rice production are nitrous oxides (N_2O) from nitrogen inputs to managed soils. IPCC (2006b) give an emission factor of 0.3 % of N_2O-N emissions from N inputs.

Emission factor	Default value	Uncertainty range
EF_1 for N additions from mineral fertilisers, organic amendments and crop residues, and N mineralised from mineral soil as a result of loss of soil carbon [kg N_2O–N (kg N)$^{-1}$]	0.01	0.003 - 0.03
EF_{1FR} for flooded rice fields [kg N_2O–N (kg N)$^{-1}$]	0.003	0.000 - 0.006
$EF_{2\,CG,\,Temp}$ for temperate organic crop and grassland soils (kg N_2O–N ha^{-1})	8	2 - 24
$EF_{2\,CG,\,Trop}$ for tropical organic crop and grassland soils (kg N_2O–N ha^{-1})	16	5 - 48
$EF_{2F,\,Temp,\,Org,\,R}$ for temperate and boreal organic nutrient rich forest soils (kg N_2O–N ha^{-1})	0.6	0.16 - 2.4
$EF_{2F,\,Temp,\,Org,\,P}$ for temperate and boreal organic nutrient poor forest soils (kg N_2O–N ha^{-1})	0.1	0.02 - 0.3
$EF_{2F,\,Trop}$ for tropical organic forest soils (kg N_2O–N ha^{-1})	8	0 - 24
$EF_{3PRP,\,CPP}$ for cattle (dairy, non-dairy and buffalo), poultry and pigs [kg N_2O–N (kg N)$^{-1}$]	0.02	0.007 - 0.06
$EF_{3PRP,\,SO}$ for sheep and 'other animals' [kg N_2O–N (kg N)$^{-1}$]	0.01	0.003 - 0.03

Sources:

EF_1: Bouwman et al. 2002a,b; Stehfest & Bouwman, 2006; Novoa & Tejeda, 2006 in press; EF_{1FR}: Akiyama *et al.*, 2005; $EF_{2CG,\,Temp}$, $EF_{2CG,\,Trop}$, $EF_{2F,Trop}$: Klemedtsson *et al.*, 1999, IPCC Good Practice Guidance, 2000; $EF_{2F,\,Temp}$: Alm *et al.*, 1999; Laine *et al.*, 1996; Martikainen *et al.*, 1995; Minkkinen *et al.*, 2002: Regina *et al.*, 1996; Klemedtsson *et al.*, 2002; $EF_{3,\,CPP}$, $EF_{3,\,SO}$: de Klein, 2004.

Figure (5): Default N_2O emission factor for managed soils.

3.4 Framework for assessment of eco-toxicity

3.4.1 Description of USetox

Part of the calculation is an assessment of the eco-toxicological impacts from paddy rice production in organic and conventional farming. As the eco-toxicity cannot be easily measured under practical conditions we analyze the eco-toxicological impact potential of the systems. This is done by assigning each emission of potential eco-toxic substances a characterization factor relative to its potential of harming freshwater ecosystems. These characterization factors are derived from the USetox model (Hauschild et al. 2008, Rosenbaum et al. 2008).

The USEtox model is an environmental model for characterization of human toxicological and eco-toxicological impacts in life cycle assessment. It has been developed by a team of researchers from the Task Force on Toxic Impacts under the UNEP-SETAC Life Cycle Initiative (Hauschild et al. 2008, Rosenbaum et al. 2008).

3.4.2 Description of approach

As part of the data acquisition the use of all pesticides and the amount have been reported. Based on the active substances of the used pesticides we conducted a search in the USetox database for organic substances (USetox version 2.01, Input Data/USetox_substance_data_organics.xlsx).

Not all active substances were found in the database. For plant strengtheners in organic farming we assumed no eco-toxicological issues and excluded them from further analysis. For active substances in conventional pesticides that were not in the database we searched for information on these substances. For carbosulfan we found that the major metabolite is carbofuran. Carbofuran is listed in the USetox database so we assumed carbosulfan to be identical in its effect with carbofuran.

The active substances benzobicolone, fermizone, tiadinil, and validamycin-a were not in the USetox database and we were unable to find any reliable information on the eco-toxicological effects of these substances. All of these substances are not allowed in the European Union or the United States of America.

Consequently, we had to exclude the farms that use any of these substances from our study. This lead however to a strong reduction in available datasets. Therefore, we decided to calculate these farms under the assumption that the critical substances have the same eco-toxicological properties as fipronil, which is present in the USetox database. The eco-toxicity of fipronil is very high, so that this assumption is probably conservative and may overestimate the eco-toxicological effects. The only exception from this sensitivity analysis is farm 09 which stays excluded as a total of 7 very toxic substances that were not in the USetox database have been used on this farm. We cannot justify a calculation with this lack of data.

At this point all substance data are entered in the USetox model sheet "Substance data". The next step is to choose the model parameters for adaption for the conditions in the study. In the USetox model sheet "Run" we set the Region to "7" (Default USetox) and crop residues to "paddy rice". After completion of the model run we extract the midpoint LCIA characterization factors for freshwater eco-toxicity from the USetox model sheet "Results".

The derived midpoint characterization factors are included into the FARM model as properties of the used pesticides. This is completed by the available USetox characterization factors in the ecoinvent database. These allow the inclusion of eco-toxicological impact assessment of the used processes from the ecoinvent database, such as ploughing, harvesting, or production of other inputs.

Table 2: Basic information on assessed farm, soil properties, and planting history

B (L/10a)	Substance in USetox	CAS	Characterization factor
Cinnamon extract	Coumarin	91-64-5	900
Azadirachtin (kg/10a)	Azadirachtin	11141-17-6	10112
Azoxystrobin (L/10a)	Azoxystrobin	131860-33-8	77028
Benzobicyclon (kg/10a)	-	-	2166638*
Butachlor (kg/10a)	Butachlor	23184-66-9	57245
Carbofuran (kg/10a)	Carbofuran	1563-66-2	200
Carbosulfan (kg/10a)	Carbofuran	1563-66-2	200
Fermizone (L/10a)	-	-	2166638*
Glyphosate-isopropylamine (kg/10a)	Glyphospahte	1071-83-6	351
Iprobenfos (IBP) (kg/10a)	IBP (Iprobenfos)	26087-47-8	0,98
Oxadiazon (kg/10a)	Oxadiazon	19666-30-9	71873
Propiconazole (L/10a)	Propiconazole		1283
Propyrisulfuron (kg/10a)	Prosulfuron	94125-34-5	717
Tiadinil (kg/10a)	-	-	2166638*
Tricyclazole(kg/10a)	Tricyclazole	41814-78-2	271
* CHARACTERIZATION FACTOR FOR FIPRONIL WAS USED AS ESTIMATE			

The following substances were not included in USetox. As they were only used in FARM CON09 we excluded this farm completely from the analysis of eco-toxicity.

Imazosulfuron: Only used once in farm con09. Considered very toxic.

Oxadiargyl: Only used in farm con09. Considered very toxic.

Thiacloprid: Only used in farm con09. Considered harmful.

3.5 Material flow model for life-cycle-inventory

The model is divided into four sections: (I) seedling preparation, (II) field preparation, (III) planting and plant protection, and (IV) water management and harvest. An overview of the model is shown in figure 1 (next page).

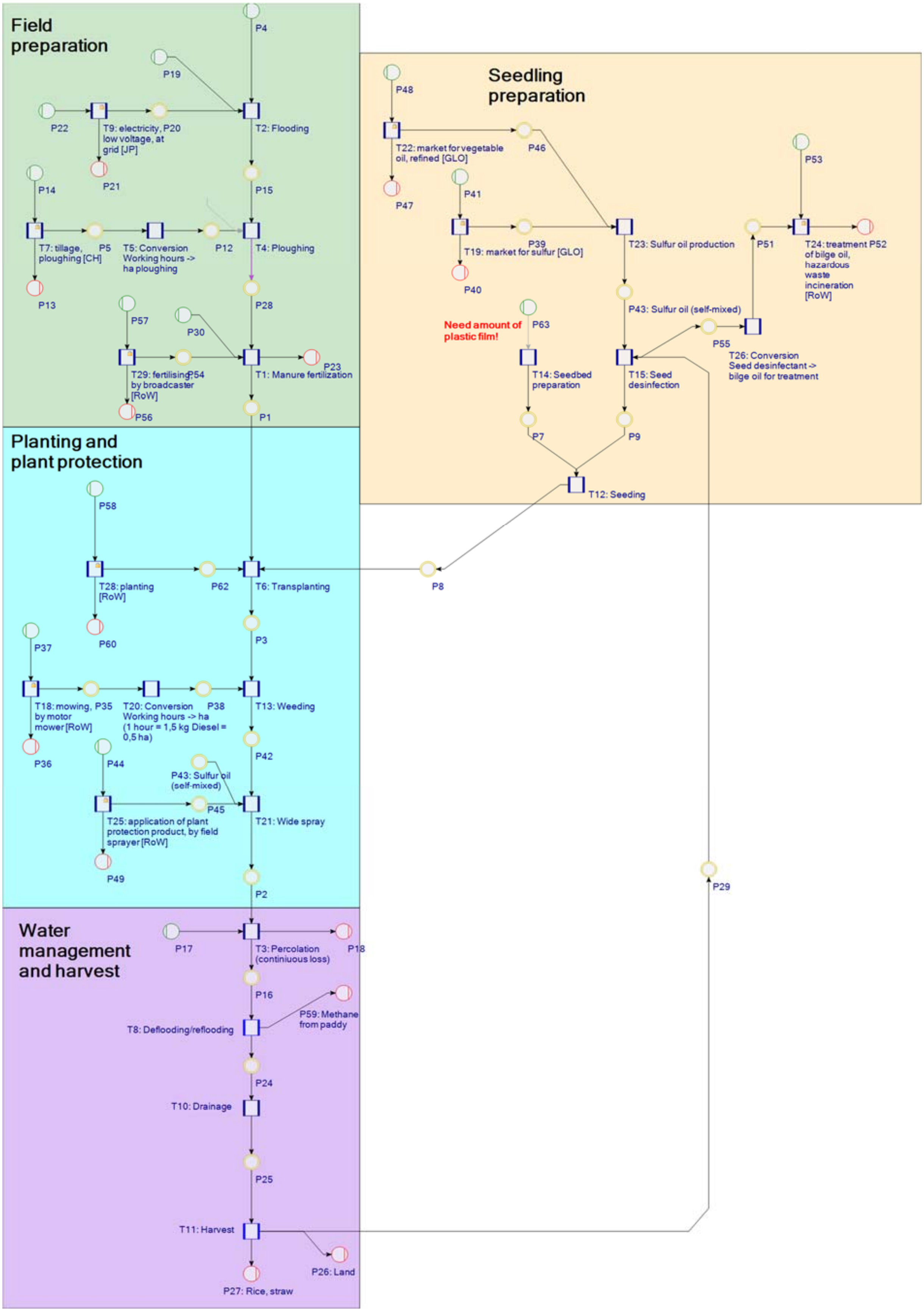


Figure 1: **Overview of the FARM model (Flow Analysis and Resource Management) for organic paddy rice production in South Korea**

3.5.1 Seedling preparation

The seedling preparation consists of 8 processes (table 6). *T23: sulfur oil production* marks a self-defined process for the mixture of sulfur with oil. The weights are 1 kg for sulfur and 0.83 kg for vegetable oil, as the density for vegetable oil is lower than water. Because the type of oil was not specified, generic vegetable oil was used from the ecoinvent database (Weidema et al. 2013). Generic vegetable oil represents the global market shares of vegetable oils, e.g. rape seed oil, soy oil, palm oil. The market shares and sources of oil production are documented in the ecoinvent 3.1 database. Similarly, the production of sulfur is calculated based on global average production mix as documented in ecoinvent 3.1. The process *T15: seed disinfection* combines the backflow of rice from the harvest with the self-mixed sulfur oil. As result disinfected seed and used sulfur oil leave the process. Process *T26: conversion* contains the conversion of used seed disinfectant to bilge oil for treatment. This is necessary as the ecoinvent database does not provide a dataset for treatment of sulfur oil. Treatment of bilge oil is assumed to be a satisfactory substitute. Consequently, the process *T24 is the dataset treatment of bilge oil* from the ecoinvent database.

Table 6: Processes in the seedling preparation section of the FARM model for organic paddy rice assessment in South Korea

Process	Description	Source	Dataset
T19: market for sulfur [GLO]	This is a constrained market. The justification for a market constraint is included in the comment field of the conditional exchange.	ecoinvent 3 (v3.1), allocation, cut-off (result)	market for sulfur [GLO]
T22: market for vegetable oil, refined [GLO]		ecoinvent 3 (v3.1), allocation, cut-off (result)	market for vegetable oil, refined [GLO]
T24: treatment of bilge oil, hazardous waste incineration [RoW]	Inventoried waste contains 100% bilge oil; . waste composition (wet, in ppm): upper heating value 4.098 MJ/kg; lower heating value 1.92 MJ/kg; H2O 900000; O 1300; H 10000; C 84000; S 3650; N 1000; P 0.0004; B n.a.; Cl n.a.; Br n.a.; F n.a.; I n.a.; Ag n.a.; As n.a.; Ba n.a.; Cd n.a.; Co n.a.; Cr n.a.; Cu n.a.; Hg n.a.; Mn n.a.; Mo n.a.; Ni 0.079; Pb 0.001; Sb n.a.; Se n.a.; Sn n.a.; V 33.1; Zn n.a.; Be n.a.; Sc n.a.; Sr n.a.; Ti n.a.; Tl n.a.; W n.a.; Si 0.6; Fe 2.8; Ca 0.6; Al n.a.; K n.a.; Mg n.a.; Na 3.5; Share of carbon in waste that is biogenic 0%. Net energy produced in HWI: 17.11MJ/kg electric energy and 1.27MJ/kg thermal energy Allocation of energy production: no substitution or expansion. 100% of burden allocated to waste disposal function of HWI. One kg of this waste produces 0.001425 kg of residues, which are landfilled. Additional solidification with 0.0005702 kg of cement.	ecoinvent 3 (v3.1), allocation, cut-off (result)	treatment of bilge oil, hazardous waste incineration [RoW]
T12: Seeding		Self defined	
T14: Seedbed preparation		Self defined	
T15: Seed desinfection		Self defined	
T26: Conversion Seed desinfectant -> bilge oil for treatment		Self defined	
T23: Sulfur oil production		Self defined	

T14 Seedbed preparation is a placeholder process as the amounts of plastic film for seedbed tunnels as well as the source of planting substrate are not known as this point. *T12: Seeding* combines the prepared seedbed with the disinfected rice seeds.

3.5.2 Field preparation

The field for organic rice production is prepared in three steps. Because concrete data was lacking, it was assumed for modelling, that the flooding is done with an electric pump with a power of 1 kW and a flow-rate of 15,000 litres water per hour. Consequently 1/15000 kWh are needed per litre water. An initial flooding of 20 litres per m^2 is assumed. As no specific dataset for Korean electricity production exists, the dataset with the grid mix of Japanese electricity production is used.

The diesel demand for ploughing is known. In the dataset 26.1 kg diesel fuel are used per ha. Therefore, a conversion rate of 0.0318 ha per litre diesel is needed to connect these processes using the conversion process T5.

For the fertilization with manure (*T1*) the dataset *fertilization by broadcaster (T29)* is used from the ecoinvent database. The common factor is the area fertilized. The scope of the dataset is rest-of-world making it applicable to Korean conditions. Based on IPCC (2006b), the N_2O emissions of compost applied to paddy soil are calculated as 0.007 kg N_2O-N per kg N applied.

Not included is the effect of water management on nitrous oxides emissions. This is not dealt with in IPCC (2006a) but should be considered in further development of the model.

An overview of the processes and the exact dataset name and source are presented in table 7.

Table 7: Processes in the field preparation section of the FARM model for organic paddy rice production in South Korea

Process	Description	Source	Dataset
T9: electricity, low voltage, at grid [JP]	This dataset describes the transformation from medium to low voltage as well as the distribution of electricity at low voltage.	ecoinvent 2.2, with infrastructure (result)	electricity, low voltage, at grid [JP]
T7: tillage, ploughing [CH]	This dataset represents an example of a Four-furrow plough. The functional unit (FU) is one ha ploughed. The operation time is 2.10 h/FU.	ecoinvent 3 (v3.1), allocation, cut-off (result)	tillage, ploughing [CH]
T29: fertilising, by broadcaster [RoW]	Fertiliser broadcaster, 500l carrying capacity, fertiliser not included. FU is one ha fertilised.	ecoinvent 3 (v3.1), allocation, cut-off (result)	fertilising, by broadcaster [RoW]
T1: Manure fertilization		Self defined	
T2: Flooding		Self defined	
T4: Ploughing		Self defined	

3.5.3 Planting and plant protection

For the transplanting of the rice seedlings the ecoinvent dataset planting with scope rest-of-world - including Korea - is used. The unit for calculation is one hectare planted. Weeding is done per hand as well as with machinery. For this study manual labour is not included, as no emissions are allocated to manual labour. Based on the diesel fuel consumption for ploughing we estimate that typical mowing machinery uses between 1.6 and 2.5 kg diesel fuel per hour. The ecoinvent dataset for mowing, by motor assumes 3 kg diesel fuel per ha. We use the lower value for diesel consumption per hour and therefore a conversion of 0.5 ha mowed per working hour is performed (T20). For the application of sulfur oil the production of sulfur oil is calculated as described in the seedling preparation section combined with the dataset for application of plant protection product from the ecoinvent database. An overview of the processes and the exact dataset name and source are presented in table 8.

Table 8: Processes used for the planting and plant protections section of the FARM model for organic paddy rice production in South Korea

Process	Description	Source	Dataset
T28: planting [RoW]	Two-row planter, driver plus 2 persons as crew. Time need very variable, depending on culture, stocking density. Typical values between 5 and 30 Th/ha, planting material not included. FU is one ha planted.	ecoinvent 3 (v3.1), allocation, cut-off (result)	planting [RoW]
T18: mowing, by motor mower [RoW]	Motor mower, working width 1,9 m. Petrol engine 8 kW. FU is one ha mowed area.	ecoinvent 3 (v3.1), allocation, cut-off (result)	mowing, by motor mower [RoW]
T25: application of plant protection product, by field sprayer [RoW]	Field sprayer, 15 m working width, 800 l carrying capacity, plant protection product not included. FU is one ha treated crop.	ecoinvent 3 (v3.1), allocation, cut-off (result)	application of plant protection product, by field sprayer [RoW]
T6: Transplanting		Self defined	
T13: Weeding		Self defined	
T20: Conversion Working hours -> ha (1 hour = 1,5 kg Diesel = 0,5 ha)		Self defined	

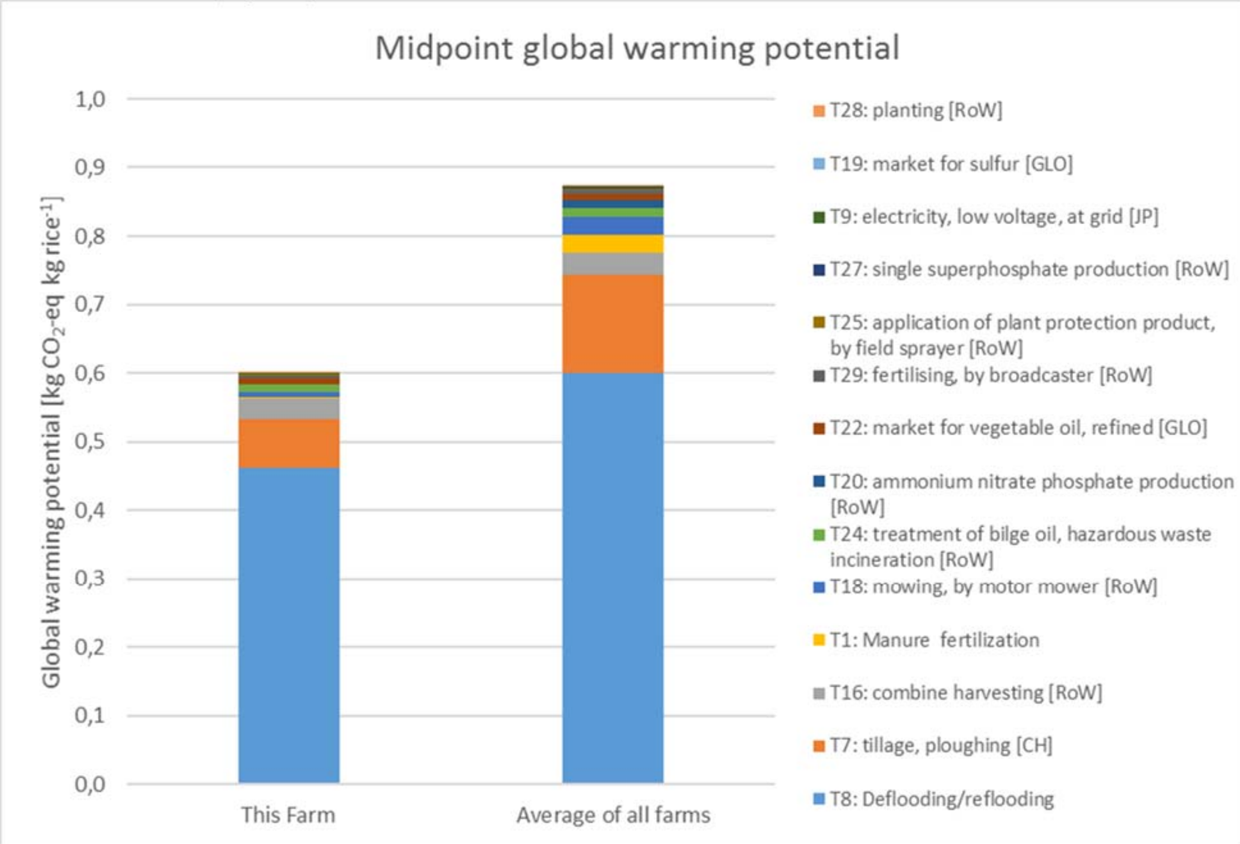
3.5.4 Water management and harvest

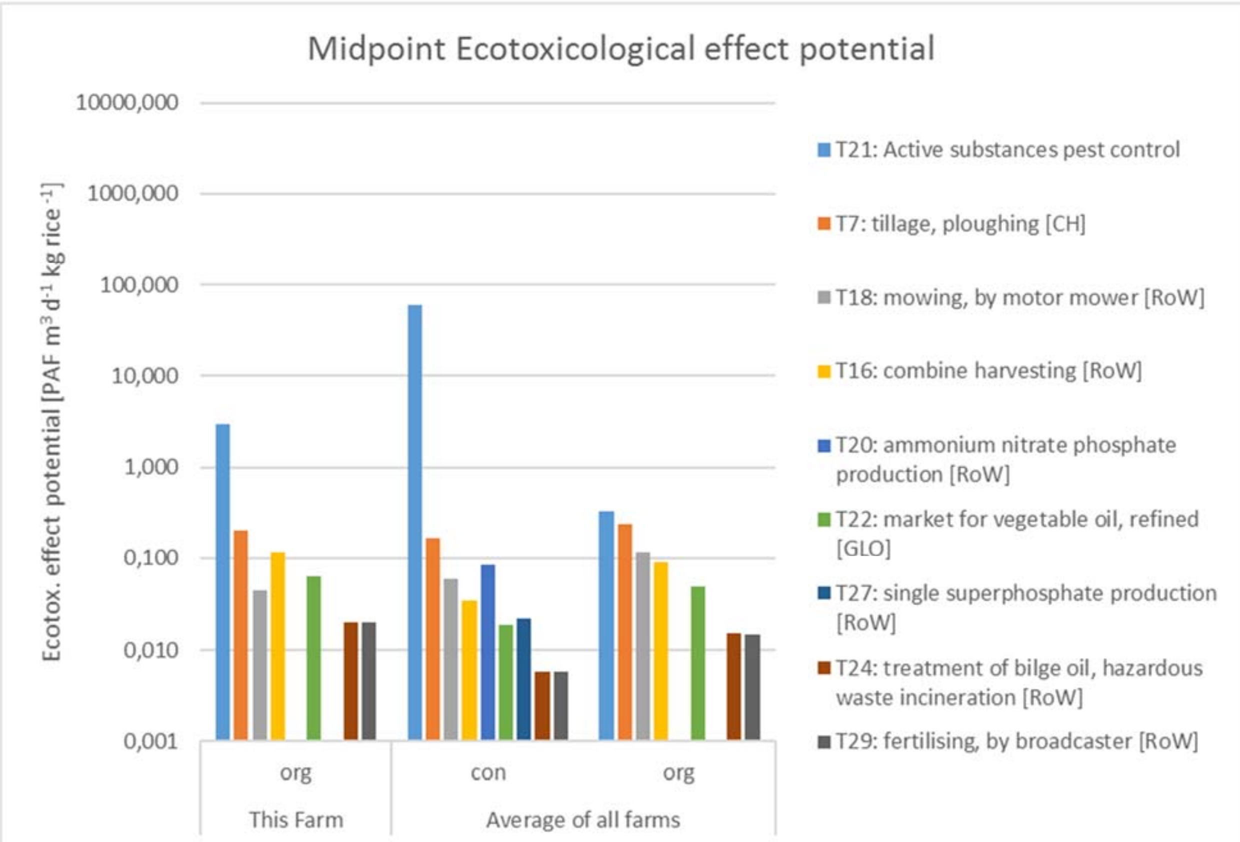
The water management and harvest section consists only of self-defined processes. The process *T3: Percolation* calculates the water outflow by continuous loss. Yoo et al. (2014) assume a daily loss of 4 mm water. Over a growing period of 120 days this leads to 30 cm water loss meaning 3000 litres water per m^2 farmed area.

4 Results

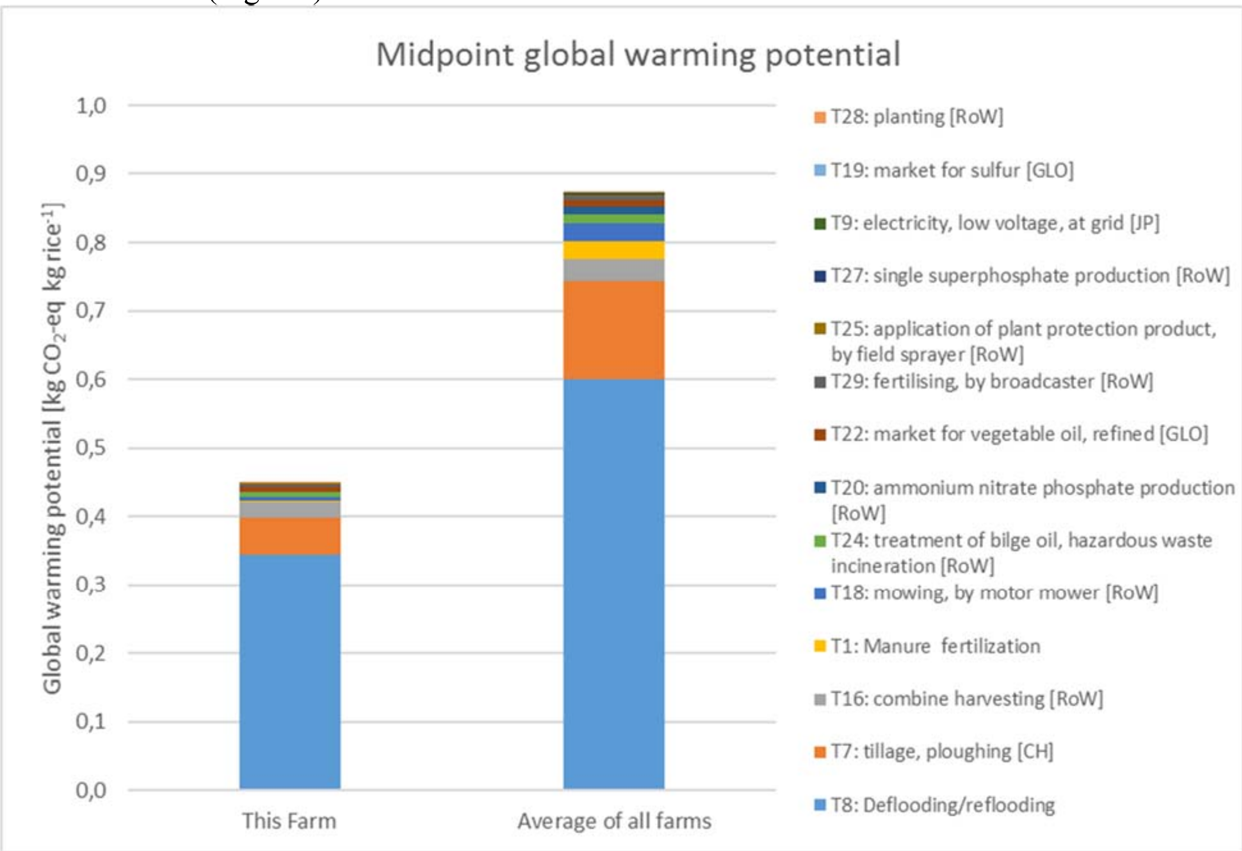
The FARM model was run for each farm individually and the results saved into a local database. In the following the product related GHG emissions for each farm are shown against the average of all farms. The eco-toxicological impact potential is shown for each farm for the 9 highest contributing processes against the average values for each the average organic and the average non-organic results.

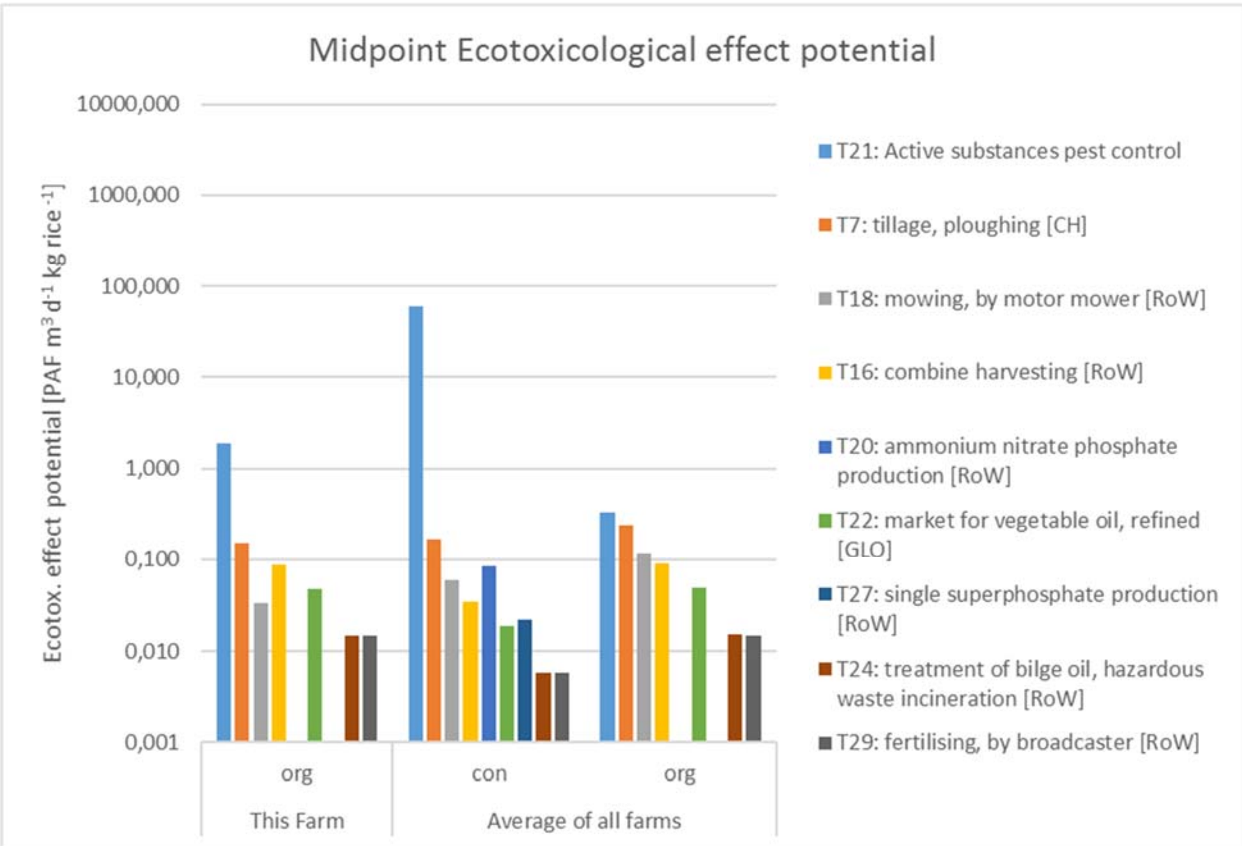
FARM ORG01 (organic)



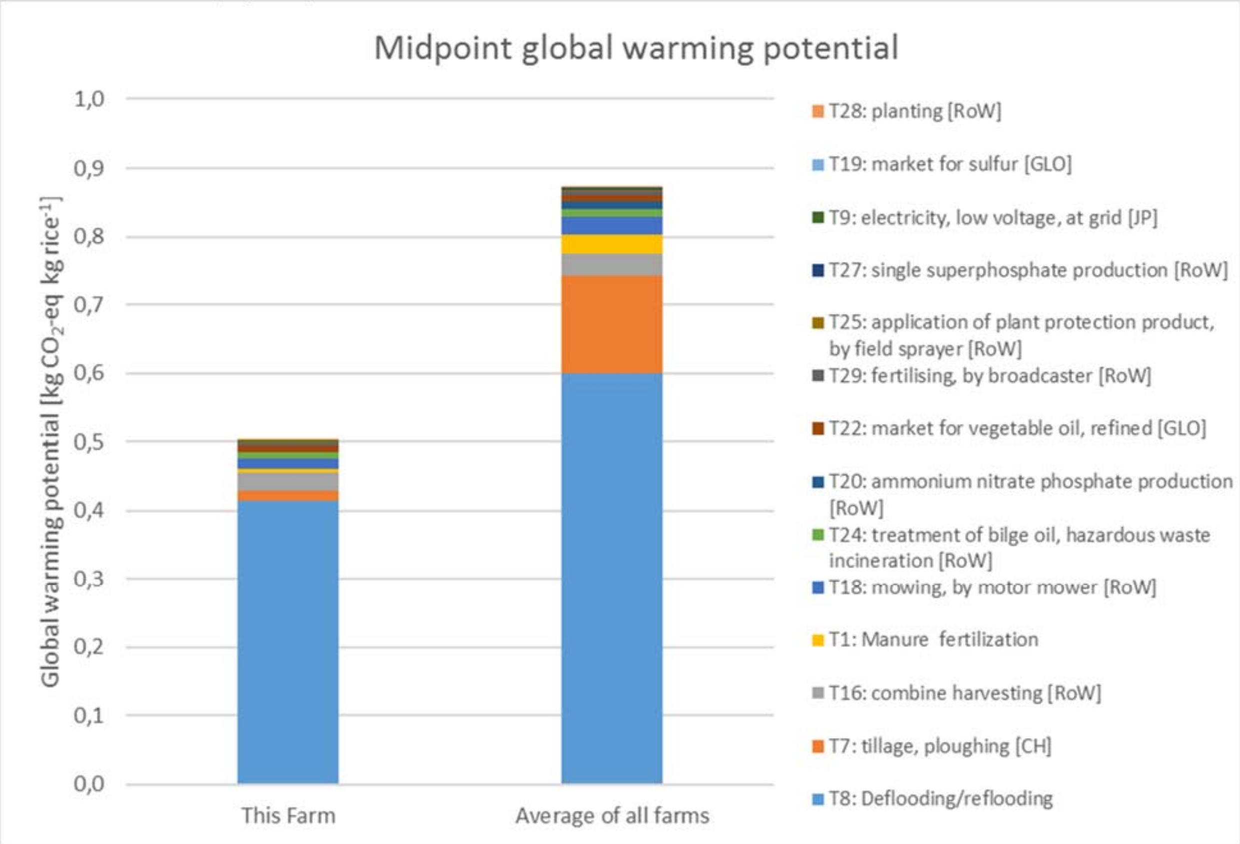


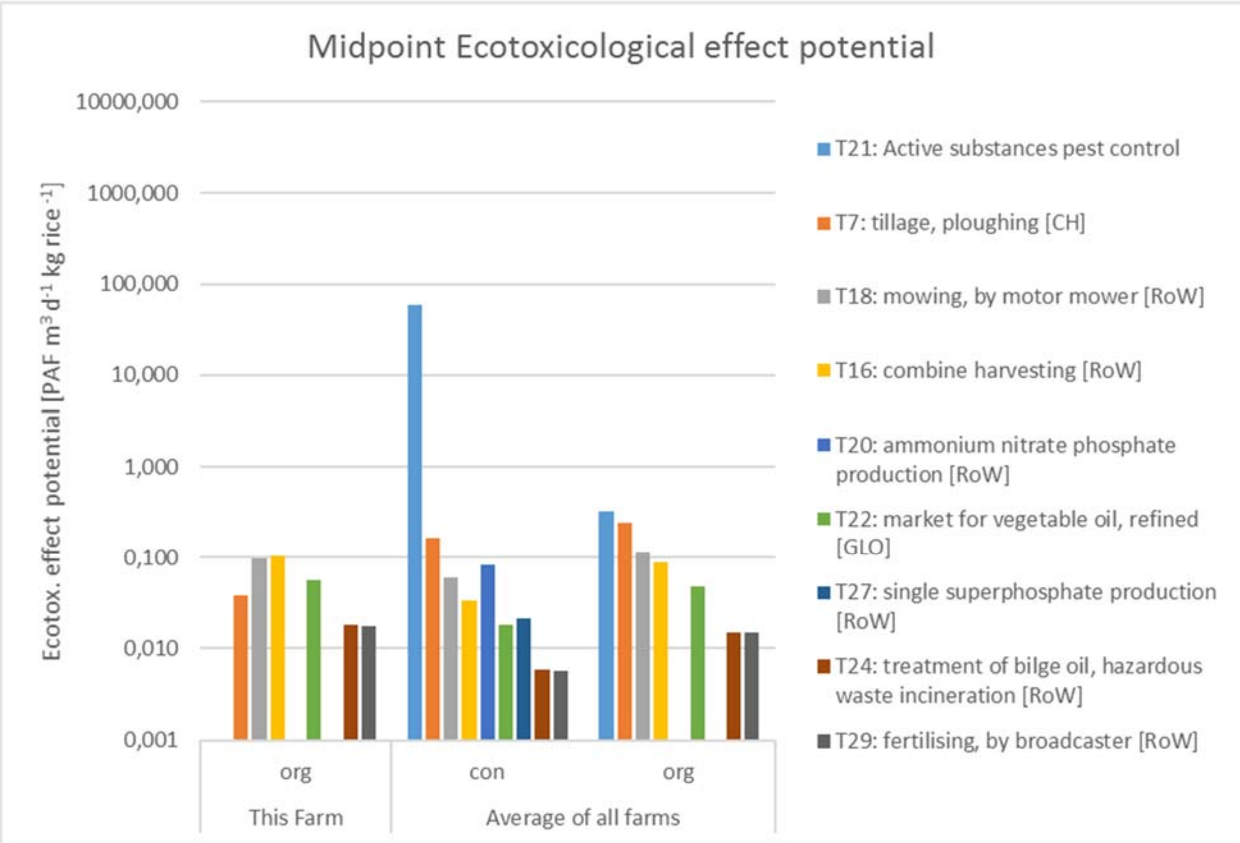
FARM ORG02 (organic)



