SLU

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Revised version

Greenhouse gas emissions from cultivation of agricultural crops for biofuels and production of biogas from manure.

- Implementation of the Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources.

Revised edition according to new interpretations of the directive regarding reference land use and crop drying

Serina Ahlgren
Per-Anders Hansson
Marie Kimming
Pär Aronsson
Helene Lundkvist

PREFACE

In December 2008, the Swedish University of Agricultural Sciences (SLU) was commissioned by the Swedish Ministry of Agriculture to 'calculate greenhouse gas emissions within the framework of the EU sustainability criteria for biofuels'. The task was to calculate the greenhouse gas impact of biofuels and other bioliquids, as well as biogas produced with liquid and solid manure as raw material. It was to be calculated in accordance with Article 19 in the directive for environmental sustainability criteria for biofuels (2009/28/EC). See Appendix 1 for a complete task description. On 12 January 2009, the Vice-Chancellor of SLU appointed Helene Lundkvist as task coordinator (Appendix 2) with the mandate to put together a working group for the mission. The work was reported in Swedish as well as in English and presented at DG Energy in Brussels (30 July, 2009)

In October 2010 SLU was asked to make complementary calculations for three more grain species for ethanol production and for a number of agricultural crops as raw material for biogas production, see Appendix 3 for the complete description of the additional task. The report was finalised on the 1st of December 2010.

The SLU group responsible for the original task also took on the work with the complementary one;

Pär Aronsson, Associate Professor, Dept. of Crop Production Ecology. Assistant coordinator and expert in bioenergy.
Per-Anders Hansson, Professor, Dept. of Energy and Technology. Expert in environmental and energy systems analysis.
Serina Ahlgren, Ph.D, Dept. of Energy and Technology. Expert in environmental and energy systems analysis and responsible for section on liquid biofuels.
Marie Kimming, Ph.D. student, Dept. of Energy and Technology. Expert in environmental and energy systems analysis and responsible for section on biogas.
Niclas Ericsson, Ph.D. student, Dept. of Energy and Technology. Expert in environmental and energy systems analysis, (new in the working group).

The reference group consisted of the following members that were also part of the reference group for the original task:
Sven-Olov Ericson, Deputy Director, Energy Division, Ministry of Enterprise, Energy and Communications.
Anna Lundborg, Programme Manager at the Energy Technology Department, Swedish Energy Agency.
Alarik Sandrup, Director Economic Policy, Lantmännen energi
Camilla Lagerkvist Tolke, Advisor at the Swedish Board of Agriculture, Bioenergy Division.
The group above was enlarged with three new members appointed for the additional task;
Linus Hagberg, Programme Manager at the Energy Analysis Department, Swedish Energy Agency
Björn Holmström, Energy Politics Expert, LRF, The Federation of Swedish Farmers
Mattias Svensson, Research Manager, SGC Swedish Gas Centre

Within the SLU working group, Serina Ahlgren and Per-Anders Hansson, who had developed the calculation model, collected data and performed the calculations for cultivation of the added raw materials for liquid biofuels, and produced the corresponding section of the report. Marie Kimming in collaboration with Per-Anders Hansson carried out the same work for the additional raw materials for biogas. Other members of the working group contributed expertise and supplementary data.

The working group met with the reference group at one occasion. The SLU group and the reference group also had mail and telephone contacts during the course of the work and writing process. SLU wishes to thank the reference group and other persons who have contributed with expertise during the course of this work.

The present report is a revised version according to new information from the European Commission on the Directive interpretation (see Appendix 4 of this report). It has been made clear that crop drying is not to be included in the calculations. Although it seems natural to include crop drying in the cultivation part of the calculations, the Directive does not give clear guidance on the matter and to harmonize the calculations with the calculations behind the tables in Annex V in the Directive and amongst the Member States the Commission has given recommendations to not include drying. Further, the subtraction of a reference land use has also been recommended to be removed from the calculations. While the subtraction would be an accepted calculation procedure in a scientific LCA-report, it is not in line with the Directive calculations. As we understand it, the reason is in this case also to harmonize the results with Member States. Therefore, in the present report, crop drying and reference land use deduction are removed from the calculations.

Uppsala, 22 June 2011 Helene Lundkvist

SUMMARY

This report presents the results of a task performed by the Swedish University of Agricultural Sciences (SLU) at the behest of the Swedish Ministry of Agriculture. It describes the greenhouse gas emissions from the cultivation of agricultural crops for production of biofuels and the production of biogas from solid and liquid manure. The calculations are based on life cycle assessment (LCA) methodology, which was adapted to comply with the EU Directive for which this task was performed (European Parliament, 2009). Interpretations of the Directive were sometimes necessary. A basic condition of the study was that the results had to be representative of the situation in the year 2010.

Based on the assumptions made, the following results were obtained for emissions of greenhouse gases (g CO_{2eq}/ MJ fuel) from the cultivation of winter wheat, Triticale, spring barley, winter rapeseed, spring wheat, rye and oats:

County	Winter wheat (ethanol)	Triticale (ethanol)	Spring barley (ethanol)	Winter rapeseed (RME)	Spring wheat (ethanol)	Rye (ethanol)	Oats (ethanol)
Stockholm	19	19	20		23		19
Uppsala	20	19	18		21	15	17
Södermanland	21	18	18	22	23	16	20
Östergötland	19	18	21	19	21	17	18
Jönköping	19	21	22				19
Kronoberg	19	17	19				14
Kalmar	18	21	22	17	16		20
Gotland	19	18	19	20	23	17	21
Blekinge	18	19	19		21		21
Skåne	18	20	18	21	25	17	18
Halland	20	16	18	22	20		20
V:a Götaland	21	19	22	20	22	17	21
Värmland	22	19	23				22
Örebro	19	20	18		20	21	18
Västmanland	20	18	18		21		18
Dalarna	19		21				21
Gävleborg			20				25
Västernorrland			23				
Jämtland			19				
Västerbotten			25				23
Norrbotten			23				

Sensitivity analyses showed that the choice of methodology and input data when calculating nitrous oxide emissions from crop cultivation could alter the results considerably. Crop cultivation on organic soils would result in 3- to 4-fold higher values than those presented above. The use of nitrogen (N) fertilizer produced with old technology, without catalytic cleaning of nitrous oxide, would increase total emissions by approximately 36% for winter wheat. The analyses also showed that cultivation of winter wheat for ethanol production using a dedicated wheat variety and reduced nitrogen fertilization would reduce average emissions by 15%.

Since crops for biogas production do not have default values in the directive, the results are calculated as g CO_{2eq}/kg dry matter crop. This also facilitates the use of the results for biogas

producers. However, emissions expressed per MJ vehicle gas were also calculated and are presented in chapter 6.2 of this report. Emissions (g CO_{2eq}/kg dry matter crop) were calculated for cultivation of sugar beets (including tops), maize (including straw), straw from cereal production, ley and reed canary grass (RCG):

County	Sugar beets incl. tops	Silage maize	Wheat straw	Ley	RCG
Stockholm		125	9	150	95
Uppsala		126	9	151	95
Södermanland		126	9	150	95
Östergötland		145	9	140	96
Jönköping		142	9	136	99
Kronoberg		138	9	135	98
Kalmar	103	111	9	134	97
Gotland	125	114	9	132	96
Blekinge	89	109	9	135	98
Skåne	104	104	10	136	99
Halland	107	122	9	137	99
V:a Götaland		136	9	136	98
Värmland		145	9	151	96
Örebro		131	9	150	95
Västmanland		126	9	150	95
Dalarna			9	148	95
Gävleborg		159		150	95
Västernorrland				148	95
Jämtland				149	96
Västerbotten				147	95
Norrbotten				142	93

For biogas production from manure, the calculated emissions were compared with a reference system in which manure is stored in tanks before spreading in the field (i.e. conventional handling of manure in agriculture). The results are presented here, both separately for each system and as the difference between biogas production and the reference system (g CO_{2eq}/MJ fuel):

	Biogas production	Reference system	Net emissions
Solid manure (cattle)	4	29	-26
Liquid manure (cattle)	6	45	-39
Liquid manure (swine)	5	46	-41

Biogas production thereby *reduced* the emissions of greenhouse gases to the atmosphere, given the assumptions made. The sensitivity analyses showed that the results are relatively sensitive to assumptions regarding the emissions of methane and nitrous oxide during storage and spreading of manure and digestion residues, respectively. Furthermore, these calculations assumed that modern technology is used for upgrading the gas to vehicle fuel quality. Old technology with higher methane leakage would result in significantly higher emissions of greenhouse gases.

CONTENTS

1. INTRODUCTION

On 23 January 2008, the European Commission presented its proposal for a climate-energy legislative package, including a proposal for a Directive on the promotion of the use of energy from renewable sources (European Parliament, 2009). One of the purposes of this Directive is to ensure that biofuels are produced in a sustainable manner. Sustainability criteria with which the biofuels must comply have been developed for this purpose. If these criteria are not complied with, the biofuel may not be taken into account when measuring compliance with national targets for the use of biofuels and is not eligible for financial support for the consumption of biofuels.

The greenhouse gas emission savings from the use of the biofuel must be at least 35% compared with the use of a reference fossil fuel. Moreover, there are specific requirements on the cultivation of agricultural crops for biofuels. When calculated at NUTS-level 2, the use of the simplified methodology to calculate greenhouse gases, where default values are given in Annex V to the Directive, is only permitted if the cultivation of winter wheat for ethanol production generates no more than 23 g CO_{2eq}/MJ ethanol, and the cultivation of rapeseed for rape methyl ester (RME) generates no more than 29 g CO_{2eq}/MJ RME. When calculated at NUTS-level 3, calculated values can be used regardless of actual values, according to Annex V to the Directive.

The Swedish Ministry of Agriculture commissioned the Swedish University of Agriculture (SLU) to calculate the greenhouse gas impact of cultivation of agricultural crops for biofuels in Sweden. The task also included calculation of greenhouse gases from production of biogas from solid and liquid manure.

2. METHODOLOGY

A basic condition for this study was that the results would be representative of the situation in the year 2010, which is the first year in which the EU Directive (2009/28/EC) could come into effect. This condition was fulfilled either by making projections for the year 2010 (for example regarding yields and drying techniques) or, when appropriate, by assuming that available data are valid for the situation in 2010. Considering the rapid technical development in the agricultural sector, the emergence of new scientific knowledge on the quantification of greenhouse gas emissions and the potentially large financial significance of the results of the calculations, it is recommended that the study be updated at relatively short intervals.

The choice of methodology for the study was to a large extent based on the text of the Directive (European Parliament, 2009), according to which the greenhouse gas emissions from the production and use of transport fuels, biofuels and other bioliquids shall be calculated as:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee}$$

where:

E = Total emissions from the use of the fuel

e_{ec} = Emissions from the extraction or cultivation of raw materials

e_l = Annualized emissions from carbon stock changes caused by land use change

e_p = Emissions from processing

e_{td} = Emissions from transport and distribution

e_u = Emissions from the fuel in use

e_{sca} = Emission savings from soil carbon accumulation via improved agricultural management

e_{ccs} = Emission savings from carbon capture and geological storage

e_{ccr} = Emission savings from carbon capture and replacement

e_{ee} = Emission savings from excess electricity from co-generation.

Emissions from the manufacture of machinery and equipment shall not be taken into account.

The same characterisation factors as are used in the EU Directive on the promotion of the use of energy from renewable sources were used in this study:

CO_2: 1
N_2O: 296
CH_4: 23

Data on emissions from the production and distribution of electricity in the year 2005 were obtained from the Swedish Energy Agency (Tobias Persson, Swedish Energy Agency, pers. comm. I). More recent data are not available and therefore the value for 2005 was assumed to remain valid for 2010. In the base scenarios, average emissions from the Swedish electricity generation mix (22.6 g CO_{2eq}/kWh) were assumed. Data on emissions from the production and distribution of diesel and oil were obtained from Uppenberg et al. (2001).

2.1 Cultivation of agricultural crops for biofuel production

SLU's task was to calculate $e_{ec,}$, which means the emissions from the extraction or cultivation of raw materials. The EU Directive does not mention whether crop drying should be taken into account in calculating e_{ec} , but after discussions with the reference group, SLU decided to include it.

The Directive contains very little information on the methodology for calculating the emissions of greenhouse gases from cultivation of crops for biofuel production. In Article 19, Annex V, Chapter C, Item 6, the following is stated regarding the calculation methodology:

> 'Emissions from the extraction or cultivation of raw materials, *eec,* shall include emissions from the extraction or cultivation process itself; from the collection of raw materials; from waste and leakages; and from the production of chemicals or products used in extraction or cultivation. Capture of CO2 in the cultivation of raw materials shall be excluded. Certified reductions of greenhouse gas emissions from flaring at oil production sites anywhere in the world shall be deducted. Estimates of emissions from cultivation may be derived from the use of averages calculated for smaller geographical areas than those used in the calculation of the default values, as an alternative to using actual values.'

However, the Directive is clear on the choice of allocation method; co-products shall be allocated a share of the greenhouse gas emissions proportional to the lower heating value of the products. Agricultural crop residues are not assumed to have any value and are not burdened with any of the emissions from the cultivation (Article 19, Annex V, Chapter C, Items 17 and 18):

> 'Where a fuel production process produces, in combination, the fuel for which emissions are being calculated and one or more other products ('co-products'), greenhouse gas emissions shall be divided between the fuel or its intermediate product and the co-products in proportion to their energy content (determined by lower heating value in the case of co-products other than electricity).'
>
> 'Wastes, agricultural crop residues, including straw, bagasse, husks, cobs and nut shells, and residues from processing chains, including raw glycerine (glycerine which has not been refined) shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of these materials.'

According to the task description to SLU from the Swedish Ministry of Agriculture, the calculations should be conducted on NUTS level 2 (regional level) and NUTS level 3 (county level).

Four agricultural crops were originally included in this report (September 2009); winter wheat, spring barley, Triticale and winter rapeseed. In November 2010, three additional crops were added; spring wheat, rye and oats. The new crops are calculated using the same methodology and data sources as was used in the previous report. In total six agricultural crops for ethanol production are now included; winter wheat, spring barley, Triticale, spring wheat, rye and oats, as well as winter rapeseed used for production of rape methyl ester (RME).

In addition, five crops to be used for biogas production were added to the report in November 2010. These crops are sugar beets including tops, silage maize (the entire crop), straw from cereal production, ley and reed canary grass (RCG). The same calculation methodology has been used for these crops as for the previous calculations, and therefore only data and methodological parts that are different for the additional crops have been added to the report (chapter 4). Crop drying does not apply to the biogas crops. Straw from cereal production is according to the Directive Annex V, section C, item 18 considered a residue and has zero life cycle emissions up to the process of collection. There are no default values in Annex V to the Directive assigned to the production of crops for biogas production. As the yield of biogas is very dependent on the configuration of each plant, it will be easier for biogas producers if the emissions are presented per kg dry matter (DM) harvested crop. Considering this, results are presented both as CO_2-eq/MJ upgraded and compressed biogas and as CO_2-eq/kg DM of harvested crop.

To the greatest extent possible, typical values for input data were used in order for the results to reflect typical values for each crop and county. The input data were mainly obtained from Statistics Sweden.

In this version of the report, no subtraction of reference land use is done.

The calculations of greenhouse gas emissions were made for typical agricultural crops produced with conventional cultivation methods on mineral soils, both on regional and county level. However, the calculations had to comply with the EU Directive, so the methodologies, system boundaries and input data used were therefore a combination of common LCA practices and interpretations of the Directive. For the interpretations of the Directive, SLU consulted the reference group.

2.2 Biogas from manure

According to the task description, SLU was to calculate greenhouse gas emissions from production of biogas from manure, to be used as vehicle fuel. A biogas plant using manure as substrate is likely to be an on-farm biogas installation, since long distance transportation of manure (which contains a relatively low fraction of dry matter) is not a practical or economic option. However, a farm would typically not be able to invest in expensive technology for upgrading the biogas to vehicle fuel quality and, moreover, the fuel would be located far from the end-users. In the system analysed, it was therefore assumed that the raw gas is produced on a farm, with substrate (solid and liquid manure) from the farm's animal stock. The raw gas is dried and pumped via pipelines to a central upgrading plant where it is cleaned, odorized and compressed, ready to be used as vehicle fuel. The farms were assumed to have in the order of 100-500 animal units and the upgrading facility was assumed to have a production capacity of 10 000 MWh vehicle fuel per year. At the farm, the digestion residues from the biogas plant were assumed to be returned to the fields.

The calculation of the biogas production system was conducted as a comparative study against a reference system, in which the manure is collected in a storage tank and spread on the fields without digestion. The methane emissions from digestion residues (during storage and spreading) are significantly lower than those from the undigested manure, which means that greenhouse gas emissions can be significantly reduced via the production of biogas. A double climate benefit is thus achieved, which is recognized by, for example, the Joint Research Centre (JRC), in a report to the European Commission during preparation of the EU Directive on the promotion of the use of energy from renewable sources (Edwards et al., 2008). The results for the biogas production system and the reference system are, however, presented separately.

The system boundary was drawn where the manure is collected and stored in the open storage tank. The system includes all process steps until the manure/digestion residues are spread on the fields. In accordance with Annex V of the Directive, the production of the manure was assumed to not contribute to the production of greenhouse gas emissions, and was thus assumed to be 'for free' from a climate perspective.

The study did not differentiate between geographical regions. Factors that are likely to vary with the climate conditions in, for example, Northern and Southern Sweden are the heating demand for the digestion process, and methane and nitrous oxide emissions from storage and spreading of undigested manure and digestion residues, respectively. Regarding greenhouse gas emissions from storage, the available data were not sufficient to allow for geographical differentiation within Sweden.

3. INPUT DATA FOR CULTIVATION OF CROPS FOR ETHANOL AND RME PRODUCTION

3.1 Area cultivated with each crop type

Only Swedish counties where the respective crop types are cultivated over a significant area were considered in the study (Table 1). Due to lack of data, some calculations could not be performed. These mainly concerned cultivation of winter wheat and triticale in northern counties and cultivation of winter rapeseed in counties where the cultivation is limited and statistical data therefore insufficient.

Table 1. Cultivated area (ha) of each crop type in Sweden 2007 (SCB, 2008a)

County	Winter wheat	Spring barley	Triticale	Winter rapeseed	Spring wheat	Rye	Oats
Stockholm	13694	7777	1294	1327	1148	829	5125
Uppsala	30461	29648	1297	1328	7137	2248	9534
Södermanland	24202	10877	3009	995	3376	1152	10505
Östergötland	45403	14694	9206	8886	3389	4093	9685
Jönköping	923	5977	1161	180	239	15	6756
Kronoberg	342	2462	715	53	568	53	4090
Kalmar	9732	12501	4216	2537	1086	790	4257
Gotland	5763	15763	3836	2572	2349	1007	1805
Blekinge	1958	3731	980	390	1017	212	865
Skåne	91244	84721	4788	21020	6175	17430	9149
Halland	8383	19573	4283	1730	2571	354	8946
V:a Götaland	58336	34898	13658	8450	5918	5110	72340
Värmland	3085	9315	2363	206	753	451	13405
Örebro	11691	13118	1984	463	5822	1824	15304
Västmanland	15682	15864	869	187	4975	513	15151
Dalarna	1507	9600	107	..	658	515	3206
Gävleborg	720	10300	61	..	635	29	3550
Västernorrland	51	3506	67	..	53	..	556
Jämtland	..	2007	..	..	40	..	289
Västerbotten	..	8381	20	..	174	1	1069
Norrbotten	..	3696	..	..	214	..	449

3.2 Seed rate

A seed rate of 210 kg seed per hectare was assumed for winter wheat production, 170 kg/ha for spring barley, 180 kg/ha for Triticale, 6 kg/ha for winter rapeseed, 230 kg/ha for spring wheat, 180 kg/ha for rye and 205 kg/ha for oats (Lantmännen Lantbruk, 2007). Instead of adding this to the cultivation, this amount was subtracted from the yield. Processing of the seed, such as cleaning, packaging, etc. was thereby not included in the calculation.

3.3 Yields

Yield levels for each crop type in the respective counties were calculated based on average yields for crops cultivated with conventional cultivation methods between the years 2002 and 2007, i.e. for the base year 2005 (SCB, 2008b). However, with a selective choice of crop variety, crop breeding research and general technical development in the agricultural sector, yield levels are increasing over time. As the calculations were intended to be representative for the year 2010, a certain increase in yields compared with the average yields during the period 2002-2007 can be expected. An increase over five years was therefore calculated (2005 to 2010). Based on data from 1965 onwards, there is a trend for a 63 kg increase per hectare and year for winter wheat (Figure 1). For spring barley, winter rapeseed, spring wheat, rye and oats the corresponding increase is 33, 19, 41, 68 and 25 kg, respectively, per hectare and year. For triticale, data are only available from 1995 onwards, and the increase is calculated at 34 kg per hectare and year. The calculated yields for the year 2010 that were used for this study are presented in Table 2.

Table 2. Calculated yields (kg/ha) in the year 2010, based on the average for five years with conventional cultivation methods, including an assumed yield increase after 2005 and after deduction of seed. Moisture content: Cereals 14%; oilseeds 9%

County	Winter wheat	Spring barley	Triticale	Winter rapeseed	Spring wheat	Rye	Oats
Stockholm	5482	3889	5219	.	4376	4353	3593
Uppsala	6068	4512	5363	.	4941	5278	4351
Södermanland	5581	4196	5288	2703	4671	4780	4087
Östergötland	6205	4650	5528	3270	4805	6010	4453
Jönköping	5163	3127	4322	.	.	.	3304
Kronoberg	4649	2976	4195	.	.	.	3485
Kalmar	5812	3542	4385	3044	4627	.	3451
Gotland	5128	3906	4520	2933	4347	4279	3493
Blekinge	5984	3903	4537	3283	5250	.	3838
Skåne	7258	5103	5250	3385	5373	6196	4775
Halland	6113	4386	5391	3112	4961	.	4323
V:a Götaland	6043	4206	5354	3212	4550	5657	4194
Värmland	5278	3687	5309	.	.	.	3627
Örebro	6000	4485	5264	.	5367	4953	4298
Västmanland	5675	4415	5360	.	4627	.	4337
Dalarna	5000	3392		.	.	.	3467
Gävleborg		2757		.	.	.	2586
Västernorrland		2376		.	.	.	.
Jämtland		3004		.	.	.	.
Västerbotten		2280		.	.	.	2219
Norrbotten		2417		.	.	.	.

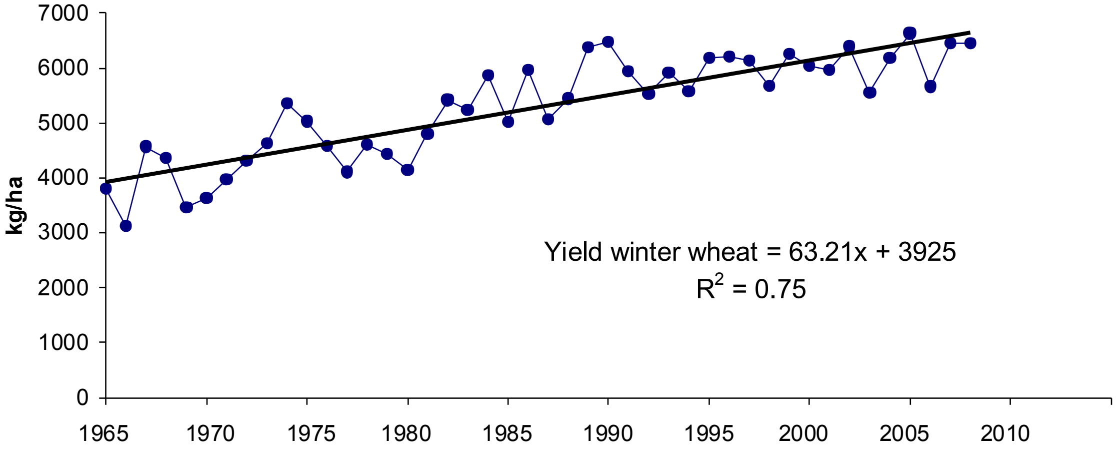

Figure 1. Yields (kg/ha) of winter wheat in Sweden 1965-2008 and trend line (SCB, 2009).

3.4 Production of commercial fertilizers

The base of most N fertilizers is ammonia. The most common method for production of ammonia is based on natural gas, but gasification of coal and oil is also used. Some of the ammonia is used for production of nitric acid. Ammonia and air react over a catalyst and the gas produced is absorbed in water. This process generates nitrous oxide. Over the last few years, the production of commercial fertilizers has become increasingly energy efficient. The difference between new and old production plants is therefore large. Moreover, many plants have been equipped with catalytic cleaning of nitrous oxide, which reduces emissions significantly.

The Swedish market for commercial fertilizers is dominated by the international company Yara, and the NPK fertilizers sold in Sweden are produced in Finland (Yara, 2008). Sweden has no production of commercial fertilizers, since the ammonium nitrate produced in Köping is used solely in explosives. In this study, it was assumed that all commercial fertilizers are produced in Finland and transported to Sweden by boat and then by truck to the respective counties. The commercial fertilizers were assumed to be produced in a modern factory equipped with catalytic cleaning of nitrous oxide. According to Yara, the emissions of greenhouse gases during production of nitrogen fertilizers for the Swedish market was estimated to be on average be 2.9 kg CO_2-eq/kg N in 2010 (Erlingson, 2009), which is the value used in the calculations. A sensitivity analysis was performed to determine the effects on the results if commercial fertilizers produced without catalytic cleaning of nitrous oxide were to be used.

Data on phosphorus (P) and potassium (K) production were taken from LowCVP (2004). The emissions figures used were 0.71 kg CO_2-eq/kg P and 0.46 kg CO_2-eq/kg K.

3.5 Fertilizer application rate

Data on the quantities of nitrogen, phosphorus and potassium utilized per county and crop type were taken from the report ‘Use of Fertilizers and Animal Manure in Agriculture’, produced by Statistics Sweden (SCB, 2008c). The data for that report were collected via phone interviews with 3200 farmers at the end of the cultivation season and provide information on fertilizer use in the fertilizer year 2006/2007. A fertilizer year is the period during which fertilization of crops harvested during the current year takes place. It starts with fertilization for autumn sowing, and includes all fertilization up to harvest in summer/autumn the following year. Statistics Sweden was commissioned by SLU to conduct a special analysis with the geographical distribution relevant for this study (Table 3).

Table 3. Use (kg N/ha) of commercial fertilizer nitrogen 2006/07 on soil fertilized with commercial fertilizers only (reworked data from SCB, 2008c). Missing figures (..) are confidential data and cannot be published. However, all figures were included in the calculations

County	Winter wheat	Spring barley	Triticale	Winter rapeseed	Spring wheat	Rye	Oats
Stockholm	..	..	..		..		..
Uppsala	149	83	..		..	..	77
Södermanland	147	77	..	..	..	..	87
Östergötland	141	109	113	..	..	..	81
Jönköping	..	..	..				..
Kronoberg	..	..	..				..
Kalmar	..	..	..	..	..		..
Gotland	..	80	..	..	..	..	..
Blekinge	..	..	..		..		..
Skåne	165	98	..	173	166	120	94
Halland	..	82	..	..	..		93
V:a Götaland	156	101	113	160	..	..	99
Värmland	..	..	..				..
Örebro	139	90	..		..	..	82
Västmanland	..	..	..		..		84
Dalarna	..	..					..
Gävleborg		..					..
Västernorrland		..					..
Jämtland		..					..
Västerbotten		..					..
Norrbotten		..					..

3.6 Pesticides

Data on the amount of pesticides used (kg active substance per hectare) for each crop type and county are estimates produced by Statistics Sweden. The base data are from a survey by Statistics Sweden (SCB, 2008d). Data on emissions related to the production of pesticides were taken from Olesen et al. (2004). No differentiation was made between different preparations and the values are only based on the amount of active substance used (Table 4).

Table 4. Emissions from the production of chemical pesticides (kg/kg active substance). From Olesen et al. (2004)

CO_2	CH_4	N_2O
4.92	0.00018	0.0015

3.7 Field operations

Input data from field operations were calculated for each crop type and county. The same field operations were assumed to be required in all counties, i.e. it was assumed that the cultivation methods for each crop type did not differ between counties. The operations required for each crop type are presented in Table 5.

Table 5. Assumptions on number of field operations required for cultivation of the four crop types studied

	Winter wheat	Spring barley	Triticale	Winter rapeseed	Spring wheat	Rye	Oats
Ploughing	1	1	1	1	1	1	1
Harrowing	3	3	3	3	3	3	3
Sowing	1	1	1	1	1	1	1
Fertilizing	2	1	1	1	1	2	1
Application of pesticides	3	1	3	1	1	3	1
Threshing	1	1	1	1	1	1	1

For calculation of diesel consumption and the corresponding carbon dioxide emissions, data were taken from Lindgren et al. (2002) for machine operations not including soil preparation. For operations that include soil preparation, for example ploughing, the diesel consumption is dependent on the soil type. A calculation model in which energy consumption is dependent on the clay content was used (Johan Arvidsson, SLU, pers. comm.). As an example, the calculation for ploughing is:

Specific draught force requirement for the plough: $29.8 + 1.36x$ (kN/m^2)

where x is the percentage clay content.

In order to calculate the diesel consumption, the efficiency in converting fuel to draught force at ploughing depth was calculated for each operation. The ploughing depth was assumed to be 20 cm. The conversion factor for draught force to fuel was assumed to be 0.00014 l diesel/kNm (Johan Arvidsson, SLU, pers. comm.) and each litre of diesel was assumed to emit 2.6 kg carbon dioxide during combustion (Lindgren et al., 2002).

In 2007, the consumption of RME in agricultural machinery was just over 1% of the energy supplied in the form of diesel (Swedish Energy Agency, 2008). However, the Swedish Petroleum Institute (SPI) estimates the share of biodiesel to be higher, around 5%, i.e. similar to the blend in Swedish MK1-diesel (Ebba Tamm, SPI, pers. comm.). Therefore, the share of biofuel in the calculations was set to 5% in the year 2010. The emissions of GHG from the production and use of RME was calculated according to Bernesson (2004).

3.8 Crop drying

Crop drying is not included in this version of the report! The following text (in light grey) is the remains of a previous version of the report.

After harvesting the crop, drying is necessary before storage. Grain should be dried to a moisture content of 14% if it is to be stored for one year (Jonsson, 2006). Winter rapeseed should be dried to 8% moisture content (Wallenhammar, 2009). Data on moisture content at harvest were taken from crop variety trials at SLU (SLU Fältforsk, 2009). The moisture content at harvest varies between 18.3% and 20.8% in the Swedish counties where winter wheat is cultivated. A corresponding variation has been found for spring barley (17.5-18.6%), triticale (15.5-21.1%), spring wheat (17.8-21.8%), rye (16.8-18.2%) and oats (15.4-19.8%). For winter rapeseed, the variation between counties could not be determined and therefore an average value of 12.3% moisture content at harvest was assumed for all counties.

There are several possible systems for crop drying. Grain can be dried in on-farm dryers or delivered wet to a central drying plant. For on-farm drying, the most common system is oil fuelled hot air dryers, but there are also unheated air dryers and a few biofuelled hot air dryers. According to the Swedish government's climate policy proposal, farmers will no longer be exempt from the national carbon dioxide tax. In the year 2010, it is therefore likely that the share of biofuelled dryers will have increased. However, replacing oil as the fuel is not a simple task, since crop drying requires high power output during a short period of time. Investing in a biofuelled boiler with sufficient power output can be expensive. Another possibility is that more farmers will deliver to central drying plants, with better possibilities to use biofuels.

According to the Swedish Institute of Agricultural and Environmental Engineering (JTI), 10-15% of central grain drying plants are biofuelled today, most of them using low-quality grain and waste products separated from the grain before drying (Gunnar Lundin, JTI, pers. comm.). In 2005, an estimated 40% of all grain was dried in central plants (Figure 2), which would mean that a total of 5% of all grain was dried in biofuelled plants in that year.

In spite of the number of central drying plants diminishing, the total capacity has increased. Thus, more grain is expected to be dried in central plants in 2010. Given the policy incentives steering consumers away from fossil fuels that are expected in the future, a higher share of biofuels in central drying plants can also be expected. In the base scenarios, it was therefore assumed that 25% of total crops are dried in biofuelled dryers. For this, wood pellet was assumed to be the fuel. The energy requirement was assumed to be 5 MJ/kg evaporated water (Jonsson, 2006). Data on emissions from fuel oil and wood pellet production were taken from Uppenberg et al. (2001).

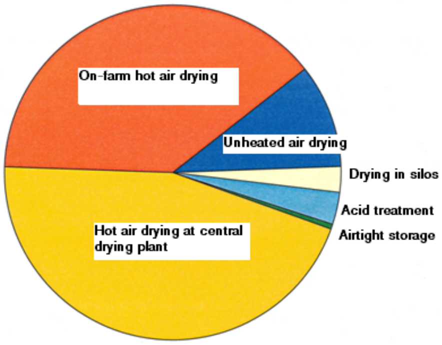

Figure 2. Preservation methods for Swedish grain, 2005 (Nils Jonsson, JTI, pers. comm.).

3.9 Nitrous oxide emissions from cultivation

When there is an excess of mineral nitrogen in the soil, microbial activity can produce nitrous oxide under certain conditions. The amount of mineral nitrogen converted to nitrous oxide depends on many factors, for example the initial form of the nitrogen, the supply of organic material, temperature, soil moisture content and oxygen supply (Kasimir Klemedtsson, 2001). Excess nitrogen in cultivated soil can also cause nitrogen leaching to groundwater or runoff water. A certain proportion of the nitrogen leaching out with the runoff water is also assumed to volatilize as nitrous oxide, giving indirect emissions of the gas.

There are few published studies presenting measurements of nitrous oxide emissions from Swedish cultivated land over a significant period of time. On an international level, many different studies have been conducted, but the results show great variations (Åsa Kasimir Klemedtsson, pers. comm.). Very few studies show a statistically verifiable relationship between different parameters, for example nitrous oxide emissions and available nitrogen (Berglund et al., 2009). In order to estimate the nitrous oxide emissions from Swedish agriculture, Kasimir Klemedtsson (manuscript) synthesized measurement series relevant for Swedish conditions and suggests an alternative method for calculation of nitrous oxide emissions from cultivation of crops on agricultural soil. This method is based on extensive, mainly international, base data. Calculations using this method show that the nitrous oxide emissions correspond to 4.1±2.5 and 5.0±7.2 kg N_2O/ha and year for fertilization with less than, and more than, 100 kg N/ha and year respectively.

The Joint Research Centre (JRC) gathered measured data on nitrous oxide emissions from different studies and inserted these into a soil model (Edwards et al., 2007). They concluded that there is a direct relationship between soil organic carbon and nitrous oxide emissions, with production of nitrous oxide increasing with soil organic carbon content. The nitrous oxide emissions from grain cultivation were quantified in a JRC study at 2.23 kg N_2O per hectare and year on average for all EU member states, whereas cultivation of winter rapeseed emits 3.12 kg N_2O per hectare and year based on the assumption that this crop is mainly cultivated in Northern Europe, where the carbon concentration in the soil is generally higher. For indirect emissions of nitrous oxide, JRC uses the IPCC model (see description below).

Another way to calculate nitrous oxide emissions from agriculture is the so-called ‘top-down’ method developed by Crutzen et al. (2008). By studying air bubbles in ice cores, a pre-industrial level of nitrous oxide in the atmosphere could be determined. By assuming that the increase in nitrous oxide levels in the atmosphere since then is anthropogenic and deducting the documented emissions from industrial activities, the contribution from agriculture can be calculated. Using this method, the emissions of nitrous oxide are estimated to be 3-5% of added nitrogen. However, the method is very coarse – for example, no differentiation between different soil types is possible – but it can be suitable for estimations of greenhouse gas emissions on a national level.