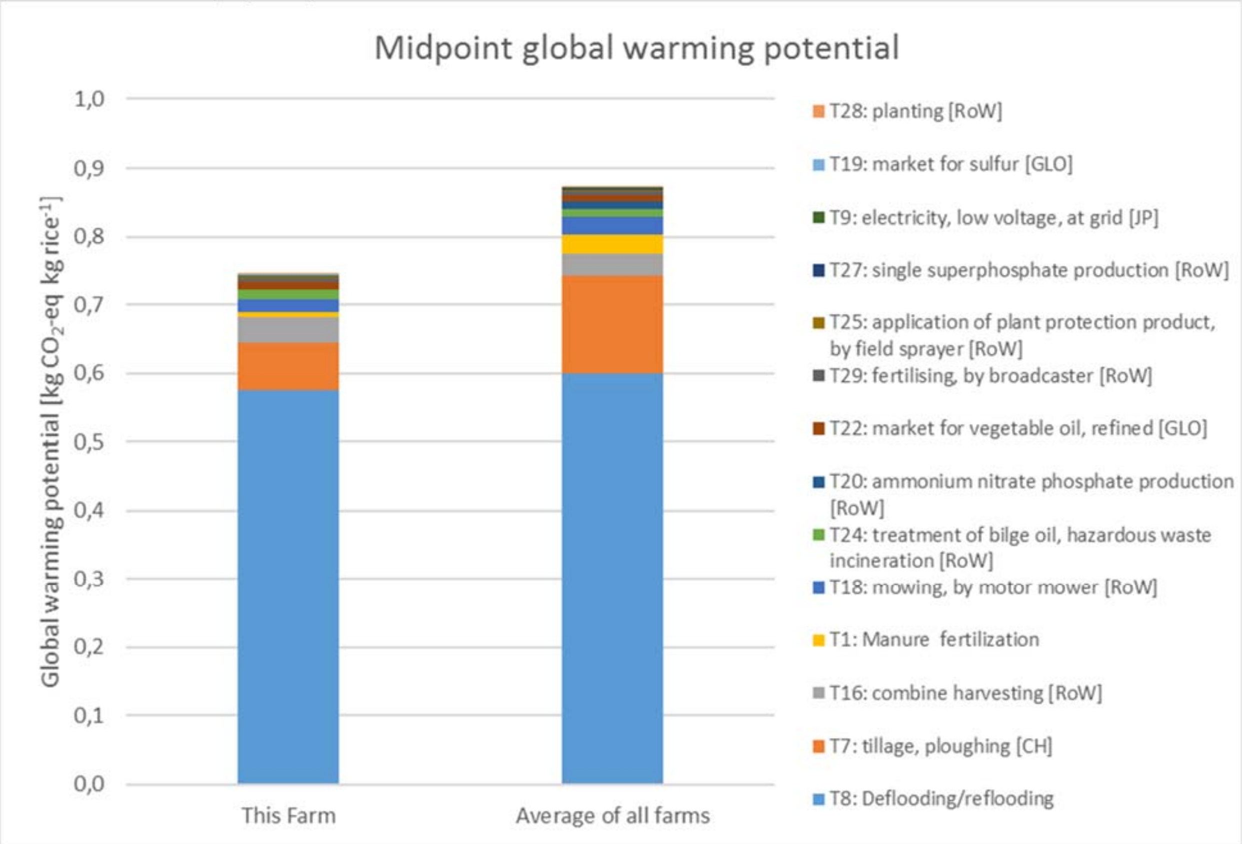


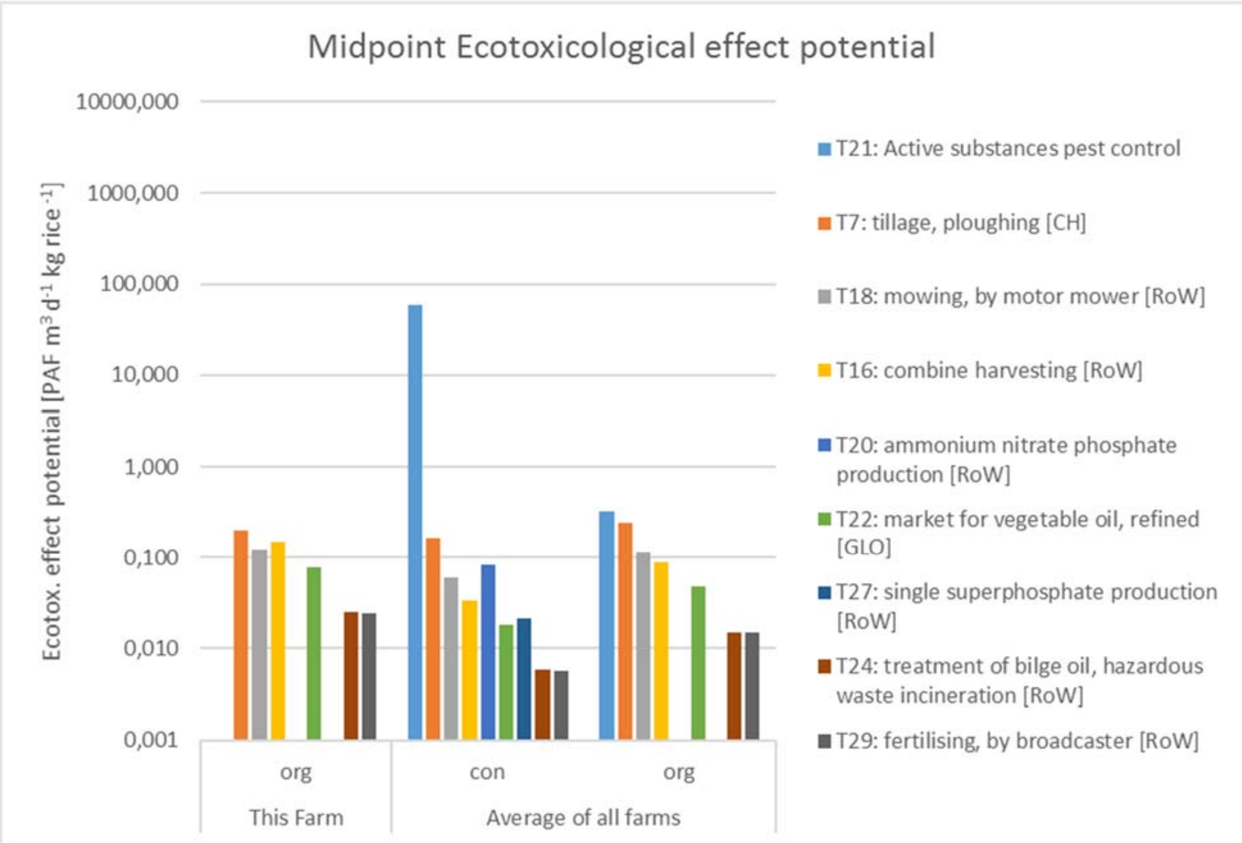
FARM ORG03 (organic)



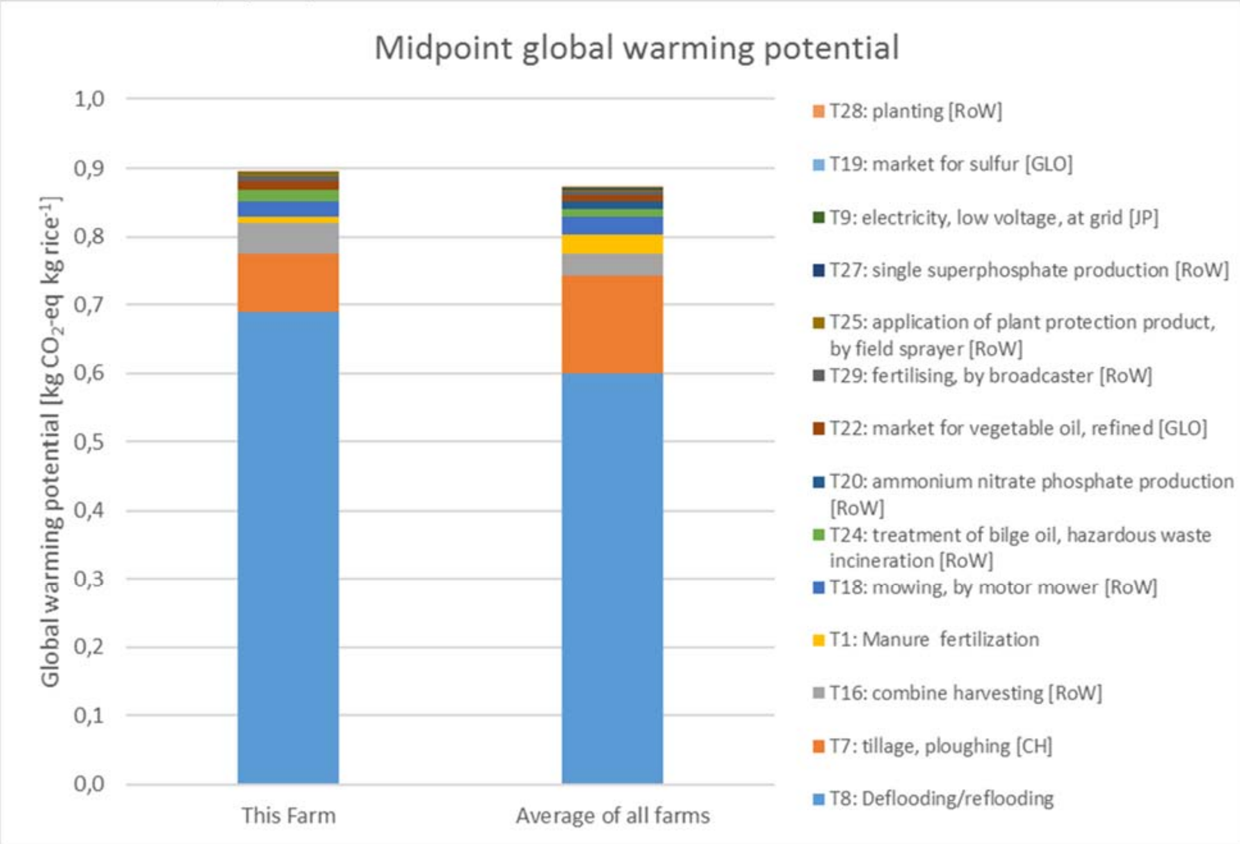


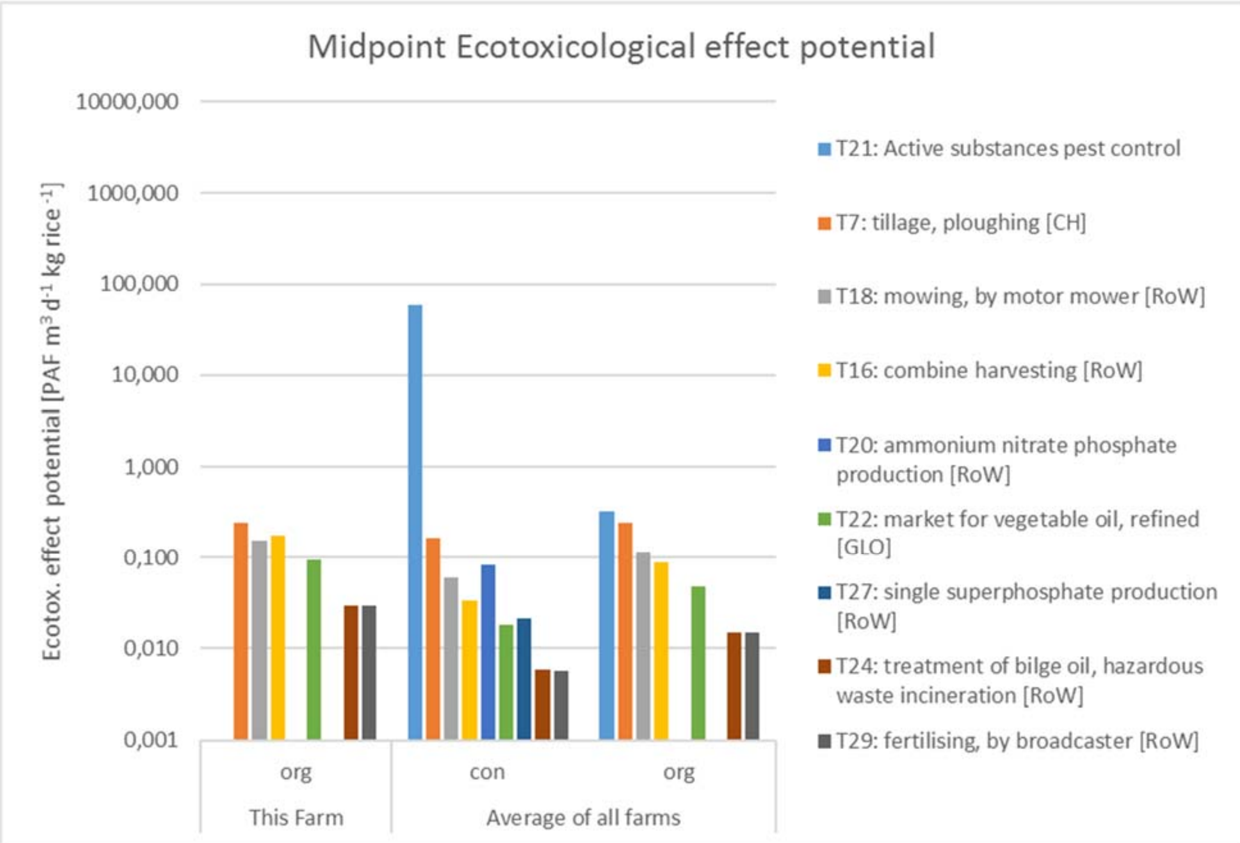
FARM ORG04 (organic)



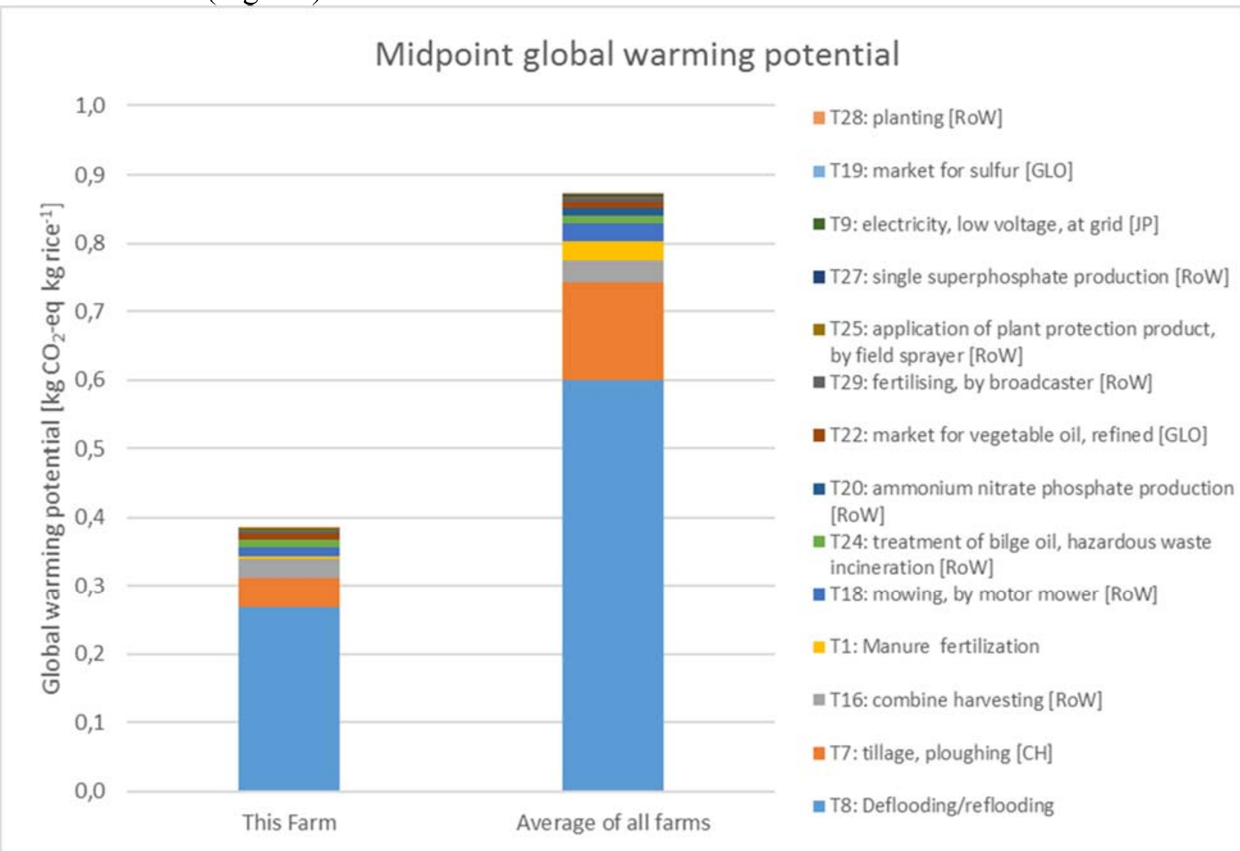


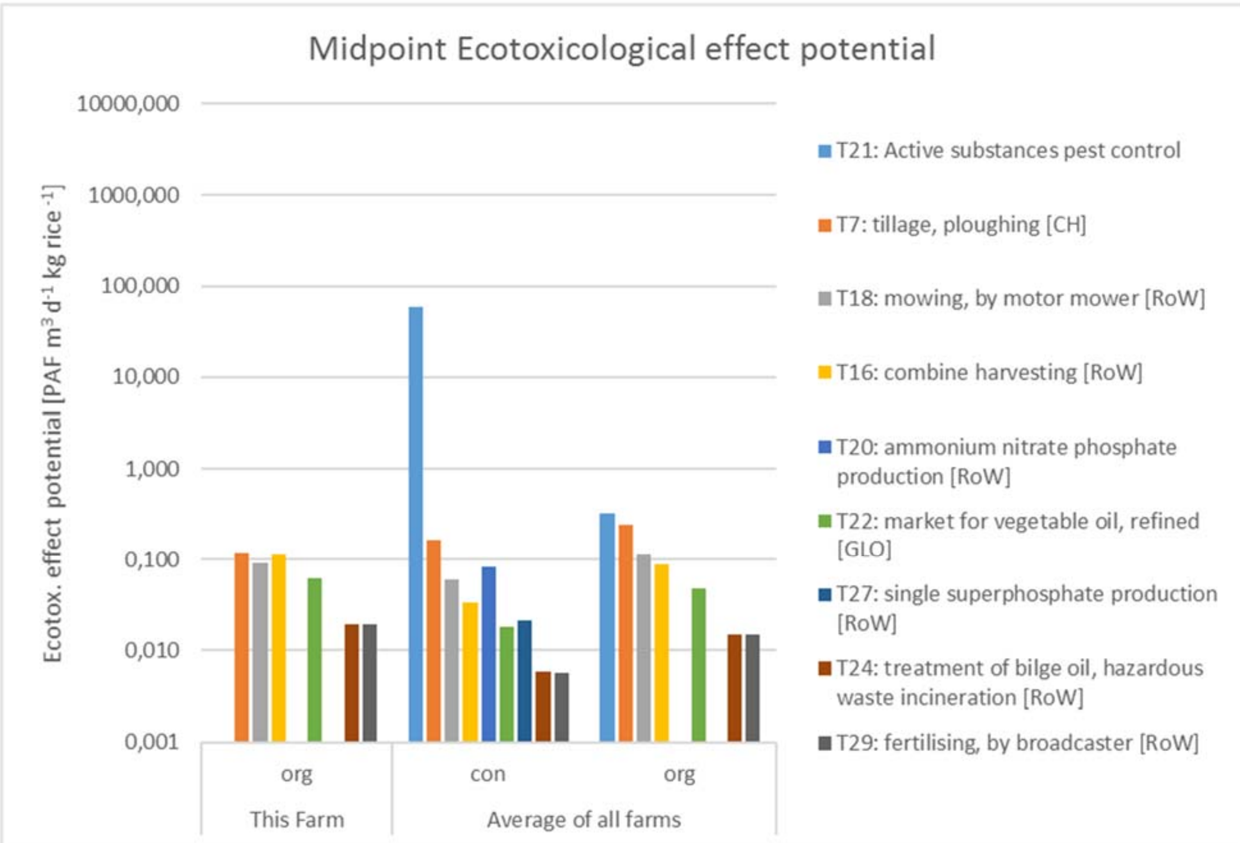
FARM ORG05 (organic)





FARM ORG06 (organic)





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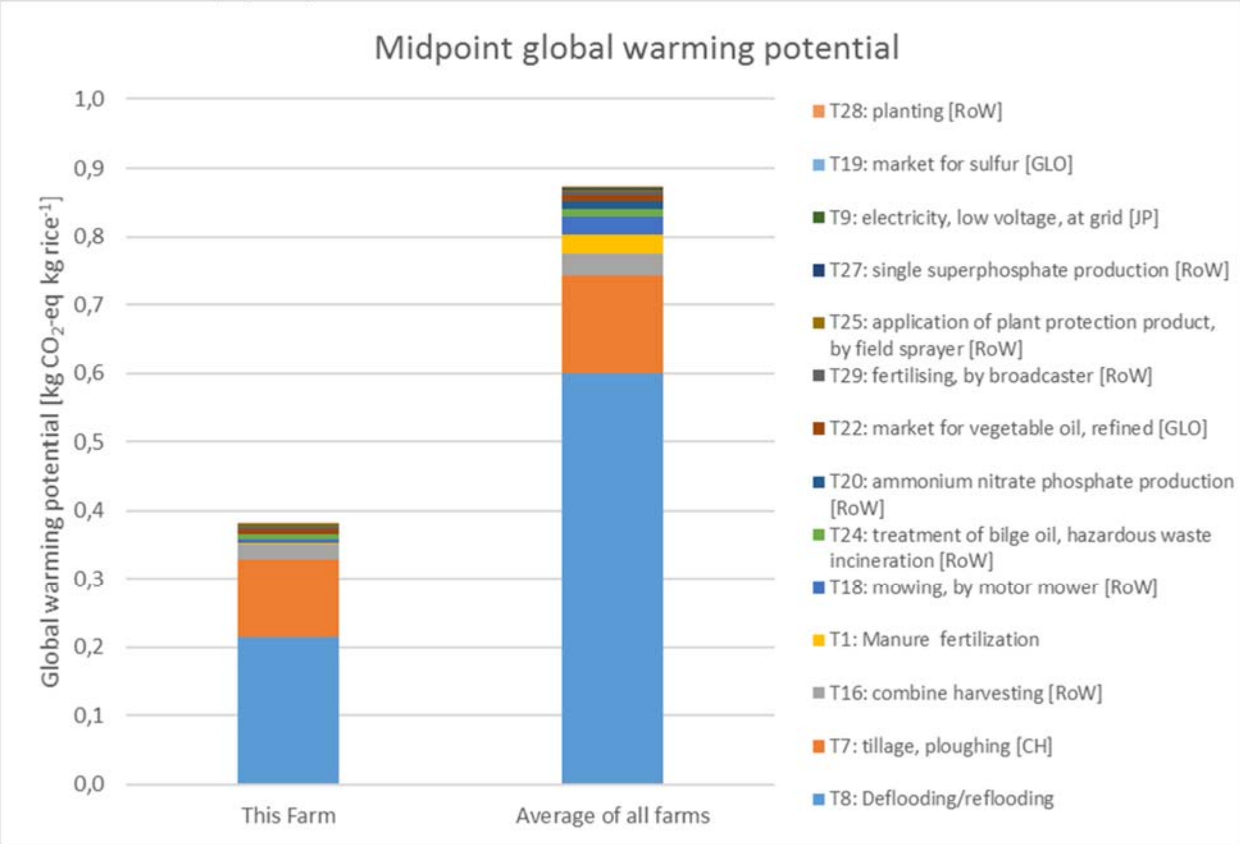
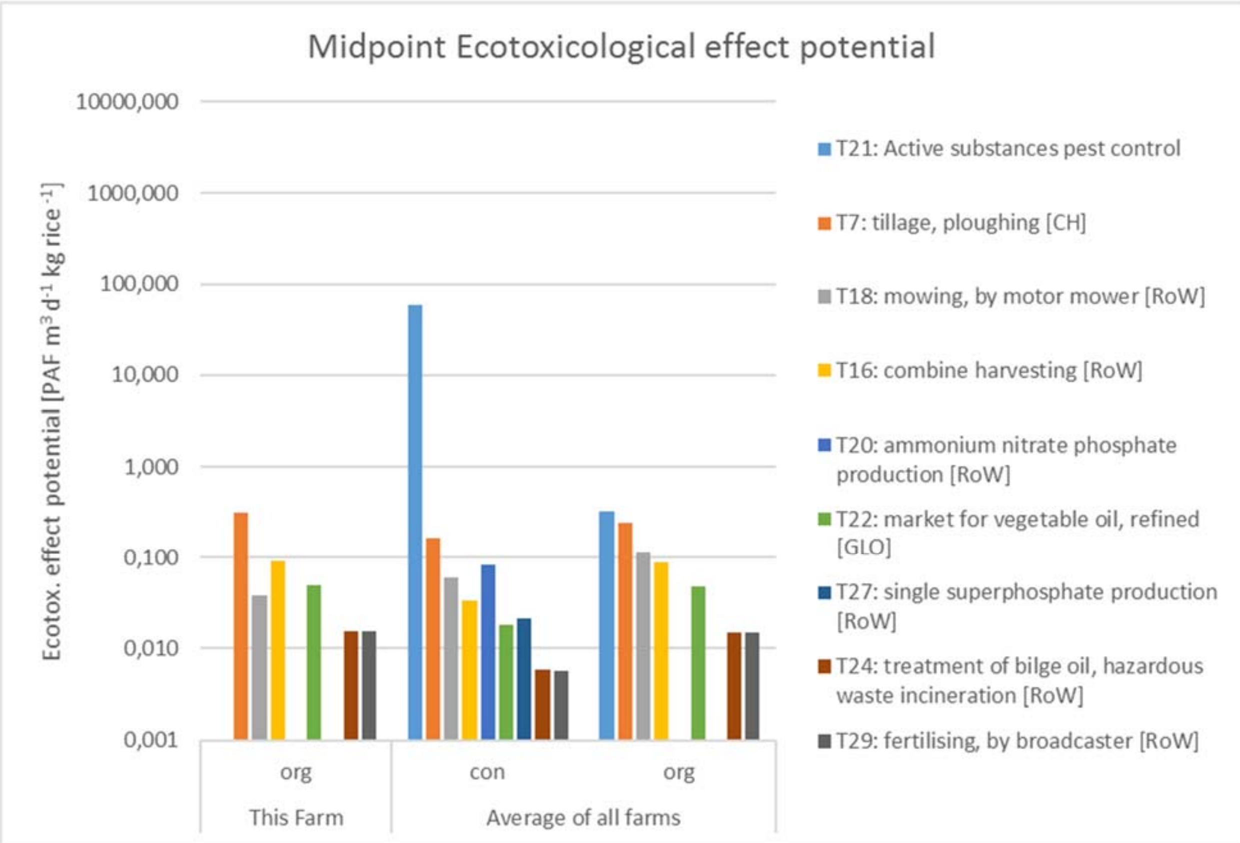
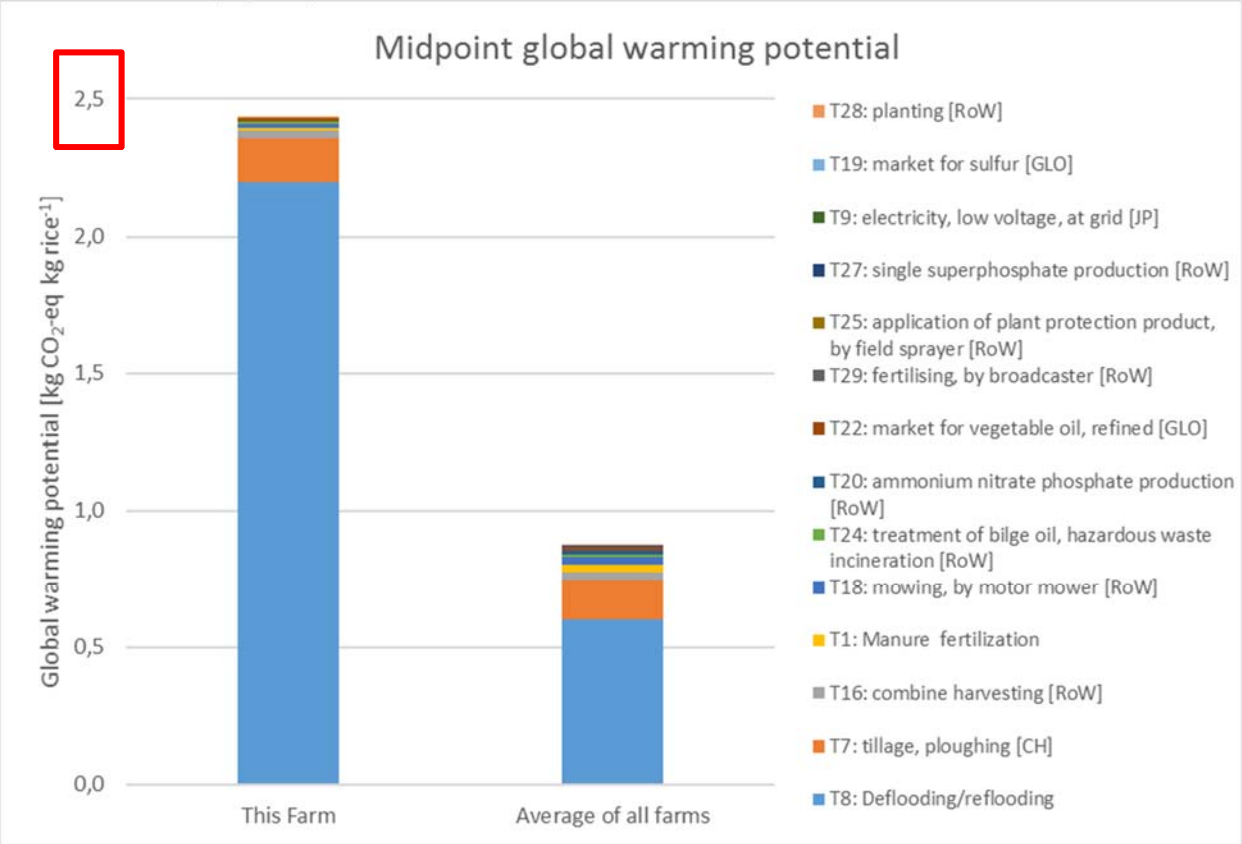
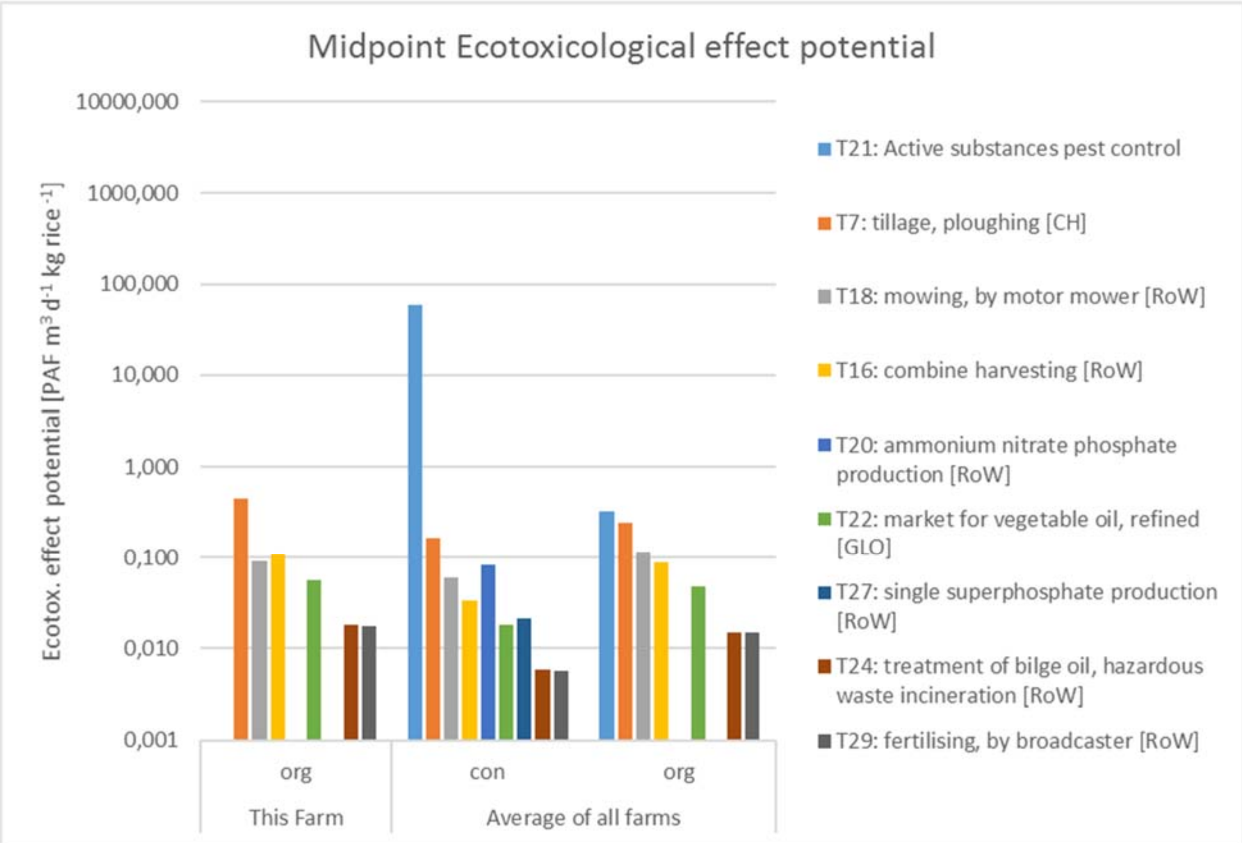