IPCC (2006) has developed a method for estimating direct emissions of nitrous oxide from agriculture, intended for national reporting of greenhouse gas emissions. The method is based on assumption of a linear relationship between nitrous oxide emissions and the amount of nitrogen added to the soil in the form of commercial fertilizers, farmyard manure and nitrogen-fixing crops. With measurements as base data, IPCC (2006) assumes that 1% of applied nitrogen is emitted as nitrous oxide. However, an unfertilized soil also emits nitrogen, which to a large extent is assumed to stem from crop residues above and below ground. Therefore, the contribution of crop residues to nitrous oxide emissions is also included in the calculations, and 1% of the nitrogen in crop residues (above-ground and below-ground) is assumed to volatilize as nitrous oxide. Mineralization of nitrogen from depletion of soil organic matter due to cultivation, for example crop cultivation on organic soils (in this study only applied in the sensitivity analysis), is also included. Moreover, IPCC has developed a method for the calculation of indirect emissions of nitrous oxide. The method takes into account "downstream" nitrous oxide emissions from nitrogen leached out with runoff water from the field, as well as the proportion of added nitrogen that volatilizes as ammonia and is re-deposited on the ground, causing the formation of nitrous oxide.

None of the methods described above can exactly determine how much nitrous oxide is emitted from cultivation of different crop types in different counties in Sweden. SLU opted to apply the IPCC method for this study. The IPCC method is a tool intended for national estimations of greenhouse gases, but is still the most detailed of the methods described in the sense that it can reflect the differences between counties in nitrogen application, nitrogen leaching, the amount of crop residues, etc. Nitrous oxide emissions from organic soils can be calculated using a separate factor for such soils. In the calculations, the emission factors provided in the IPCC guidelines are applied, but with national base data (the so-called Tier 1 method). The emission factors provided have a very large uncertainty range, which is taken into account in the sensitivity analysis.

3.9.1 Deduction of reference system

No deduction of reference land use was done in this version of the report! The following text (in light grey) is the remains of a previous version of the report.

We want to determine how much of the total nitrous oxide emissions from a field should be accounted to the cultivation of biofuels. It is therefore necessary to determine a reference system. In this study, we chose to calculate the nitrous oxide emissions compared with emissions stemming from unfertilized grassland (see section 2.1 for definition of extensive grassland).

Deducting for a reference land use when using the IPCC method is not without controversy, and some interpret the method to be already subtracting a reference. However, this is not the case. We suspect that the reason for the diverging opinions is due to the confusion regarding the terminology and difficulties in communication, mostly related to the use of the words "background", "natural" and "reference". We understand the IPCC method as primarily quantifying the total emissions from land under active cultivation. Based on measurements, IPCC states that 1% of the added nitrogen is converted to nitrous oxide. However zero fertiliser addition does not mean zero nitrous oxide (Figure 3). Footnote 7, chapter 11, in the 2006 IPCC report state:

"*Natural N2O emissions on managed land are assumed to be equal to emissions on unmanaged land. These latter emissions are very low. Therefore, nearly all emissions on managed land are considered anthropogenic. Estimates using the IPCC methodology are of the same magnitude as total measured emissions from managed land. The so-called 'background' emissions estimated by Bouwman (1996) (i.e., approx. 1 kg N_2O–N/ha/yr under zero fertiliser N addition) are not "natural" emissions but are mostly due to contributions of N from crop residue. These emissions are anthropogenic and accounted for in the IPCC methodology.*"

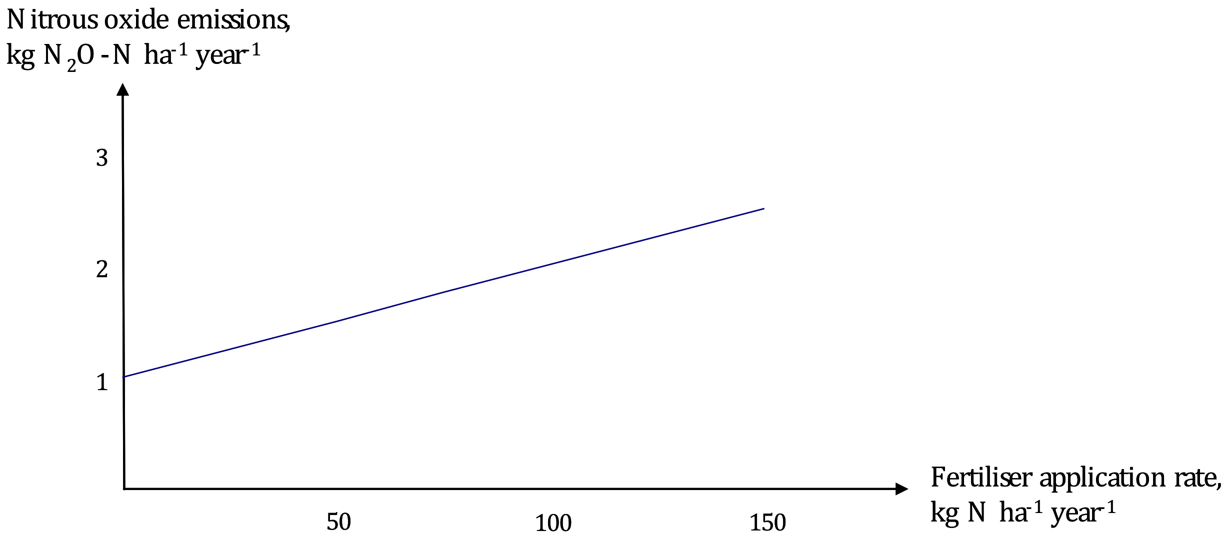

Figure 3. Relationship between fertiliser application rate and nitrous oxide emissions. Interpretation by authors of the IPCC (2006) report chapter 4.

Thus, IPCC claims that there is a "natural" emission which is very small. The approximate 1 kg N_2O-N/ha and year (the intercept in Fig. 3 above) is not a natural or background emission, but mainly due to crop residues. However, instead of just adding 1 kg to the calculations, IPCC recommends crop residues to be calculated separately (as 1% of N-content in crop residues).

SLU has followed the IPCC recommendation to calculate the nitrous oxide emissions as a factor of applied fertilisers and by adding the crop residues separately. However, since we are aiming at determining the net effect of cultivating crops for biofuels as compared to just maintaining the land as arable land ready to be used for ordinary cropping, we subtracted the nitrous oxide emissions from the reference system (i.e. unfertilized grassland). It is the result of a *difference* in management method we are calculating, not a subtraction of natural or background emissions.

This approach was discussed with Keith Smith (co-author of IPCC 2006, pers. comm.), who supported that a deduction could be made for nitrous oxide emissions from the grassland in order to calculate the difference between the two cultivation systems.

Based on data from a study by Stehfest and Bouwman (2006), Kasimir Klemedtsson (manuscript) has synthesized the published measurement data from unfertilized, ungrazed grasslands that resemble Swedish conditions. On average, the nitrous oxide emissions from these grasslands are 90.32 ± 0.09 kg N_2O-N per hectare and year. This value was subtracted from the calculated direct emissions of nitrous oxide.

3.9.2 Calculation of direct N_2O emissions

Based on IPCC, 2006, the direct emissions were calculated as:

N_2O (direct) = $(F_N + F_{VO}*(1-F_{VB})*N_{VO} + F_{VU}*N_{VU})* EF_N*44/28$ (kg N_2O/ha)

where:

F_N = Amount of mineral nitrogen added (kg N/ha)
EF_N = Emission factor, see Table 7
F_{VO} = Amount of crop residues above-ground (kg DM/ha)
F_{VB} = Fraction residues removed
F_{VU} = Amount of crop residues below-ground (kg DM/ha)
N_{VO} = Nitrogen content in crop residues above-ground (% of DM)
N_{VU} = Nitrogen content in crop residues below-ground (% of DM)

For conversion of N_2O-N emissions to N_2O emissions, the factor 44/28 is used.

The amount of crop residues above-ground, F_{VO} (straw), was calculated as a factor of the grain yield for each crop type (Table 6) based on data from the Swedish Environmental Protection Agency (SEPA) (Naturvårdsverket, 2009). A proportion of the straw (varying between counties) is removed from the fields (SCB, 1999), denoted as F_{VB}. The amount of crop residues below-ground, F_{VU}, was calculated in accordance with the IPCC method (IPCC, 2006). Data on the nitrogen content in straw above-ground, $N_{VO,}$ for different straw types were taken from SEPA (Naturvårdsverket 2009) and the nitrogen content below-soil, N_{VU}, from IPCC (2006).

Table 6. Parameters chosen for calculation of direct nitrous oxide emissions caused by crop residues

	Winter wheat	Spring barley	Triticale	Winter rapeseed	Spring wheat	Rye	Oats
Fraction of crop residues relative to (DM) harvested grains	0.87	0.83	1.08	0.47	0.96	1.08	0.89
N content in crop residues above-ground (% of DM)	0.51	0.77	0.60	1.07	0.44	0.60	0.73
Crop residues below-ground (% of above-ground biomass)	22	22	22	22	22	22	22
N content in crop residues below-ground (% of DM)	0.9	0.9	0.9	0.9	0.9	0.9	

Table 7. Emission factors for calculation of nitrous oxide emissions (IPCC, 2006)

Factor	Value
EF_N = Emission factor for added nitrogen (kg N_2O-N/kg N)	0.01
EF_L = Emission factor for leaked nitrogen (kg N_2O-N/kg N)	0.0075
EF_D = Emission factor for volatilization and re-deposition (kg N_2O-N/kg NH_3-N)	0.01

3.9.3 Calculation of indirect N_2O emissions

Indirect nitrous oxide emissions are calculated as (IPCC, 2006):

N_2O (indirect) = $F_L*EF_L + F_A*EF_D *44/28$ (kg N_2O/ha)

where:

F_L = Amount of nitrogen emitted via leaching (kg N/ha)
F_A = Amount of ammonia emitted from mineral fertilizer application
EF_L = Emission factor, see Table 7
EF_D = Emission factor, see Table 7

Data on nitrogen leaching, F_L, from crops fertilized with mineral fertilizers was based on Johnsson et al. (2008) and was recalculated from PO18[*] to county level (Table 8). The leaching from crops fertilized only with mineral fertilizers is generally slightly lower than leaching from crops to which a combination of farmyard manure and mineral fertilizers is applied. Leaching from Triticale is not included in the base data from Johnsson et al. (2008), but was considered equal to that from rye after discussions with Kristina Mårtensson, SLU (pers. comm.).

The nitrogen deposition on the soil via air pollution also contributes to leaching. However, the contribution of nitrogen deposition was deducted from the results, based on the assumption that the deposited nitrogen leaches to the same extent as added mineral nitrogen. Data on the amount of nitrogen deposited were taken from Johnsson et al. (2008). Nitrogen leaching from the respective crop type and county are presented in Table 8.

The amount of ammonia, F_A, emitted from mineral fertilizers was assumed to be 1.2% of the nitrogen fertilizer applied, according to data from SEPA (Naturvårdsverket 2009). The IPCC factor (IPCC, 2006) is 10% of applied nitrogen, but this is considered to be an unrealistic figure for Swedish conditions. This high figure could possibly be applied in an international perspective, as urea and even pure ammonia are used as fertilizers in some countries.

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[*] PO18: Production area 18, which is a commonly used division of the country into 18 agricultural regions. The division PO8 is also frequently used.

Table 8. Average nitrogen leaching (kg N/ha yr) from winter wheat, spring barley, Triticale (rye) and winter rapeseed fertilized with commercial fertilizers only, as an average value for all soil types occurring in the respective counties. Data from Johnsson et al. (2008), re-calculated from PO18 to county level, with nitrogen leaching caused by nitrogen deposition deducted.

County	Winter wheat	Spring barley	Triticale	Winter rapeseed	Spring wheat	Rye	Oats
Stockholm	14	13	11		12	11	12
Uppsala	14	13	11		12	11	12
Södermanland	14	13	11	20	12	11	12
Östergötland	31	29	25	37	33	27	27
Jönköping	31	32	25			24	27
Kronoberg	31	32	25			24	27
Kalmar	26	27	24	38	29	25	23
Gotland	28	26	22	29	23	22	25
Blekinge	29	31	29	41	30	28	29
Skåne	32	36	31	52	37	30	36
Halland	27	32	30	41	38	30	37
V:a Götaland	33	32	28	36	29	27	29
Värmland	34	29	27		28	27	27
Örebro	16	16	12		13	12	14
Västmanland	14	13	11		13	11	13
Dalarna	25	23			22		23
Gävleborg		22			22		22
Västernorrland		21					21
Jämtland		18					20
Västerbotten		23					21
Norrbotten		23					21

3.9.4 Calculation of N_2O emissions, summary

To summarize, SLU opted to use the method described in IPCC (2006) for calculation of nitrous oxide emissions from cultivation. Direct emissions were calculated with the assumption that 1% of added mineral nitrogen is volatilized as nitrous oxide. Crop residues left on the fields were also assumed to contribute to the nitrous oxide emissions. Indirect emissions of nitrous oxide were calculated with the assumption that 0.75% of the nitrogen leached is volatilized as nitrous oxide. Application of mineral fertilizers was also assumed to contribute to the indirect emissions, via volatilization of ammonia re-deposited on the ground. The following change were made to the IPCC methodology:

- The emission factor for the amount of ammonia volatilized from applied mineral fertilizer was assumed to be 1.2% instead of 10%, based on Swedish common fertilization practices

3.10 Energy balance and allocation

The results of the calculations are presented as g CO_2-equivalents per MJ fuel. However, the task description to SLU did not include instructions on how to determine the energy balance per unit mass of the crop. The following assumptions were therefore made:

- Grain is cultivated for ethanol production. From 1 kg grain, 7.93 MJ ethanol is obtained (2.67 kg grain for 1 litre ethanol) (Bernesson et al., 2006)
- Allocation to ethanol is 60.8%, based on the energy content in ethanol and the co-product, DDGS (dried distillers' grains with solubles), with 9% moisture content (Bernesson et al., 2006)
- Rapeseed is cultivated for RME-production. From 1 kg rapeseed, 16.3 MJ RME are obtained (Bernesson et al., 2004)
- Allocation to RME is 64.4% based on the energy content in RME, rapeseed meal and glycerine (Bernesson et al., 2004)

The emissions per MJ fuel have thus been calculated as:
Emissions (gCO_2-eq/MJ) = Total emissions per hectare (gCO_2 -eq/ha)/yield (kg/ha)*fuel obtained (kg crop/MJ fuel)*allocation factor

4. INPUT DATA FOR CULTIVATION OF CROPS FOR BIOGAS PRODUCTION

4.1 Area cultivated with each crop type

Only Swedish counties where the respective crop types are cultivated over a significant area were considered in the study (Table 9). Due to lack of data, some calculations could not be performed.

Table 9. Cultivated area (ha) of each crop type in Sweden. Data for sugar beets, wheat straw and ley are from 2007 (SCB, 2008a). Data for silage maize and RCG is for 2009 (SCB 2010 and Swedish Board of Rural Development 2010 respectively).

	Sugar beets	Silage maize	Wheat straw	Ley	RCG
Stockholm		79	13694	32970	18
Uppsala		185	30461	44932	
Södermanland		199	24202	41872	75
Östergötland		769	45403	67026	6
Jönköping		134	923	65191	2
Kronoberg		152	342	36940	11
Kalmar	695	3746	9732	68081	1
Gotland	47	1757	5763	39187	43
Blekinge	825	328	1958	15111	
Skåne	38357	4801	91244	101037	18
Halland	737	1963	8383	44785	1
V:a Götaland		1458	58336	172892	20
Värmland		95	3085	61473	47
Örebro		123	11691	33248	
Västmanland		122	15682	23603	1
Dalarna		0	1507	34021	2
Gävleborg		28	720	44312	1
Västernorrland		19	51	41145	37
Jämtland		22	..	36052	5
Västerbotten		1	..	50451	486
Norrbotten		1	..	26750	21

4.2 Seed rate

A seed rate of 20 kg/ha was assumed for ley and RCG (Lantmännen SW Seed, 2010), 25 kg/ha for sugar beet production and 23 kg/ha for maize production (Christansson, Syngenta, pers. comm.).

4.3 Yields

Yields of sugar beets and wheat straw were calculated based on average yields for crops cultivated with conventional cultivation methods 2002-2007 (SCB, 2008b) and including expected increase up until 2010. The fraction of sugar beet tops to beets was set to 0.66 (Naturvårdsverket 2009). The straw is residues from winter wheat production and the fraction of straw to seed was set to 0.87.

Statistics on ley yield as produced by Statistics Sweden were not considered to be representative for the yields expected from ley cultivated for biogas production as they include a significant share of unfertilized and unmanaged ley. Ley yields were therefore estimated based on results from a variety trial reported by Halling (2008), weighted for an assumed composition of 15% white clover, 30% timothy, 40% meadow fescue and 15% perennial ryegrass. The yields were reduced by 20% from the reported results to correct for differences between variety trials and large scale cultivation. Fertilization rate of N, P and K were assumed to be identical to application rates in the trials. The ley plantations were assumed to be renewed every 3 years.

Maize was not grown in Sweden until recently, and no statistical data on yields for silage maize are currently available. Data on yields and fertilization has therefore been collected from advisors at the Swedish Rural Economy and Agricultural Societies at each NUTS3-level, estimating the expected yield in 2010. When there are two Societies operating in a NUTS3 region, a weighted average based on area cultivated with maize in each region was used. The yield data is including the entire plant.

RCG is cultivated in several counties in Sweden, but only Västerbotten has currently a significant cultivated area (485 hectares in 2009). There are no statistical data available for yields or fertilization rate, and data has instead been collected through a literature study. Yields in the case of RCG do not differ significantly depending on the latitude, and therefore the same yield and fertilization rate was assumed for all counties, based on data from Lomakka (1993). Field operations and use of field machines was assumed to be identical to ley cultivation. Nitrogen leaching was, due to lack of specific data for RCG fields, assumed to be identical to leaching from ley fields. The RCG plantations were assumed to have a lifetime of 7 years.

The estimated yields for each crop and county are shown in Table 10. Yields include the entire crop except stubble.

Table 10. Calculated yields (kg/ha) in the year 2010. Yields for sugar beets and wheat straw are based on an average for five years with conventional cultivation methods, including an assumed yield increase after 2005. Yields for maize, ley and RCG have been estimated for 2010.