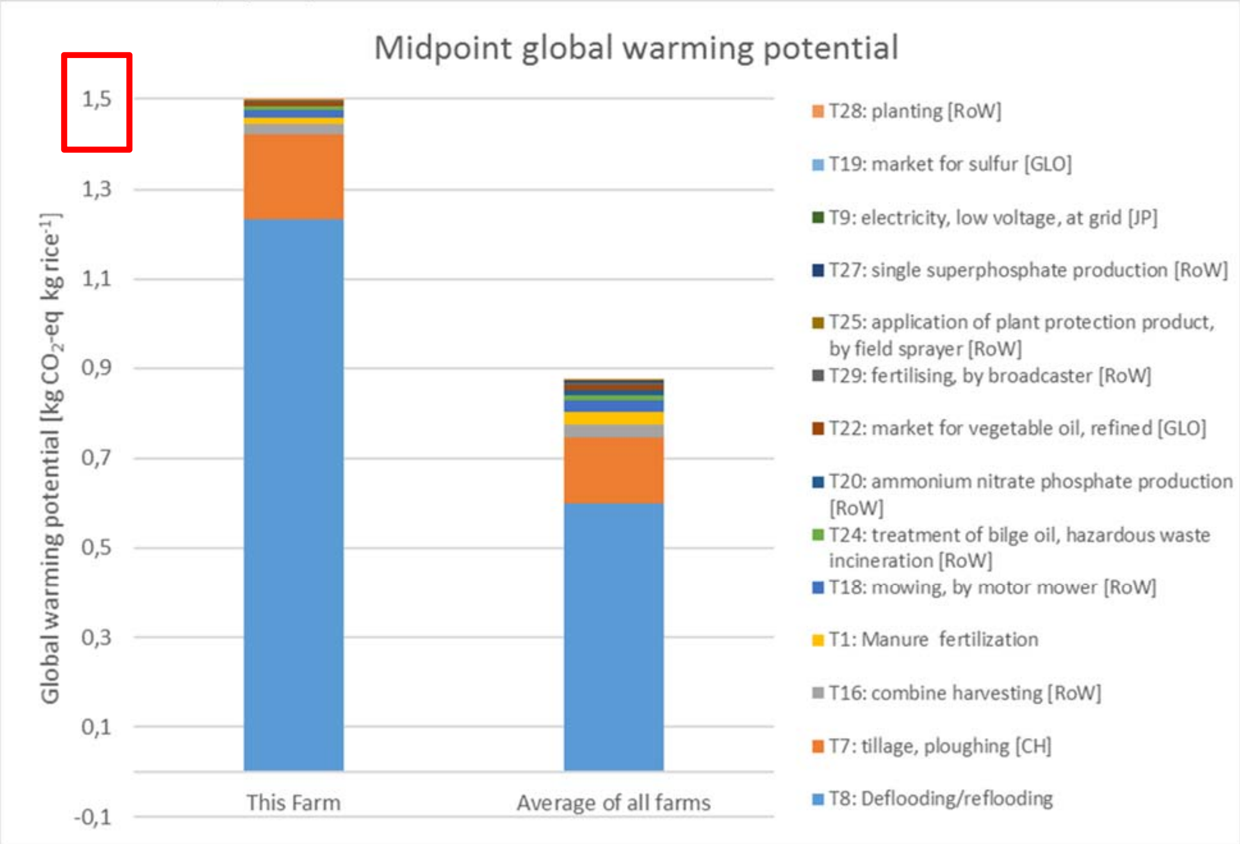


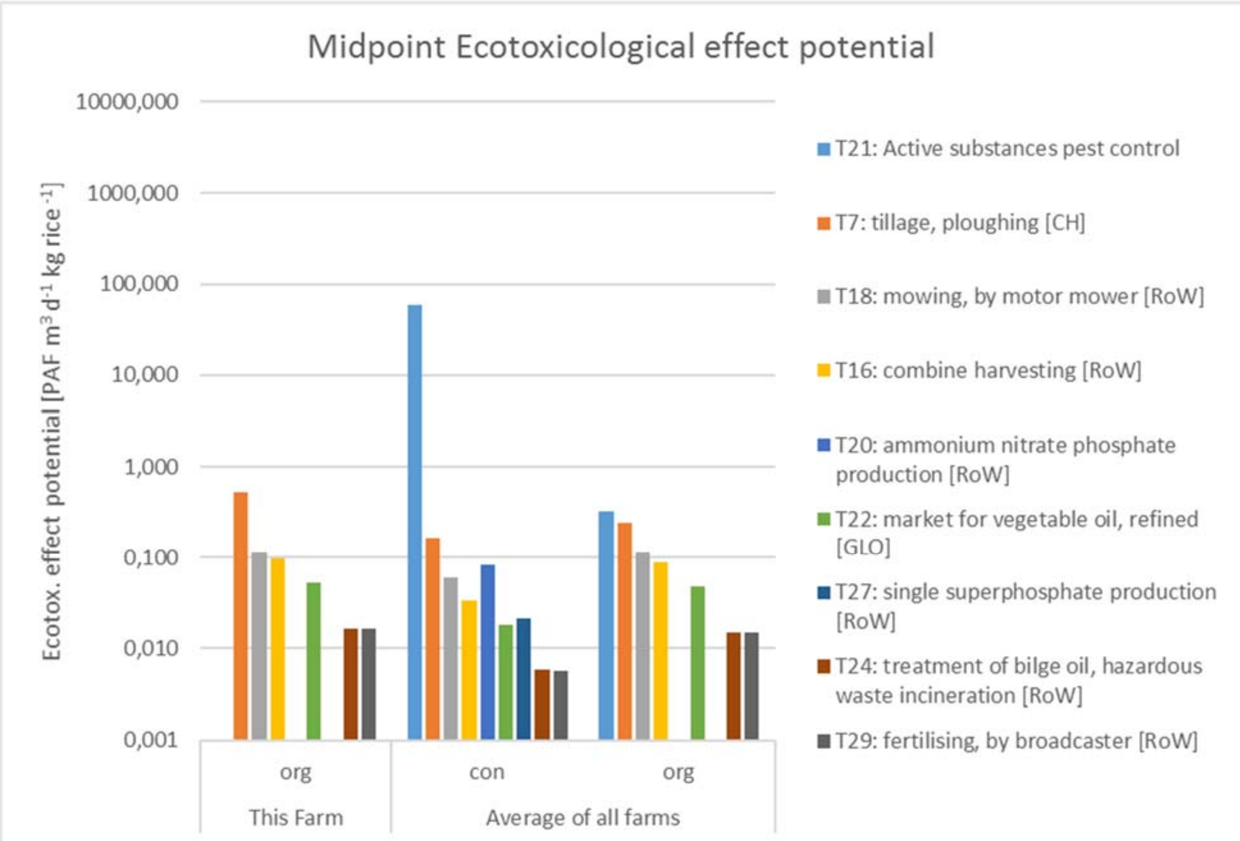
FARM ORG08 (organic)



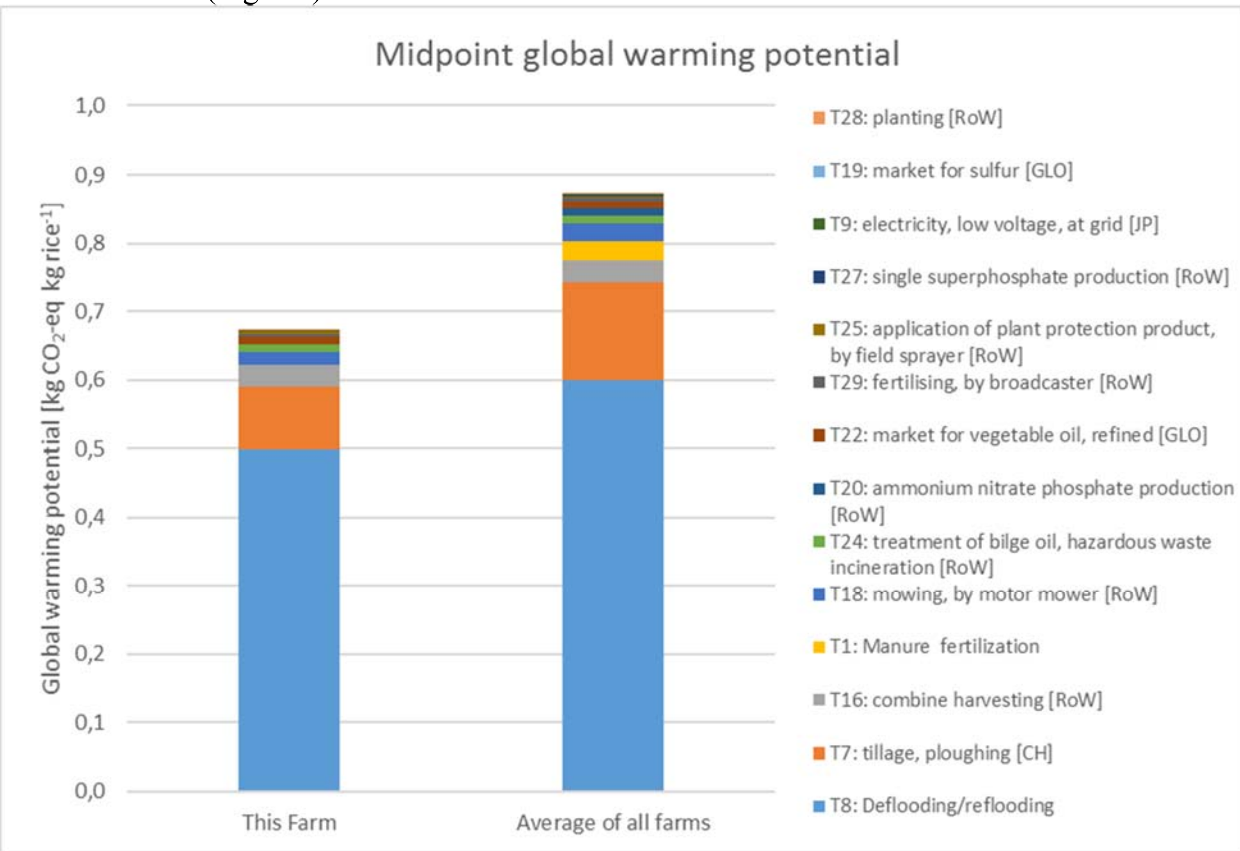


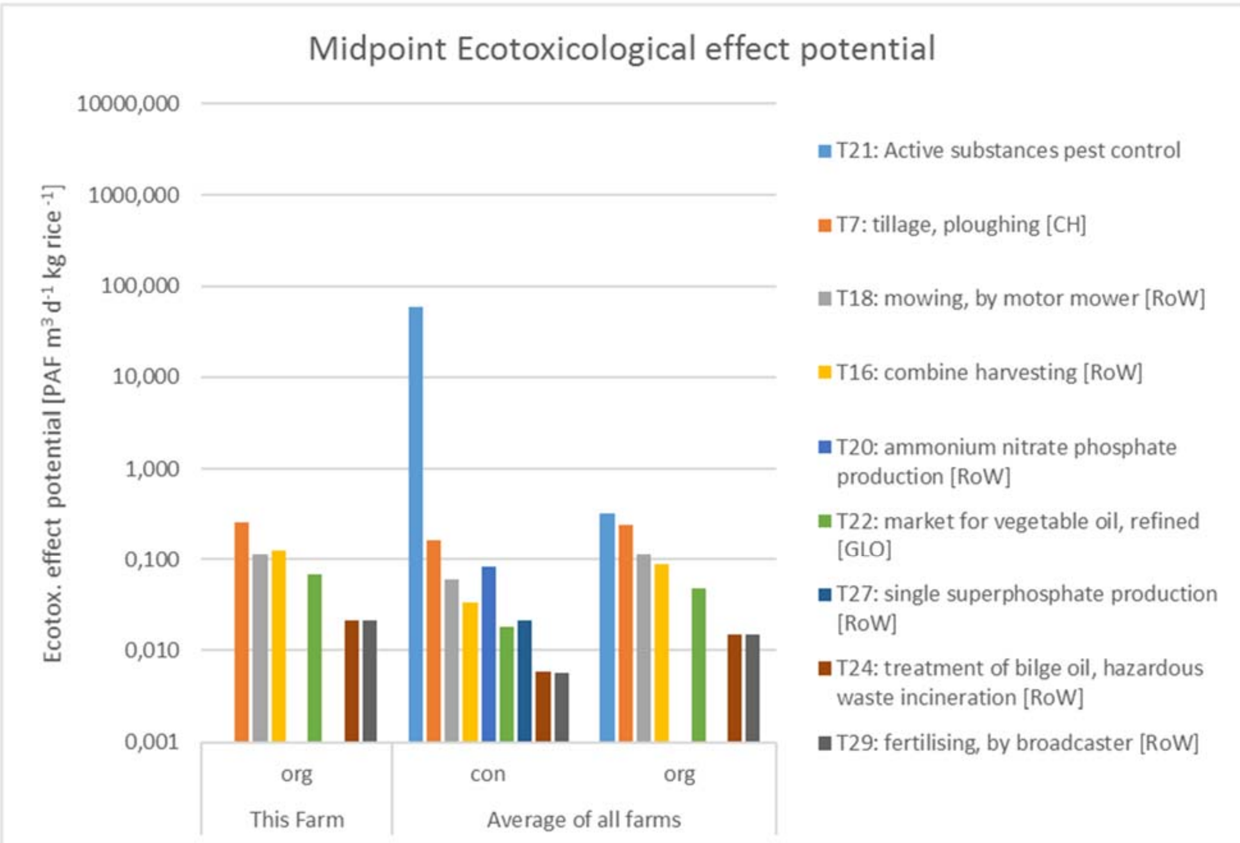
FARM ORG09 (organic)



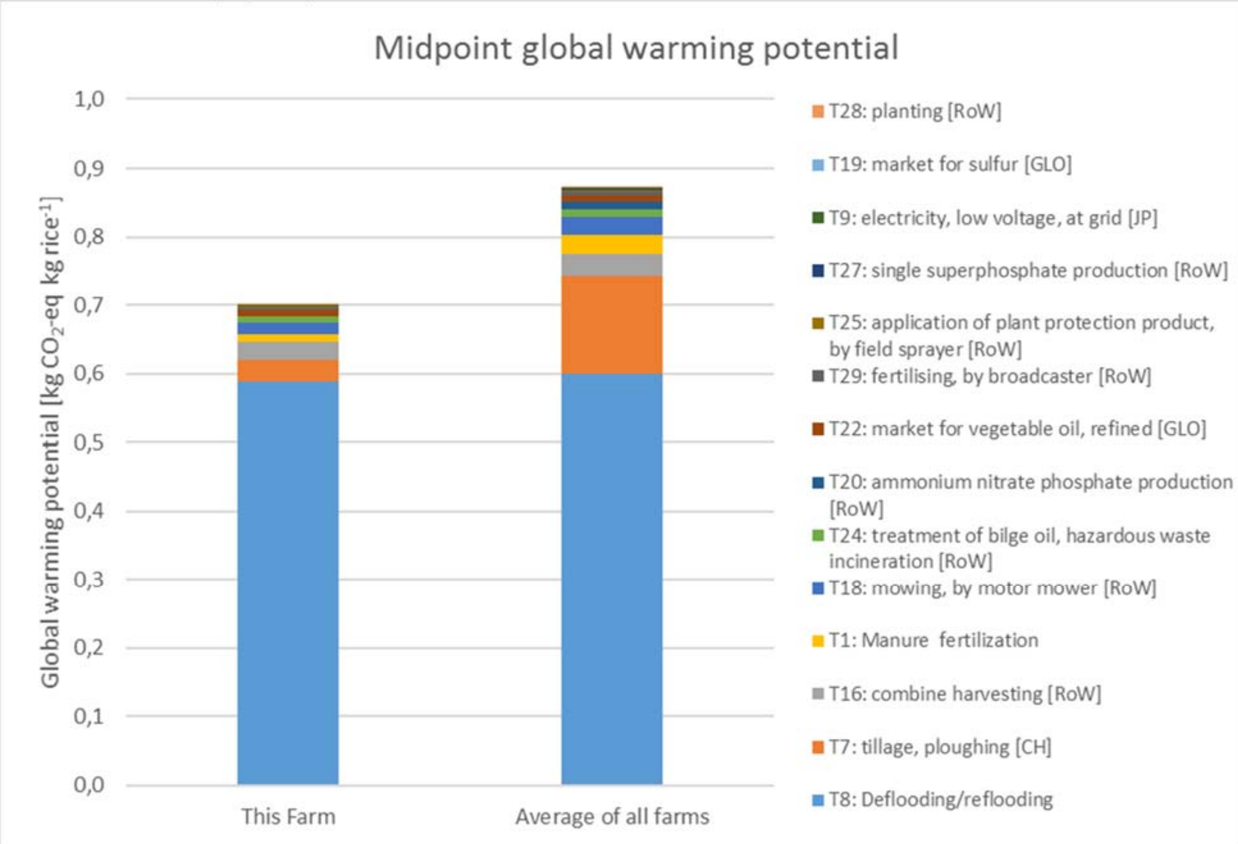


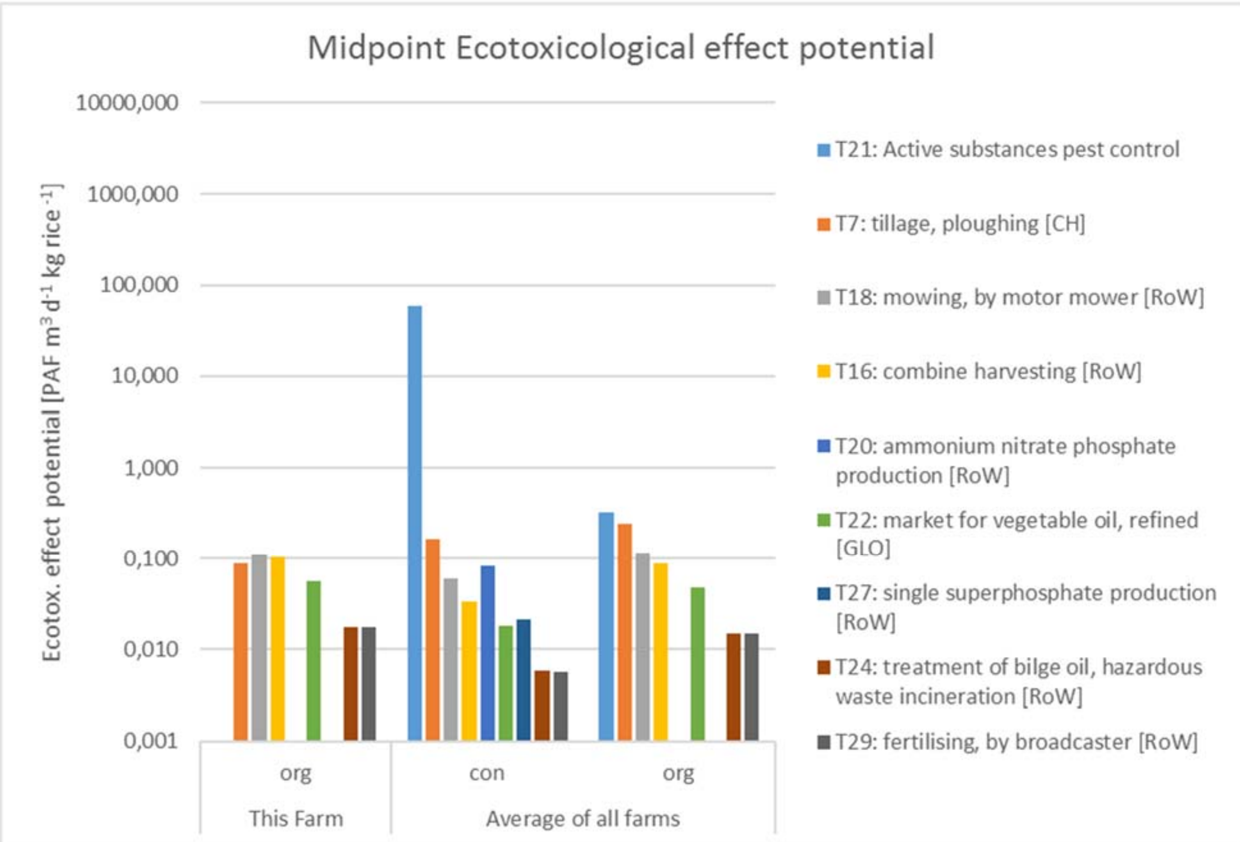
FARM ORG10 (organic)





FARM ORG11 (organic)





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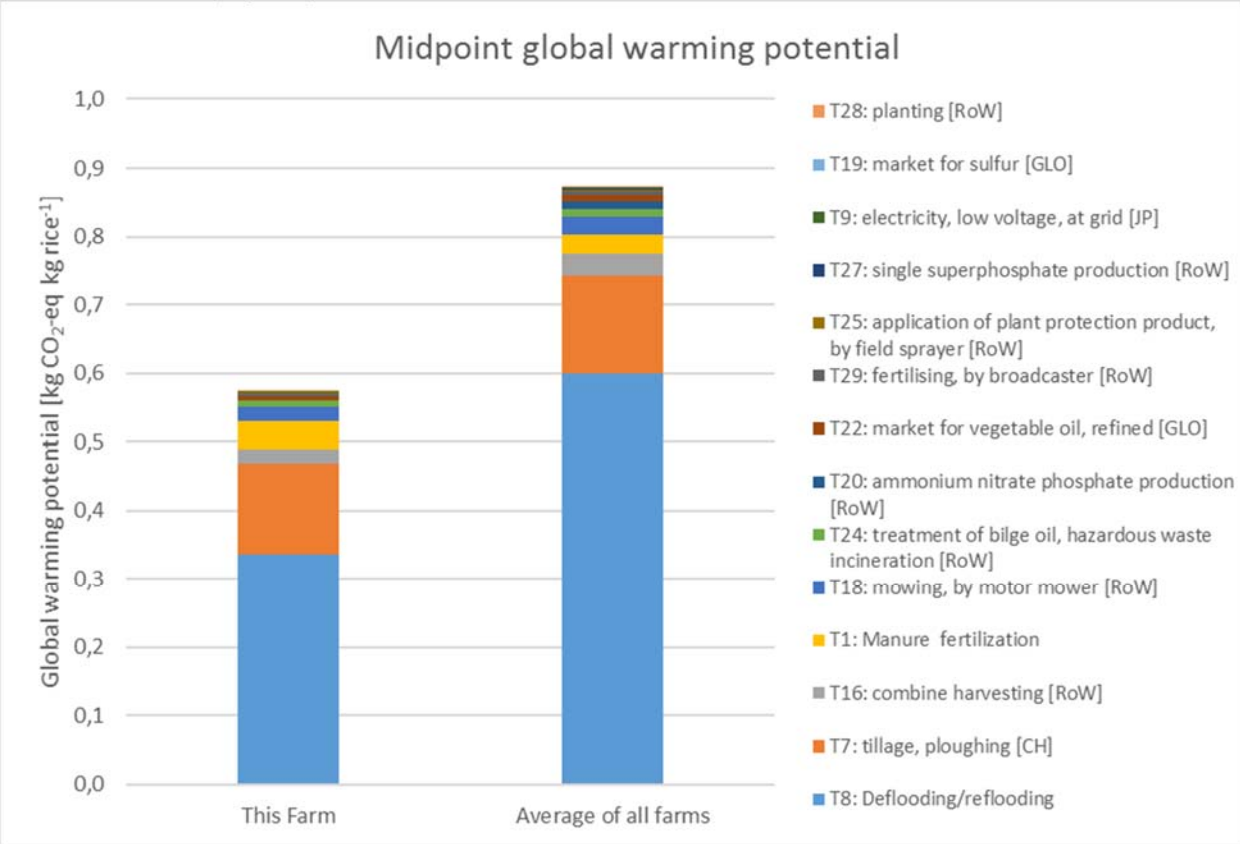

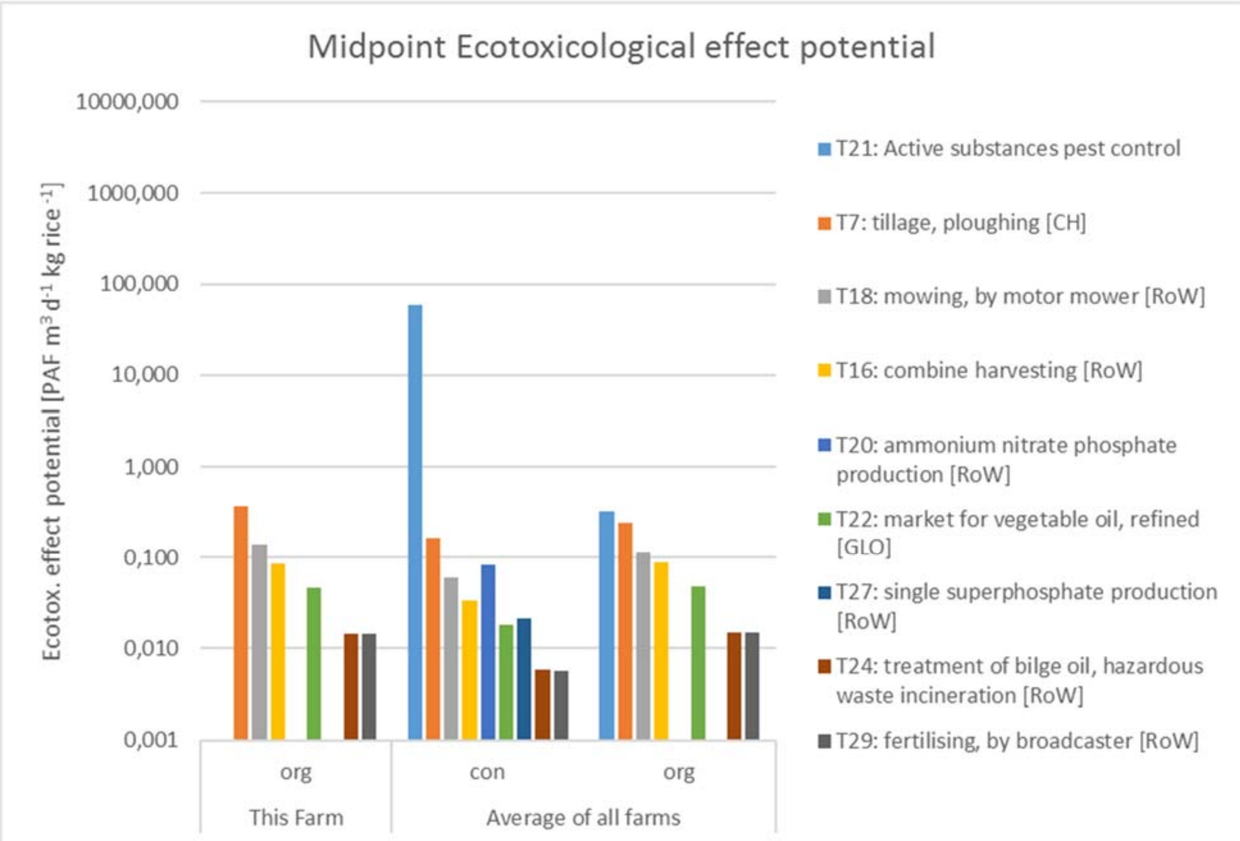

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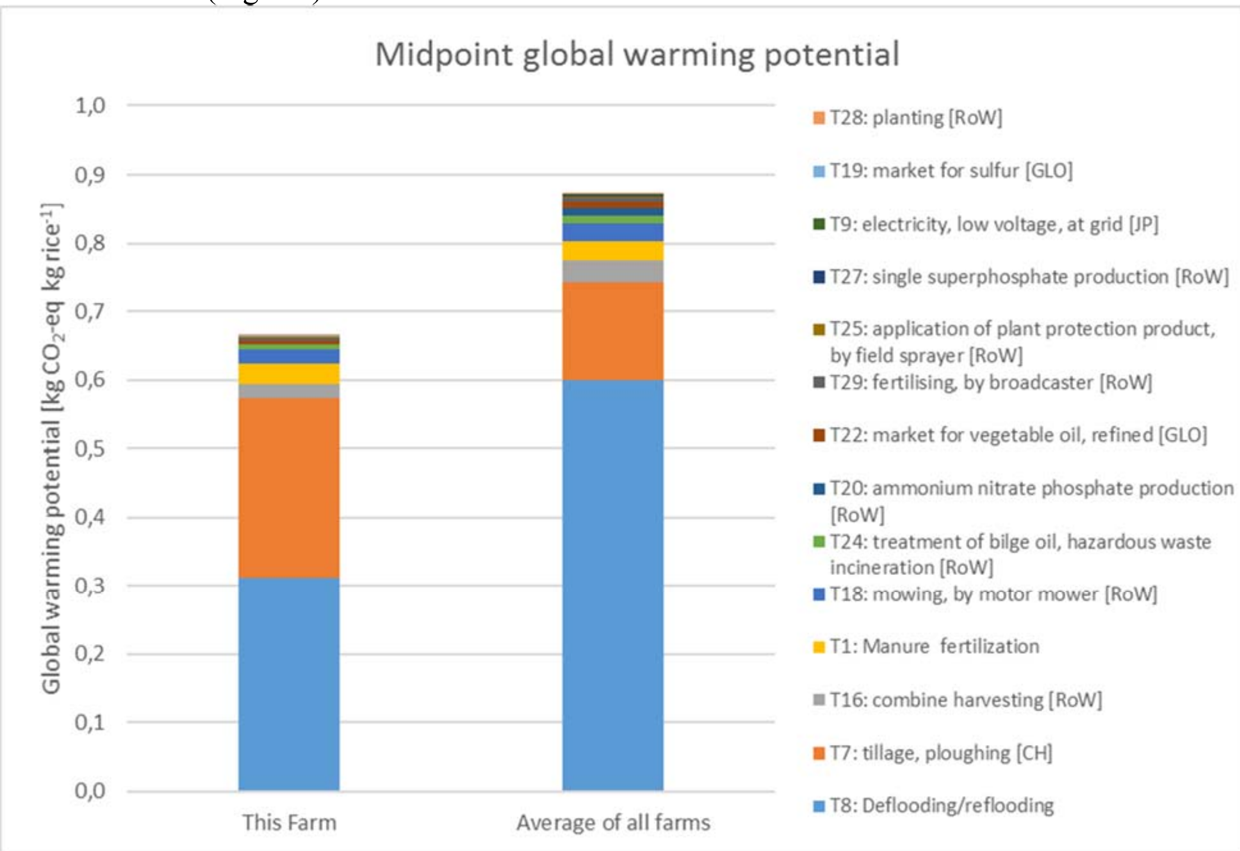

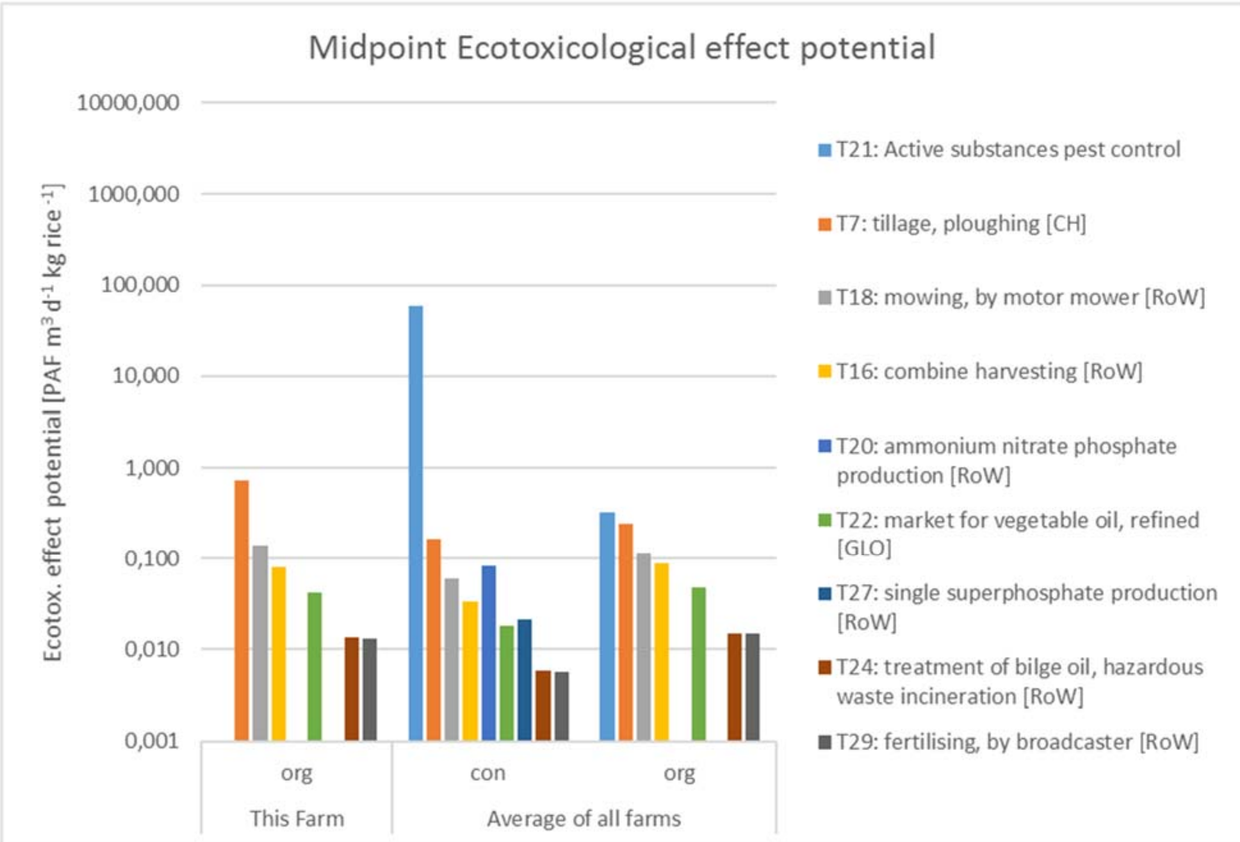

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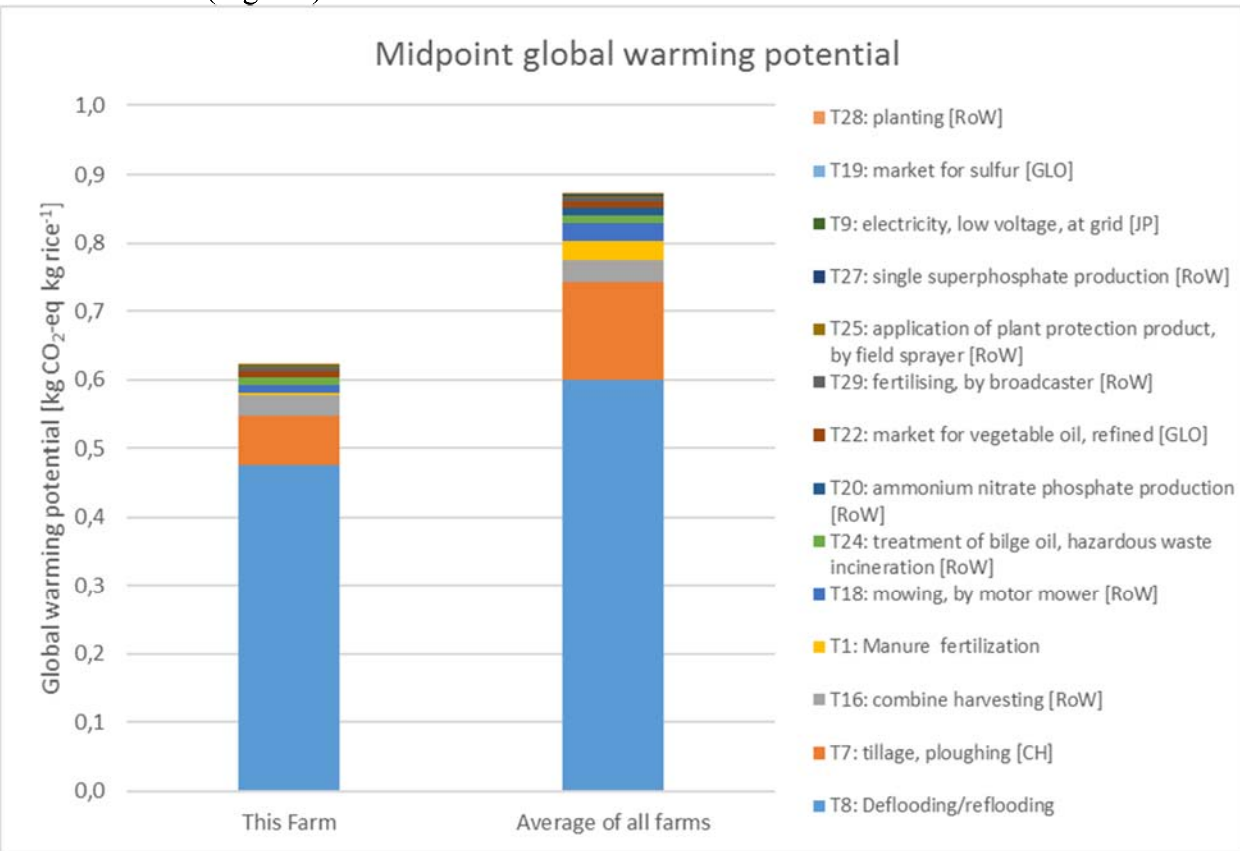
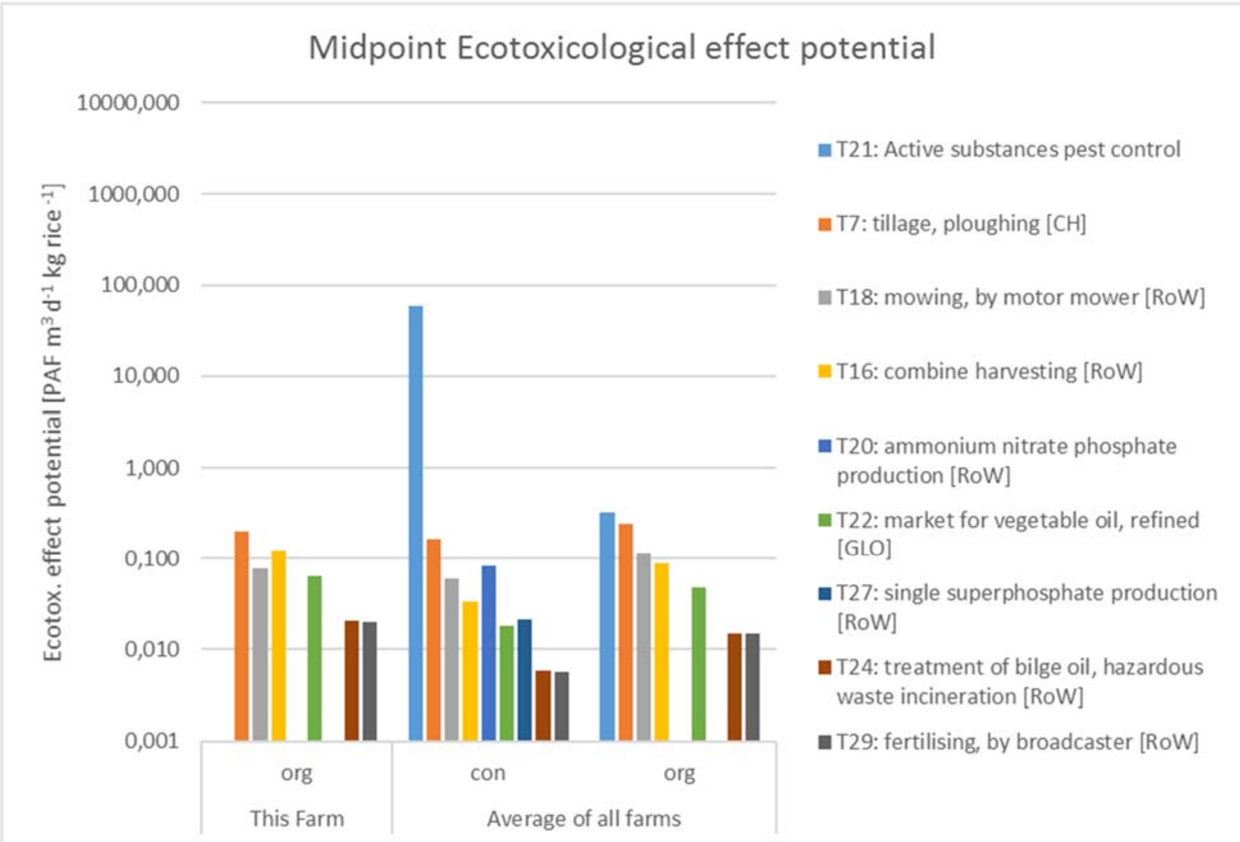
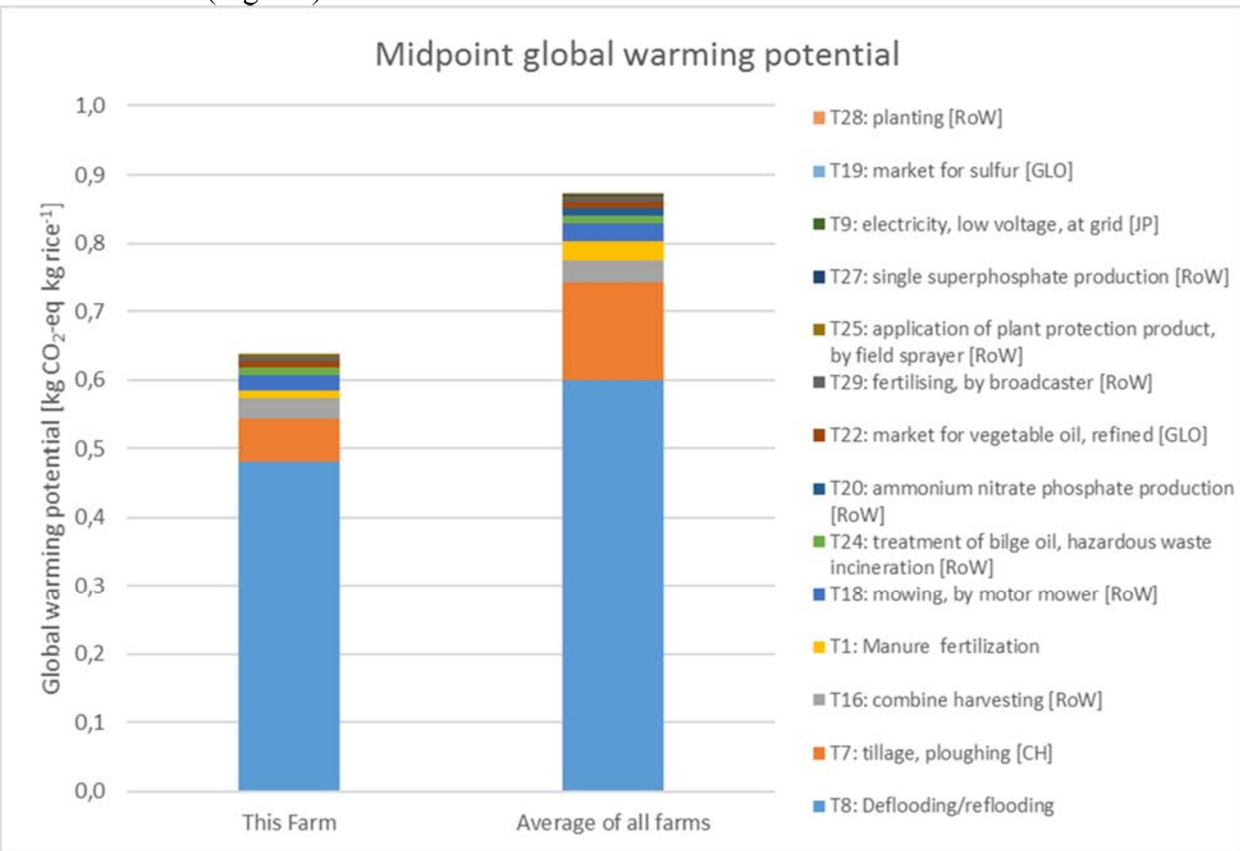
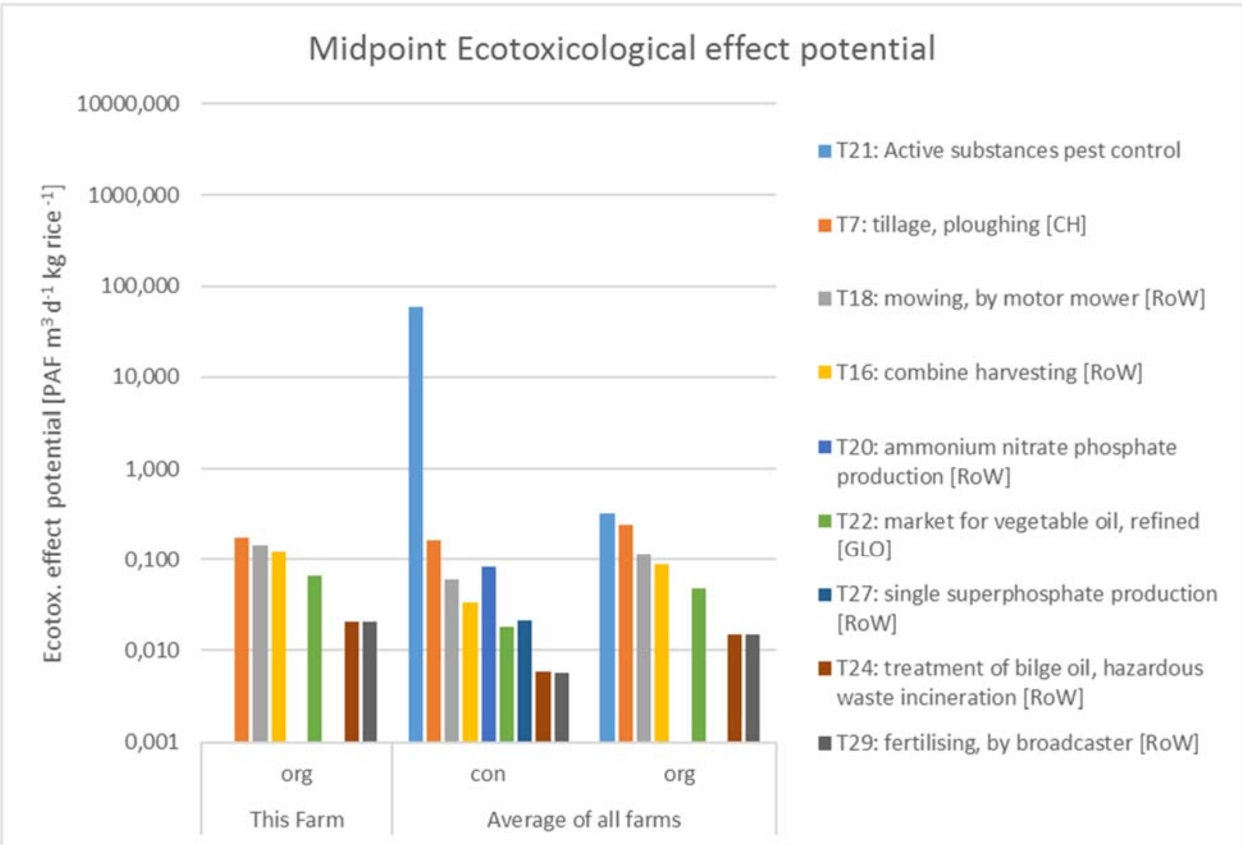




FARM ORG15 (organic)





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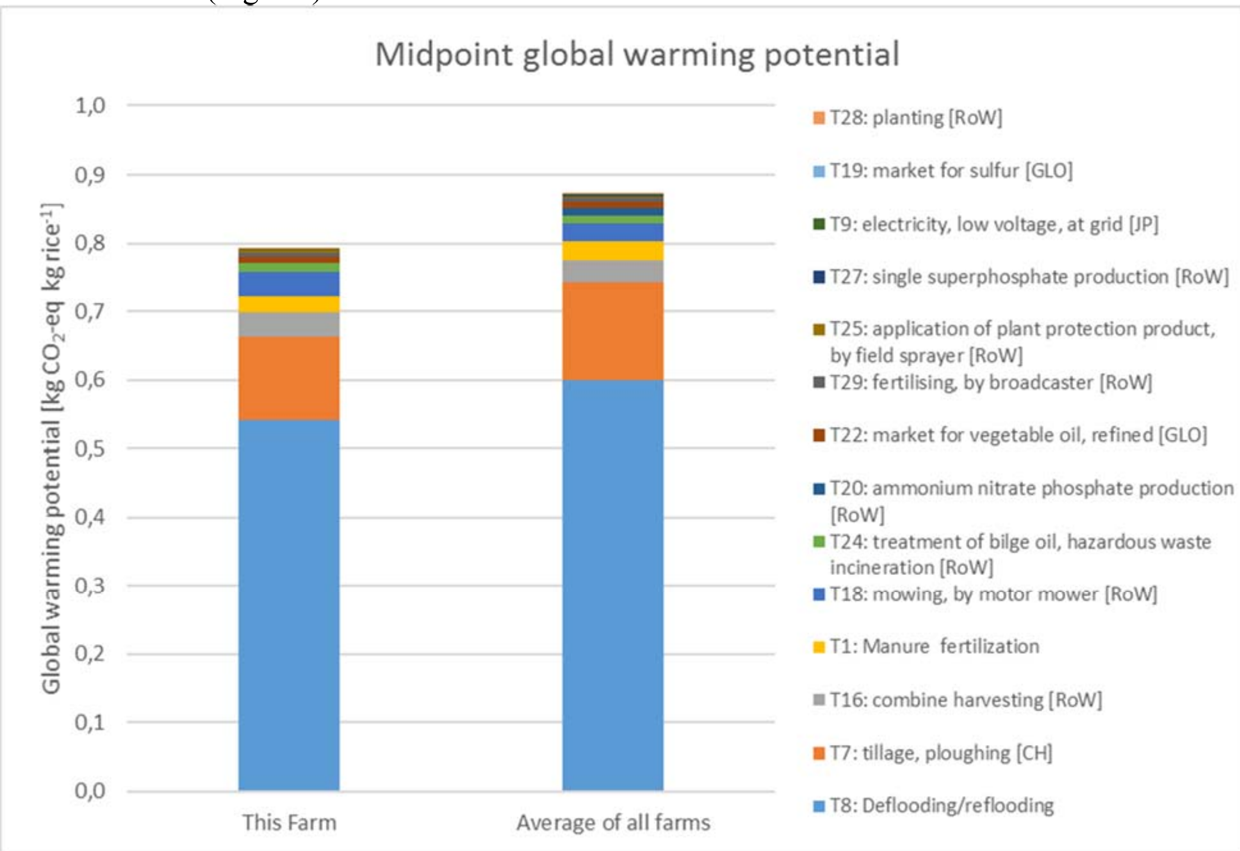

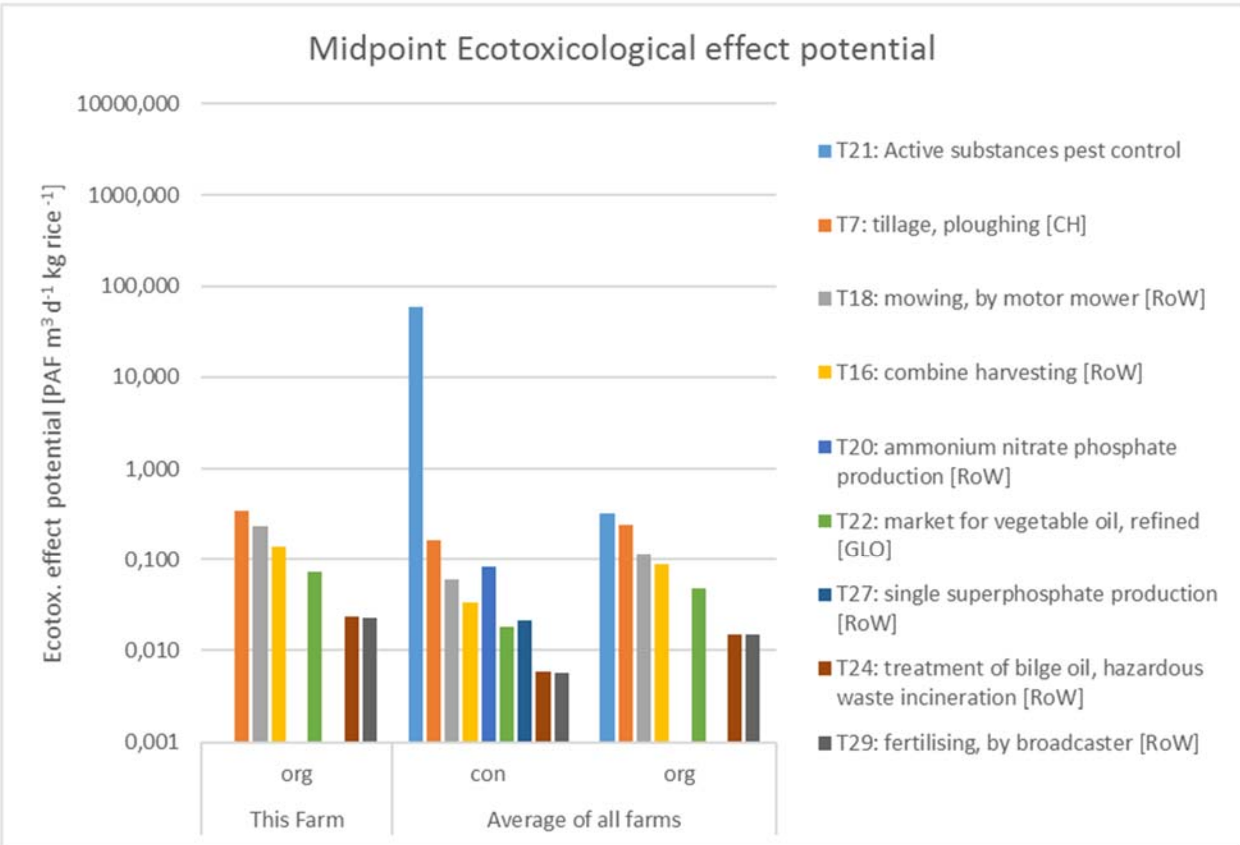

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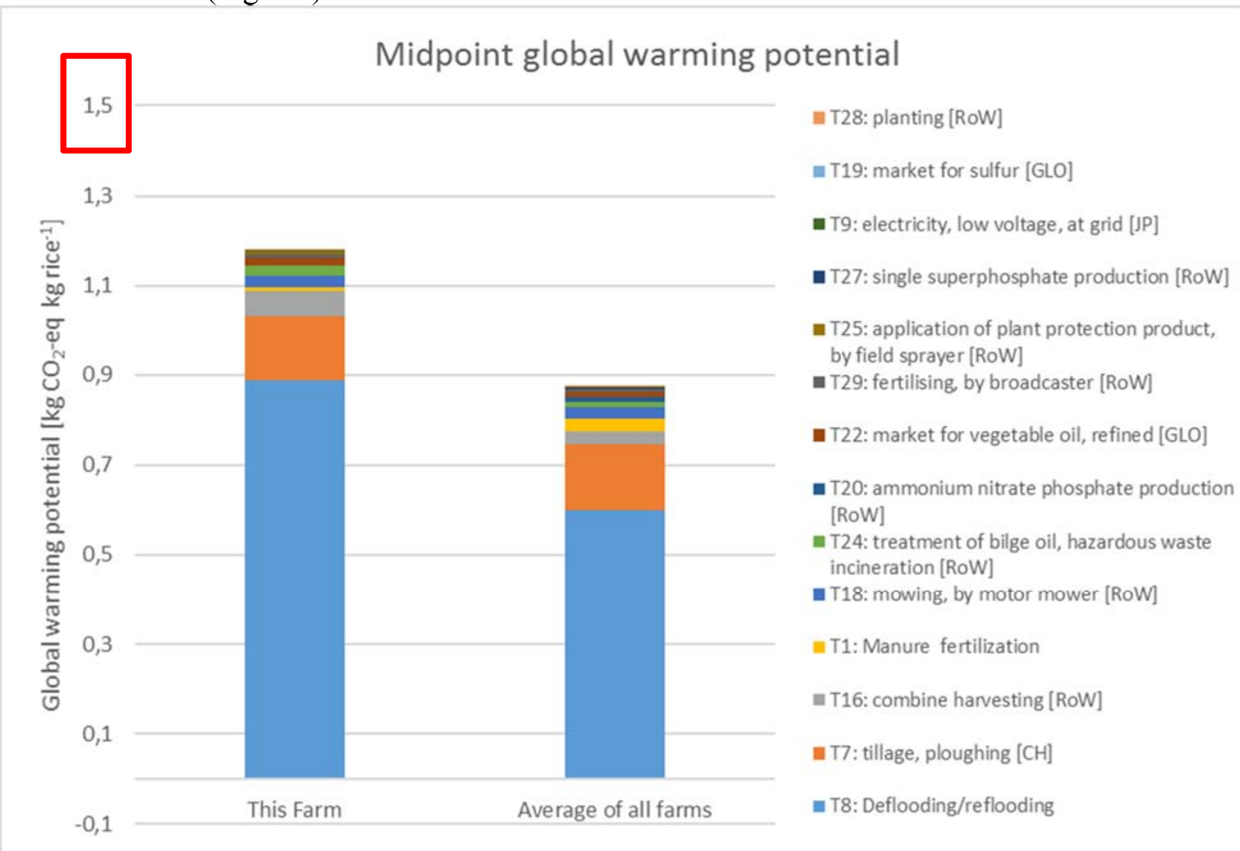

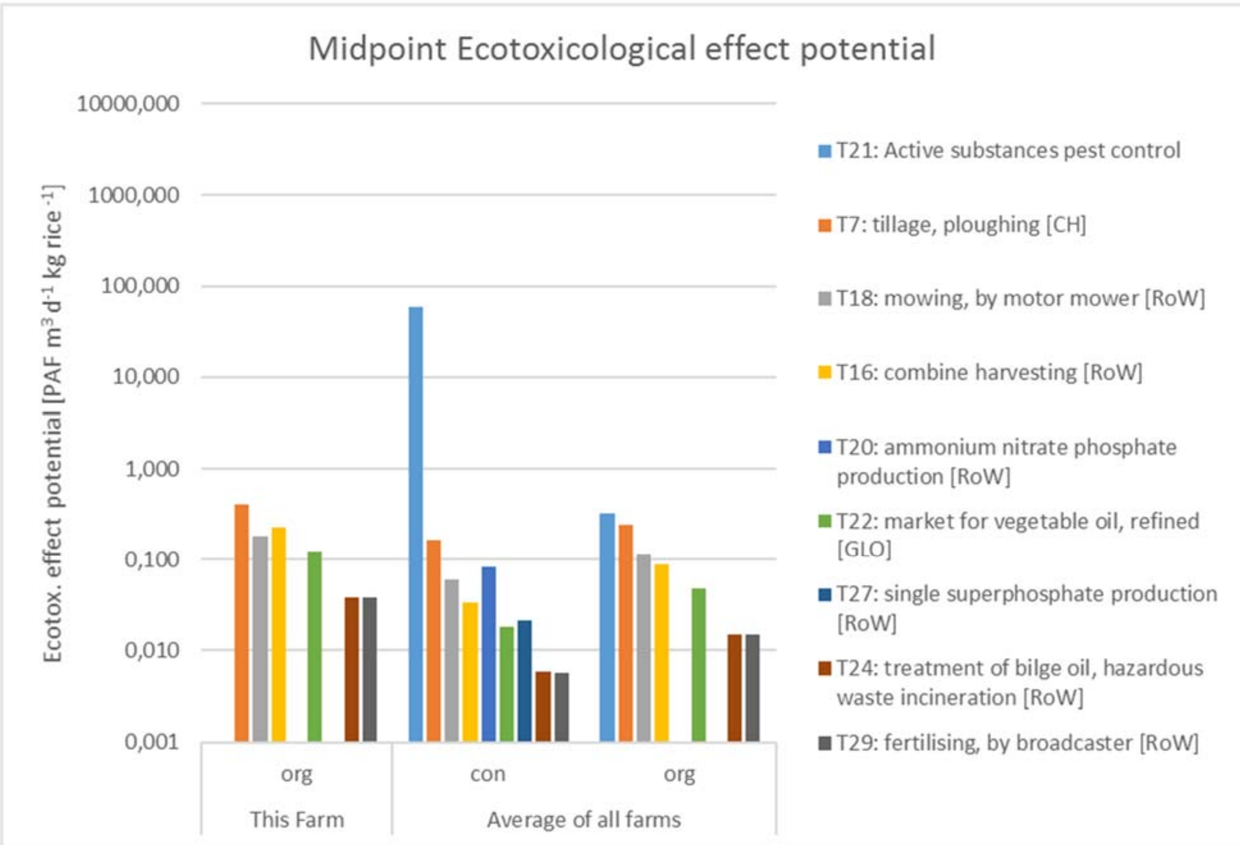

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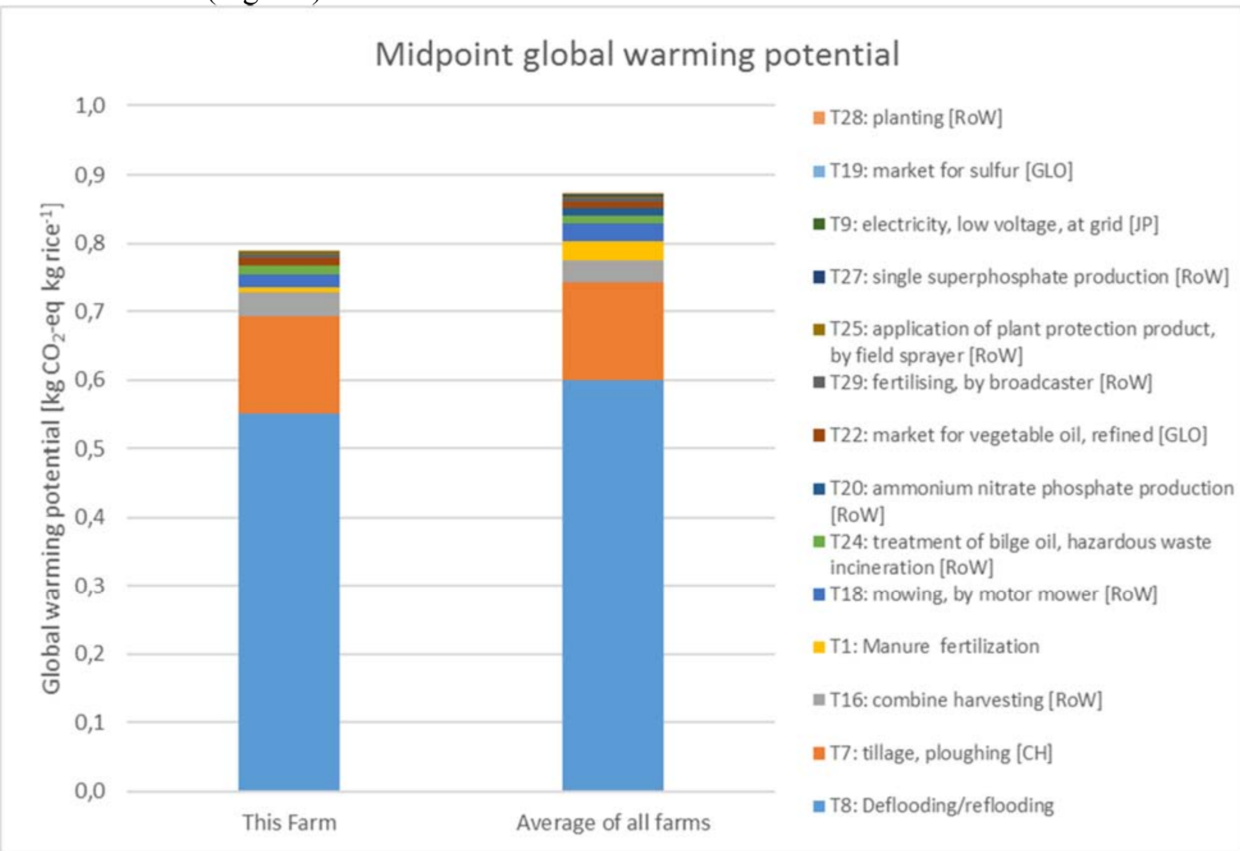
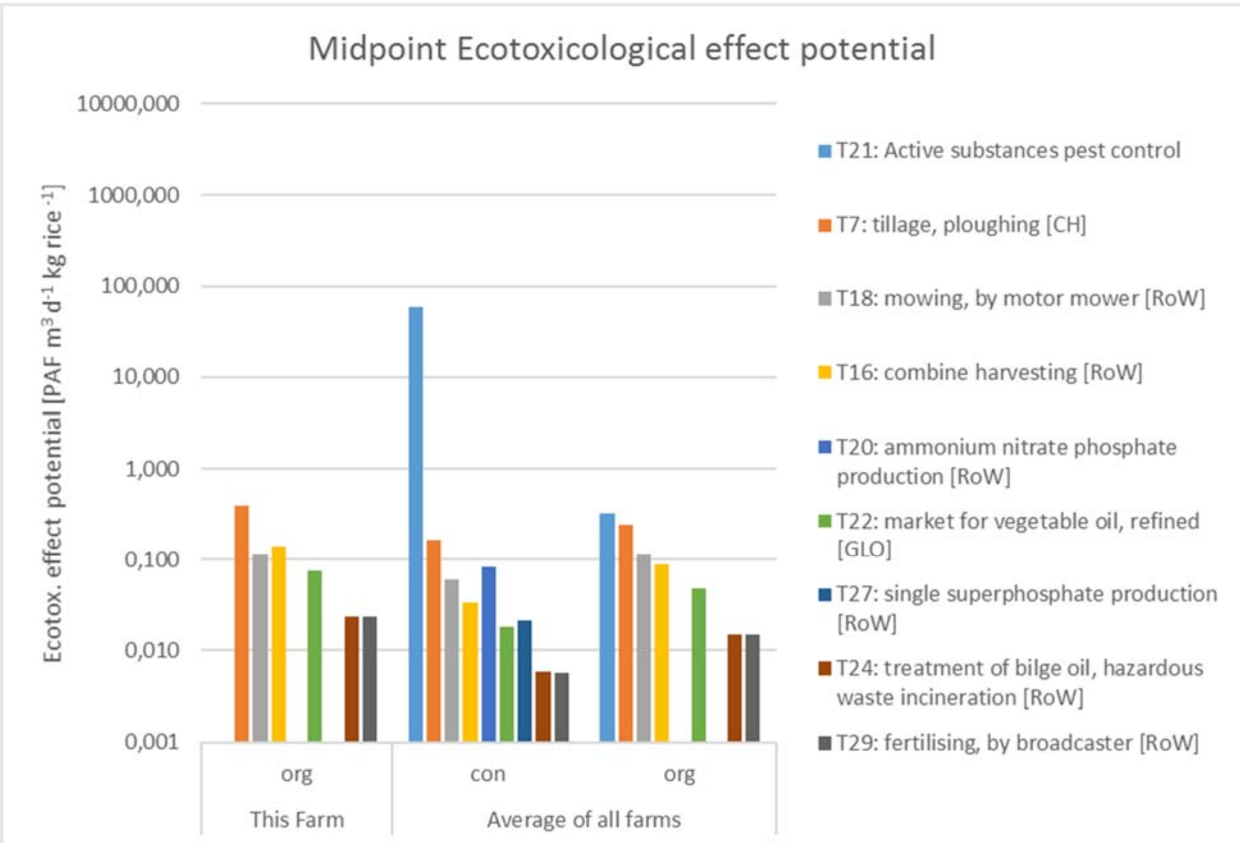
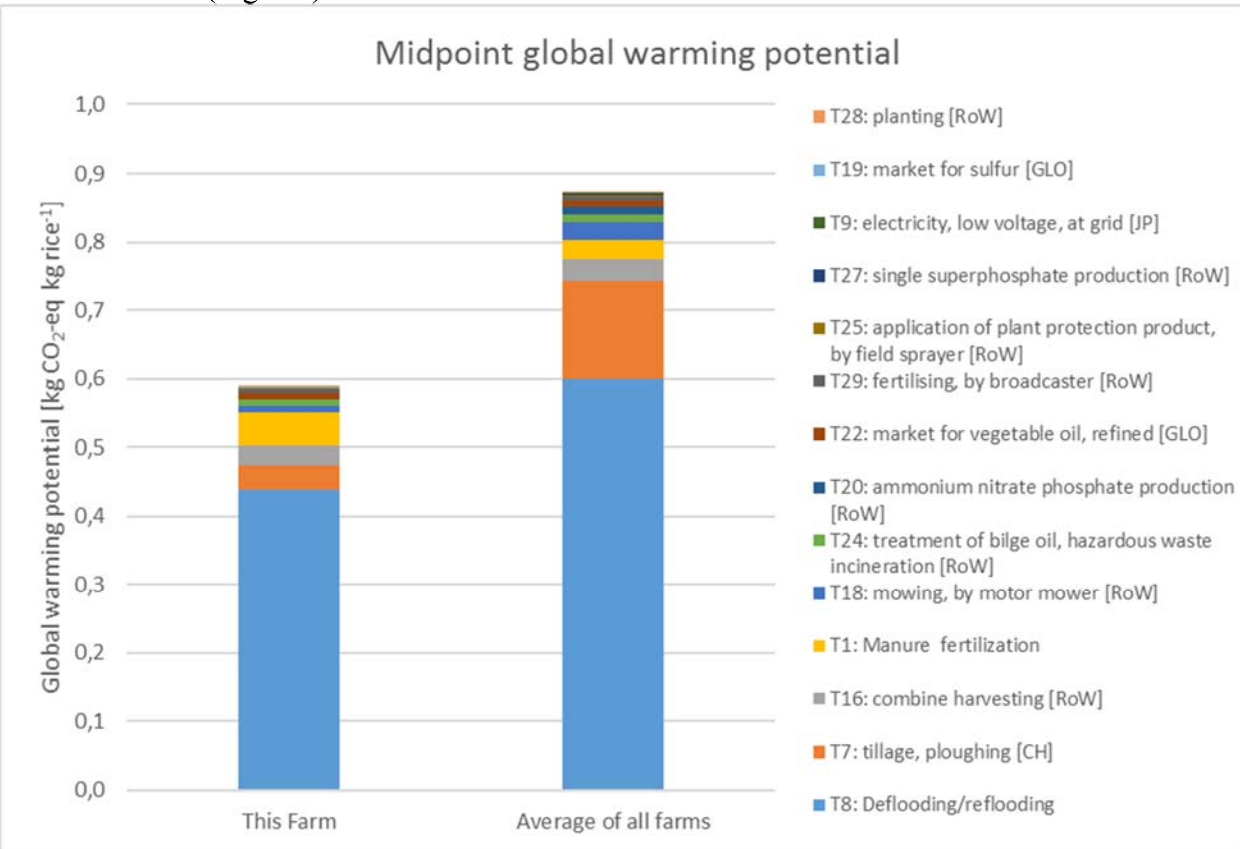
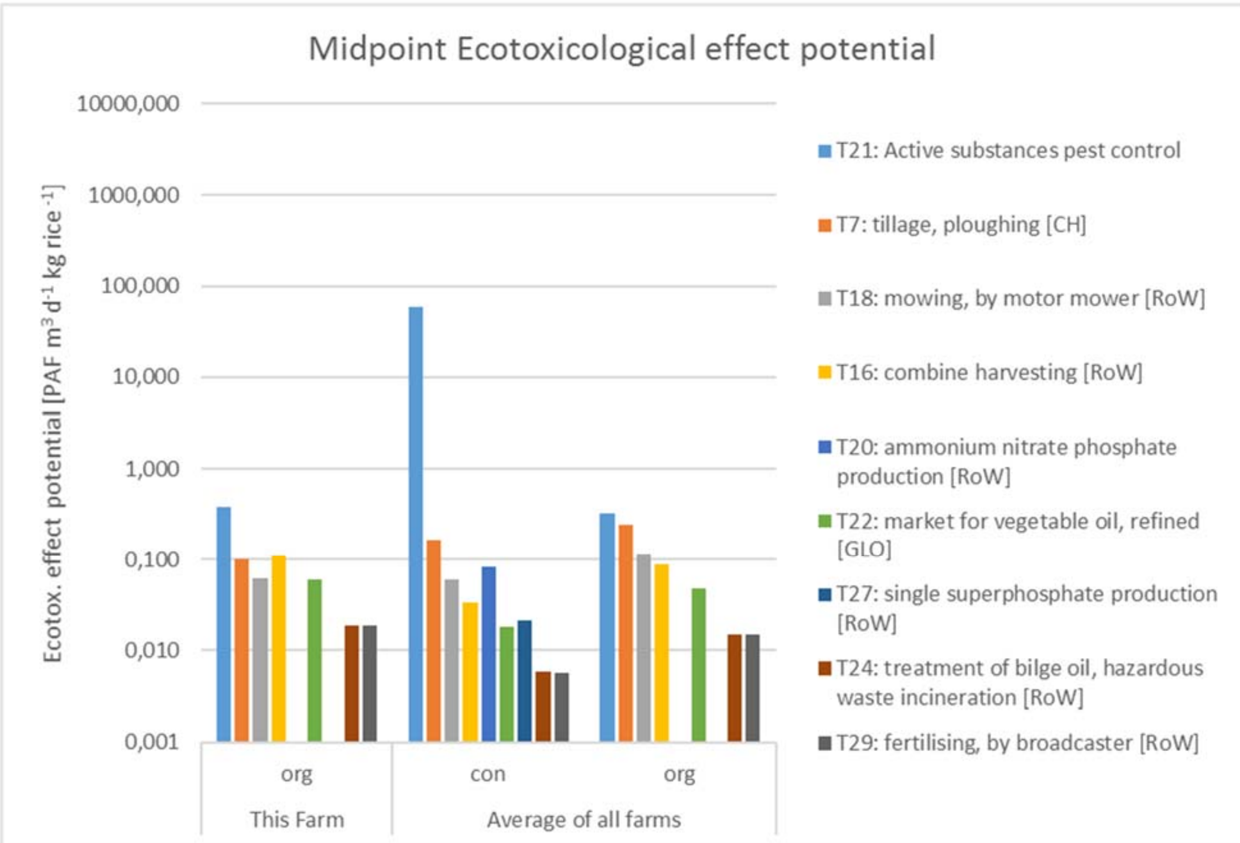