	Sugar beets excl. tops	Silage maize	Ley	RCG	Wheat straw
Moisture content	*75%*	*71%*	*20-27%*	*30%*	*18%*
Stockholm		37908	10249	12857	3289
Uppsala		37908	10249	12857	3641
Södermanland		37908	10249	12857	3349
Östergötland		34460	10922	12857	3723
Jönköping		34460	11259	12857	3098
Kronoberg		34460	11259	12857	2789
Kalmar	50765	43425	11259	12857	3487
Gotland	41723	41356	11340	12857	3077
Blekinge	52931	43425	11300	12857	3590
Skåne	54528	41356	11300	12857	4355
Halland	50339	39632	11286	12857	3668
V:a Götaland		34460	11300	12857	3626
Värmland		29287	10249	12857	3167
Örebro		31011	10249	12857	3600
Västmanland		37908	10249	12857	3405
Dalarna			10249	12857	3000
Gävleborg		29287	10249	12857	0
Västernorrland			10249	12857	0
Jämtland			10249	12857	0
Västerbotten			10249	12857	0
Norrbotten			10249	12857	0

4.4 Production of commercial fertilizer

See section 3.4.

4.5 Fertilization application rate

In the anaerobic digestion process, biogas and residual slurry are produced. In the slurry, basically the entire amount of nutrients (N, P and K) that were in the substrate remains, and commonly this slurry is returned to the fields as a fertilizer. This is also an efficient way to handle this product, which due to the high moisture content is unpractical to store or transport. The rate of application of commercial fertilizers was lowered with the corresponding amount of N, P and K available in the residues, calculated based on nutrient content data from IPCC (2006) and Claesson and Steineck (1991) and assuming no losses. The calculated supplementary use of commercial fertilizers per crop is presented in table 12.

Table 11. Contents of N, P and K (%) in each crop type. The entire nutrient content is assumed to remain in the residual slurry after anaerobic digestion and is spread on the fields on which the corresponding crops were grown.

	Sugar beets	Sugar beet tops	Maize	Ley	RCG
N	0.2	0.45	0.60	1.50	1.50
P	0.035	0.05	0.31	0.30	0.30
K	0.2	0.6		2.4	2.4

Table 12.Use (kg N/ha) of commercial fertilizer nitrogen 2006/2007 on soil fertilized with a combination of digestion residues and commercial fertilizers (reworked data from SCB, 2008c). Missing figures are counties where data is missing and therefore are not included. Boxes containing (...) represent confidential data and cannot be published. However, these figures are included in the calculations.

	Sugar beets incl. tops	Maize (silage)	Ley	RCG
Stockholm		84.0	42.7	4.3
Uppsala		84.0	42.7	4.3
Södermanland		84.0	42.7	4.3
Östergötland		90.0	35.1	4.3
Jönköping		90.0	31.3	4.3
Kronoberg		85.0	31.3	4.3
Kalmar	…	79.4	31.3	4.3
Gotland	…	78.0	30.3	4.3
Blekinge	…	74.4	30.8	4.3
Skåne	80.7	58.0	30.8	4.3
Halland	…	81.0	31.0	4.3
V:a Götaland		80.0	31.3	4.3
Värmland		69.0	42.7	4.3
Örebro		66.0	42.7	4.3
Västmanland		84.0	42.7	4.3
Dalarna			42.7	4.3
Gävleborg		89.0	42.7	4.3
Västernorrland			42.7	4.3
Jämtland			42.7	4.3
Västerbotten			42.7	4.3
Norrbotten			42.7	4.3

4.6 Pesticides

Data on the amount of pesticides used (kg active substance per hectare) for each crop type and county are estimates produced by Statistics Sweden. The base data are from a survey by Statistics Sweden (SCB, 2008d).

4.7 Field operations

Input data from field operations were calculated for each crop type and county. The same field operations were assumed to be required in all counties, i.e. it was assumed that the cultivation methods for each crop type did not differ between counties. However, the diesel use for each field operation is dependent on the clay content of the soil which differs. The operations required for each crop type are presented in Table 13.

Table 13. Assumptions on number of field operations per year required for cultivation of the four crop types studied. Ley and RCG plantations are renewed every 3 and 7 years respectively, hence the fractions for field operations that are not performed annually.

	Sugar beets incl. tops	Maize	Straw	Ley	RCG
Ploughing	1	1	-	1/3	1/7
Harrowing	3	3	-	2/3	3/7
Sowing	1	1	-	1/3	1/7
Fertilizing	2	1	-	1	1
Application of pesticides	4	2	-	2/3	1/7
Harvest/baling	2	1	2	2	2

4.8 Crop drying

Crops cultivated for biogas production are not normally dried. A common storage method is ensiling. Emissions related to ensiling have not been included in the calculations.

4.9 Nitrous oxide emissions from cultivation

See section 3.9 for a full description of the methodology used for calculation of nitrous oxide emissions from cultivation.

Table 14 shows crop residues with nitrogen content for crops cultivated for biogas production. This table corresponds to table 6 for crops cultivated for production of ethanol and RME. For silage maize the fraction of crop residues relative to harvested seeds is not relevant as the whole plant is harvested as an entity. Residuals left on the fields after harvest have been considered by assuming 95% rate of removal. The same rate of removal was assumed for sugar beet tops, however, for this calculation sugar beets and sugar beet tops have been considered separately as they are harvested in two separate field operations.

It has however not been considered here that the use of wheat straw for biogas production reduces the emissions of nitrous oxide downstream the collection phase, since the straw in this case is removed from the fields.

Table 14. Parameters chosen for calculation of direct nitrous oxide emissions caused by crop residues

	Sugar beets	Silage maize	Ley	RCG
Amount of crop residues relative to (DM) harvested seeds	0.66	n/a	0.25	0.25
N content in crop residues above-ground (% of DM)	1.9	0.60	1.5	1.5
Crop residues below-ground (% of above-ground biomass)	20	22	54	80
N content in crop residues below-ground (% of DM)	1.4	0.7	1.6	1.2

Table 15 shows assumed average nitrogen leaching from the respective crops. No statistical data could be obtained for silage maize, and it was therefore assumed to equal to that from spring barley as both are spring crops.

Table 15. Average nitrogen leaching (kg N/ha yr) from fertilization of sugar beets, silage maize, ley and RCG as an average value for all soil types occurring in the respective counties. Data from Johnsson et al. (2008), re-calculated from PO18 to county level.

County	Sugar beets	Silage maize	Ley	RCG
Stockholm		13	2.8	2.8
Uppsala		13	2.8	2.8
Södermanland		13	2.8	2.8
Östergötland		29	6.5	6.5
Jönköping		32	10.5	10.5
Kronoberg		32	10.5	10.5
Kalmar	21	27	7.6	7.6
Gotland	16	26	7.8	7.8
Blekinge	21	31	10.6	10.6
Skåne	28	36	11.4	11.4
Halland	29	32	11.7	11.7
V:a Götaland		32	8.2	8.2
Värmland		29	6.1	6.1
Örebro		16	3.7	3.7
Västmanland		13	3.1	3.1
Dalarna		23	4.0	4.0
Gävleborg		22	4.3	4.3
Västernorrland		21	4.3	4.3
Jämtland		18	5.0	5.0
Västerbotten			8.7	8.7
Norrbotten			8.4	8.4

These calculations are not relevant for wheat straw as the cultivation up until collection is considered to have zero emissions.

4.10 Energy balance and allocation

The methane potential is the amount of methane that can be extracted and collected from each crop in a controlled anaerobic digestion process. This potential varies between crops depending on composition. Data on methane potential were taken from Lehtomäki et. al. (2006) and Edström et. al. (2008) and are shown in table 16.

Table 16. Methane potential (m^3CH4/kg vs) assumed for each crop type*

Sugar beets incl. tops	Maize	Straw	Ley	RCG
0.3	0.41	0.3	0.3	0.3

**volatile solids*

For calculations of greenhouse gas emissions per MJ compressed vehicle gas, it was assumed that all of the crops loose 5% dry matter substance during storage as ensilage. During the upgrading process, a methane loss of 0.5% was assumed.

Allocation shall according to the Directive be based on energy content. In the anaerobic digestion, biogas (containing approximately 60% methane and 40% carbon dioxide) and a residue in the form of slurry (containing residual organic matter and nutrients) are produced. Normally, the slurry has very low dry matter content and cannot efficiently be utilized for energy production purposes. Therefore, 100% of the emissions were allocated to the biogas and 0% to the digestion residue.

The emissions per MJ fuel have thus been calculated as:
Emissions (gCO_2-eq/MJ) = Total emissions per hectare (gCO_2 -eq/ha)/yield (kg/ha)*fuel obtained (kg crop/MJ fuel)*(1-Fraction losses during ensiling)*(1-Fraction losses during upgrading)

5. INPUT DATA FOR BIOGAS PRODUCTION FROM MANURE

5.1 System description of biogas plant

Three different substrates for biogas production were analysed; solid and liquid manure from cattle, and liquid manure from swine. For each substrate, the greenhouse gas emissions were also calculated for the reference system, i.e. a system in which the respective manure type is not digested in a biogas reactor but collected in a storage tank to be spread on the fields. Figure 4 shows a schematic diagram of the essential steps in the biogas production system and in the reference system. The biogas production system follows the full line (to the left) and the reference system follows the dotted line (to the right).

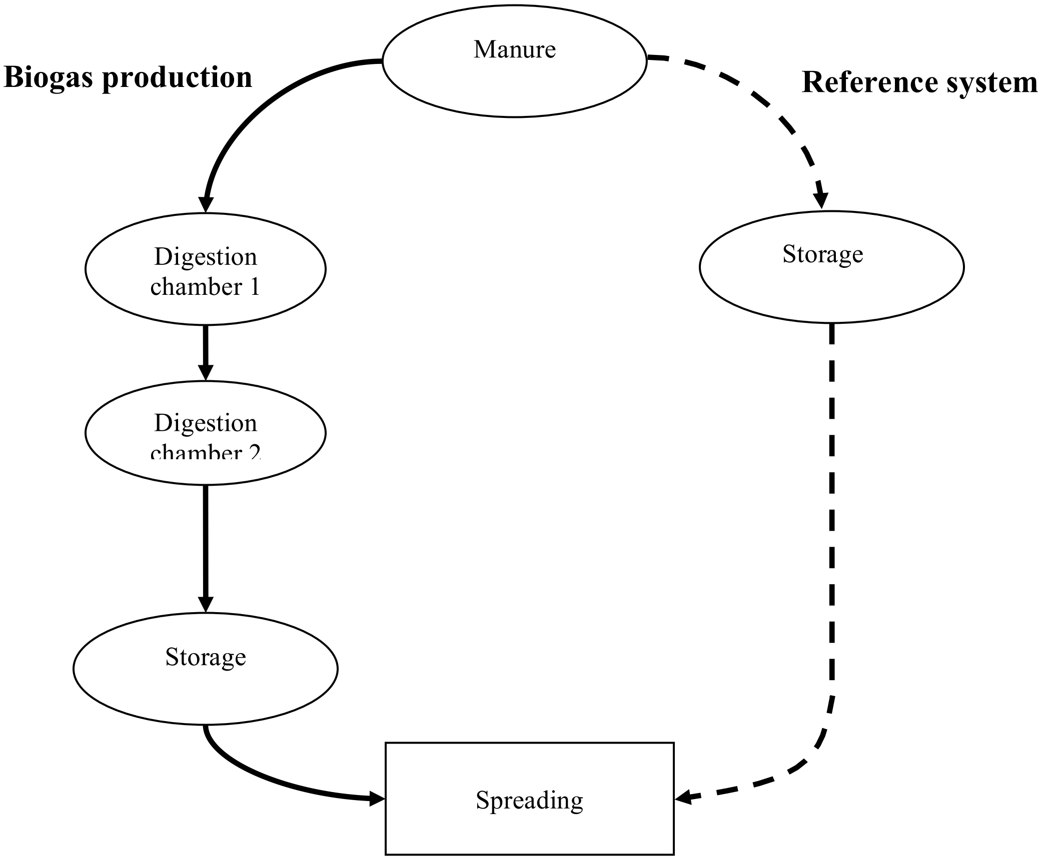


Figure 4. Schematic image of the biogas production system and the reference system.

Manure is collected and stored in an open tank. In the reference system, the manure is stored until spread on the fields (dotted line). In the biogas production system, the manure passes through digestion chambers 1 and 2 before being pumped to a storage tank for digestion residues and spread on the fields (full line).

The substrates are fed to the biogas plant, which consists of a continuously mixed primary digestion chamber, a secondary digestion chamber and a storage tank (Figure 5). In the first case (solid manure from cattle), the substrate passes through a mixing tank where a process liquid is added, in order to lower the DM content from 16% to 9%. In systems 2 and 3, the DM content of the substrate is initially 9% and the substrate is fed directly to the digestion chamber.

In the primary digestion chamber, mesophilic temperature (37ºC) is maintained using a biofuelled boiler. The retention time is 20 days and the biogas produced is collected in the double membrane which constitutes the top of the chamber. The assumed methane potential of each substrate is shown in table 17. The gas, at this stage 'raw gas', is led in pipelines from the individual farms via a central pipeline to an upgrading plant located a few tens of kilometres away. Between the farm and the upgrading plant the gas passes through a gas dryer. In the upgrading plant, it is cleaned to vehicle gas quality via water absorption and compressed, ready to be delivered to the gas station.

Table 17. Methane potential (m^3CH4/kg vs) assumed for each substrate*

Cattle manure, Solid	Cattle manure, Liquid	Swine manure, Liquid
0.23	0.248	0.3

**volatile solids*

After approximately 20 days in the primary digestion chamber, the digested material is pumped to an unheated secondary digestion chamber, where it is retained for another 20 days in order to extract as much methane as possible from the substrate. This system is preferable to a single, large digestion chamber because it decreases the risk of substrate passing through the system undigested in the continuously mixed system. The biogas produced in the secondary digestion chamber is collected and led to the same pipeline for raw gas as the gas from the primary digestion chamber, and the digestion residues are diverted to a storage tank. Both manure and digestion residues are assumed to be stored in an open storage tank before spreading.

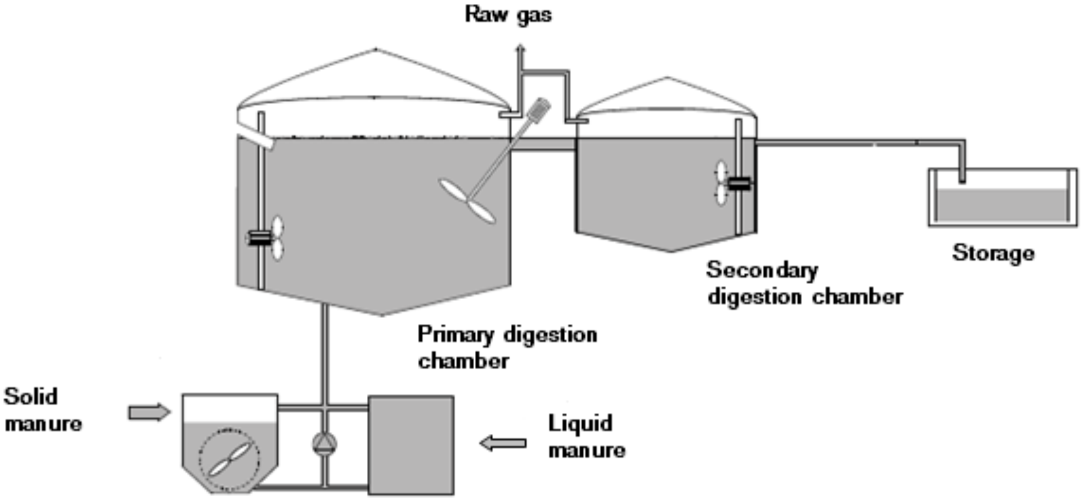


Figure 5. Schematic image of the biogas plant. Image: Kim Gutekunst (Edström et al., 2008).

The amount of manure produced per animal unit and year and the corresponding nutrient content are presented in Table 18, while the corresponding data for digestion residues are presented in Table 19. The amount of faeces and urine produced per animal unit and year and the corresponding N and P content were taken from Steineck et al. (2000). Nutrient losses during digestion were assumed to be negligible (Edström et al., 2008).

Table 18. Amount of manure produced per year and cow/swine stall place, and corresponding nutrient content. Reworked data from Steineck et al. (2000)

Origin	Manure (kg ww/yr)	Manure (kg DM/yr)	P (kg/yr)	N (kg/yr)	P (% of DM)	N (% of DM)
Per dairy cow, solid manure	12450	1990	14	38	0.7	1.9
Per dairy cow, liquid manure	19810	1780	14	96	0.8	5.4
Per swine stall place, liquid manure	1540	140	1.5	7	1.1	5.1

Table 19. Amount of digestion residues produced per year and cow/swine stall place, and corresponding nutrient content. Reworked data from Steineck et al. (2000)

Origin	Digestion residues (kg ww/ yr)	Digestion residues (kg DM/ yr)	P (kg/yr)	N (kg/yr)	P (% of DM)	N (% of DM)
Per dairy cow, solid manure	21270	1060	14	38	1.3	3.6
Per dairy cow, liquid manure	18970	950	14	96	1.5	10.1
Per swine stall place, liquid manure	1460	60	1.5	7	2.5	12.0

5.2 System description of upgrading plant

The upgrading of raw gas was assumed to take place via absorption of water in a water scrubber, which is currently the most commonly used technology in Sweden (Persson, 2003). A schematic image of the technology is shown in Figure 6.

The technology is based on the fact that carbon dioxide, hydrogen sulphide and, to a certain extent, methane dissolve in pressurized water. The raw gas is compressed and led into the absorption column from the bottom, where it meets the water which is led in from the top. The cleaned gas leaves the column at the top and continues to an adsorption dryer. The gas is then odorized and compressed under high pressure, ready to be pumped to gas stations. The water is led to a flash tank with lower pressure, where methane is separated (and returned to the clean gas) and then to a desorption column, where it is cleaned from carbon dioxide. It is then ready to be used again in the absorption column.

The upgrading plant was assumed to have a capacity of 10 000 MWh upgraded biogas per year, corresponding to 1.02 million Nm³ of clean gas or 1 million litres of diesel.