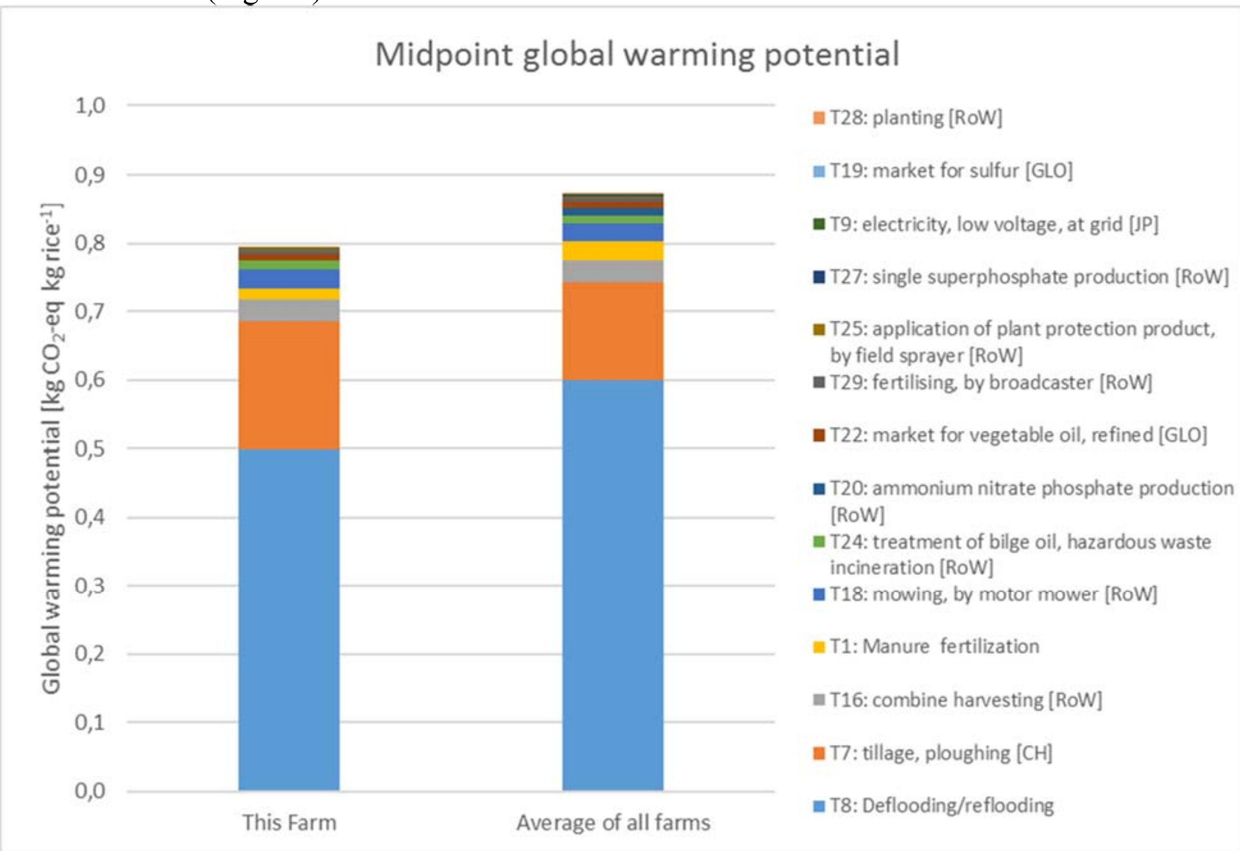


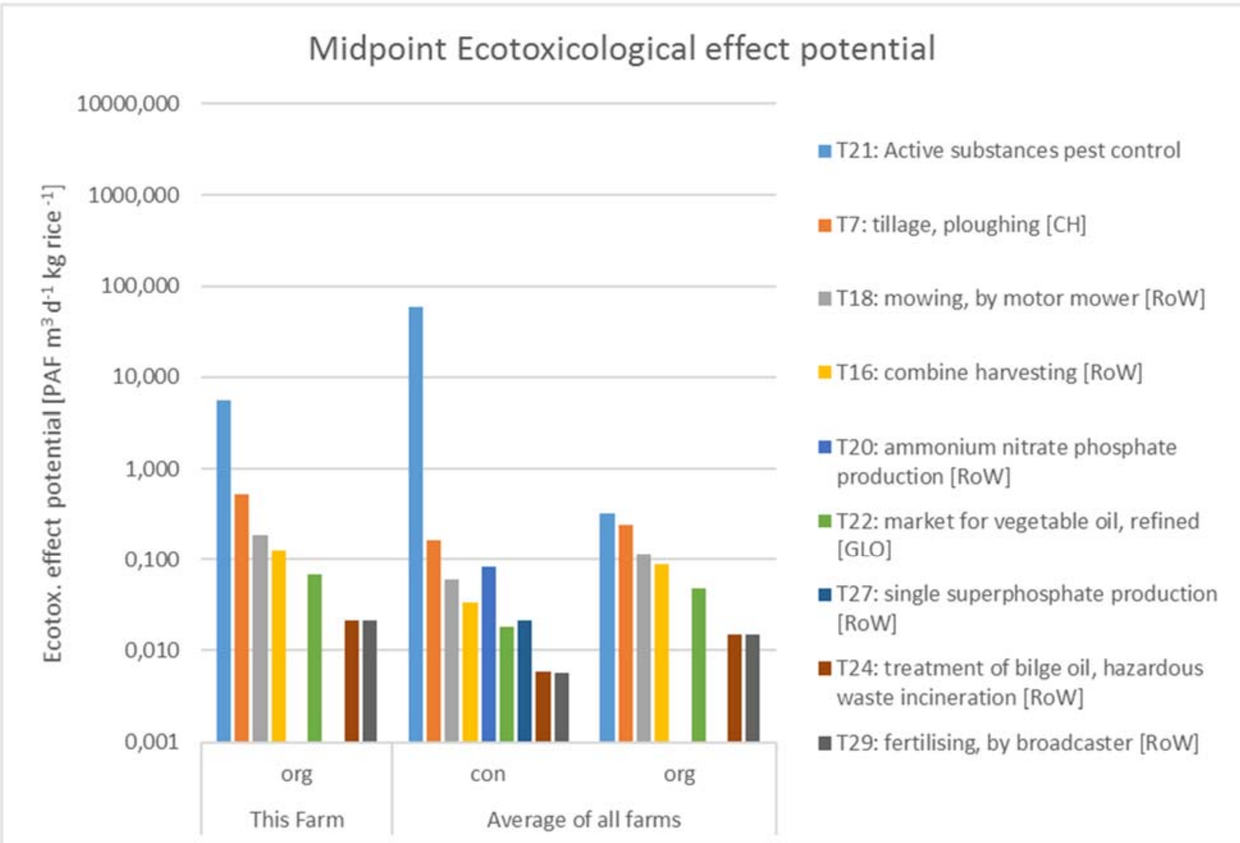
FARM ORG19 (organic)



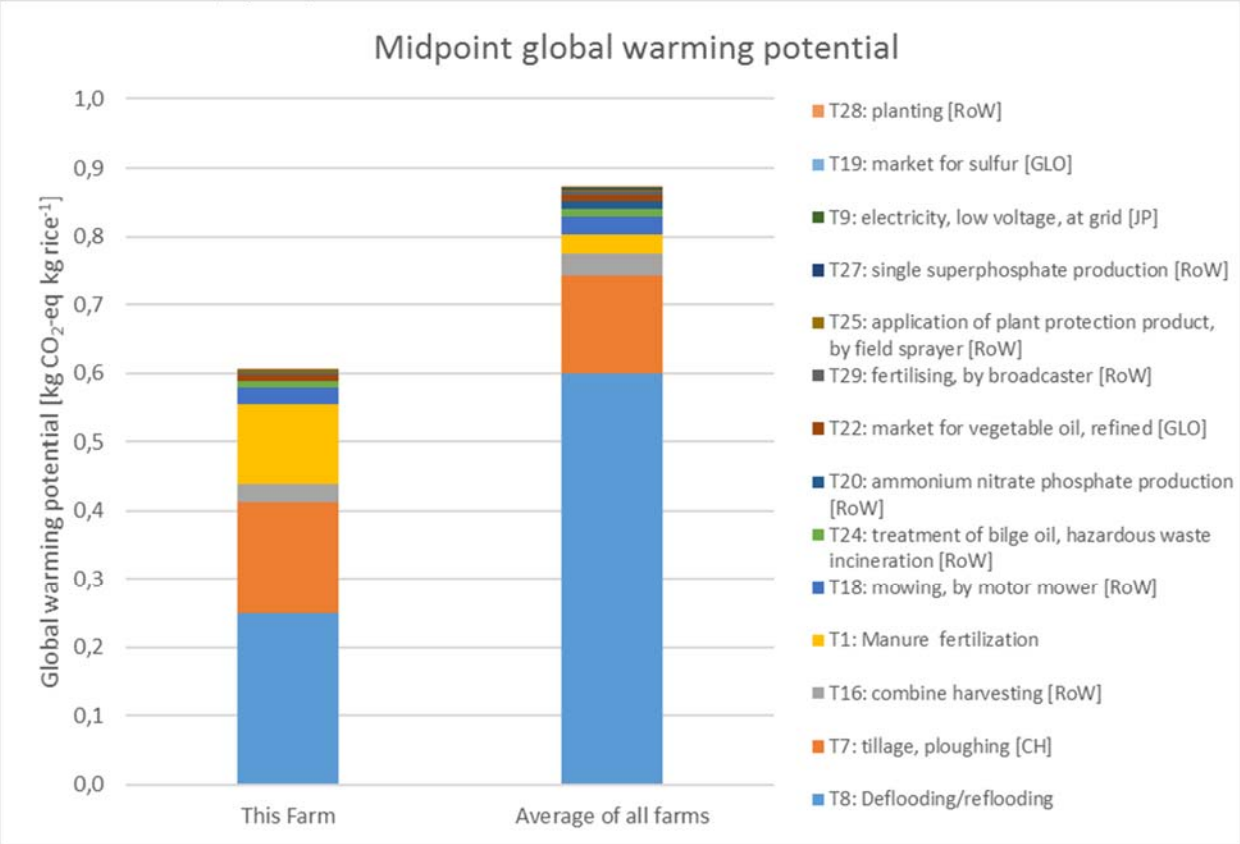


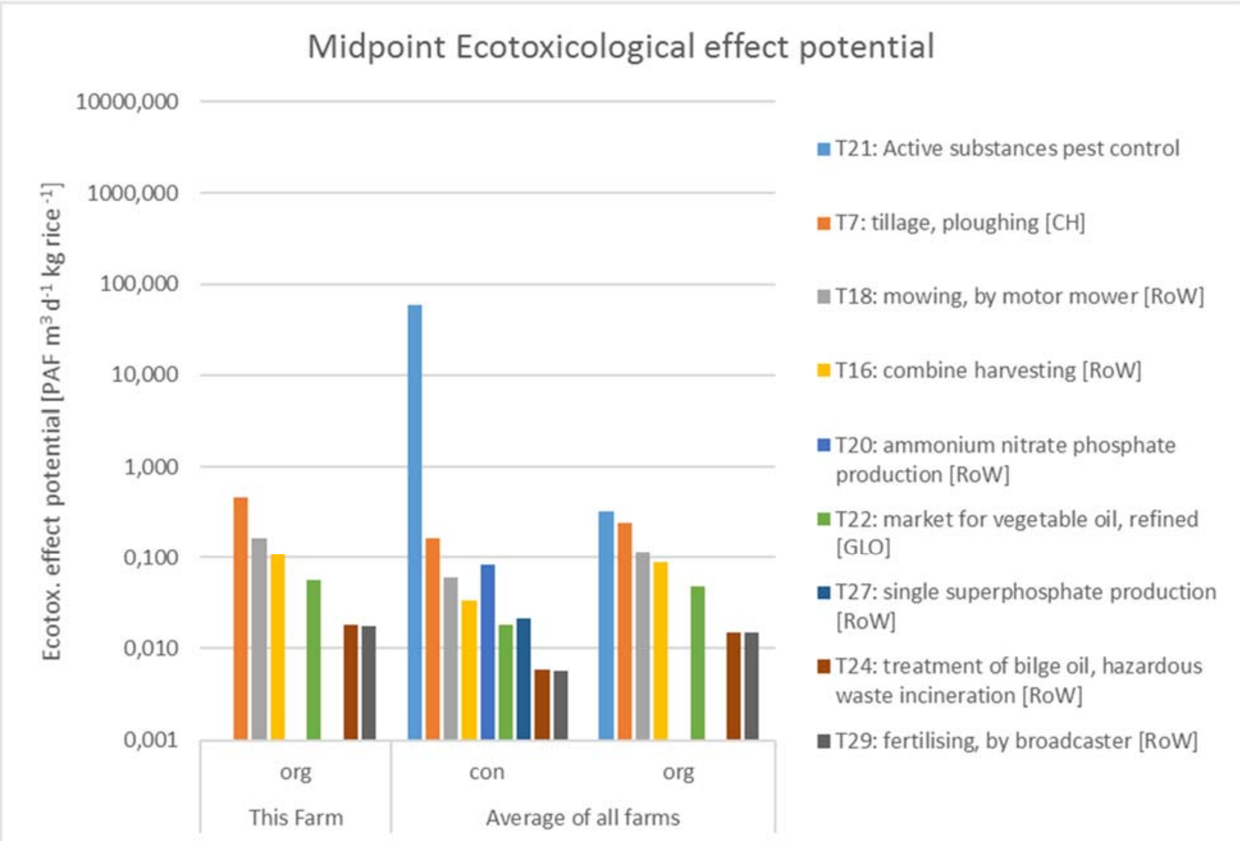
FARM ORG20 (organic)



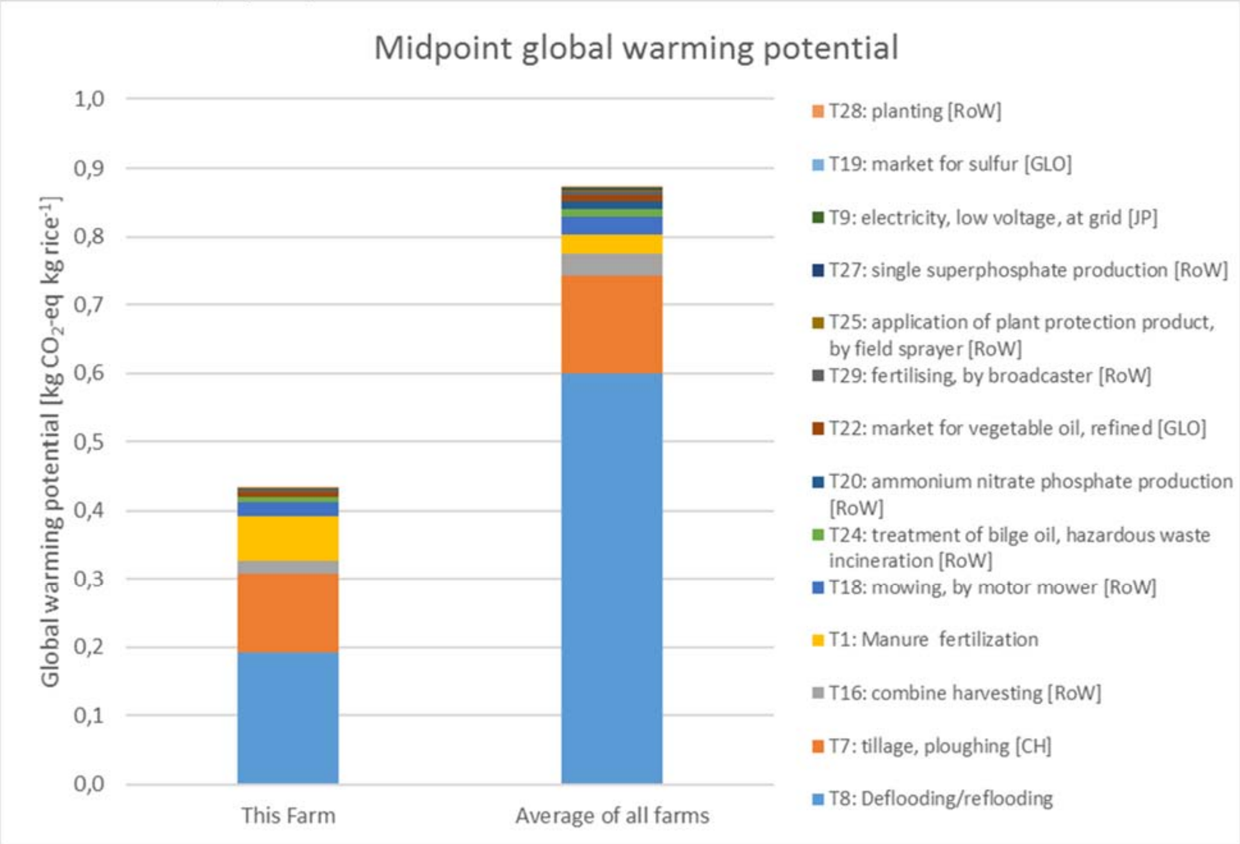


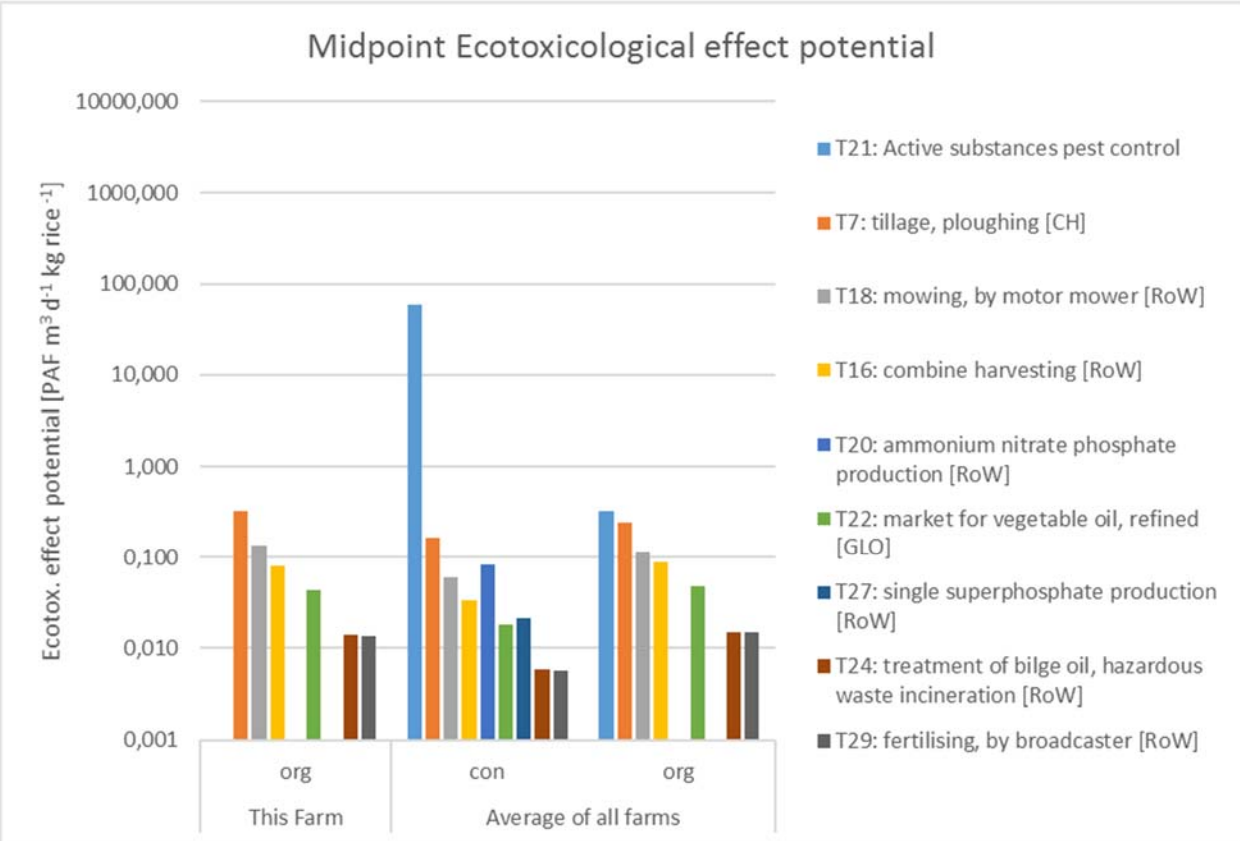
FARM ORG21 (organic)



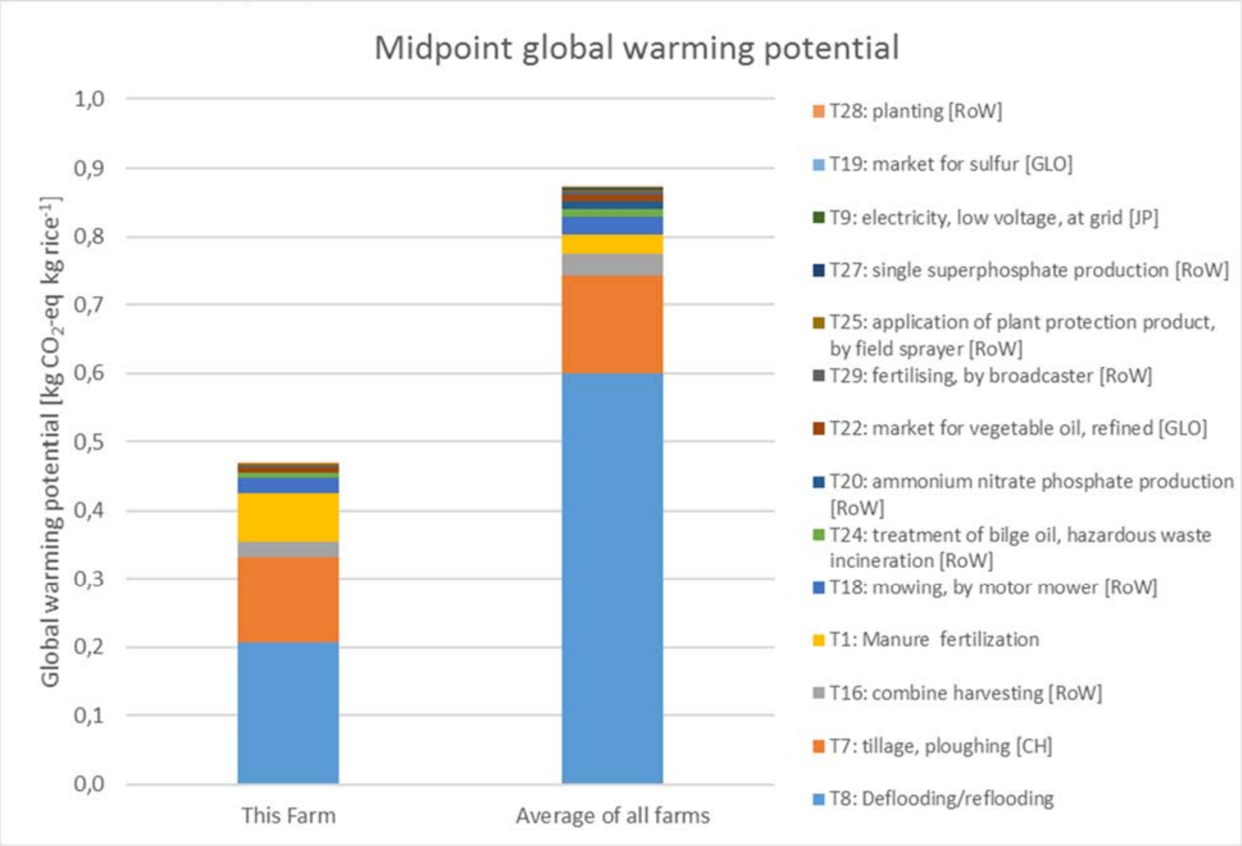


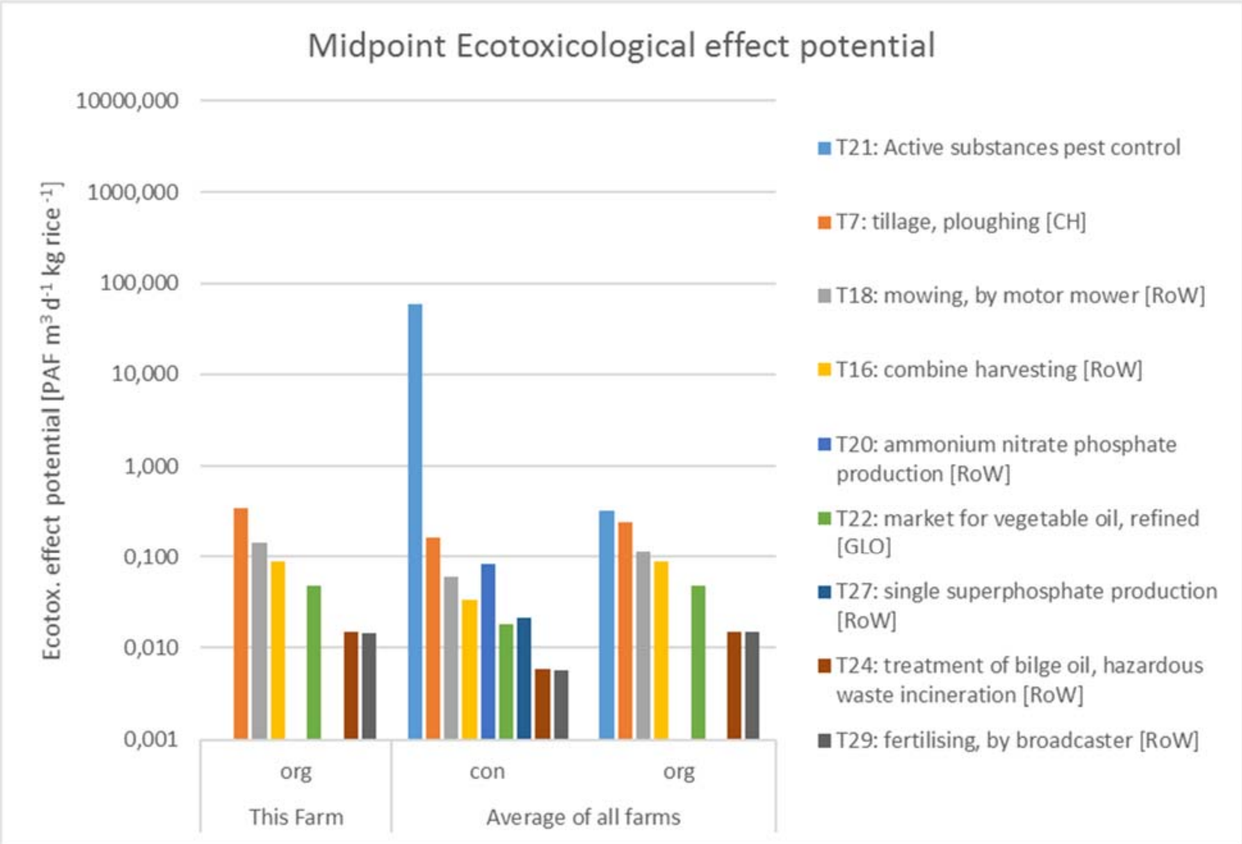
FARM ORG22 (organic)





FARM ORG23 (organic)





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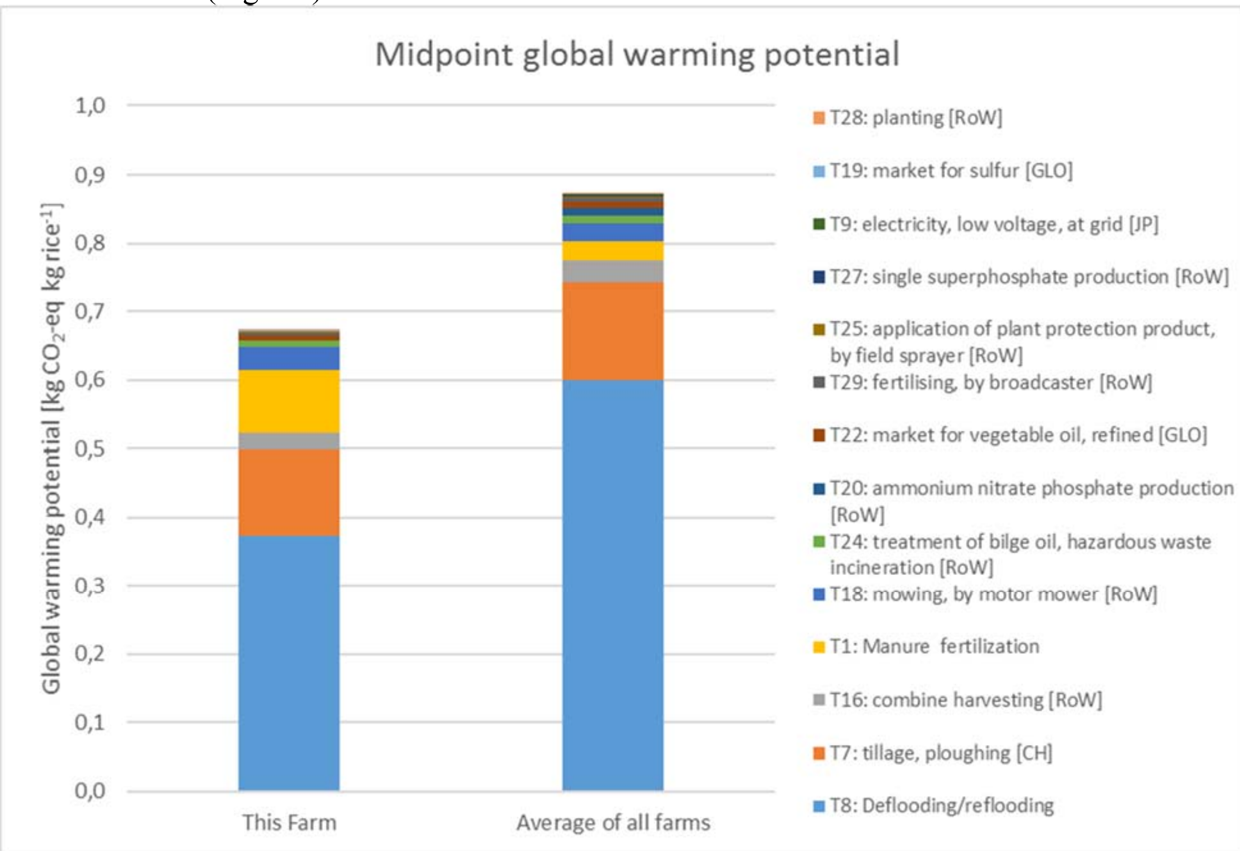
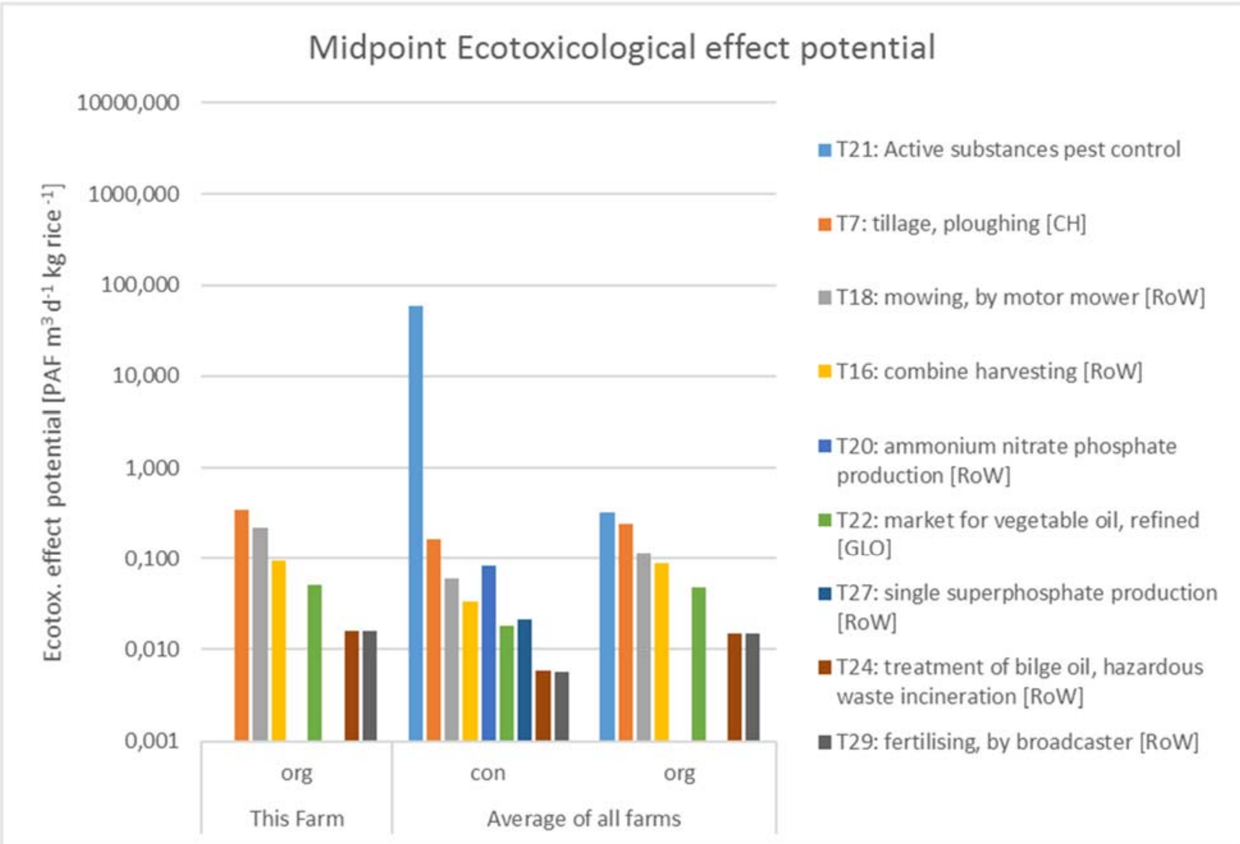
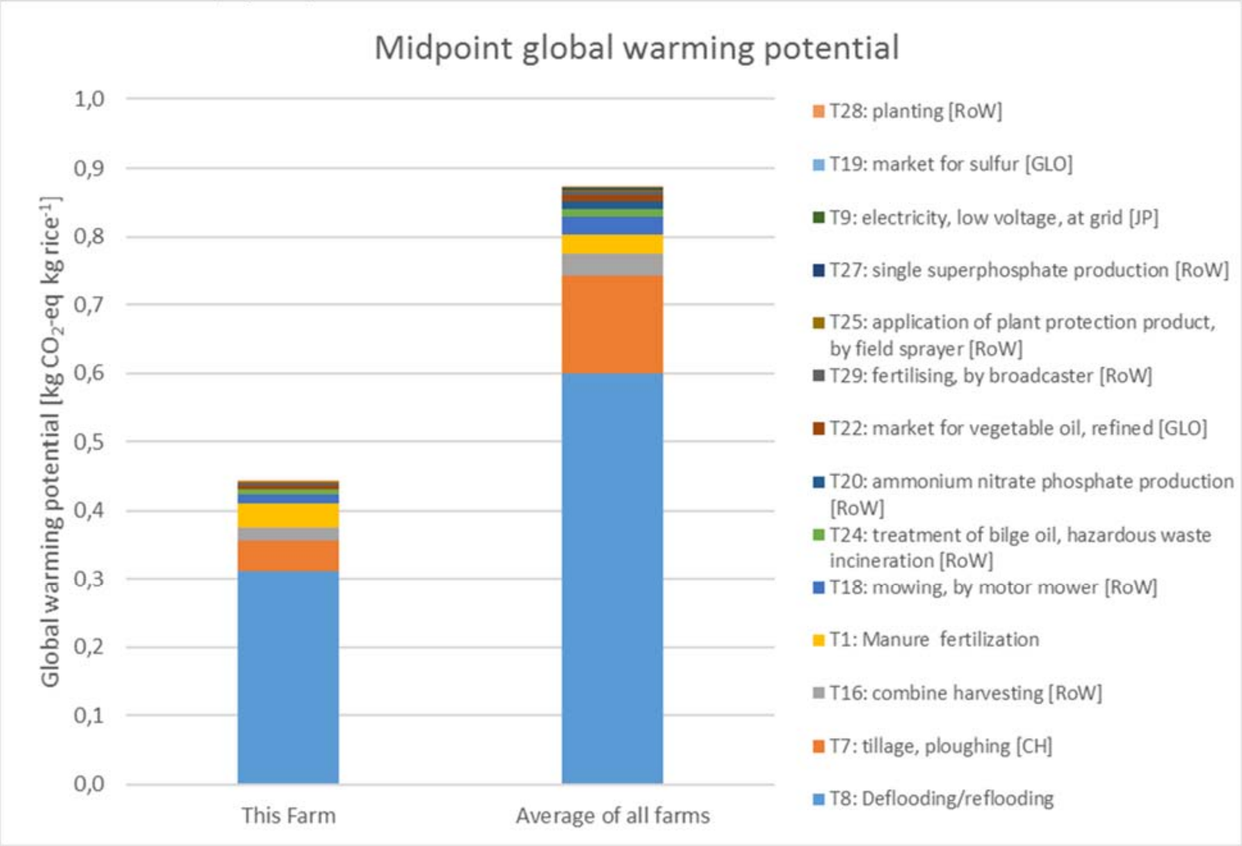
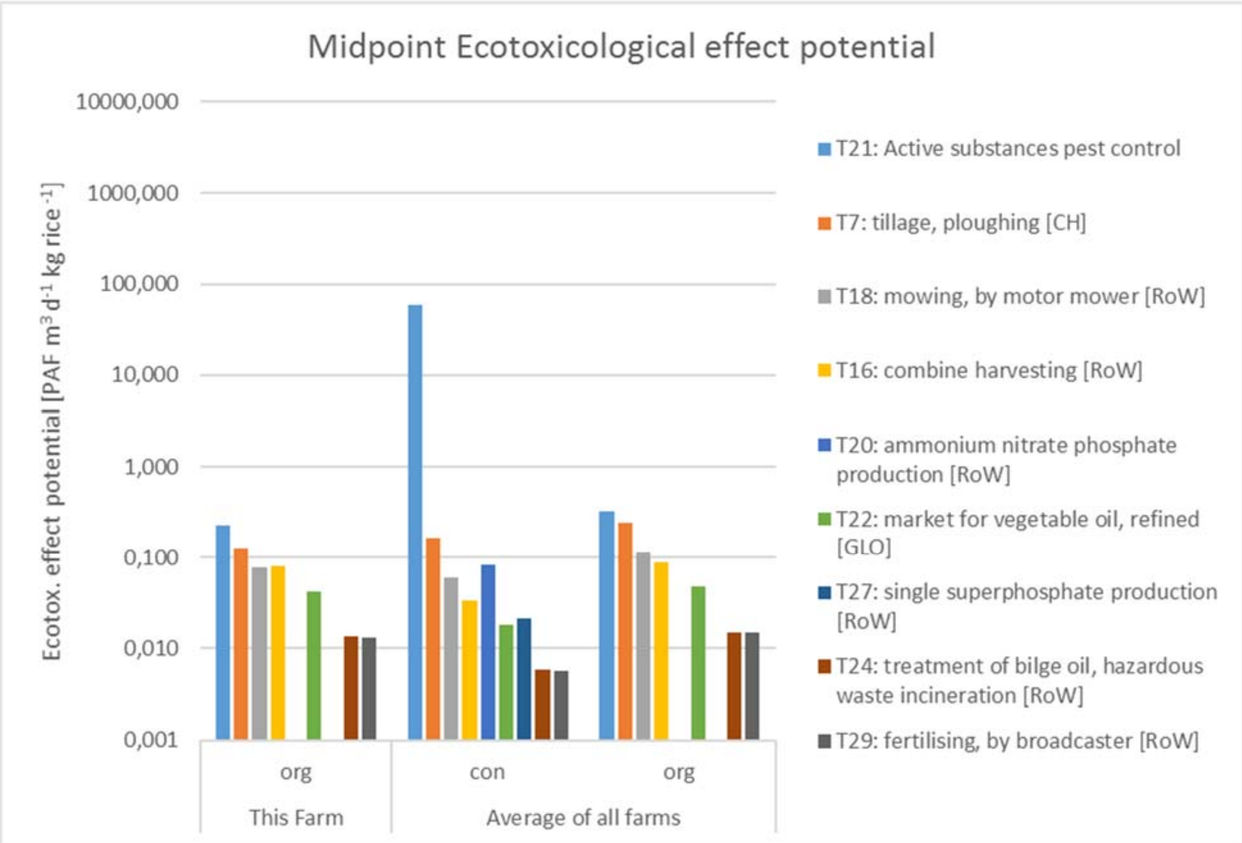