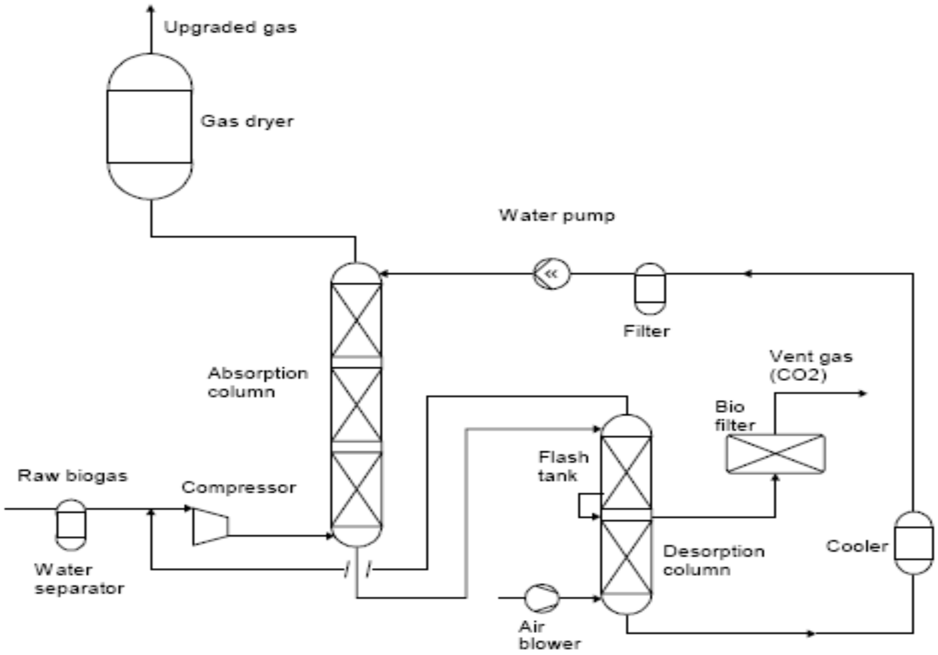


Figure 6. Absorption with recirculating water (Persson, 2003).

5.3 Emissions of methane and nitrous oxide

During the upgrading process, some methane will leak out. For a recirculating water scrubber, the methane losses can be as high as 18%, but leakage corresponding to less than 2% has also been reported (Persson, 2003). The methane leakage at an upgrading facility in Boden where the water scrubber technique is applied (estimated at 3% at the facility) was used here. The methane is eliminated via catalytic combustion which simultaneously provides heating for the plant buildings. This results in methane leakage to the atmosphere of less than 0.1% of the vehicle gas produced (Held et al., 2008), and the value 0.1% was therefore used in this calculation.

Methane will also volatilize during storage of the digestion residues or, in the reference case, storage of the manure. The difference in methane emissions between these two systems is the final result. These emissions were calculated in accordance with the IPCC (2006) method:

$$\textit{Methane emissions} = G_{OM} \times B_0 \times 0{,}71 \times MCF \quad (\text{kg CH}_4)$$

Nitrous oxide is emitted in small quantities during storage of manure and digestion residues and these were also calculated using the IPCC (2006) method:

$$\textit{Nitrous oxide emissions} = G_{DM} \times Frac_{N-tot} \times \left(\frac{44}{28}\right) \times EF \quad (\text{kg N}_2\text{O})$$

where G_{OM} and G_{DM} are the amount of substrate (manure or digestion residues) per kg organic matter (OM), i.e. dry matter minus ash, and per kg dry matter (DM), respectively. The organic matter was assumed to be 80% of the dry matter [1]. B_0 is the maximum methane producing capacity of the substrate, given in Nm^3/kg OM. In the digestion residues, B_0 is lower than for manure as most of the methane has already been extracted in the digestion chambers. Values for B_0 were taken from [1]. $Frac_{N-tot}$ is the share of nitrogen (N-tot) in the substrate, calculated based on data on nutrient content in faeces and urine from dairy cows and swine, see Tables 9 and 10.

The emission factors *Methane Conversion Factor (MCF*) and *Emission Factor (EF)* give the proportion of the maximal production of methane and the available nitrogen in the substrate, respectively, that is volatilized. In these calculations the nitrogen is converted to nitrous oxide via the conversion factor 44/28 and the methane is converted to weight units via the density 0.71 kg/m^3. The emission factors are different for solid and liquid manure, as shown in Table 20. The digestion residues were assumed to have the same emission factor as liquid manure, as comparable emission factors for digestion residues were not available.

Table 20. Emission factors for methane (MCF) and nitrous oxide (EF) during storage of solid manure and liquid manure/digestion residues respectively (IPCC, 2006; Dustan 2002)

	MCF (%)	EF (%)
Solid manure	1	2
Liquid manure	10	0.1
Digestion residues	10	0.1

Methane emissions from the system can in theory also occur via leakage of raw gas from tanks and pipelines. However, the construction of the system was assumed not to allow for such losses.

5.4 Process electricity and process heat

Process electricity is required for the digestion process (pumps, macerators, mixers, etc.) and for the upgrading process. The electricity was assumed to be Swedish electricity mix with average emissions of 22.6 g CO_2-eq/kWh (Tobias Persson, Swedish Energy Agency, pers. comm. I). The heat requirement for digestion was calculated according to the formula below. The heat was assumed to be produced in a biofuelled boiler with 90% efficiency. Emission data from the production and use of pellets were taken from Uppenberg et al. (2001)

$$\text{Process heat} = G_{ww} \times (T_{mesophilic} - T_{storage}) \times ((Frac_{H_2O} \times 4.2) + (Frac_{DM} \times 1.0)) \quad \text{(kJ)}$$

where G_{ww} is the amount of manure (kg ww) in the digestion chamber, T is the temperature in the digestion chamber (mesophilic temperature, ~37 ºC) and in the storage tank (i.e. the temperature of the manure before being fed into the digestion chamber) respectively. $Frac_{H_2O}$ and $Frac_{DM}$ are the fractions of water and dry matter, and the values 4.2 and 1.0 are the specific heat capacities of water and dry matter in kJ/kg K.

5.5 Diesel consumption during spreading of digestion residues/manure

A blend of 5% biofuels was assumed in diesel used for spreading of digestion residues and manure, just as for machine operations during cultivation of biofuel crops. Emissions from the production and distribution of RME were taken from Bernesson (2004). The diesel consumption (in litres) for spreading was calculated as:

$$\textit{Diesel consumption} = \left(\frac{G_{tot}}{G_{application}} \times DC_{ha}\right) + \left(\frac{G_{tot}}{LC} \times DC_{km,loaded} \times X\right) + \left(\frac{G_{tot}}{LC} \times DC_{km,empty} \times X\right)$$

where *G* is the amount of manure or digestion residues (kg) calculated for this specific system, *DC* is the specific diesel consumption (l/ha or l/km) and *X* is the distance between storage and field, which was assumed to be 1.6 km based on interviews with farmers (Rodhe et al., 2008). *LC* is the load capacity, which for the liquid manure spreader was assumed to be 15 000 l and for the solid manure spreader 12000 kg (Rodhe et al., 2008). Data on diesel consumption of the spreaders were taken from Lindgren et al. (2002). Emissions from the production (extraction, refinery and distribution) of diesel are included in the calculations (Blinge et al., 1997, reworked by Börjesson, 2006).

6. RESULTS

6.1 Greenhouse gas emissions from cultivation of crops for biofuel production

The calculated direct and indirect nitrous oxide emissions per crop type and county are presented in Tables 21 and 22, respectively. The highest direct nitrous oxide emissions stemmed from cultivation of winter rapeseed and winter wheat. Emissions from spring barley were slightly lower and the lowest direct emissions were from Triticale (Table 12). The highest indirect nitrous oxide emissions were from winter rapeseed and the lowest from Triticale (Table 13). Indirect emissions were about 10% of direct emissions.

Table 21. Calculated direct emissions of nitrous oxide (kg N_2O/ha yr)

County	Winter wheat	Spring barley	Triticale	Winter rapeseed	Spring wheat	Rye	Oats
Stockholm	2.55	1.80	2.40		2.43		1.56
Uppsala	2.92	1.83	2.48		2.40	1.94	1.71
Södermanland	2.84	1.69	2.33	2.69	2.52	1.82	1.83
Östergötland	2.82	2.22	2.39	2.70	2.20	2.42	1.77
Jönköping	2.25	1.40	2.08				1.32
Kronoberg	1.89	1.11	1.64				0.96
Kalmar	2.50	1.64	2.12	2.22	1.65		1.48
Gotland	2.26	1.55	1.88	2.70	2.35	1.66	1.58
Blekinge	2.58	1.60	2.00		2.57		1.75
Skåne	3.23	2.00	2.44	3.07	3.12	2.61	1.96
Halland	2.89	1.71	1.98	3.12	2.28		1.90
V:a Götaland	3.05	2.04	2.37	2.85	2.30	2.30	2.02
Värmland	2.65	1.84	2.43				1.74
Örebro	2.75	1.92	2.55		2.60	2.48	1.77
Västmanland	2.69	1.83	2.31		2.22		1.81
Dalarna	2.27	1.49					1.60
Gävleborg		1.12					1.33
Västernorrland		1.09					
Jämtland		1.18					
Västerbotten		1.15					0.90
Norrbotten		1.10					

Table 22. Calculated indirect emissions of nitrous oxide (kg N_2O/ha yr)

County	Winter wheat	Spring barley	Triticale	Winter rapeseed	Spring wheat	Rye	Oats
Stockholm	0.19	0.17	0.15		0.17		0.15
Uppsala	0.20	0.17	0.15		0.17	0.15	0.15
Södermanland	0.20	0.17	0.15	0.27	0.17	0.15	0.16
Östergötland	0.39	0.37	0.32	0.46	0.41	0.34	0.33
Jönköping	0.38	0.39	0.31				0.33
Kronoberg	0.38	0.38	0.31				0.33
Kalmar	0.33	0.33	0.30	0.47	0.36		0.28
Gotland	0.35	0.32	0.28	0.37	0.30	0.27	0.31
Blekinge	0.37	0.39	0.36		0.38		0.36
Skåne	0.41	0.44	0.39	0.64	0.46	0.38	0.45
Halland	0.34	0.39	0.37	0.52	0.47		0.46
V:a Götaland	0.42	0.40	0.35	0.45	0.37	0.33	0.36
Värmland	0.42	0.36	0.34				0.33
Örebro	0.22	0.20	0.17		0.18	0.17	0.18
Västmanland	0.20	0.17	0.15		0.17		0.16
Dalarna	0.31	0.29					0.28
Gävleborg		0.27					0.27
Västernorrland		0.26					
Jämtland		0.22					
Västerbotten		0.28					0.26
Norrbotten		0.28					

Tables 23-29 show total greenhouse gas emissions for the different cultivation steps for each crop type and county (NUTS 3). In Table 30. the total emissions of greenhouse gases for each crop are presented on regional level (NUTS 2).

Table 23. Emissions of greenhouse gases from cultivation of winter wheat (g CO_2-eq/MJ ethanol)

County	Field operations	Crop drying	Fertilizer production and transport	Pesticide production	Direct N_2O emissions from soil	Indirect N_2O	Total
Stockholm	2.37		5.45	0.01	10.56	0.80	19.2
Uppsala	2.34		5.74	0.02	10.92	0.74	19.8
Södermanland	2.45		6.14	0.02	11.56	0.80	21.0
Östergötland	2.09		5.36	0.02	10.33	1.43	19.2
Jönköping	1.89		5.33	0.00	9.90	1.68	18.8
Kronoberg	2.07		5.37	0.01	9.23	1.85	18.5
Kalmar	1.80		5.46	0.05	9.79	1.29	18.4
Gotland	1.97		5.38	0.03	10.03	1.54	19.0
Blekinge	1.67		5.18	0.05	9.80	1.39	18.1
Skåne	1.40		5.40	0.07	10.11	1.29	18.3
Halland	1.66		5.92	0.04	10.74	1.27	19.6
V:a Götaland	1.84		6.15	0.02	11.46	1.58	21.0
Värmland	2.18		6.12	0.03	11.39	1.82	21.5
Örebro	2.02		5.54	0.02	10.40	0.82	18.8
Västmanland	2.45		5.76	0.04	10.77	0.78	19.8
Dalarna	2.16		5.56	0.02	10.30	1.43	19.5
Gävleborg							
Västernorrland							
Jämtland							
Västerbotten							
Norrbotten							

Table 24. Emissions of greenhouse gases from cultivation of spring barley (g CO_2-eq/MJ ethanol)

County	Field operations	Crop drying	Fertilizer production and transport	Pesticide production	Direct N_2O emissions from soil	Indirect N_2O	Total
Stockholm	3.36		5.21	0.04	10.51	0.99	20.1
Uppsala	3.16		4.33	0.03	9.19	0.85	17.6
Södermanland	3.28		4.40	0.02	9.17	0.90	17.8
Östergötland	2.81		5.58	0.03	10.83	1.78	21.0
Jönköping	3.15		5.54	0.09	10.19	2.80	21.8
Kronoberg	3.26		4.64	0.10	8.45	2.91	19.4
Kalmar	2.97		6.08	0.04	10.54	2.13	21.8
Gotland	2.61		5.02	0.03	9.01	1.85	18.5
Blekinge	2.58		5.03	0.10	9.30	2.24	19.3
Skåne	2.01		4.68	0.07	8.88	1.97	17.6
Halland	2.33		4.58	0.05	8.83	2.04	17.8
V:a Götaland	2.66		5.88	0.03	11.02	2.13	21.7
Värmland	3.14		6.06	0.04	11.31	2.22	22.8
Örebro	2.72		4.88	0.03	9.70	1.01	18.3
Västmanland	3.17		4.50	0.04	9.40	0.89	18.0
Dalarna	3.21		5.70	0.06	10.00	1.92	20.9
Gävleborg	4.06		4.85	0.05	9.26	2.20	20.4
Västernorrland	4.74		5.66	0.10	10.38	2.44	23.3
Jämtland	3.62		4.58	0.00	8.92	1.69	18.8
Västerbotten	4.52		6.35	0.06	11.47	2.80	25.2
Norrbotten	4.33		5.70	0.00	10.36	2.64	23.0

Table 25. Emissions of greenhouse gases from cultivation of Triticale (g CO_2-eq/MJ ethanol)

County	Field operations	Crop drying	Fertilizer production and transport	Pesticide production	Direct N_2O emissions from soil	Indirect N_2O	Total
Stockholm	2.49		5.16	0.01	10.45	0.67	18.8
Uppsala	2.64		5.51	0.01	10.50	0.65	19.3
Södermanland	2.59		5.00	0.01	10.01	0.66	18.3
Östergötland	2.35		4.84	0.01	9.81	1.30	18.3
Jönköping	2.26		6.09	0.03	10.94	1.64	21.0
Kronoberg	2.29		4.30	0.05	8.90	1.66	17.2
Kalmar	2.39		5.98	0.03	10.98	1.54	20.9
Gotland	2.23		4.93	0.07	9.47	1.41	18.1
Blekinge	2.20		5.20	0.02	9.99	1.79	19.2
Skåne	1.94		5.46	0.05	10.54	1.67	19.7
Halland	1.88		3.93	0.03	8.34	1.57	15.8
V:a Götaland	2.07		5.15	0.03	10.05	1.48	18.8
Värmland	2.17		5.36	0.03	10.38	1.46	19.4
Örebro	2.30		5.70	0.03	10.99	0.72	19.7
Västmanland	2.60		4.80	0.02	9.77	0.64	17.8
Dalarna							
Gävleborg							
Västernorrland							
Jämtland							
Västerbotten							
Norrbotten							

Table 26. Emissions of greenhouse gases from production of winter rapeseed (g CO_2-eq/MJ RME)

County	Field operations	Crop drying	Fertilizer Production and transport	Pesticide production	Direct N_2O emissions from soil	Indirect N_2O	Total
Stockholm							
Uppsala							
Södermanland	2.35		6.80	0.03	11.63	1.16	22.0
Östergötland	1.83		5.56	0.06	9.66	1.64	18.8
Jönköping							
Kronoberg							
Kalmar	1.54		5.09	0.07	8.54	1.80	17.0
Gotland	1.54		6.23	0.04	10.76	1.47	20.0
Blekinge							
Skåne	1.35		6.30	0.06	10.62	2.22	20.6
Halland	1.46		7.03	0.05	11.74	1.95	22.2
V:a Götaland	1.57		6.16	0.05	10.39	1.64	19.8
Värmland							
Örebro							
Västmanland							
Dalarna							
Gävleborg							
Västernorrland							
Jämtland							
Västerbotten							
Norrbotten							

Table 27. Emissions of greenhouse gases from cultivation of spring wheat (g CO_2-eq/MJ ethanol)

County	Field operations	Crop drying	Fertilizer production and transport	Pesticide production	Direct N_2O emissions from soil	Indirect N_2O	Total
Stockholm	2.98		6.84	0.02	12.60	0.88	23.3
Uppsala	2.89		6.07	0.02	11.05	0.77	20.8
Södermanland	2.95		6.72	0.04	12.25	0.83	22.8
Östergötland	2.72		5.48	0.02	10.41	1.95	20.6
Jönköping							
Kronoberg							
Kalmar	2.28		4.08	0.02	8.10	1.75	16.2
Gotland	2.34		6.84	0.04	12.26	1.55	23.0
Blekinge	1.91		6.20	0.07	11.14	1.65	21.0
Skåne	1.91		7.38	0.07	13.19	1.96	24.5
Halland	2.06		5.57	0.03	10.44	2.15	20.3
V:a Götaland	2.46		6.41	0.03	11.50	1.82	22.2
Värmland							
Örebro	2.27		5.91	0.03	11.01	0.77	20.0
Västmanland	3.03		5.91	0.05	10.88	0.83	20.7
Dalarna							
Gävleborg							
Västernorrland							
Jämtland							
Västerbotten							
Norrbotten							

Table 28. Emissions of greenhouse gases from cultivation of rye (g CO_2-eq/MJ ethanol)

County	Field operations	Crop drying	Fertilizer production and transport	Pesticide production	Direct N_2O emissions from soil	Indirect N_2O	Total
Stockholm							
Uppsala	2.69		3.74	0.01	8.34	0.63	15.4
Södermanland	2.86		3.91	0.02	8.63	0.70	16.1
Östergötland	2.16		4.34	0.04	9.13	1.28	17.0
Jönköping							
Kronoberg							
Kalmar							
Gotland	2.36		4.09	0.01	8.83	1.44	16.7
Blekinge							
Skåne	1.65		4.70	0.06	9.57	1.38	17.4
Halland							
V:a Götaland	1.96		4.47	0.04	9.22	1.34	17.0
Värmland							
Örebro	2.45		5.99	0.02	11.37	0.76	20.6
Västmanland							
Dalarna							
Gävleborg							
Västernorrland							
Jämtland							
Västerbotten							
Norrbotten							