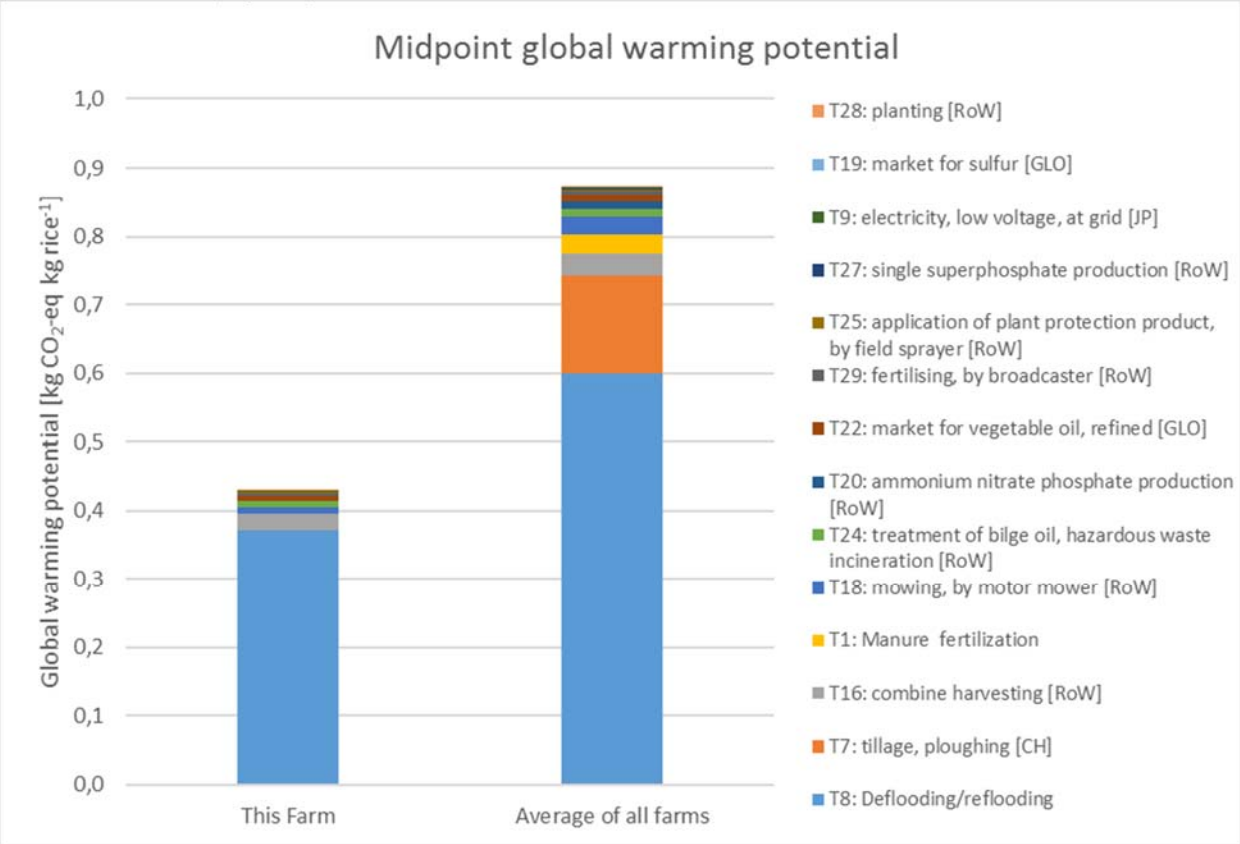


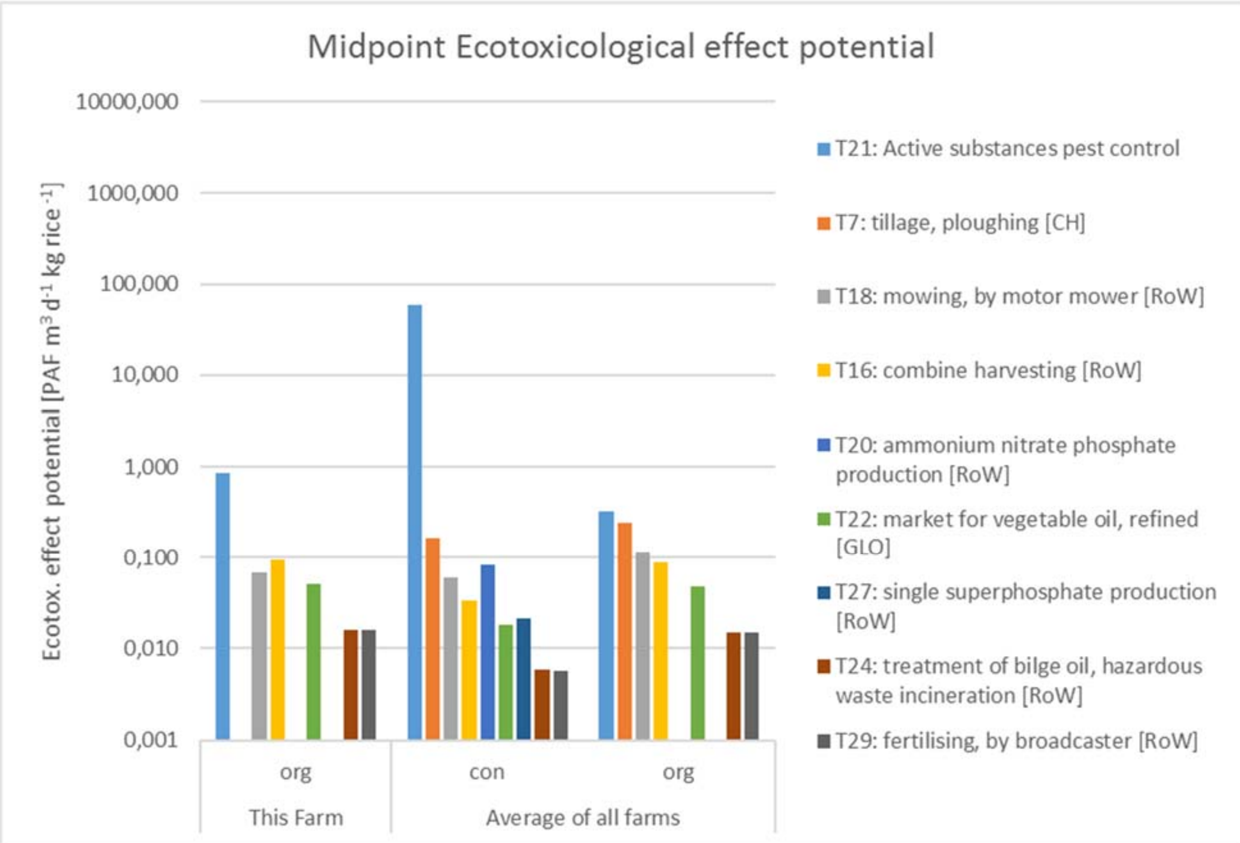
FARM ORG25 (organic)



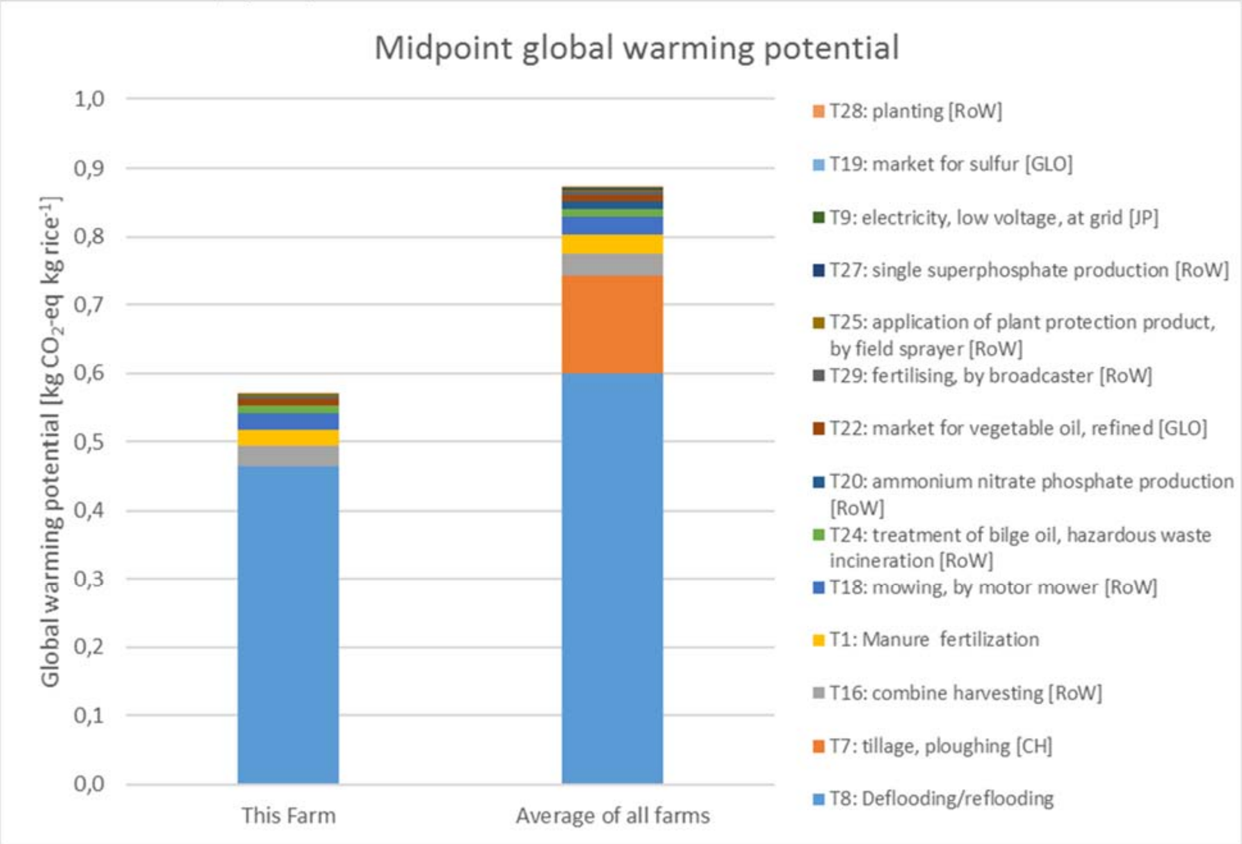


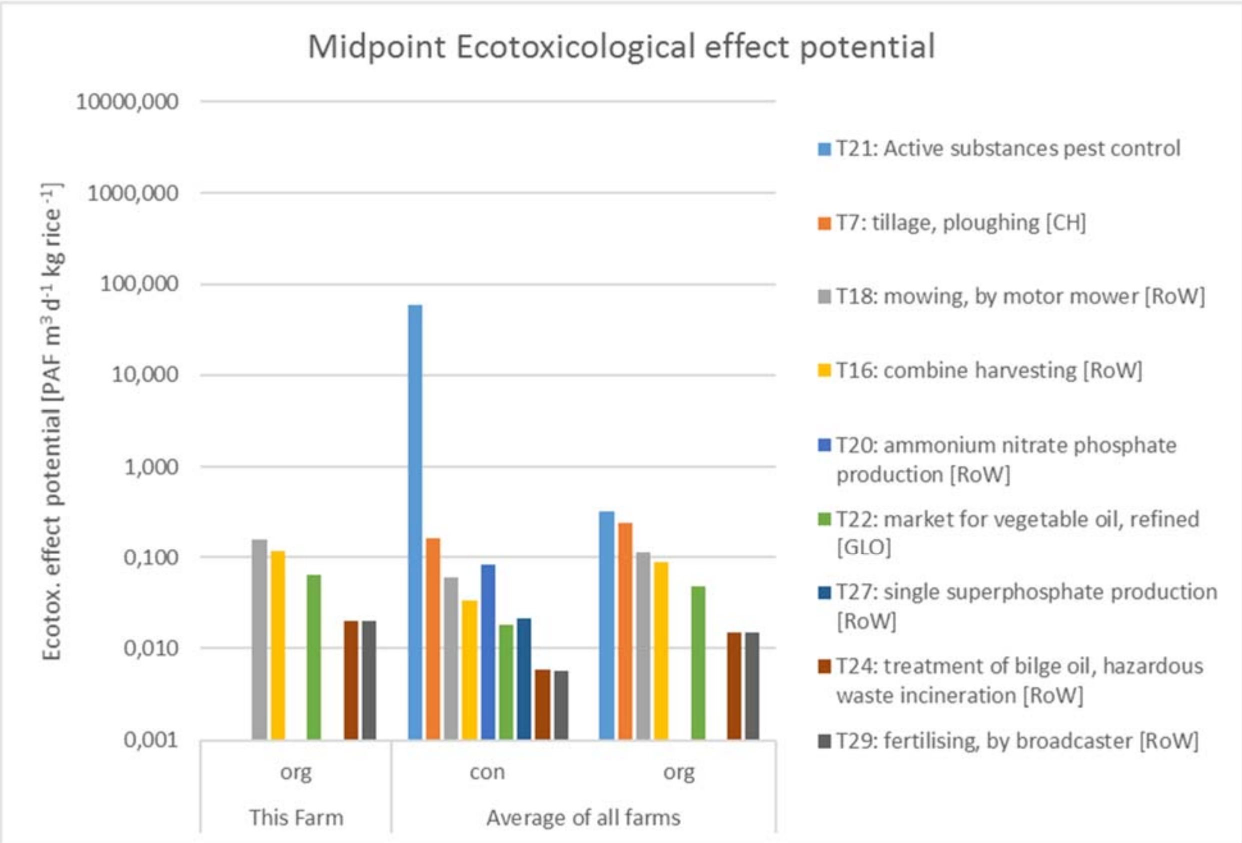
FARM ORG26 (organic)



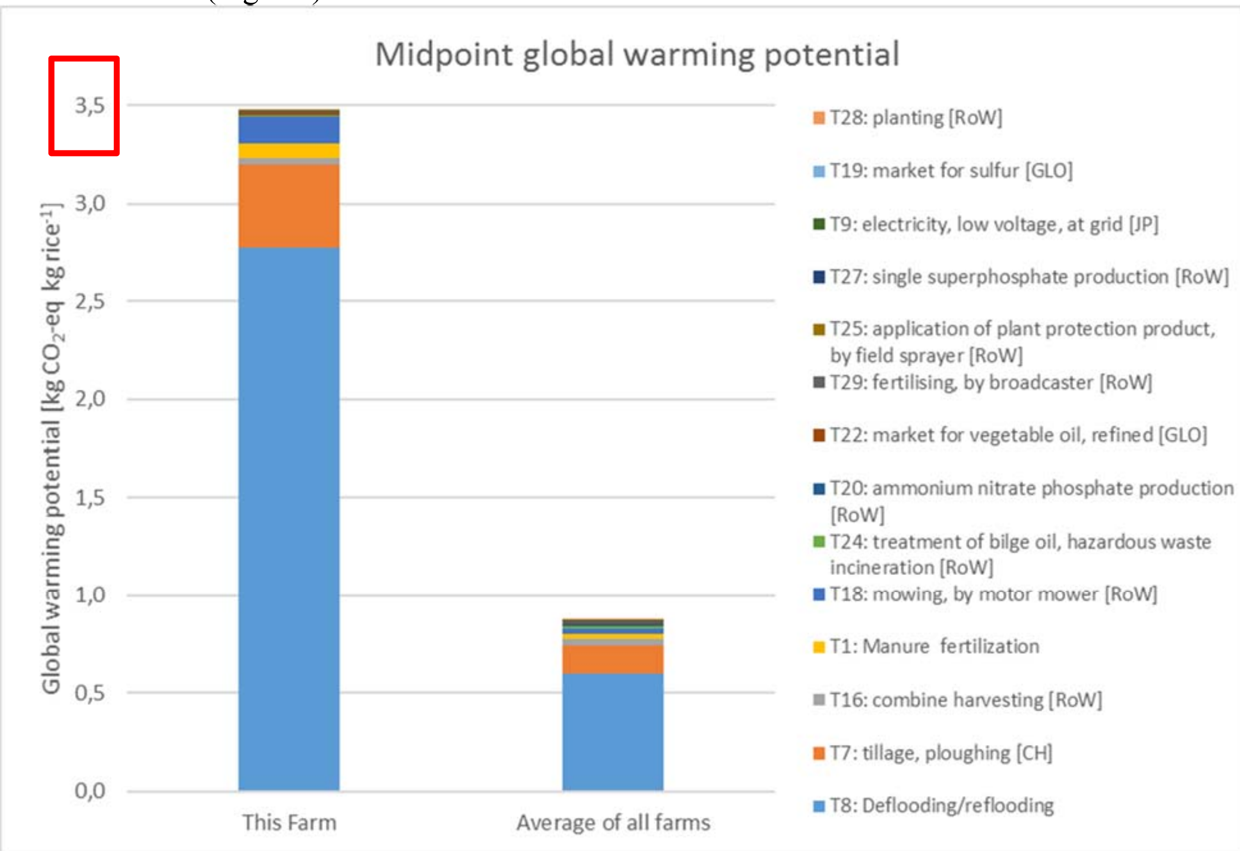


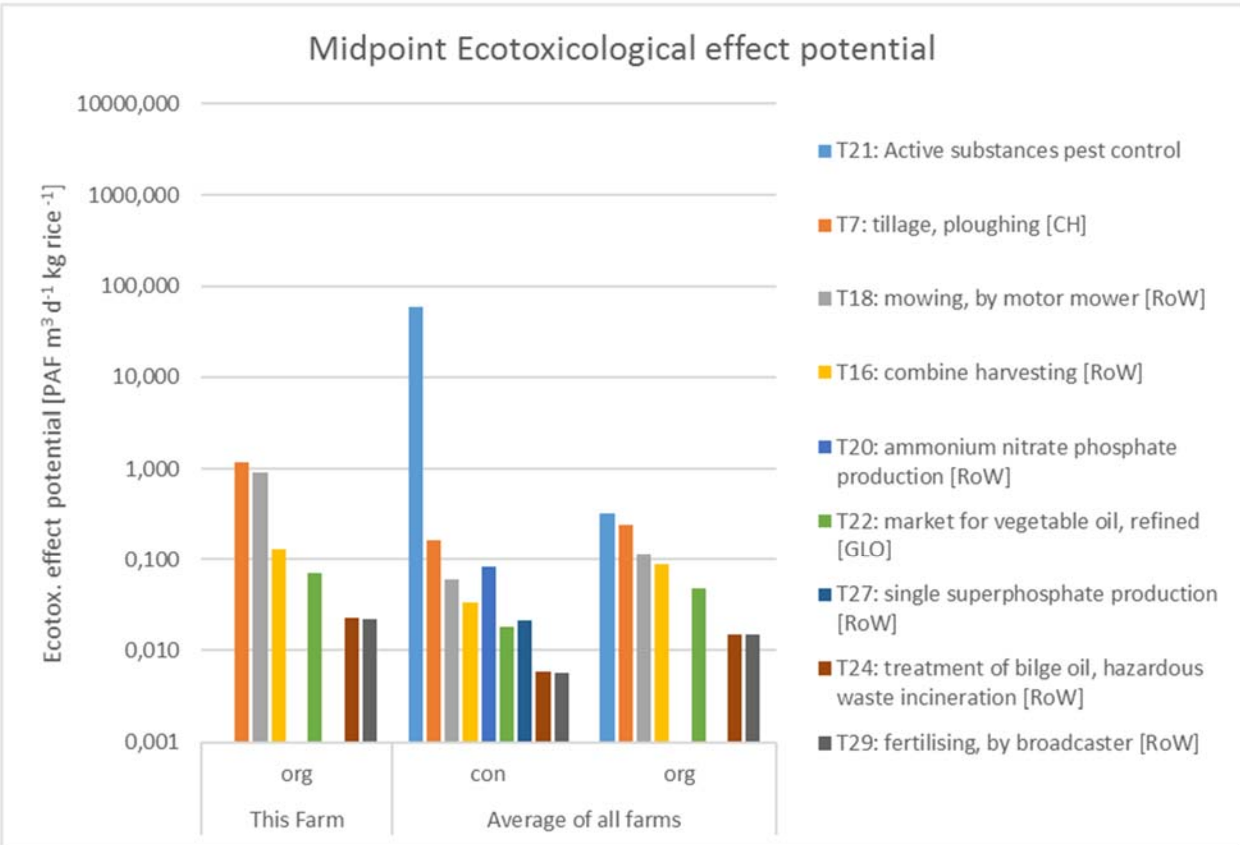
FARM ORG27 (organic)



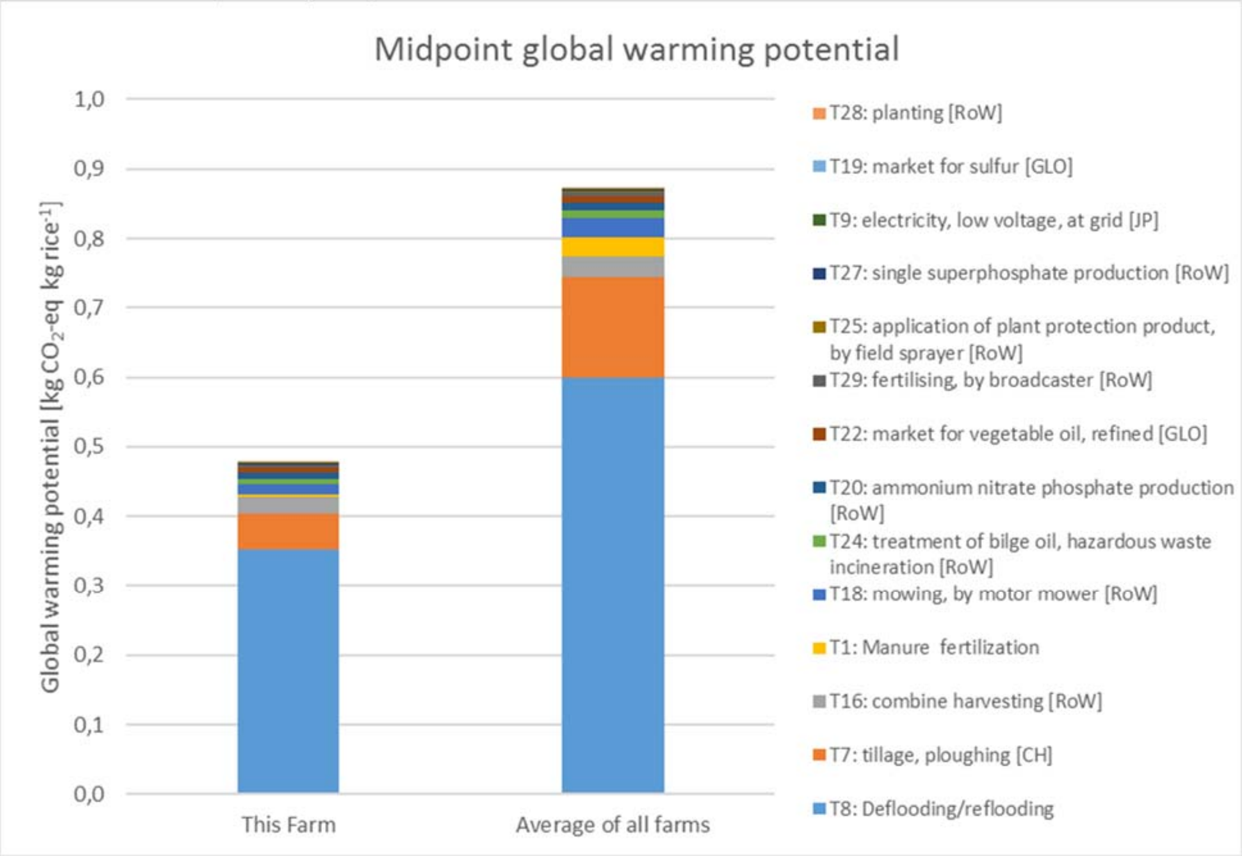


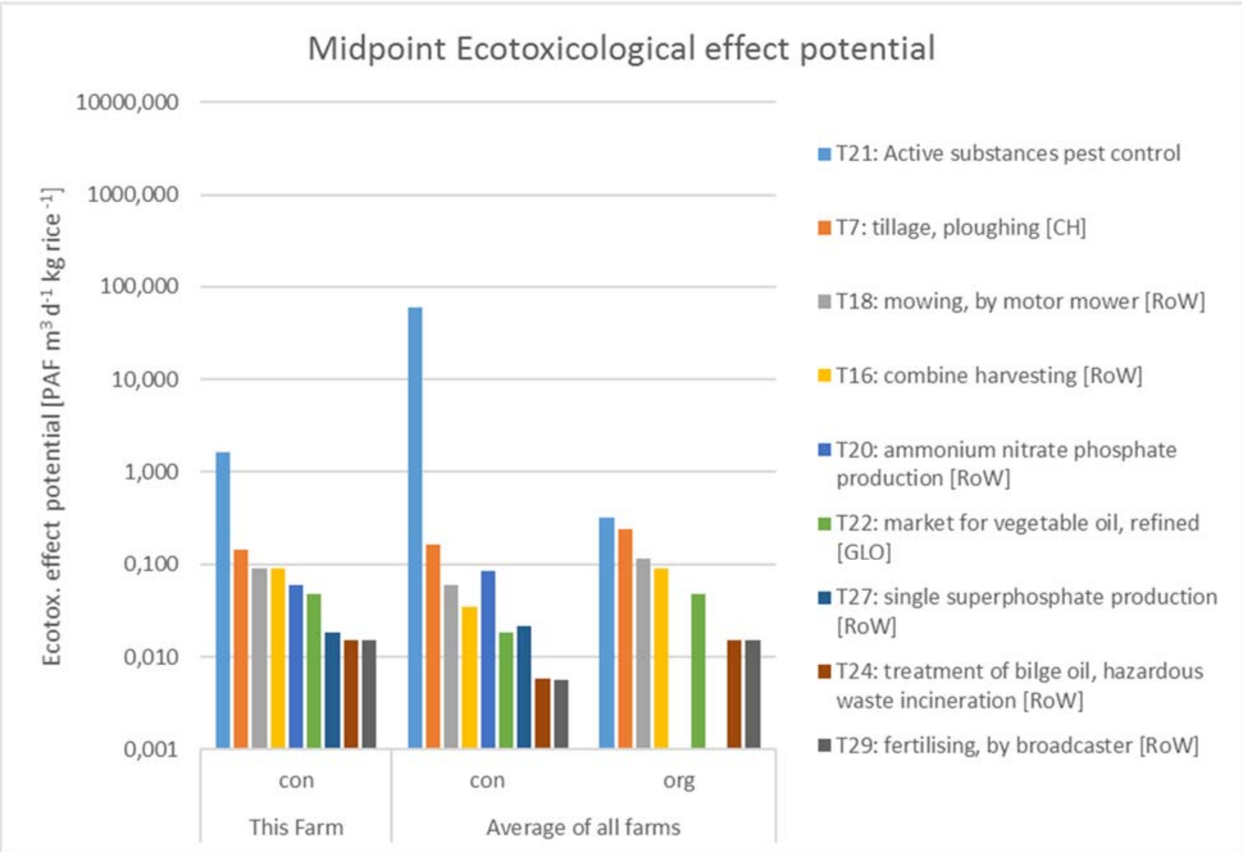
FARM ORG28 (organic)



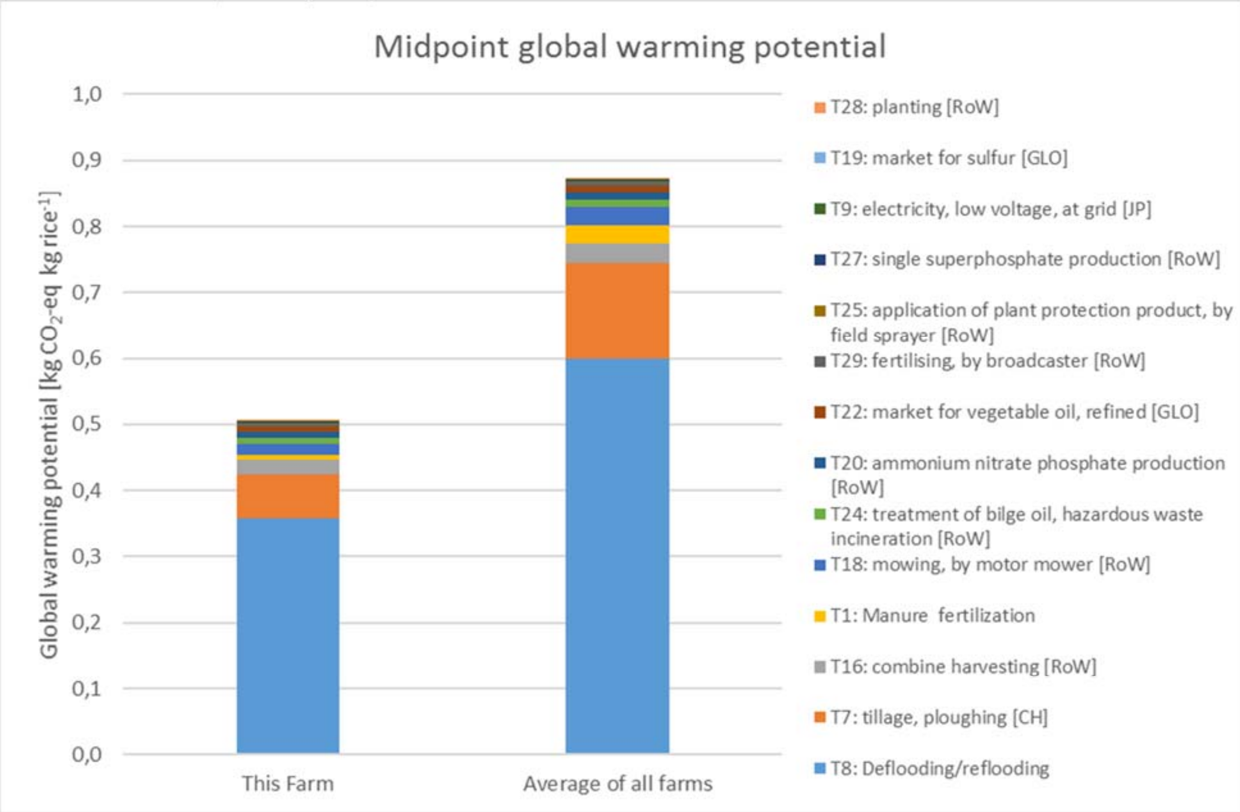


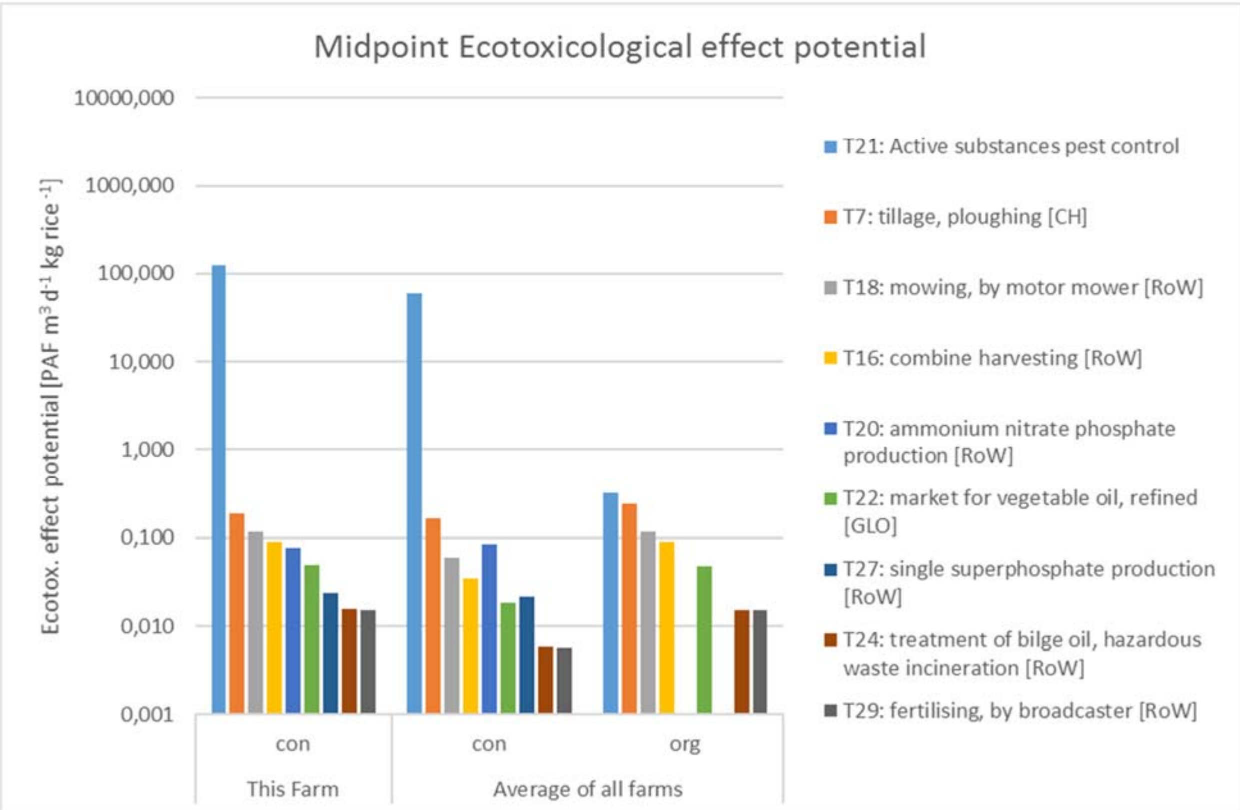
FARM CON01 (non-organic)





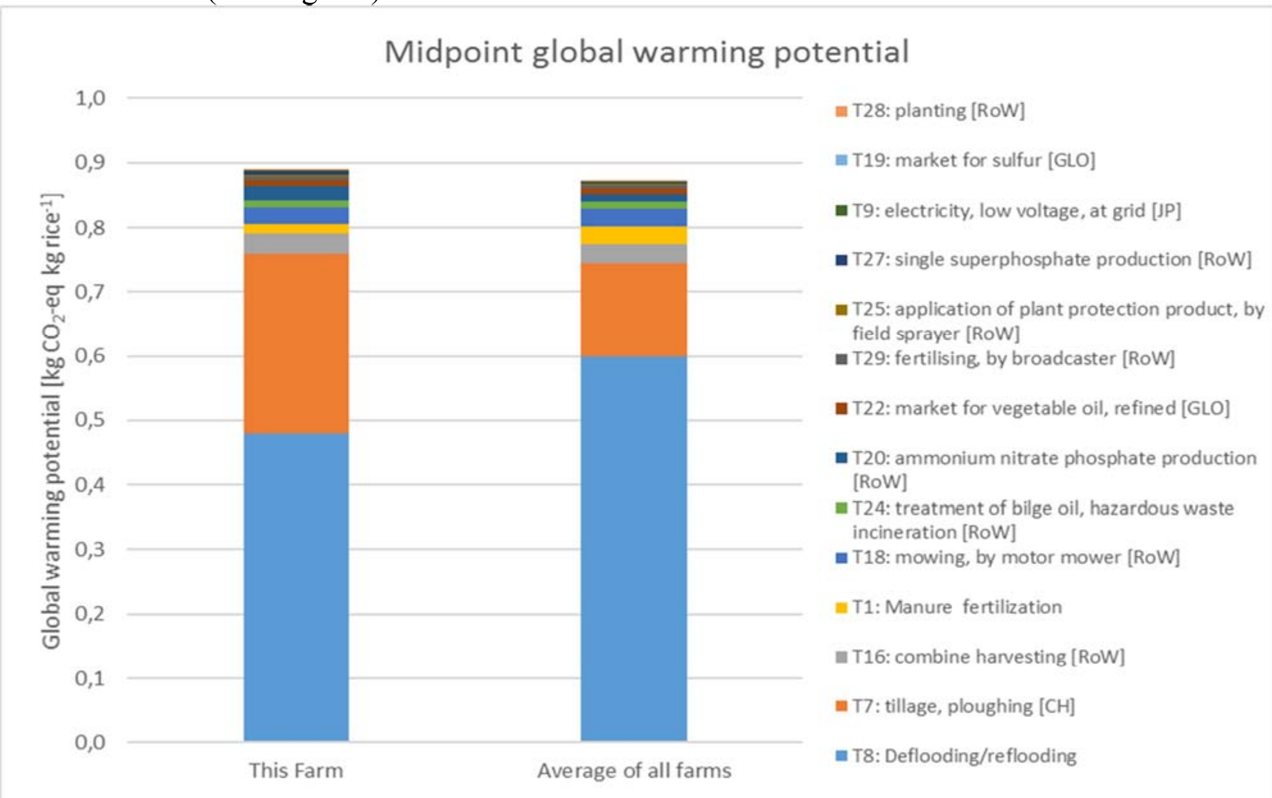
FARM CON02 (non-organic)*

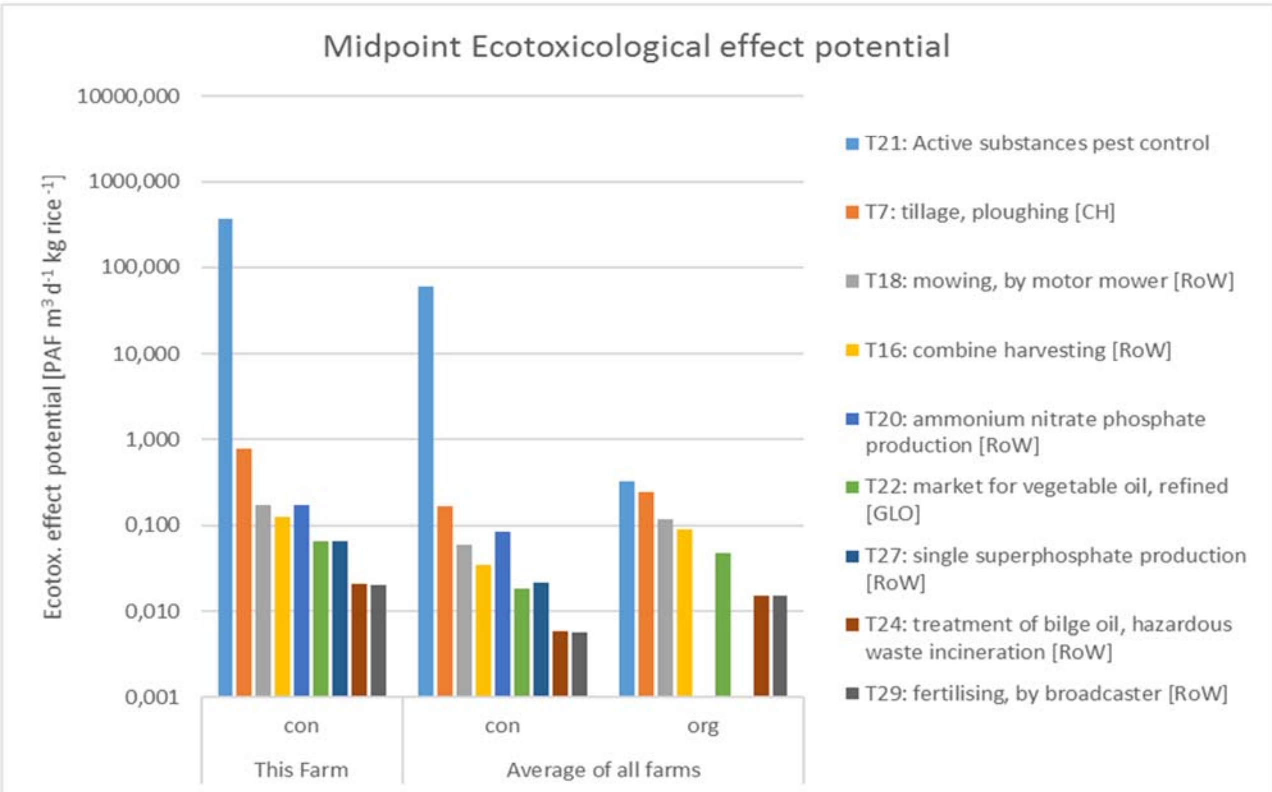




*The impacts of actual used active substances for pest control have been approximated by impacts of Fipronil.