Table 29. Emissions of greenhouse gases from cultivation of oats (g CO_2-eq/MJ ethanol)

County	Field operations	Crop drying	Fertilizer production and transport	Pesticide production	Direct N_2O emissions from soil	Indirect N_2O	Total
Stockholm	3.63		4.84	0.02	9.83	0.97	19.3
Uppsala	3.28		4.21	0.04	8.90	0.81	17.2
Södermanland	3.37		5.13	0.04	10.18	0.87	19.6
Östergötland	2.93		4.41	0.03	9.01	1.67	18.0
Jönköping	2.98		4.82	0.14	9.11	2.27	19.3
Kronoberg	2.78		3.20	0.02	6.28	2.13	14.4
Kalmar	3.05		5.35	0.02	9.72	1.85	20.0
Gotland	2.91		5.55	0.03	10.30	2.01	20.8
Blekinge	2.62		5.42	0.10	10.33	2.15	20.6
Skåne	2.15		4.82	0.07	9.30	2.12	18.5
Halland	2.37		5.30	0.05	9.98	2.40	20.1
V:a Götaland	2.67		5.78	0.03	10.96	1.93	21.4
Värmland	3.19		5.61	0.05	10.89	2.08	21.8
Örebro	2.84		4.69	0.03	9.37	0.98	17.9
Västmanland	3.23		4.66	0.04	9.49	0.86	18.3
Dalarna	3.14		5.61	0.06	10.48	1.85	21.1
Gävleborg	4.32		6.52	0.00	11.70	2.39	24.9
Västernorrland							
Jämtland							
Västerbotten	4.64		6.55	0.00	9.17	2.61	23.0
Norrbotten							

Table 30. Total emissions of greenhouse gases on region level (NUTS 2) as g CO_2-eq/MJ ethanol for winter wheat, spring barley, Triticale, spring wheat and oats, and as g CO_2-eq/MJ RME for winter rapeseed. The average results on county level (NUTS 3) are weighted in proportion to the area cultivated with each crop type in the respective region (NUTS 2)

	Winter wheat	Spring barley	Triticale	Winter rapeseed	Spring wheat	Rye	Oats
Stockholm	19	20	19				19
Eastern Mid-Sweden	20	18	19	19	21	17	18
Småland and the Islands	19	20	20	19	23	17	18
Southern Sweden	18	18	20	21	25	17	19
Western Sweden	21	20	18	20	22	17	21
Northern Mid-Sweden	21	21	19			21	22
Mid-Norrland		22					
Northern Norrland		25					

6.2 Greenhouse gas emissions from cultivation of crops for biogas

Tables 31-35 show total greenhouse gas emissions for the different cultivation steps for each crop type and county (NUTS 3) in g CO_2-eq/MJ compressed vehicle gas. Table 36 shows total greenhouse gas emissions for each crop type and county (NUTS 3) in g CO_2-eq/kg DM of the crop. In Table 37, the total emissions of greenhouse gases for the different crops are presented on regional level (NUTS 2).

Table 31. Emissions of greenhouse gases from cultivation of sugar beets incl. tops (g CO_2-eq/MJ compressed vehicle gas)

County	Field operations	Fertilizer production and transport	Pesticide production	Direct N_2O emissions from soil	Indirect N_2O	Total
Stockholm						
Uppsala						
Södermanland						
Östergötland						
Jönköping						
Kronoberg						
Kalmar	1.64	2.27	0.12	5.57	0.63	10.2
Gotland	1.95	2.99	0.10	6.68	0.60	12.3
Blekinge	1.56	1.64	0.09	4.92	0.62	8.8
Skåne	1.54	2.20	0.11	5.63	0.79	10.3
Halland	1.65	2.29	0.13	5.65	0.89	10.6
V:a Götaland						
Värmland						
Örebro						
Västmanland						
Dalarna						
Gävleborg						
Västernorrland						
Jämtland						
Västerbotten						
Norrbotten						

Table 32. Emissions of greenhouse gases from cultivation of silage maize (g CO_2-eq/MJ compressed vehicle gas)

County	Field operations	Fertilizer production and transport	Pesticide production	Direct N_2O emissions from soil	Indirect N_2O	Total
Stockholm	1.85	1.84	0.00	5.54	0.37	9.6
Uppsala	1.96	1.84	0.00	5.54	0.37	9.7
Södermanland	1.91	1.84	0.00	5.54	0.37	9.7
Östergötland	1.85	2.03	0.00	5.48	0.77	10.1
Jönköping	1.56	2.04	0.00	5.48	0.83	9.9
Kronoberg	1.55	1.95	0.03	5.32	0.83	9.7
Kalmar	1.62	1.67	0.00	5.80	0.71	9.8
Gotland	1.59	1.65	0.01	5.60	0.69	9.5
Blekinge	1.58	1.58	0.01	5.63	0.82	9.6
Skåne	1.60	1.28	0.01	4.95	0.93	8.8
Halland	1.60	1.78	0.04	5.57	0.84	9.8
V:a Götaland	1.68	1.84	0.00	5.15	0.83	9.5
Värmland	1.72	1.70	0.00	4.41	0.77	8.6
Örebro	1.77	1.60	0.00	4.44	0.43	8.2
Västmanland	1.93	1.84	0.00	5.54	0.38	9.7
Dalarna				0.00	0.56	0.6
Gävleborg	1.68	2.10	0.00	5.06	0.59	9.4
Västernorrland						
Jämtland						
Västerbotten						
Norrbotten						

Table 33. Emissions of greenhouse gases from cultivation of wheat straw (g CO_2-eq/MJ compressed vehicle gas)

County	Field operations	Fertilizer production and transport	Pesticide production	Direct N_2O emissions from soil	Indirect N_2O	Total
Stockholm	1.01					1.0
Uppsala	1.00					1.0
Södermanland	1.02					1.0
Östergötland	0.98					1.0
Jönköping	0.96					1.0
Kronoberg	1.00					1.0
Kalmar	0.98					1.0
Gotland	1.01					1.0
Blekinge	1.06					1.1
Skåne	1.01					1.0
Halland	1.01					1.0
V:a Götaland	0.98					1.0
Värmland	1.01					1.0
Örebro	1.00					1.0
Västmanland	0.97					1.0
Dalarna	1.01					1.0
Gävleborg						
Västernorrland						
Jämtland						
Västerbotten						
Norrbotten						

Table 34. Emissions of greenhouse gases from cultivation of ley (g CO_2-eq/MJ compressed vehicle gas)

County	Field operations	Fertilizer production and transport	Pesticide production	Direct N_2O emissions from soil	Indirect N_2O	Total
Stockholm	2.56	1.94	0.04	11.83	0.26	16.6
Uppsala	2.62	1.95	0.06	11.83	0.26	16.7
Södermanland	2.60	1.96	0.04	11.83	0.26	16.7
Östergötland	2.40	1.62	0.00	11.18	0.42	15.6
Jönköping	2.18	1.46	0.14	10.89	0.59	15.3
Kronoberg	2.17	1.48	0.04	10.89	0.59	15.2
Kalmar	2.21	1.47	0.03	10.89	0.46	15.1
Gotland	2.18	1.37	0.00	10.82	0.46	14.8
Blekinge	2.18	1.46	0.05	10.86	0.59	15.1
Skåne	2.19	1.48	0.05	10.86	0.63	15.2
Halland	2.19	1.47	0.12	10.87	0.64	15.3
V:a Götaland	2.24	1.48	0.08	10.89	0.48	15.2
Värmland	2.48	1.99	0.00	11.83	0.43	16.7
Örebro	2.52	1.97	0.00	11.83	0.31	16.6
Västmanland	2.61	1.96	0.00	11.83	0.28	16.7
Dalarna	2.45	1.81	0.04	11.83	0.32	16.5
Gävleborg	2.46	1.97	0.00	11.83	0.34	16.6
Västernorrland	2.47	1.84	0.00	11.83	0.34	16.5
Jämtland	2.45	1.86	0.00	11.83	0.37	16.5
Västerbotten	2.08	1.88	0.00	11.83	0.56	16.3
Norrbotten	2.09	1.91	0.03	11.19	0.54	15.8

Table 35. Emissions of greenhouse gases from cultivation of reed canary grass (g CO_2-eq/MJ compressed vehicle gas)

County	Field operations	Fertilizer production and transport	Pesticide production	Direct N_2O emissions from soil	Indirect N_2O	Total
Stockholm	1.70	0.17	0.03	8.39	0.22	10.6
Uppsala	1.73	0.17	0.05	8.39	0.22	10.6
Södermanland	1.72	0.17	0.03	8.39	0.22	10.6
Östergötland	1.70	0.19	0.00	8.39	0.37	10.7
Jönköping	1.63	0.21	0.14	8.39	0.55	10.9
Kronoberg	1.63	0.22	0.04	8.39	0.55	10.9
Kalmar	1.65	0.21	0.03	8.39	0.42	10.7
Gotland	1.64	0.17	0.00	8.39	0.43	10.7
Blekinge	1.64	0.22	0.05	8.39	0.55	10.9
Skåne	1.64	0.24	0.05	8.39	0.59	10.9
Halland	1.64	0.22	0.12	8.39	0.60	11.0
V:a Götaland	1.66	0.22	0.07	8.39	0.45	10.8
Värmland	1.67	0.20	0.00	8.39	0.36	10.7
Örebro	1.69	0.19	0.00	8.39	0.26	10.6
Västmanland	1.73	0.18	0.00	8.39	0.23	10.6
Dalarna	1.65	0.19	0.03	8.39	0.27	10.6
Gävleborg	1.66	0.19	0.00	8.39	0.28	10.6
Västernorrland	1.66	0.21	0.00	8.39	0.28	10.6
Jämtland	1.65	0.23	0.00	8.39	0.31	10.6
Västerbotten	1.37	0.24	0.00	8.39	0.47	10.5
Norrbotten	1.38	0.27	0.03	8.12	0.46	10.3

Table 36. Emissions of greenhouse gases from cultivation of each crop type (g CO_2-eq/kg DM)

County	Sugar beets incl. tops	Silage maize	Wheat straw	Ley	RCG
Stockholm		125	9	150	95
Uppsala		126	9	151	95
Södermanland		126	9	150	95
Östergötland		145	9	140	96
Jönköping		142	9	136	99
Kronoberg		138	9	135	98
Kalmar	103	111	9	134	97
Gotland	125	114	9	132	96
Blekinge	89	109	10	135	98
Skåne	104	104	9	136	99
Halland	107	122	9	137	99
V:a Götaland		136	9	136	98
Värmland		145	9	151	96
Örebro		131	9	150	95
Västmanland		126	9	150	95
Dalarna				148	95
Gävleborg		159		150	95
Västernorrland				148	95
Jämtland				149	96
Västerbotten				147	95
Norrbotten				142	93

Table 37. Total emissions of greenhouse gases on region level (NUTS 2) as g CO_2-eq/MJ compressed vehicle gas. The average results on county level (NUTS 3) are weighted in proportion to the area cultivated with each crop type in the respective region (NUTS 2)

	Sugar beets incl. tops	Silage maize	Wheat straw	Ley	RCG
Stockholm		9.6	0.0	16.6	10.6
Eastern Mid-Sweden		9.8	1.0	16.4	10.6
Småland and the Islands	10.4	9.7	1.0	15.1	10.7
Southern Sweden	10.2	8.8	1.0	15.2	10.9
Western Sweden	10.6	9.7	1.0	15.2	10.8
Northern Mid-Sweden		9.6	1.0	16.6	10.7
Mid-Norrland				16.5	9.3
Northern Norrland				16.1	10.1

6.3 Greenhouse gas emissions from production of biogas from solid and liquid manure

Table 38 presents the total emissions of greenhouse gases from production of biogas and the emissions from the corresponding amount of manure in the reference system. Table 38 also shows net emissions, i.e. the difference between the biogas system and the reference system. The largest difference between the biogas production system and the reference system as regards digestion of solid manure was the nitrous oxide emissions during storage, whereas the largest difference between the biogas production system and the reference system as regards digestion of liquid manure was the emissions of methane during storage.

Table 38. Emissions of greenhouse gases (g CO_2-eq/MJ vehicle gas) from biogas production, and emissions when the corresponding amount of manure is spread directly on the fields without passing through the digestion system (the reference system)

	Methane leakage in storage	Nitrous oxide emissions in storage	Methane leakage in upgrading	Process heat in digestion	Process electricity in digestion	Process electricity in upgrading	Spreading of digestion residues/manure	Total
<u>Solid manure (cattle)</u>								
Biogas production	0.75	1.29	0.48	0.28	0.22	0.30	0.50	3.8
Reference system	4.13	24.50					0.80	29.4
Net emissions	-3.38	-23.21	0.48	0.28	0.22	0.30	-0.30	-25.6
<u>Liquid manure (cattle)</u>								
Biogas production	0.71	3.21	0.48	0.46	0.22	0.30	0.48	5.8
Reference system	41.50	3.22					0.49	45.2
Net emissions	-40.79	-0.01	0.48	0.46	0.22	0.30	-0.02	-39.4
<u>Liquid manure (swine)</u>								
Biogas production	0.51	2.72	0.48	0.39	0.22	0.30	0.44	5.1
Reference system	42.66	2.57					0.46	45.7
Net emissions	-42.15	0.15	0.48	0.39	0.22	0.30	-0.02	-40.6

7. SENSITIVITY ANALYSIS

All life cycle assessment has embedded uncertainties, including the model chosen here. A number of sensitivity analyses were performed in order to clarify how the assumptions regarding system design, system boundaries and choice of data affected the results.

7.1 Cultivation

7.1.1 Nitrous oxide

Nitrous oxide emissions from soil have a major impact on the greenhouse gas emissions from cultivation of crops for biofuel production. However, there are great uncertainties in estimation of these emissions. Not only are there several different methods that give different results, but every method has large uncertainties associated with it. In the IPCC (2006) method used for these calculations, the emission factors have a given uncertainty range (Table 39). The impact of variations on the final results is shown in Figure 7. As can be seen from this figure, the final result can be significantly higher or significantly lower if the entire uncertainty range for the IPCC emission factors is taken into account. For example, for winter wheat in Skåne County the result varies between 10 and 42 g CO_2-eq/MJ ethanol.

Table 39. Emission factors for calculation of nitrous oxide emissions including the uncertainty range (IPCC, 2006)

	Default value	Uncertainty range
EF_N = Emission factor for added nitrogen (kg N_2O-N/kg N)	0.01	0.003 - 0.030
EF_L = Emission factor for leached nitrogen (kg N_2O-N/kg N	0.0075	0.0005 - 0.025
EF_D = Emission factor for volatilization and re-deposition (kg N_2O-N/kg NH_3-N)	0.01	0.002 - 0.050

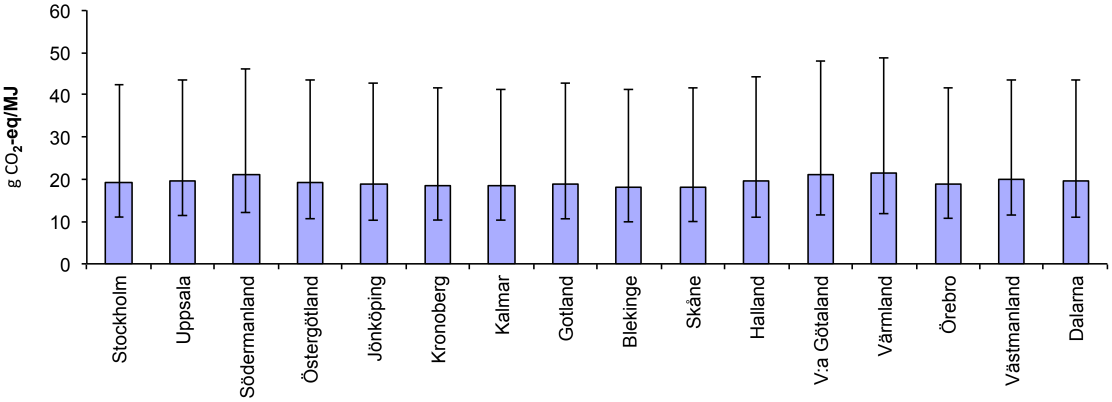


Figure 7. Greenhouse gas emissions (g CO_2-eq/MJ ethanol) from cultivation of winter wheat, including the uncertainty range for calculation of nitrous oxide emissions (IPCC, 2006). The bars indicate the result of applying the highest and lowest emission factor for nitrous oxide, respectively, in the uncertainty range presented by IPCC (2006).

7.1.2 Fertilizers

As mentioned above, the nitrogen fertilizer industry has lowered the emissions from production of fertilizers significantly over the last few years by introducing catalytic cleaning of nitrous oxide. In the base scenario, emissions of 2.9 kg CO_2-eq/kg fertilizer-N were assumed based on data from Yara (Erlingsson, 2009). However, it is important to note that not all production units are equipped with this technology yet. The average emissions value for European production of nitrogen fertilizers in 2003 was 6.8 kg CO_2-eq/kg fertilizer-N (Jenssen and Kongshaug, 2003). Today, the average is probably lower, and 6.8 CO_2-eq/kg fertilizer-N can be considered a 'worst case'. At the other end of the scale is a study by Ahlgren et al. (2008) on the possible future production of mineral nitrogen fertilizers based on gasification of biomass. If straw were used as raw material, the emissions would be reduced to 0.5 kg CO_2-eq/kg fertilizer-N. Variations in the results due to the assumptions on greenhouse gas emissions from production of nitrogen fertilizer are shown in Figure 8.