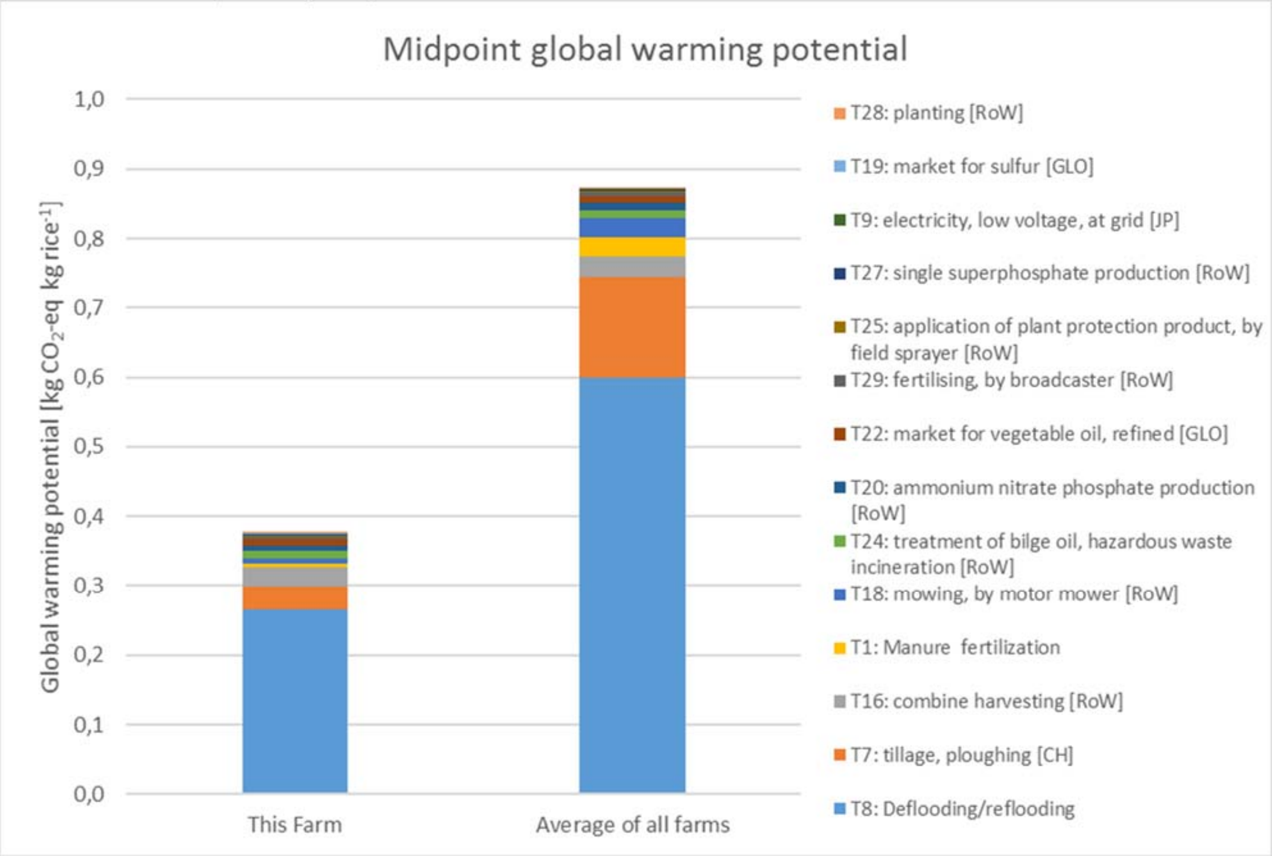
FARM CON03 (non-organic)*

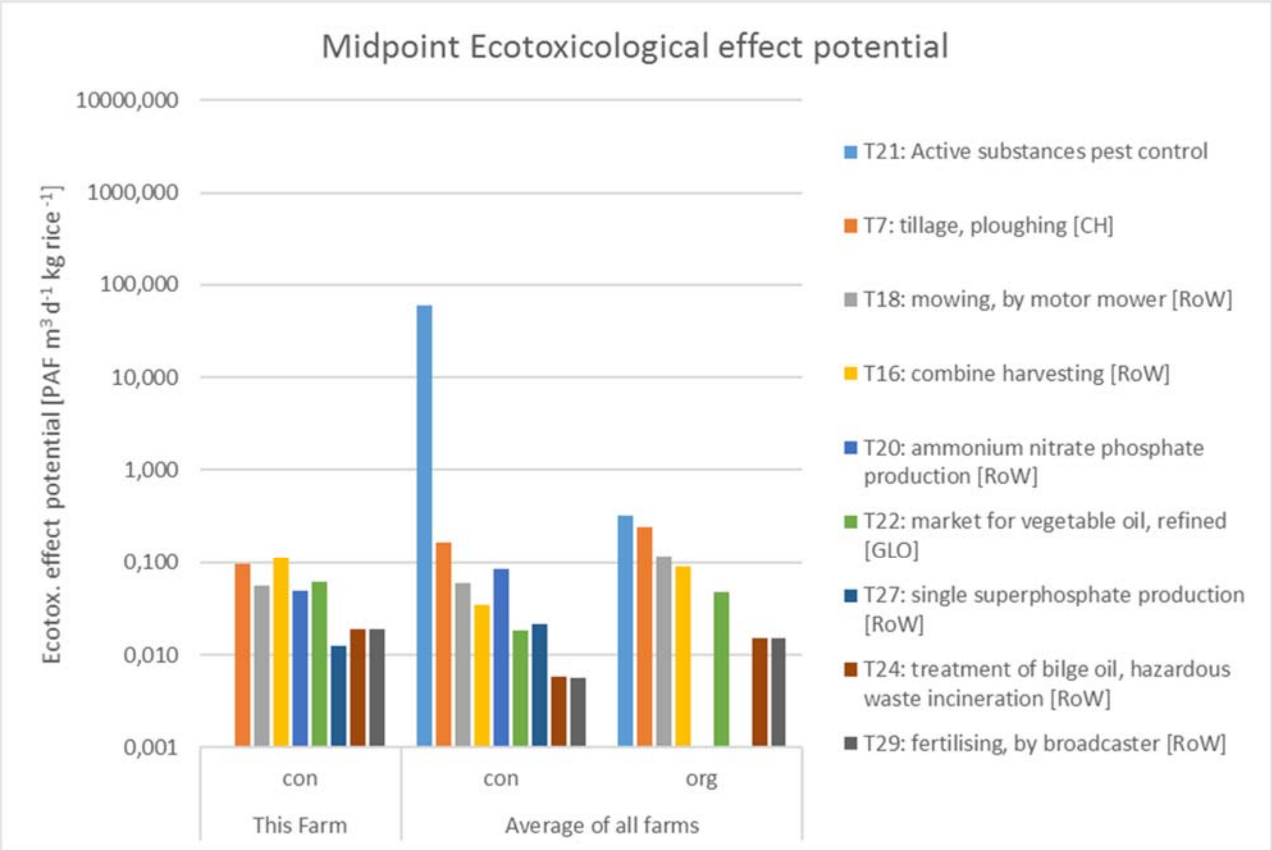




*The impacts of actual used active substances for pest control have been approximated by impacts of Fipronil.

FARM CON04 (non-organic)





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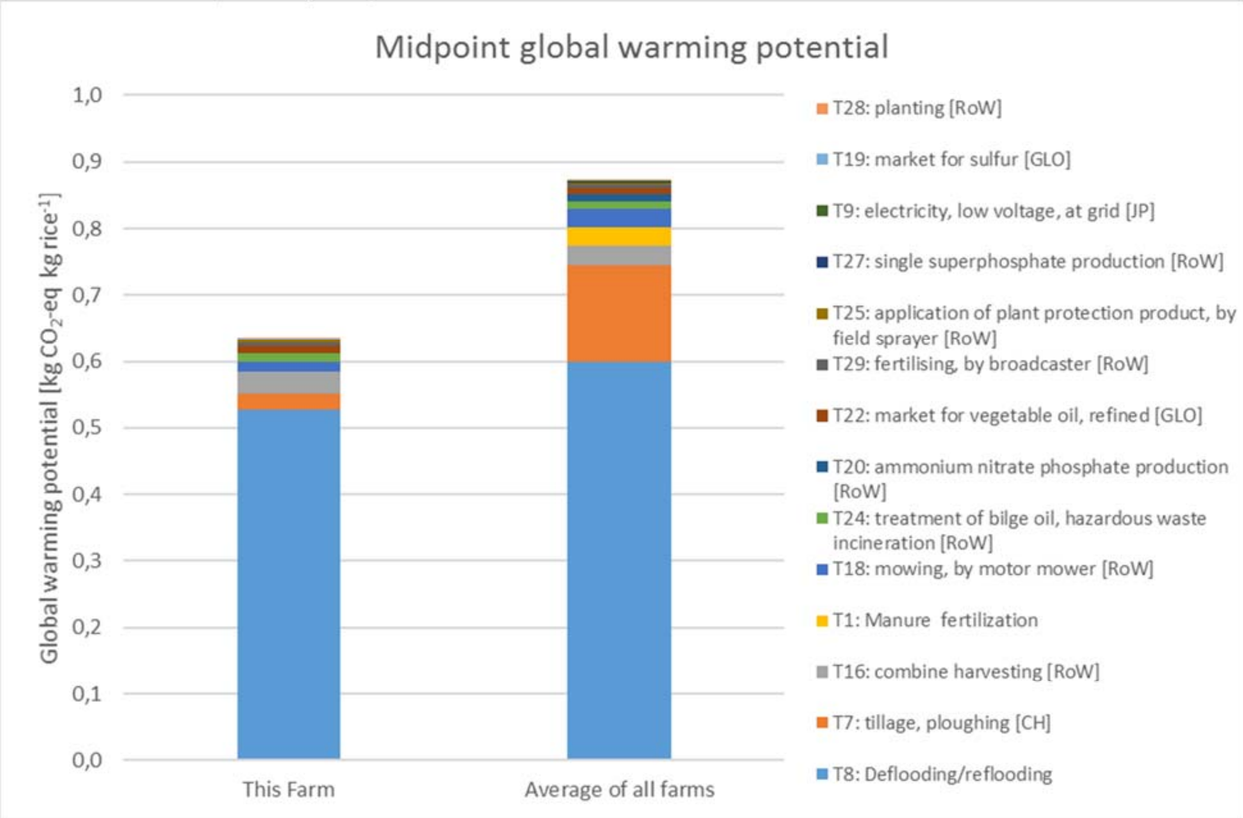
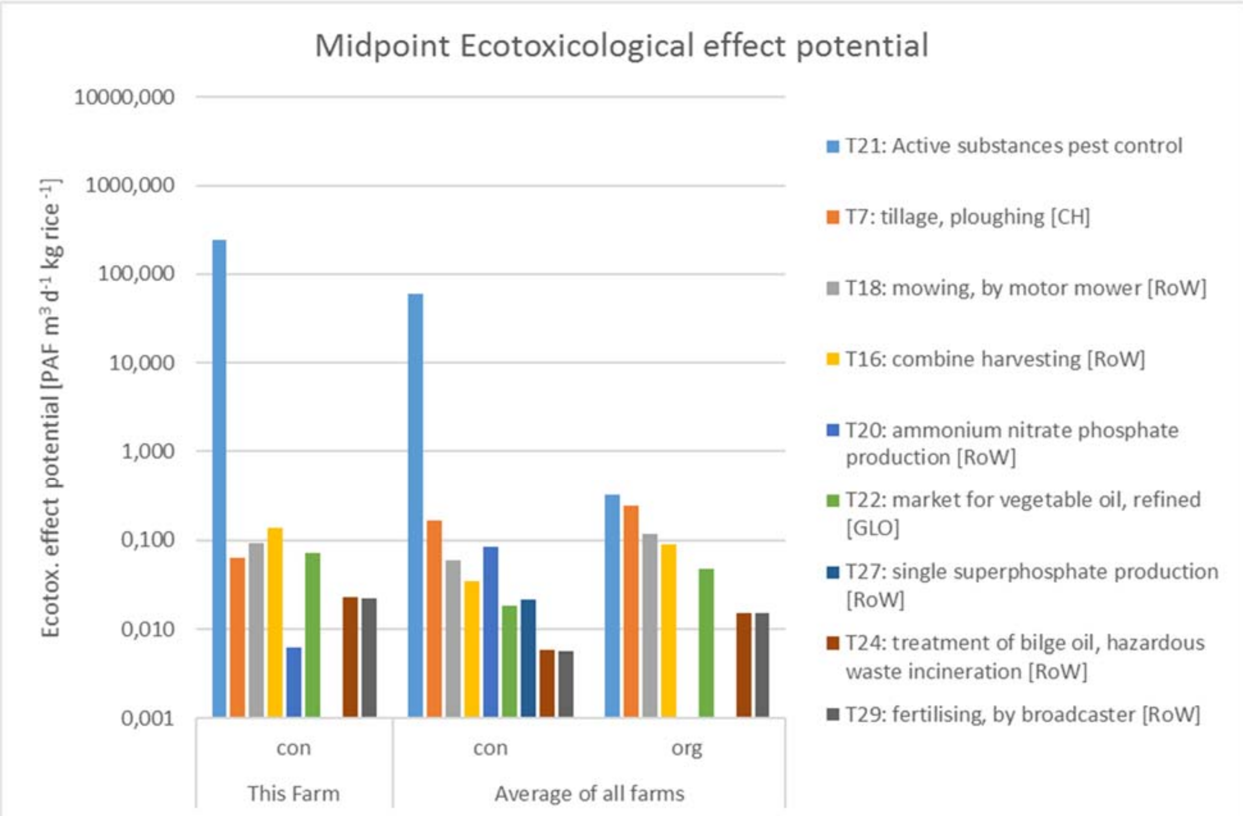
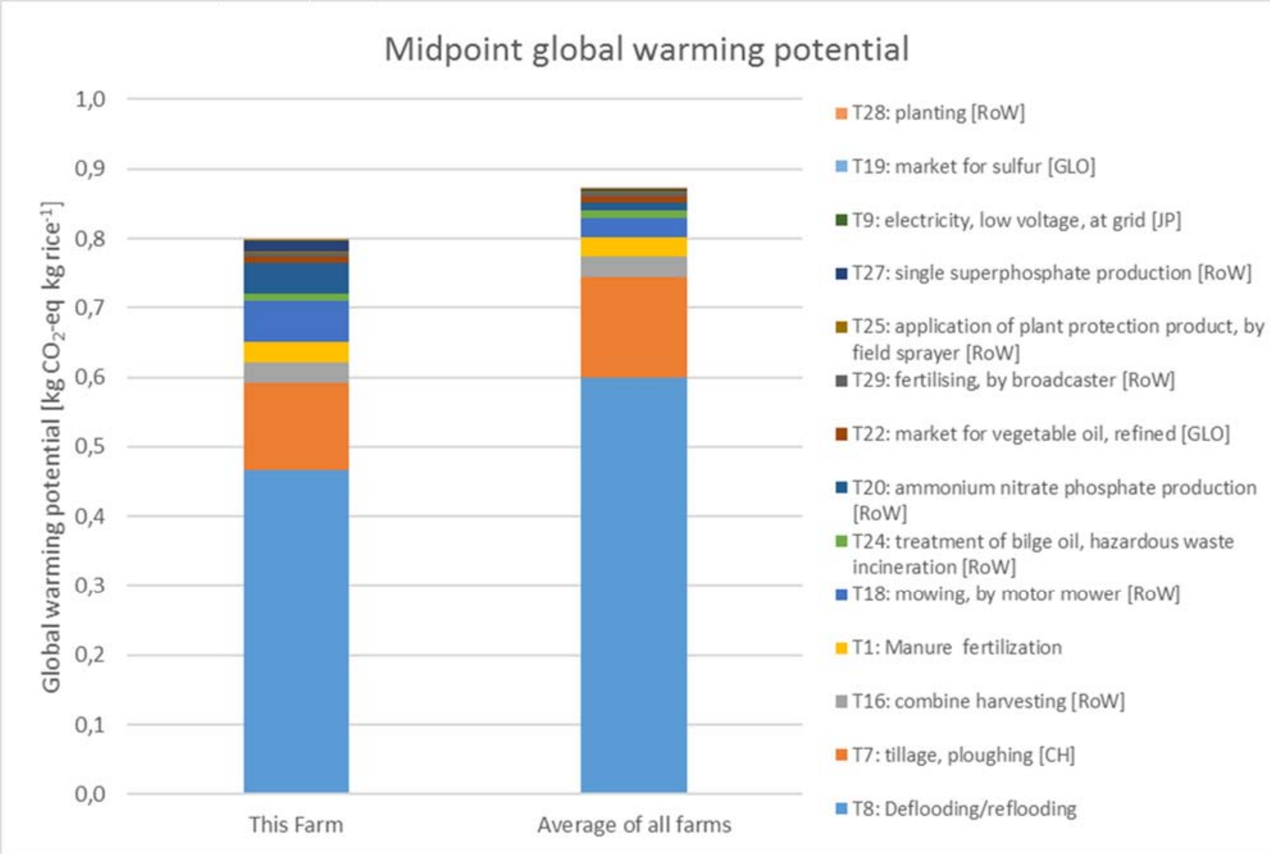
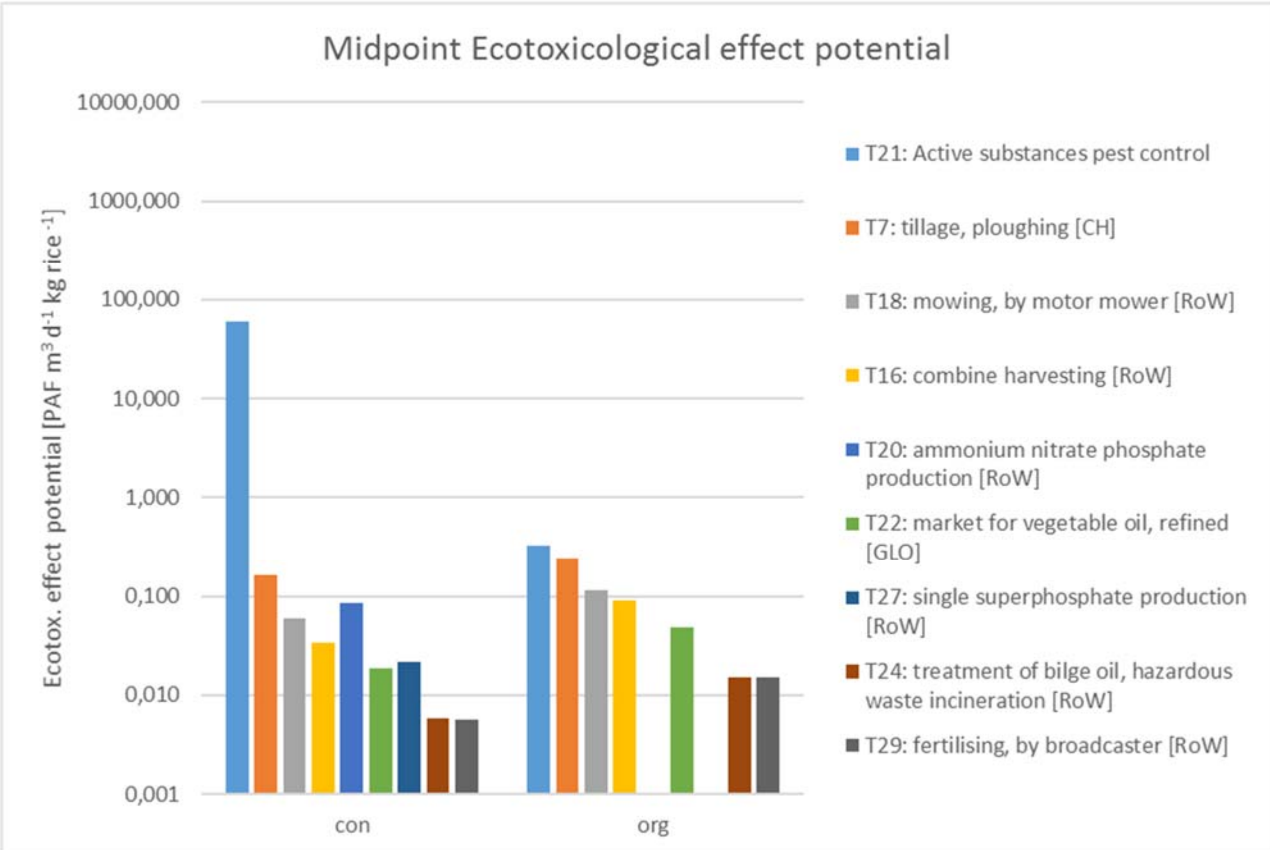




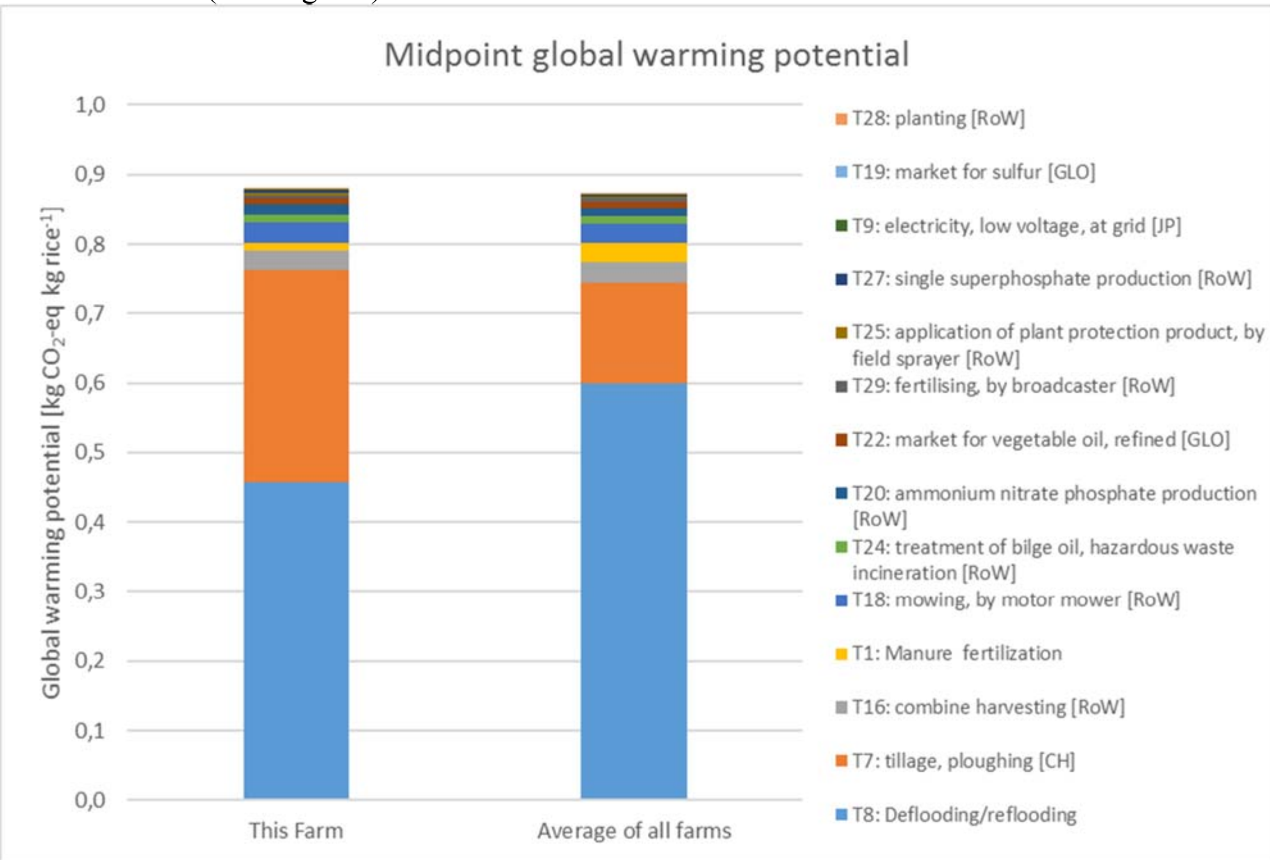
*The impacts of actual used active substances for pest control have been approximated by impacts of Fipronil.

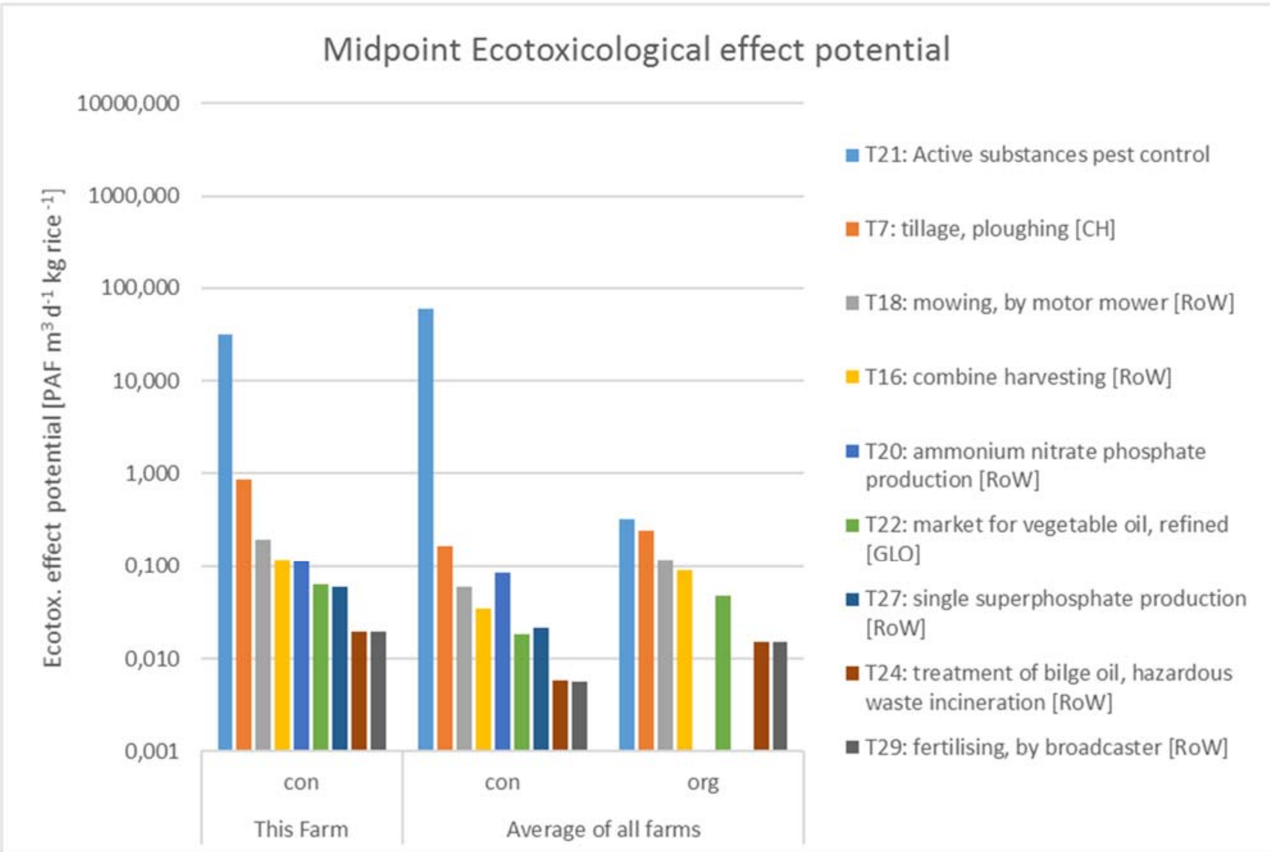
FARM CON06 (non-organic)



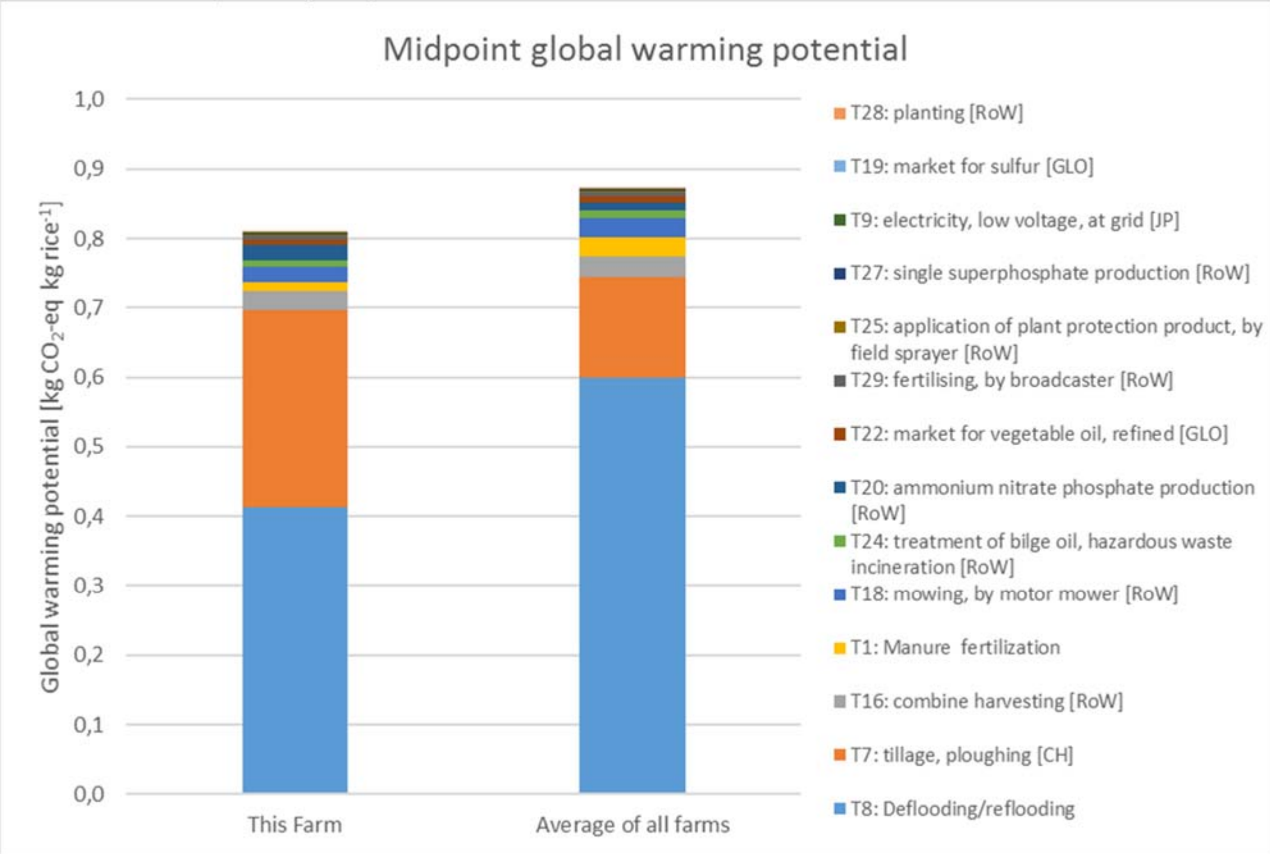


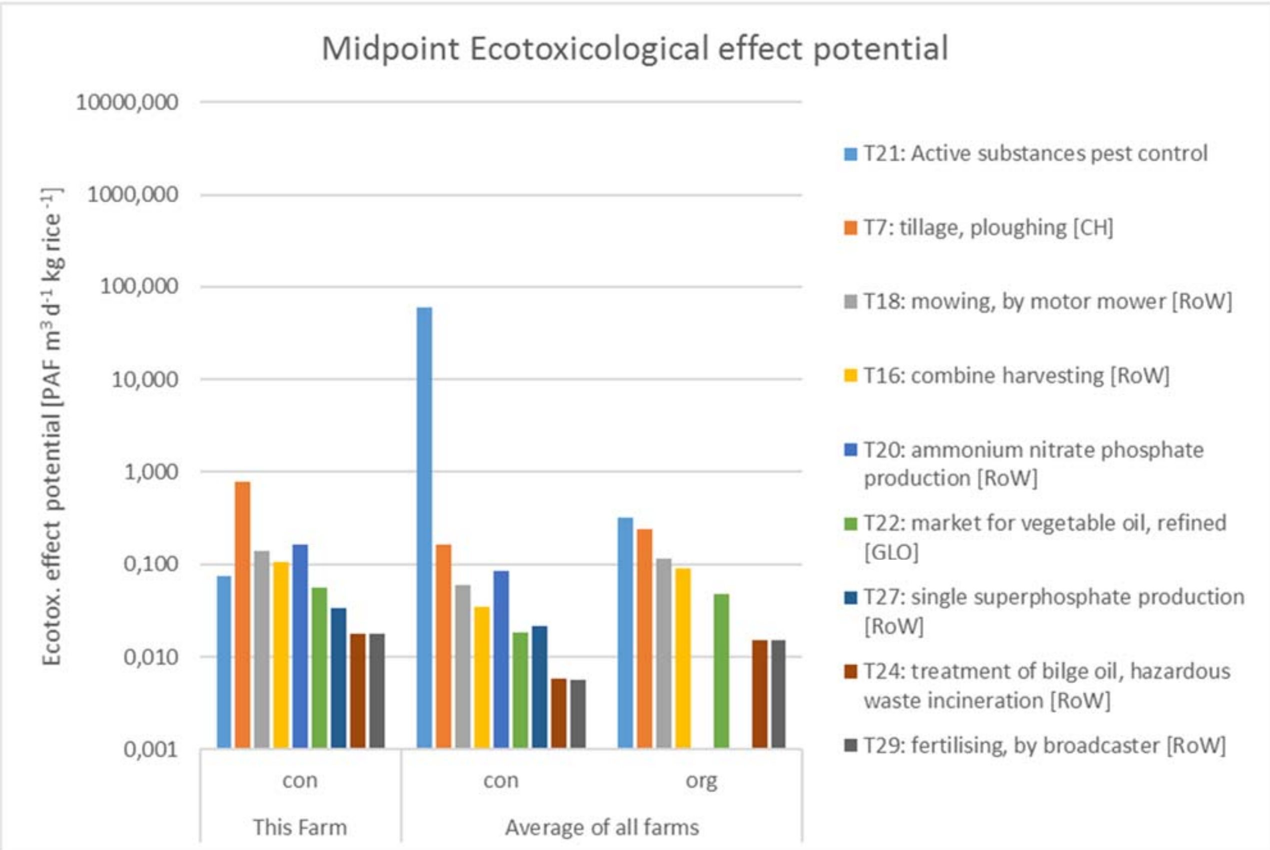
FARM CON07 (non-organic)