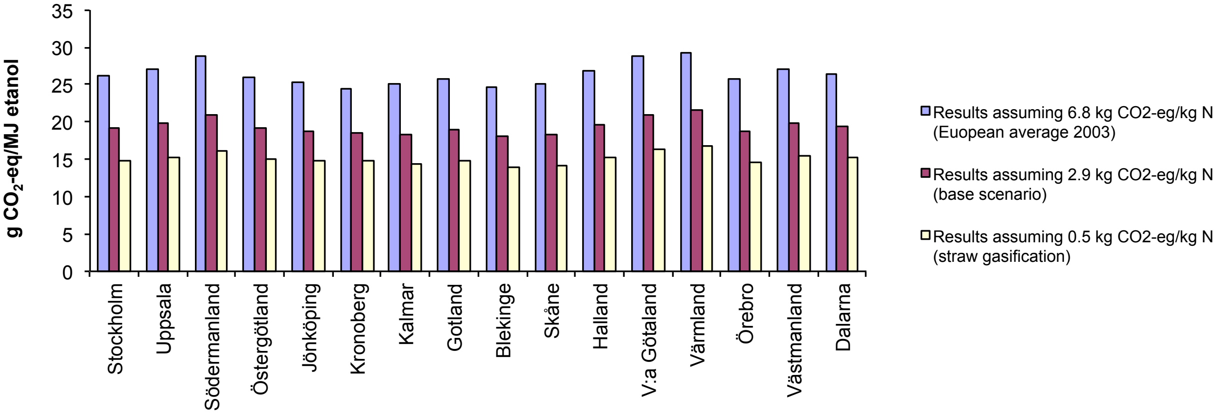


Figure 8. Greenhouse gas emissions (g CO_2-eq/MJ ethanol) for winter wheat, cultivated with nitrogen fertilizers produced by various production methods. Nitrogen fertilizers produced with best available technology are values used in the base scenarios, which are compared in the diagram with values for European average production and the more futuristic option of straw gasification.

The results are clearly sensitive to the assumption on type of fertilizer-nitrogen used for cultivation (Figure 7). On average for all counties, the total greenhouse gas emissions increased by 37% for cultivation of winter wheat using European average fertilizer-nitrogen compared with nitrogen from a production unit equipped with best available technology (base scenario). Using nitrogen fertilizers produced via gasification of straw, however, would decrease total emissions of greenhouse gases by an average of 23%.

It is also feasible that a certain proportion of the grain and oilseeds for biofuel production would be cultivated with animal manure as fertilizer. Although most farms with animals produce grain for feed, some of it is sold. Including manure in the calculations would have a large impact on the results. According to the EU Directive, production of farmyard manure does not have to be burdened with any greenhouse gas emissions for the calculation and is thereby considered to be 'for free' from a climate perspective. However, it is not clear from the Directive how far into the system it should be considered as being for free. Up until the manure is collected in a storage tank it can be considered to be for free, but after that the situation becomes more complicated. Should the emissions from the storage, the energy consumed during spreading of the manure and the nitrogen emissions stemming from spreading be included? Or should emissions associated with the use of manure be accounted for in milk/meat production? If this were the case, crop cultivation would have a 'free' fertilizer and total emissions would be lowered. However, due to the many unanswered questions, SLU opted not to present any calculations for cultivation systems fertilized with manure.

7.1.3 Dedicated ethanol grains

Today, most of the wheat cultivated in Sweden is bread wheat. If the protein content is not high enough, the wheat is used as fodder or for ethanol production. However, it is feasible that a larger proportion of dedicated ethanol wheat will be cultivated in the future with varieties developed especially for ethanol production. Such varieties include Harnesk, Tulsa and Ellvis that have lower protein content and higher starch content. The yields are also higher than for conventional bread wheat varieties such as Olivin relative to the amount of nitrogen applied (Gruvaeus, 2007). The optimal nitrogen addition is lower if maximizing the protein content is not the main aim.

According to the Swedish Rural Economy and Agricultural Society in Skara (Gruvaeus, 2007), the optimal nitrogen addition for the variety Harnesk is 58 kg N/ha (25%) lower when producing ethanol wheat instead of bread wheat, which reduces the yield by 370 kg/ha (4%). In a variety trial (Krijger, 2008), the optimal nitrogen addition for the variety Tulsa was shown to be 8 kg N/ha (4%) lower when aiming for ethanol wheat instead of bread wheat, which reduced the yield by 71 kg/ha (1%). A study by SLU and JTI analysed the potential for improving the profitability of grain cultivation (Gunnarsson, 2008) on three fictitious farms. It was concluded that the optimal nitrogen addition for winter wheat dedicated to ethanol was 25 kg/ha lower than for bread wheat, reducing the yield by 200 kg/ha.

According to the sensitivity analysis, using dedicated ethanol grain as the base scenario would affect (lower) the greenhouse gas emissions in the present study. The sensitivity analysis assumed that nitrogen addition was reduced by 25% and yield by 4% (Figure 9). Using dedicated cereal cultivars for ethanol production would reduce total greenhouse gas emissions by 3 g CO_2-eq/MJ ethanol (15%), on average for all counties.

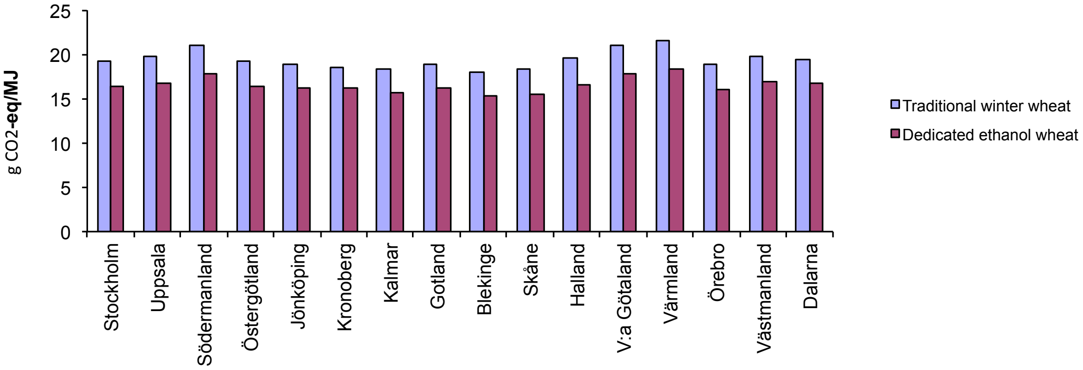


Figure 9. Greenhouse gas emissions (g CO_2-eq/MJ ethanol) for conventional wheat compared with dedicated ethanol wheat (lower nitrogen addition and lower yields).

7.1.4 Organic soils

In Sweden, some organic soils are cropped with annual crops, although leys are the dominant crop type on such soils (Berglund and Berglund, 2008). On average, 2.2% of Swedish arable land consists of organic soils cropped with annual crops (Table 40). ‘Organic’ normally refers to a soil with more than 30% soil organic matter (Kerstin Berglund, SLU, pers. comm.). A sensitivity analysis for greenhouse gas emissions from organic soil was conducted for spring barley in Örebro County (Figure 10). Winter crops are very rare on this soil type due to problems with root freezing (Anna Redner, Swedish Rural Economy and Agricultural Society in Örebro, pers. comm.). Data on nitrogen leaching from organic soils in the county have not been reported. The Department of Soil and Environment at SLU provided data for this purpose from the type area T10 (Husön) in Örebro county, which is dominated by organic soils (75%). The area is surrounded by embankments and the runoff water is pumped off. The runoff level is uncertain, and an estimated runoff value (target runoff, 200 mm/year) was used in the calculation of nitrogen transport (Johnsson et al., 2008). The average content of total nitrogen in runoff water during the runoff season 2005/06-2007/08 (15.4 mg tot-N/l) was used for the calculation. The total nitrogen transport so calculated was 30.8 kg N/ha and year.

Table 40. Area and proportion of organic soils in each county, and area and proportion of organic soils cropped with annual crops. Recalculated data from Berglund & Berglund (2008)

County	Area organic soils (ha)/proportion organic soils (%)	Proportion organic soils cropped with annual crops (%)	Proportion organic soils cropped with annual crops in relationship to total arable area (%)
Stockholm	12237/10.9	33.8	3.7
Uppsala	18817/10.3	37.8	3.9
Södermanland	16961/10.7	38.5	4.1
Östergötland	19547/7.1	27.4	2.0
Jönköping	14099/9.5	9.1	0.9
Kronoberg	12202/14.7	11.9	1.8
Kalmar	18523/8.2	19.7	1.6
Gotland	12610/9.9	29.5	2.9
Blekinge	5950/11.0	22.0	2.4
Skåne	25504/5.0	24.4	1.2
Halland	7312/5.0	26.9	1.3
V:a Götaland	47109/7.9	26.5	2.1
Värmland	2934/2.2	21.2	0.5
Örebro	16958/13.3	55.4	7.4
Västmanland	12256/8.7	50.0	4.3
Dalarna	10649/12.6	24.8	3.1
Gävleborg	5635/6.6	24.1	1.6
Västernorrland	1874/2.9	16.7	0.5
Jämtland	980/1.8	10.2	0.2
Västerbotten	3494/3.8	25.3	1.0
Norrbotten	4750/9.2	13.2	1.2
Total/mean	**270238/7.7**	**28.6**	**2.2**

Nitrogen addition to organic soils varies greatly and in this study was assumed to be 20 kg N/ha and year. However, phosphorus and potassium were assumed to be applied in the same amounts as on mineral soils in the area. The draught force requirement for soil preparation was assumed to be the same as for sandy soils. Nitrous oxide emissions were calculated according to the IPCC (2006) method.

Carbon dioxide emissions caused by mineralization of organic material from cultivation of organic soils were not included in this study. Organic soils in the area were made available for cultivation when the drainage ditches were installed, which took place long before 2008 (stipulated in the EU Directive).

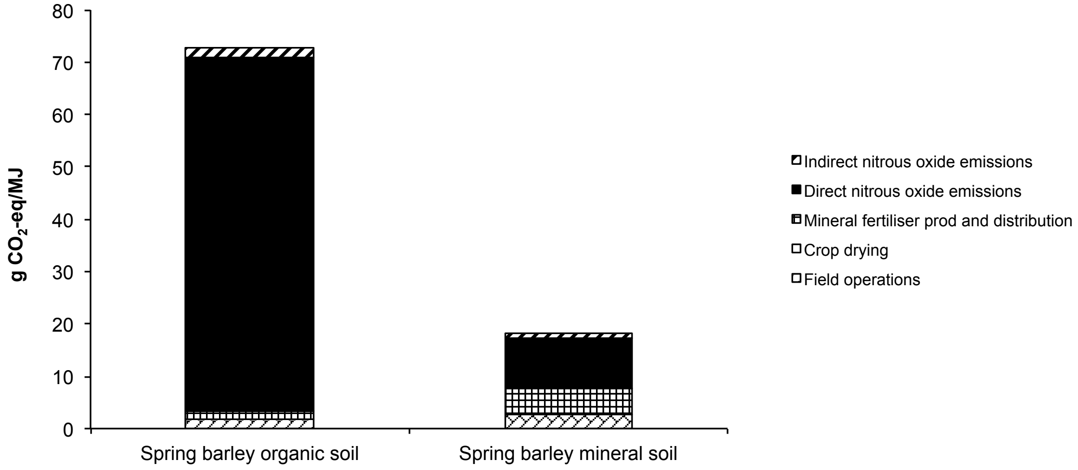


Figure 10. Greenhouse gas emissions (g CO_2-eq/MJ ethanol) from cultivation of spring barley on organic soils and mineral soils in Örebro County.

Crop production on organic soils causes large emissions of greenhouse gases. With the assumptions made in this study, spring barley on organic soils in Örebro, our example, caused emissions corresponding to 73 g CO_2-eq/MJ ethanol compared with 18 g CO_2-eq/MJ ethanol for mineral soils (Figure 10).

7.2 Biogas

In the base calculations for biogas, the emission factors for methane emissions from storage of manure used in the Swedish national inventory report on greenhouse gas emissions to the UNFCCC (Naturvårdsverket, 2007) were used. These are IPCC (2006) standard values for methane emissions (MCF) from storage of solid manure and recommended national values for Sweden for liquid manure (Dustan, 2002). The emission factors for nitrous oxide (EF) from storage and spreading of manure are from IPCC (2006) but they are highly uncertain and can vary with different conditions, as they are intended for estimations of greenhouse gas emissions on national level. The effects of variations in the emission factors for methane and nitrous oxide on the results are shown in Tables 41 and 42, respectively.

Table 41. Impact on the results of higher and lower emission factor for methane (MCF) during storage for the biogas system, with and without deduction for the reference system

	Emissions of greenhouse gases without reference (g CO_2-eq/MJ vehicle gas)			Emissions of greenhouse gases with reference (g CO_2-eq/MJ vehicle gas)		
	Base scenario	MCF +50%	MCF -50%	Base scenario	MCF +50%	MCF -50%
Solid manure (cattle)	4	4	3	-26	-27	-24
Liquid manure (cattle)	6	6	5	-39	-60	-19
Liquid manure (swine)	5	5	5	-41	-62	-20

Table 42. Impact on the results of higher and lower emission factor for nitrous oxide (EF) during storage for the biogas system, with and without deduction for the reference system

	Emissions of greenhouse gases without reference (g CO_2-eq/MJ vehicle gas)			Emissions of greenhouse gases with reference (g CO_2-eq/MJ vehicle gas)		
	Base scenario	EF nitrous oxide +50%	EF nitrous oxide -50%	Base scenario	EF nitrous oxide +50%	EF nitrous oxide -50%
Solid manure (cattle)	4	4	3	-26	-37	-14
Liquid manure (cattle)	6	7	4	-39	-39	-39
Liquid manure (swine)	5	6	4	-41	-41	-41

Methane leakage during upgrading was assumed to be as low, as can be achieved with the best available technology in Sweden today. For older plants, the leakage can be significantly higher. The leakage is often stated as 1-2% by suppliers, but up to 18% leakage has been reported (Persson, 2003). Therefore the impact on the results of one and two orders of magnitude higher methane leakage was analysed and is presented in Table 43.

Table 43. Impact on the results of different assumptions on methane leakage during upgrading, with and without deduction for the reference system

	Emissions of greenhouse gases without reference (g CO_2-eq/MJ vehicle gas)			Emissions of greenhouse gases with reference (g CO_2-eq/MJ vehicle gas)		
	Base scenario	Methane leakage 1%	Methane leakage 10%	Base scenario	Methane leakage 1%	Methane leakage 10%
Solid manure (cattle)	4	8	51	-26	-22	19
Liquid manure (cattle)	6	6	53	-39	-35	3
Liquid manure (swine)	5	9	53	-41	-37	2

The diesel consumption for spreading manure and digestion residues is relatively large. The impact on the results of higher or lower diesel consumption is presented in Table 44.

Table 44. Impact on the results of different assumptions on diesel consumption for spreading, with and without deduction for the reference system

	Emissions of greenhouse gases without reference (g CO_2-eq/MJ vehicle gas)			Emissions of greenhouse gases with reference (g CO_2-eq/MJ vehicle gas)		
	Base scenario	Diesel +50%	Diesel -50%	Base scenario	Diesel +50%	Diesel -50%
Solid manure (cattle)	4	4	4	-26	-26	-25
Liquid manure (cattle)	6	6	6	-39	-40	-39
Liquid manure (swine)	5	5	5	-41	-41	-41

Valuation of electricity in life cycle assessments is a debated issue. The integrated Nordic (via Nordpool) and to some extent European electricity markets means that the electricity produced in Sweden is not necessarily produced there. If the electricity consumed is produced in coal condensing plants in Denmark or Germany, the emissions from production are significantly higher than if the electricity had been produced in, for example, a Swedish hydropower station. However for the calculations, the EU Directive permits the assumption that the electricity is produced in a defined region (Annex V, Chapter C, Item 11), which was interpreted here as being Sweden. In addition, Sweden was a net exporter of electricity in 2008 (Swedish Energy Agency, 2009). Emissions data for the Swedish electricity mix were therefore assumed for the base scenario. Table 45 shows the impact on the results of the assumption that the electricity is produced with the Nordic electricity generation mix or in coal condensing plants, the latter frequently assumed to be the short-term marginal electricity in Europe.

Table 45. Impact on the results of different assumptions on electricity production, with and without deduction for the reference system (the base scenario is the Swedish electricity mix)

	Emissions of greenhouse gases without reference (g CO_2-eq/MJ vehicle gas)			Emissions of greenhouse gases with reference (g CO_2-eq/MJ vehicle gas)		
	Base scenario, (23 g CO_2-eq/kWh)*	Nordic mix, (88 g CO_2-eq/kWh)**	Coal condensing plant, (850 g CO_2-eq/kWh)***	Base scenario, (23 g CO_2-eq/kWh)	Nordic mix, (88 g CO_2-eq/kWh)	Coal condensing plant, (850 g CO_2-eq/kWh)
Solid manure (cattle)	4	5	23	-26	-24	-7
Liquid manure (cattle)	6	7	25	-39	-38	-20
Liquid manure (swine)	5	7	24	-41	-39	-22

* Tobias Persson, Swedish Energy Agency, pers. comm. I

** Tobias Persson, Swedish Energy Agency, pers. comm. II

*** Elforsk (2007).

6.3 Conclusions from the sensitivity analysis

The sensitivity analyses performed showed that the choice of methodology and input data when calculating greenhouse gas emissions from cultivation of agricultural crops for biofuels has a significant impact on the results. For example, the analyses showed that crop cultivation on organic soils gives 3- to 4-fold higher values than those presented above for the base scenario. Moreover, the sensitivity analyses showed that the use of nitrogen fertilizer produced with old technology without catalytic cleaning of nitrous oxide would increase total emissions by approximately 36% in the case of winter wheat. However, cultivation of winter wheat dedicated to ethanol production, with a different choice of crop variety and reduced nitrogen addition, would reduce emissions by on average 15%. For biogas production, controlling the methane leakage from the production and distribution system is crucial for limiting the net emissions from the biogas production. The choice of electricity data is also of great significance.

REFERENCES

Ahlgren, S., Baky, A., Bernesson, S., Nordberg, A., Norén, O., Hansson, P.-A. 2008. Ammonium nitrate fertiliser production based on biomass - Environmental effects from a life cycle perspective. Bioresource Technology, 99, 8034-8041.

Arvidsson, Johan, SLU institutionen för Mark och miljö, Personlig kommunikation, 2009-03-26.

Berglund, M., Cederberg, C., Clason, C., Henriksson, M., Törner, L., 2009. Jordbrukets klimatpåverkan – underlag för att beräkna växthusgasutsläpp på gårdsnivå och nulägesanalyser av exempelgårdar. Delrapport i JOKER-projektet. Hushållningsällskapet Halland.