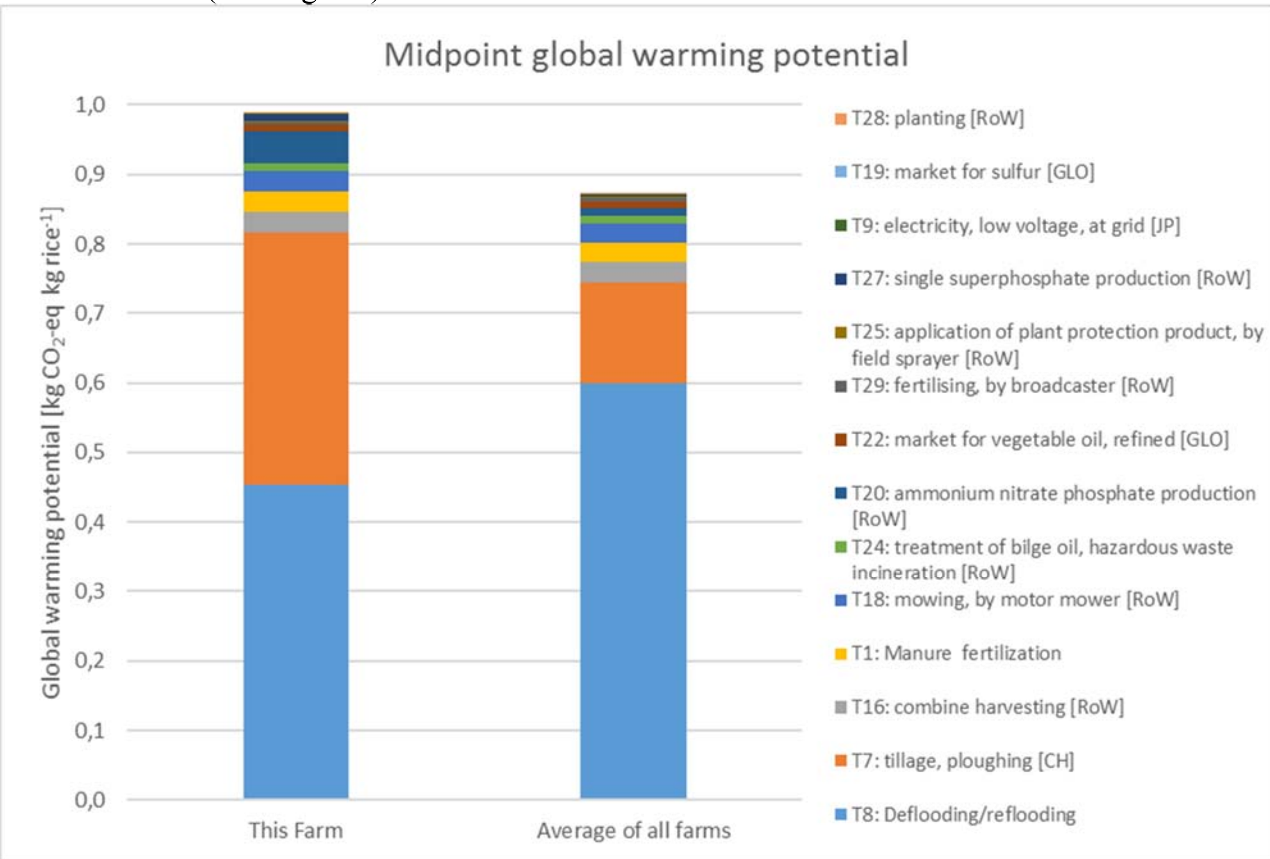


FARM CON08 (non-organic)



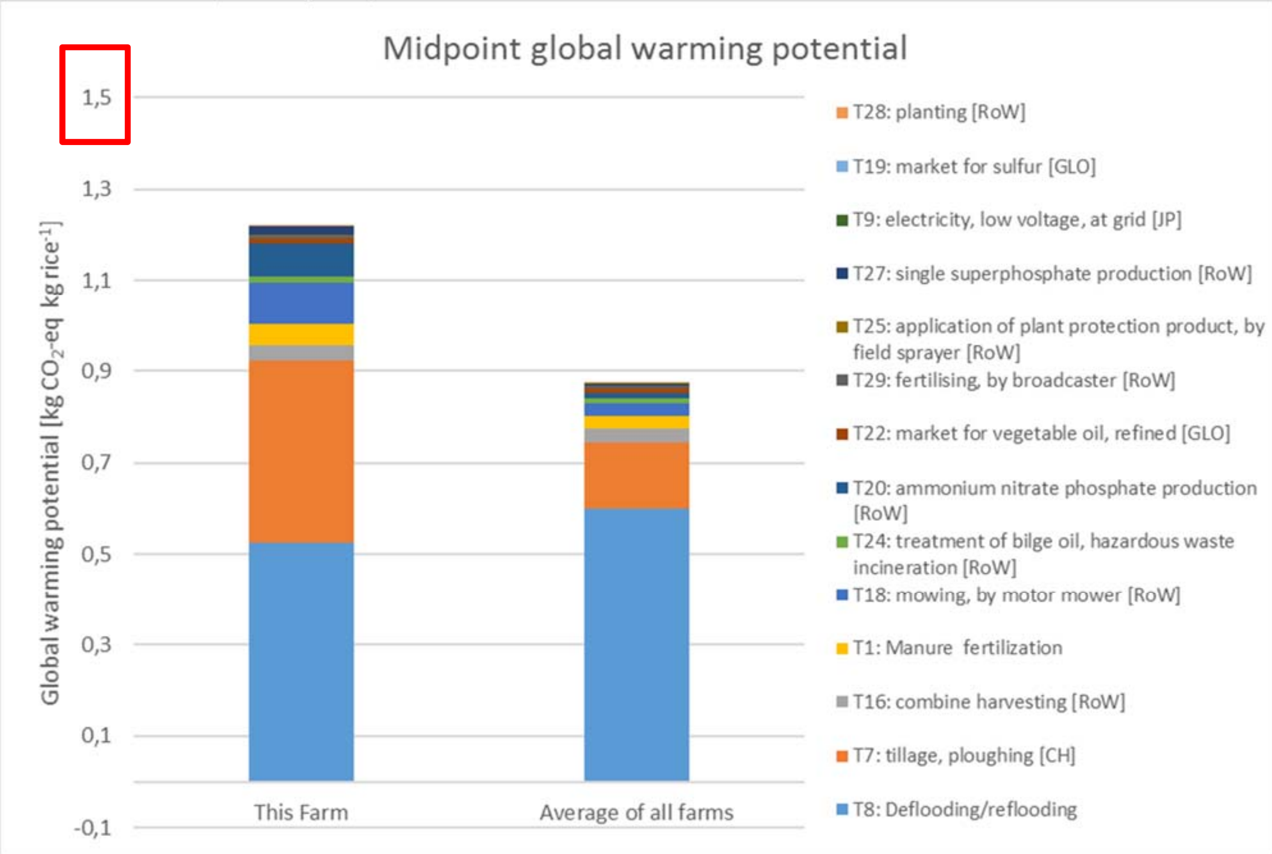


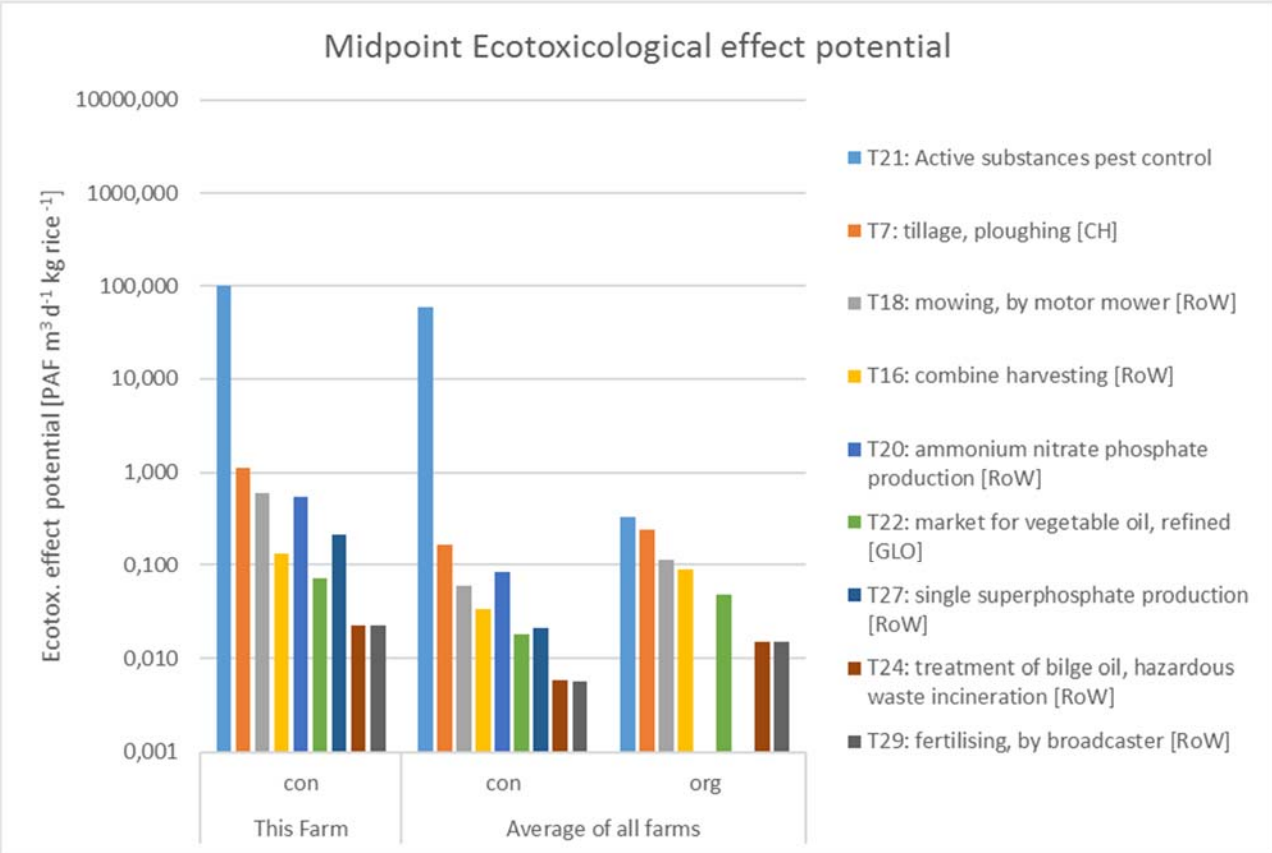
FARM CON09 (non-organic)*



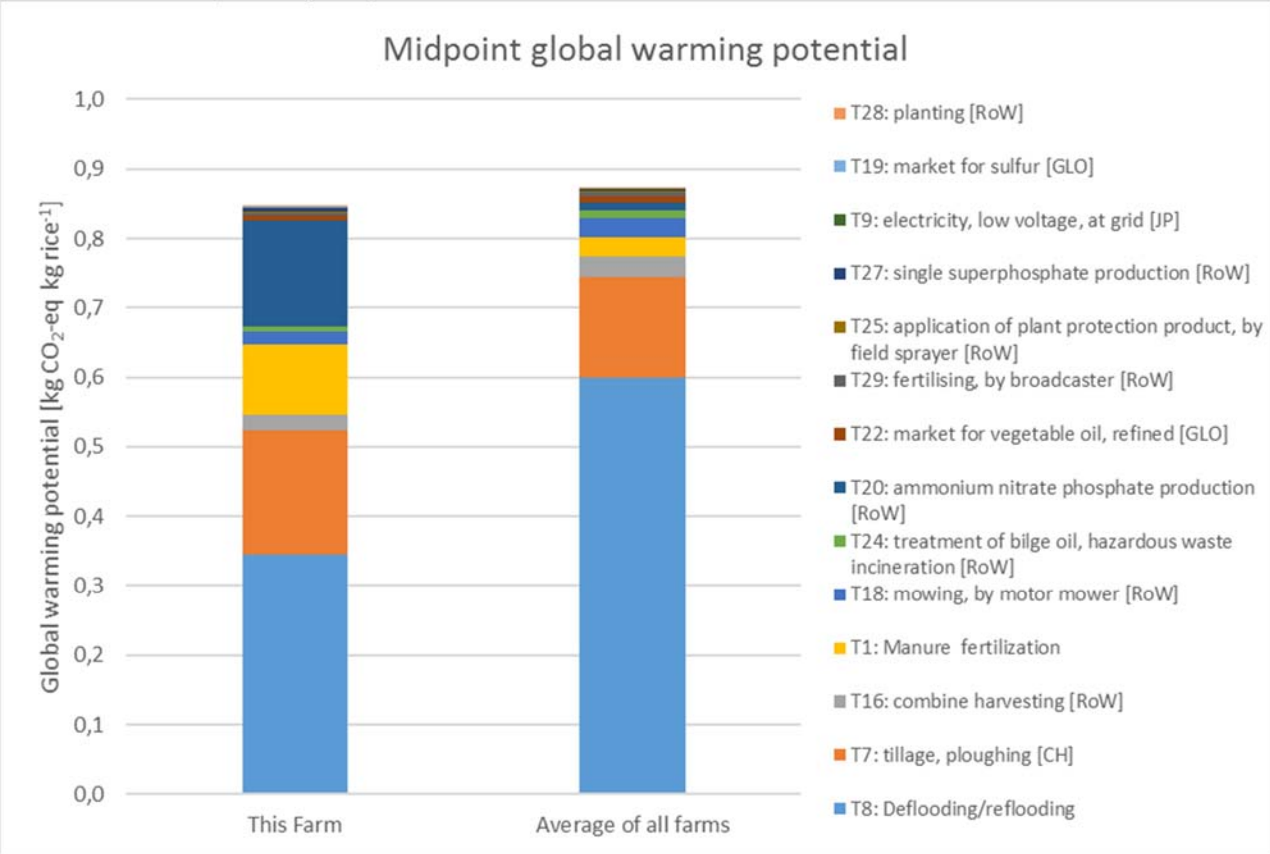
*This farm has been excluded from the eco-toxicological impact assessment.

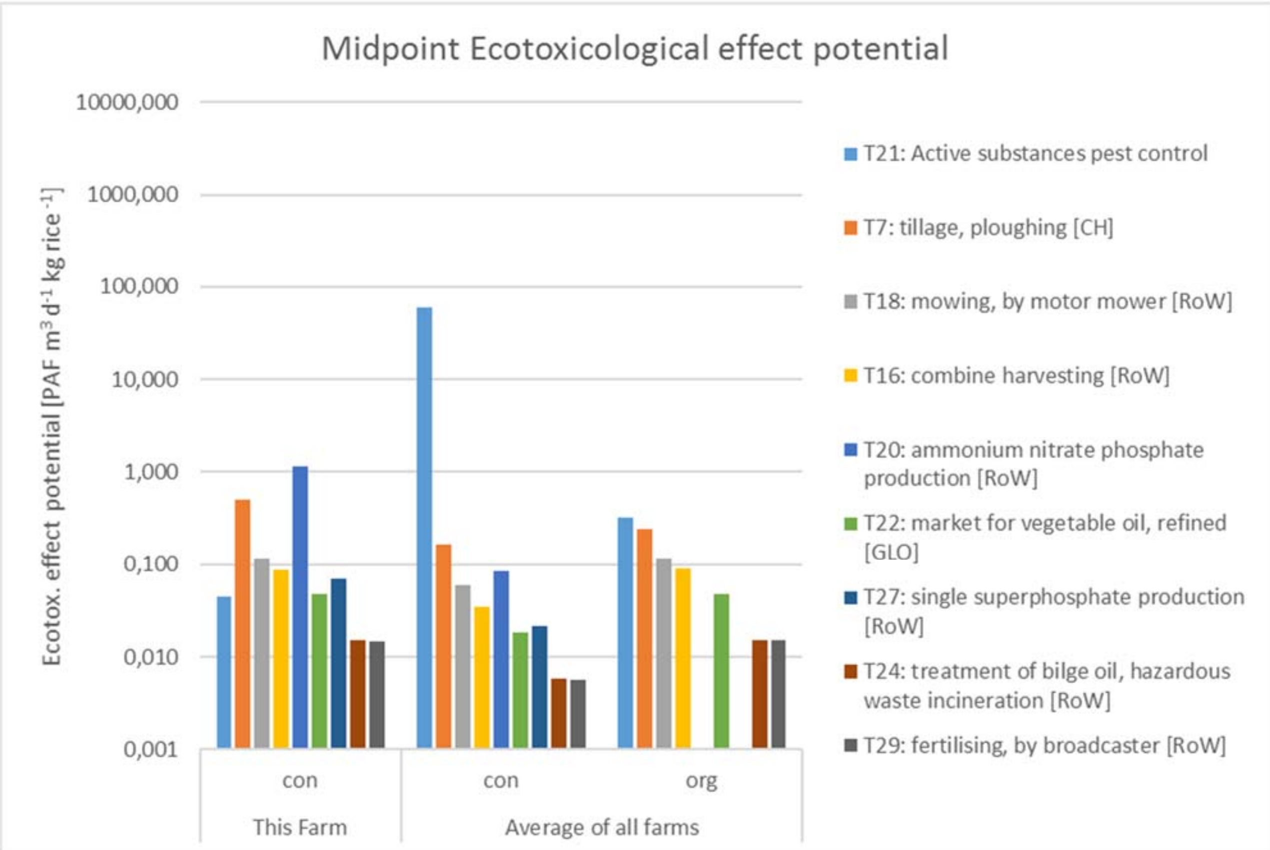
FARM CON10 (non-organic)





FARM CON11 (non-organic)





Summary of results

The following table shows an overview of the GWP per kg rice and per hectare for all assessed organic farms.

Table 9: Global warming potentials (GWP) per kg rice and per ha expressed as CO_2-equivalents for the organic farms

FARM ID	GWP per kg rice	GWP per ha
ORG01	0.60	3453.07
ORG02	0.45	3457.97
ORG03	0.50	3207.86
ORG04	0.74	3437.65
ORG05	0.90	3446.00
ORG06	0.38	2273.87
ORG07	0.38	2819.30
ORG08	2.43	15474.81
ORG09	1.50	10330.36
ORG10	0.67	3572.46
ORG11	0.70	4505.34
ORG12	0.57	4517.56
ORG13	0.66	5662.76
ORG14	0.62	3469.53
ORG15	0.64	3508.50
ORG16	0.79	3878.28
ORG17	1.18	3523.76
ORG18	0.79	3799.93
ORG19	0.59	3552.76
ORG20	0.79	4221.37
ORG21	0.60	3852.54
ORG22	0.43	3593.57
ORG23	0.47	3593.57
ORG24	0.67	4759.81
ORG25	0.44	3775.75
ORG26	0.43	3062.34
ORG27	0.57	3248.85
ORG28	3.47	17718.57
Average	**0.82**	**4847.08**

From the overview some results should be pointed out. The farms with the highest GWP per kg rice are also the farms with the highest GWP per hectare (Farms ORG08, ORG09, and ORG28). Some of the farms have very low results for their rice production. This is possible because the majority of the organic amendments is oil cake. Oil cake is not part of the IPCC (2006a) table for methane calculation from paddy rice production. However, it is probable that amendments of oil cake lead to an increase in methane production due to the organic compounds. We ran a sensitivity analysis of the entire model to see whether an inclusion of oil cake would change the results. We assumed that the effect of oil cake is comparable to compost and therefore used its scaling factor (see Equation (3) in Methods and Materials).

Table 10: Sensitivity analysis of the effect of oil cake as organic amendment

FARM ID	GWP per kg rice	Relative change
ORG01	0.61	1.8%
ORG02	0.47	3.9%
ORG03	0.55	10.2%
ORG04	0.81	9.4%
ORG05	0.98	9.4%
ORG06	0.40	4.4%
ORG07	0.40	6.0%
ORG08	2.43	0.0%
ORG09	1.50	0.0%
ORG10	0.67	0.0%
ORG11	0.70	0.0%
ORG12	0.82	42.7%
ORG13	0.85	27.7%
ORG14	0.66	6.6%
ORG15	0.74	16.8%
ORG16	0.94	18.9%
ORG17	1.26	6.7%
ORG18	0.89	13.1%
ORG19	1.21	106.1%
ORG20	0.88	11.5%
ORG21	1.15	90.9%
ORG22	0.75	72.4%
ORG23	0.81	72.4%
ORG24	1.17	74.4%
ORG25	0.81	81.9%
ORG26	0.43	0.0%
ORG27	0.71	25.2%
ORG28	3.47	0.0%
Average	**0.97**	**17.9%**

Table 11: **Global warming potentials (GWP) per kg rice and per ha expressed as CO_2-equivalents for the non-organic farms**

FARM ID	GWP per kg rice	GWP per ha
CON01	0.48	3587.82
CON02	0.51	3748.91
CON03	0.89	4915.62
CON04	0.38	2254.49
CON05	0.63	3180.57
CON06	0.80	4545.20
CON07	0.88	5102.28
CON08	0.81	5196.65
CON09	0.99	5769.48
CON10	1.22	6146.27
CON11	0.85	6491.81
Average	**0.77**	**4630.83**

The assessed GHG emissions in the non-organic farms are estimated to be lower compared to the organic farms. This is based on the use of mineral fertilizer instead of organic amendments and possibly higher yields.

5 Discussion

The results obtained in this study align generally with data from FAOSTAT (2017). Korea has methane emissions of 5,250 kg CO_2-eq per ha which is above our results. However, this could be explained by the farm sample in our study and the lowering scaling factors (see Methods and Materials).

Table 12: Comparison of direct methane emissions from paddy fields on national levels for selected countries (FAOSTAT 2017)

Country	Element	Item	Year	g CH_4 per m^2	CO_2-eq per ha
Australia	Implied emission factor for CH_4 (Rice cultivation)	Rice, paddy	2014	31.5	7875
China, Taiwan Province of	Implied emission factor for CH_4 (Rice cultivation)	Rice, paddy	2014	18.2	4550
Indonesia	Implied emission factor for CH_4 (Rice cultivation)	Rice, paddy	2014	21.2	5286
Italy	Implied emission factor for CH_4 (Rice cultivation)	Rice, paddy	2014	50.4	12600
Republic of Korea	Implied emission factor for CH_4 (Rice cultivation)	Rice, paddy	2014	21.0	5250
Viet Nam	Implied emission factor for CH_4 (Rice cultivation)	Rice, paddy	2014	17.6	4412
China	Implied emission factor for CH_4 (Rice cultivation)	Rice, paddy	2014	17.6	4390

5.1 Estimation of product-related GHG emissions on farm level

The approach taken to estimate the GHG emissions from paddy rice production is a LCA based procedure in order to include all life-cycle stages in the production of rice until the farm gate. This approach makes use of the IPCC guidelines for national GHG inventories. With LCA different aspects of uncertainty must be addressed: data uncertainty, model uncertainty, and completeness uncertainty (Costanza et al. 1992).

5.1.1 Data uncertainty

Data uncertainty concerns the quality of the data acquired on the actual farms. This issue has been dealt with by our Korean partners in regard to plausibility control. However, some of the data acquired concerns material flows that cannot easily reproduced in models unless extensive measurements are taken. This relates specifically to the (microbiological) substrates produced by the farmers themselves. The second issue concerning data uncertainty is the use of generic databases for the material flows of bought materials, such as fertilizer, and processes, such as ploughing and harvesting. While the diesel consumption for these activities is known and the processes have been scaled to that diesel consumption, the representativeness of the used datasets is still uncertain.

5.1.2 Model uncertainty

Model uncertainty concerns the ability of the model to reflect the actual material flows as well as the ability of emission factors and algorithms to predict the actual GHG emission. Direct emissions of GHG is a major issue of agriculture. However, as the emission takes place on large areas the measurement of these emissions under practical conditions is virtually impossible. Instead, algorithms are used to predict GHG emissions from agricultural areas based on activity data. In the current study, algorithms provided by the IPCC are used. These have been created to reflect GHG on a national level. It is unclear, how well they are suited to robustly predict GHG emissions on practical farms.

Based on the algorithms, inputs of organic materials have linear relationship with the GHG emissions. As we compare organic farming with conventional farming, this assumption may present a bias against organic farming. Here the input of mineral fertilizer is not allowed, so that organic fertilizers are the only possible input. We have conducted a sensitivity analysis to compare the GHG emissions of a system using only organic fertilizer with a system using only mineral fertilizer.

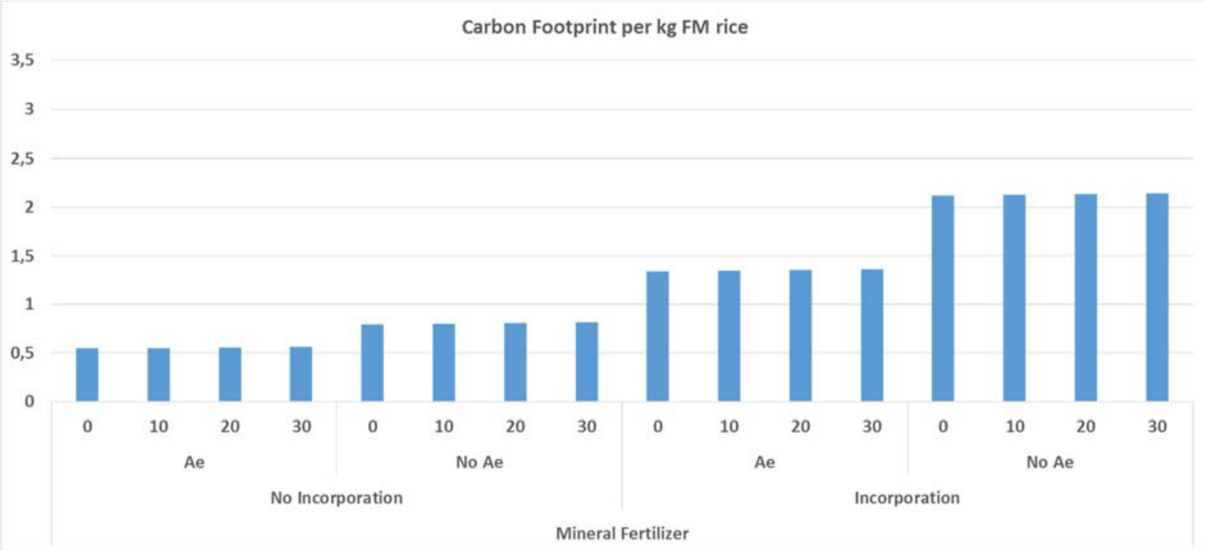


Figure 2: **Sensitivity of GHG emissions per kg rice for the use of mineral fertilizer. The factors are incorporation of rice straw vs no incorporation of rice straw, a single aeration of the paddy field during flooding (Ae) vs. no aerations during flooding (No Ae), and increased fertilizer amounts from 0 to 30 kg Nitrogen per 1000 m^2**

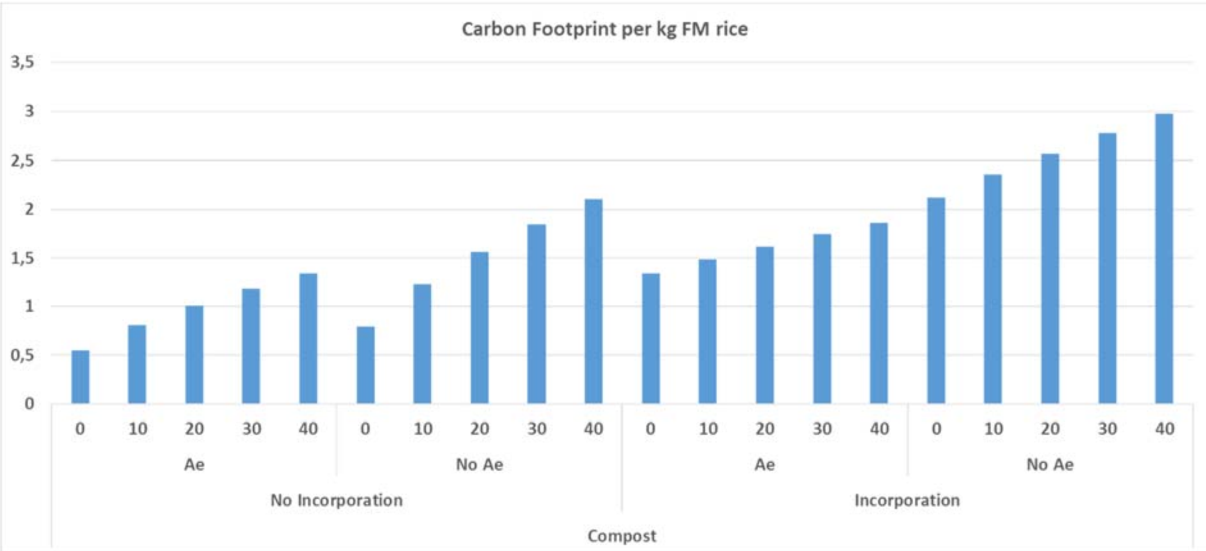


Figure 3: **Sensitivity of GHG emissions per kg rice for the use of compost. The factors are incorporation of rice straw vs no incorporation of rice straw, a single aeration of the paddy field during flooding (Ae) vs. no aerations during flooding (No Ae), and increased fertilizer amounts from 0 to 40 kg Nitrogen per 1000 m^2**

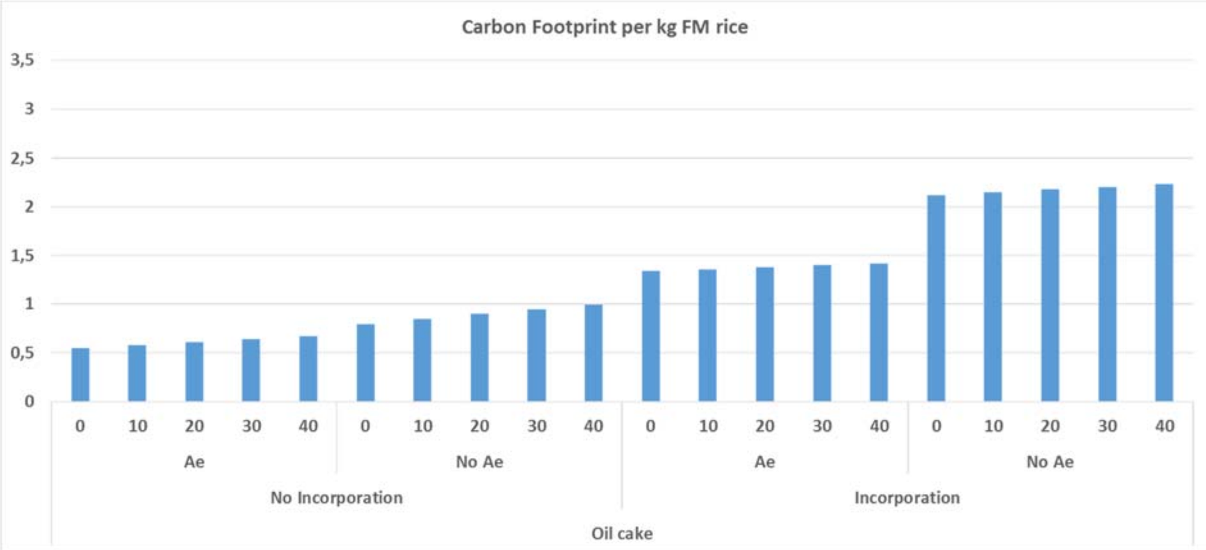


Figure 4: **Sensitivity of GHG emissions per kg rice for the use of oil cake. The factors are incorporation of rice straw vs no incorporation of rice straw, a single aeration of the paddy field during flooding (Ae) vs. no aerations during flooding (No Ae), and increased fertilizer amounts from 0 to 40 kg Nitrogen per 1000 m²**

We can see that based on the algorithms, emissions in a system with organic amendments are higher compared to mineral fertilized systems. This may present a bias against organic farming. The algorithms used are based on a statistical analysis from field measurements throughout Asia (Yan et al. 2005). With the derived algorithms, 68% of the variability in GHG emissions from paddy fields can be explained. However, conditions in organic farming have not been addressed in that study. It is therefore unclear, whether the derived algorithm apply for organic farming. Additionally, the analysis of the effects of different climates remained inconclusive in the study of Yan at al. (2005).

5.1.3 Completeness uncertainty

In the current study many of the contributors have been included in the results. The supply chain of the organic amendments (oil cake, cattle manure compost, digested swine manure) has not been included in the analysis. This is firstly because of uncertainty about the sources of these fertilizer. Secondly, it could be argued that for the Korean agriculture these organic amendments have a by-product/waste characteristic, i.e. the processes where they come from are intended for the production of different products (oil, meat, milk) and the fertilizer are an unavoidable by-product. This could then mean that no environmental burden should be allocated to the provision of these organic amendments.

5.2 Eco-toxicity

The assessment of impacts on freshwater eco-toxicity from paddy rice production is characterized by a very high uncertainty. However, the major contributing sources to eco-toxicological effects can be identified as the application of active substances for pest control and the supply chain and operation of machinery. In the first case the relationship is obvious and depends on the eco-toxicological assessment of the active substances in the USetox model. In the latter case the eco-toxicological impacts can be traces back to the emission of copper and zinc during machinery operation and production of both machineries itself and auxiliary materials. It should be noted, that the eco-toxicological impacts from copper and zinc emission are estimated to be at least one power of magnitude lower compared to active substances in pest control. The estimation of copper and zinc emissions as part of the machinery operation is part of the ecoinvent database.

5.2.1 Data uncertainty of active substances

For the uncertainty of the characterization factors of active substances for pest control we have to differentiate two cases. Firstly, the substance used is in the USetox database. The USetox database is a model for the prediction of eco-toxicological impacts of chemical substances based on their physical and toxicological properties. As with any impact assessment, no actual impact can be predicted but rather a risk of adverse impacts is calculated. This is also expressed in the unit of the characterization factors "potentially affected fraction (of species)" in relation to time and volume of water.

As the USetox model calculates the same characterization factor for the same substance, regardless of the place of emission, it is quite possible that the actual effects differ from the prediction due to environmental factors. The results are presented on a logarithmic scale. Consequently, differences between farms are different in orders of magnitude. We think that the used method allows the differentiation between farms when the differences are in orders of magnitude.

As a second case of uncertainty of active substances is the absence of the active substance in the USetox database. The method to deal with this is outlined in the material and methods section of this report. The farms where we had to estimate the impact of unknown substances based on the eco-toxicity of Fipronil are farms CON02, CON03, and CON05 (all non-organic). The eco-toxicological assessment of all of these farms show a high estimate. The amount of the substances are therefore not negligible and further efforts should be made to allow a better approximation of the eco-toxicological impacts associated with these active substances.

6 Outlook

In the cooperative project the partners continued an intensive discussion about the concrete aims of the project. The multiple visit of the South Korean partners in Germany, as well as the visits of the German researchers on farms and different sites in Korea has shown that the use of the UMBERTO software for developing a specific FARM model for South Korean farms is a good possibility to look for different production systems and/or situations of organic paddy rice production with the aim to identify examples of best-practice, and to assess potential eco-benefits of organic paddy rice farming.

With the modeling framework from the FARM model (Flow Analysis and Resource Management), the model described above has been developed by the Thünen Institute. It is currently in a state where data from Korean organic farms can be applied. For further development it is vital to collaborate on iterative data acquisition as well as model validation. Furthermore, current scientific knowledge needs to be collected to improve the model validity. Also, the model should be optimized with real data of nutrient losses and nitrate leaching.

6.1 Recommendation for further work on GHG emissions

Based on the assessed farms, the used methodology for national inventories, and the potential bias against organic farms, we strongly recommend to validate the results by GHG measurements of organic paddy rice production in Korea. Additionally, we encourage efforts to build a model with the ability to dynamically reflect Carbon flows within the paddy soil, to create better understanding of the interactions between soil and GHG fluxes in organic paddy rice farming.

6.2 Recommendations for further work on eco-toxicity

Regardless of the uncertainty of the acquired results, the orders of magnitude differences between organic and non-organic farms show the high sensitivity towards eco-toxicity of the agricultural production systems when performing chemical pest control. Because the differences are orders of magnitude these impacts cannot be compensated by higher yields. It is therefore encouraged to avoid the use of highly toxic chemicals for pest control.

Secondly, the high uncertainty of the eco-toxicological impacts show the need for validation. This validation should be done for near-practical conditions and include measurements of the impacts of substances for pest control both for organic and non-organic paddy rice systems.

7 Annual Financial Report

In the first year of cooperation the research fund was 40,000 US$ or 36,808.69 €, which was funded by the RDA of the Republic of Korea. In 2015 there was a rest of 5,286.90 €, which was available in the second year of the project. In the second year the research fund was 30,000 US$ resp. 26,800.07 €. In sum 32,086.97 € was available in 2016. In table 12 the detailed information of the financial activities is given and summarized.

Living expenses for the stay of Dr. Hong from April to the end of June were paid to him as agreed in the project contract.

For modelling the Korean Farm model it was necessary to have an Ecoinvent ‚licence owner'-licence and the e!Sankey 4 pro-licenses for the preparation of figures for an easier understanding of the complex model information. Also some additional computer accessories were necessary, which were bought from the grant.

At the Thünen Institute of Organic Farming Maximilian Schüler is specialist in modelling with UMBERTO. He developed the FARMN model and gave the Korean researcher Dr. SeungGil Hong a training in handling the UMBERTO software. Also, Mr. Schüler did the modelling work in this project in both of the project years, so that he got some salaries for his work. The indirect costs were 10% of the project sum. These costs are reserved and paid to the central Thünen administration in Braunschweig

Some scientific books such as about paddy rice production, life cycle assessment, organic farming etc. were needed and bought from the grant. Most of the books were bought and shipped to our Korean colleagues.

In sum, nearly all the costs could be financed by the grant. The small deficit was compensated by the Thünen Institute.

Table 12: Detailed financial activity report of the year 2016

	year 2016				
	planned amount in US $	**planned amount in Euro**	**expended amount in Euro**	**costs in Euro**	**detailed description**
project grant RDA	**30,000.00**	**26,800.07**			
Rest of 2015		**5,286,90**			
Living expenses	9,000.00	8,040.02	7,926.48	7,926.48	Living expenses Dr. SeungGil Hong
Research supplies	14,500.00	12,953.37	21,707.02	899.64	Software e!Sankey 4pro-licenses
				595.00	Ecoinvent ‚licence owner'-licence
				1,223.78	Computer accessories
				2,301.28	Travel expenses Dr. SeungGil Hong
				634.70	Scientific books and shipping costs
				16,052.62	salaries of Mr. M. Schüler and indirect costs of Thünen administration
Air tickets	3,500.00	3,126.68	2,488.62	1,157.81	Air ticket Dr. Herwart Böhm
				1,330.81	Air ticket M. Schüler
Total		**32,086,97**	**32,122,12**		
			- 35,15		

*) Conversion factor in 2016 from US$ to Euro = 0.8958 €

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