Berglund, Ö. & Berglund, K., 2008. Distribution and cultivation intensity of agricultural peat and gyttja soils in Sweden and estimation of greenhouse gas emissions. Geoderma, doi:10.1016/j.geoderma.2008.11.035.

Berglund, Kerstin, institutionen för Mark och miljö, SLU, Personlig kommunikation, 2009.

Bernesson, S., Nilsson, D., Hansson, P.A., 2004. A limited LCA comparing large- and small-scale production of rape methyl ester (RME) under Swedish conditions. Biomass & Bioenergy, 26, 545-559.

Bernesson, S., Nilsson, D., Hansson, P.A., 2006. A limited LCA comparing large- and small-scale production of ethanol for heavy engines under Swedish conditions. Biomass & Bioenergy, 30, 46-57.

Blinge, M., P-O. Arnäs, S. Bäckström, Å. Furnander, Hovelius, K. 1997. Livscykelanalys av drivmedel. KFB-Meddelande 1997:5. Kommunikationsforskningsberedningen, Stockholm.

Börjesson, P., 2006. Livscykelanalys av Salixproduktion. Lunds tekniska högskola. Institutionen för teknik och samhälle. Avdelningen för miljö- och energisystem. Rapport nr 60, Lund.

Claesson, S., Steineck, S. 1991. Växtnäring, hushållning – miljö. SLU – Speciella skrifter 41. Uppsala

Christensson, I. Syngenta, Personlig kommunikation 2010-11-03

Crutzen P.J., Mosier A.R., Smith K.A. & W. Winiwarter. 2008 N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmospeheric Chemistry and Physics 8: 389-395.

Dustan A. 2002. Review of methane and nitrous oxide emission factors for manure management in cold climates. JTI – Swedish Institute of Agricultural and Environmental Engineering, Uppsala. Report 299.

Edström, M., L-E. Jansson, M. Lantz, L-G. Johansson, U. Nordberg, Nordberg, Å. 2008. Gårdsbaserad biogasproduktion - System ekonomi och klimatpåverkan. JTI-rapport RKA 42

Edwards, R., Larivé, J.-F., Mahieu, V., Rouveirolles, P., 2007. Well-to-Wheels analysis of future automotive fuels and powertrains in the European context. Well-to-tank report Version 2c. CONCAWE & EUCAR for the Joint Research Centre. March, 2007.

Edwards, R., S. Szekeres, F. Neuwahl, Mahieu, V. 2008. Biofuels in the European Context: Facts and Uncertainties. JRC-rapport.

Elforsk, 2007. Miljövärdering av el – med fokus på utsläpp av koldioxid. www.elforsk.se/elforsk/miljovardering_elanvand.pdf.

Energimyndigheten, 2009. "Pressmeddelande: Elstatistik 2008." from http://www.energimyndigheten.se/sv/Press/Pressmeddelanden/Elstatistik-2008/.

Energimyndigheten, 2008. Energianvändning inom jordbruket 2007. Energimyndigheten och Statistiska centralbyrån.

Erlingsson, Mogens. Yara Sverige. Personlig kommunikation 2009-05-03.

European Parliament, 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. COD(2008)0016 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

Gunnarsson, C., Olsson, J., Lundin, G., de Toro, A. 2008. Spannmål till energi - ökad lönsamhet genom anpassning av odlingssystemet JTI-rapport R 369, Uppsala.

Gruvaeus, I. 2007. Kvävegödsling av olika sorters höstvete. Försöksrapport 2007 Mellansvenska Försökssamarbetet. http://www.sveaforsoken.nu/Mellansvenska/rapport2007.htm

Halling, M. 2008. Forage species for cutting, grazing and green fodder. SLU – institutionen för växtproduktionsekologi. Uppsala

Held, J., A. Mathiasson, Nylander, A. 2008. Biogas ur gödsel, avfall och restprodukter - Goda svenska exempel.Svenskt Gastekniskt Center, Svenska Gasföreningen och Svenska Biogasföreningen.

Hushållningssällskapet. Personlig kommunikation, Nov 2010
HS Blekinge. Hans Hedström
HS Halland Linda Karlsson
HS Gotland. Göran Qviberg
HS Gästrikland. Henrik Bergman
HS Jönköping. Stina Pettersson
HS Kalmar. Linda af Geijerstam
HS Kristianstad. Mats Håkansson
HS Kronoberg. Lina Pettersson
HS Malmöhus. Kerstin Andersson
HS Sjuhärad. Johannes Nilsson
HS Skaraborg. Fredrik Johansson
HS Södermanland, Uppland, Västmanland, Stockholm. Johan Kullsand
HS Värmland. Linda Ulff Delprato
HS Östergötland. Pernilla Kvarnmo
HS Örebro. Anna Redner

IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventory. Volume 4 Agriculture, Forestry and Other Land Use, Chapter 11: N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application.

Jenssen, T., Kongshaug, G. 2003. Energy consumption and greenhouse gas emissions in fertiliser production Proceedings No. 509. International Fertiliser Society, York, UK.

Johnsson, H., Larsson, M., Lindsjö, A., Mårtensson, K., Persson, K. & Torstensson, G. 2008. Läckage av näringsämnen från svensk åkermark. Beräkningar av normalläckage av kväve och fosfor för 1995 och 2005. Rapport 5823 Naturvårdsverket.

Jonsson, Nils, 2009. Forskare, Institutet för jordbruks och miljöteknik (JTI). Personlig kommunikation 2009-05-05.

Jonsson, N. 2006. Uppdatering av gårdens spannmålstork. Ett projekt utfört på uppdrag av SLA. JTI – Institutet för jordbruks- och miljöteknik. http://www.sla-arbetsgivarna.org/LitiumDokument20/GetDocument.asp?archive=1&directory=580&document=3769.

Jordbruksverket, 2010. Areal Energigrödor.

Kasimir Klemedtsson, Åsa, FD, Inst för geovetenskaper, Göteborgs universitet, Personlig kommunikation fortlöpande under perioden januari till maj 2009.

Kasimir-Klemedtsson, Å. 2001. Metodik för skattning av jordbrukets emissioner av lustgas: underlag för Sveriges nationalrapport till Klimatkonventionen. Naturvårdverket Rapport 5170.

Kasimir-Klemedtsson, Å. 2009. Odling av bioenergi på åkermark i olika delar av Sverige, Hur mycket lustgas blir det? Opublicerad rapport, Inst. För Geovetenskaper Göteborgs Universitet.

Krijger, A.-K., 2008. Kvävegödsling av olika sorters höstvete. Försöksrapport 2008 Mellansvenska Försökssamarbetet. http://www.sveaforsoken.nu/Mellansvenska/rapport2008.htm.

Landström, S., Lomakka, L., Andersson, S. 1996. Harvest in spring improves yield and quality in reed canary grass as an energy crop. Biomass and Bioenergy 11:4 333-341.

Lantmännen Lantbruk, 2007. Växtodlaren. Fälthandbok

Lantmännen SW Seed, 2010. Rätt utsädesmängd på www.swseed.se

Lehtomäki, A. 2006. Biogas from energy crops and crop residues. Jyväskylä studies in biological and environmental science 163, University of Jyväskylä

Lindgren, M., Petterson, O., Hansson, P.-A. & Norén, O. 2002. Jordbruks- och anläggningsmaskiners motorbelastning och avgasemissioner – samt metoder att minska bränsleförbrukning och avgasemissioner. Uppsala: JTI-rapport 308, Lantbruk & Industri. JTI - institutet för jordbruks och miljöteknik

Lomakka, L. Odlingstekniska försök avseende skördetid, gödsling och produktkvalitet samt sortförsök i rörflen. Till biobränsle och fiberråvara 1991/92 och 1992/93. SLU – institutionen för växtproduktionsekologi. Uppsala

LowCVP, 2004. Well-to-Wheel Evaluation for Production of Ethanol from Wheat. A Report by the LowCVP Fuels Working Group, WTW Sub-Group. FWG-P-04-024.

Lundin, Gunnar, 2009. Forskare, Institutet för jordbruks och miljöteknik (JTI). Personlig kommunikation 2009-05-05.

Mårtensson, Kristina. Forskningsassistent Mark och Miljö SLU. Personlig kommunikation 2009-03-19.

Naturvårdsverket, 2007. Sweden's national inventory report 2008 – Submitted under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Naturvårdsverket, Stockholm.

Naturvårdsverket, 2009. National Inventory Report 2009, Sweden. Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. www.naturvardsverket.se/upload/05_klimat_i_forandring/statistik/2008/NIR2009_sweden.pdf.

Olesen, J.E., Weiske, A., Asman, W.A., Weisbjerg, M.R., Djurhuus, J. & Schelde, K. 2004. FarmGHG. A model for estimating greenhouse gas emissions from livestock farms. Documentation. Danish Institute of Agricultural Sciences.

Persson, M. 2003. Utvärdering av uppgraderingstekniker för biogas. Lund, Svenskt Gastekniskt Center.

Persson, Tobias, Energimyndigheten, Personlig kommunikation I, maj 2009.

Persson, Tobias, Energimyndigheten, pers. komm., II, november 2008.

Rodhe, L., E. Salomon, Edström, M. 2008. Handling of digestate on farm level. JTI - Institutet för jordbruks- och miljöteknik, Rapport nr R347.

SCB, 1999. Utnyttjande av halm och blast från jordbruksgrödor1997. Statistiska meddelanden Mi 63 SM 9901.

SCB, 2008a. Jordbruksmarkens användning 2008. Statistiska meddelanden JO 10 SM 0901.

SCB, 2008b. Normskördar 2008. Statistiska meddelanden JO0602.

SCB, 2008c. Gödselmedel i jordbruket 2006/07. Mineral- och stallgödsel till olika grödor samt hantering och lagring av stallgödsel. Statistiska meddelanden MI 30 SM 0803.

SCB, 2008d.Växtskyddsmedel i jord- och trädgårdsbruket 2006. Användning i grödor. Statistiska meddelanden MI 31 SM 0701 korrigerad version.

SCB, 2009. Skördar efter gröda. År 1965-2008. Statistikdatabasen, www.scb.se.

SCB, 2010. Areal i majs enligt Lantbruksregistret 2000-2008. LBR

SLU Fältforsk, 2009. Seriesammanställning medelvärde 2004-2008 svensk sortblandning för höstvete, vårkorn, rågvete och höstraps. www.ffe.slu.se.

Smith, Keith A. Sen. Hon. Professorial Fellow, School of GeoSciences, University of Edinburgh, UK, Personlig kommunikation 2009-05-16.

Stehfest E. &. Bouwman, L. 2006. N_2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modelling of global emissions. Nutrient Cycling in Agroecosystems 74; 207-228.

Steineck, S., A. Gustafson, A. Richert-Stintzing, E. Salomon, Å. Myrbeck, A. Albihn, Sundberg, M. 2000. Växtnäring i Kretslopp. SLU Kontakt 11. Sveriges lantbruksuniversitet.

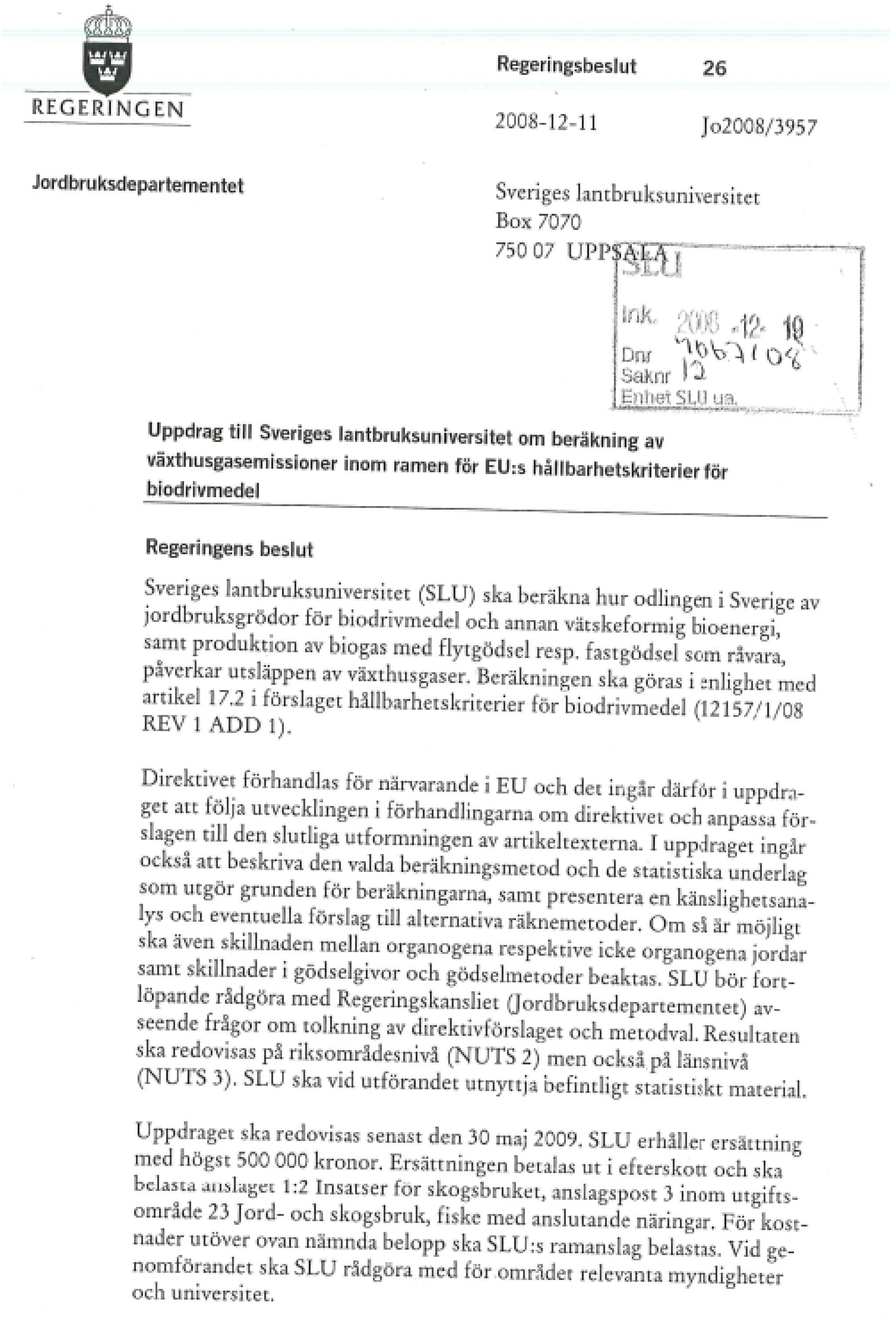
Tamm, Ebba. Svenska Petroleum Institutet, Personlig kommunikation 2009-05-20

Uppenberg, S., Alemark, M., Lindfors, L.-G., Marcus, H.-O., Stripple, H., Wachtmeister, A. & Zetterberg, L. 2001. Miljöfaktabok för bränslen. Del 2. Bakgrundsinformation och Teknisk bilaga. Stockholm, Sweden: IVL Rapport B1334B-2.

Wallenhammar, A-C. 2009. Raps (Brassica napus) och rybs (Brassica rapa) http://www.sjv.se/download/18.3c40f0106de78b9888000261/Raps+o+rybs.pdf

Yara, 2008. Växtpressen nr 2 september 2008. Årgång 37. http://fert.yara.se/library/attachments/news_room/publications/brochures/VP2_08%20www.pdf.

Appendix 1



REGERINGEN

Regeringsbeslut 26

2008-12-11 Jo2008/3957

Jordbruksdepartementet

Sveriges lantbruksuniversitet
Box 7070
750 07 UPPSALA

SLU
Ink. 2008 -12- 19
Dnr 7067/08
Saknr 12
Enhet SLU ua.

Uppdrag till Sveriges lantbruksuniversitet om beräkning av växthusgasemissioner inom ramen för EU:s hållbarhetskriterier för biodrivmedel

Regeringens beslut

Sveriges lantbruksuniversitet (SLU) ska beräkna hur odlingen i Sverige av jordbruksgrödor för biodrivmedel och annan vätskeformig bioenergi, samt produktion av biogas med flytgödsel resp. fastgödsel som råvara, påverkar utsläppen av växthusgaser. Beräkningen ska göras i enlighet med artikel 17.2 i förslaget hållbarhetskriterier för biodrivmedel (12157/1/08 REV 1 ADD 1).

Direktivet förhandlas för närvarande i EU och det ingår därför i uppdraget att följa utvecklingen i förhandlingarna om direktivet och anpassa förslagen till den slutliga utformningen av artikeltexterna. I uppdraget ingår också att beskriva den valda beräkningsmetod och de statistiska underlag som utgör grunden för beräkningarna, samt presentera en känslighetsanalys och eventuella förslag till alternativa räknemetoder. Om så är möjligt ska även skillnaden mellan organogena respektive icke organogena jordar samt skillnader i gödselgivor och gödselmetoder beaktas. SLU bör fortlöpande rådgöra med Regeringskansliet (Jordbruksdepartementet) avseende frågor om tolkning av direktivförslaget och metodval. Resultaten ska redovisas på riksområdesnivå (NUTS 2) men också på länsnivå (NUTS 3). SLU ska vid utförandet utnyttja befintligt statistiskt material.

Uppdraget ska redovisas senast den 30 maj 2009. SLU erhåller ersättning med högst 500 000 kronor. Ersättningen betalas ut i efterskott och ska belasta anslaget 1:2 Insatser för skogsbruket, anslagspost 3 inom utgiftsområde 23 Jord- och skogsbruk, fiske med anslutande näringar. För kostnader utöver ovan nämnda belopp ska SLU:s ramanslag belastas. Vid genomförandet ska SLU rådgöra med för området relevanta myndigheter och universitet.

Bakgrund

Europeiska kommissionen presenterade sitt förslag till klimat- och energipaket den 23 januari 2008. Energi- och klimatpaketet består av fyra delar: i) direktiv om främjande av användningen av förnybar energi, ii) ansvarsfördelning av EU:s klimatmål i den icke-handlande sektorn, iii) översyn av EU:s utsläppshandelssystem för perioden efter 2012 och iv) regelverk för koldioxidavskiljning och lagring.

Syftet med direktivet om främjande av användningen av förnybar energi är bl.a. att säkerställa att den europeiska biodrivmedelsproduktionen sker på ett hållbart sätt. Detta sker genom förslag till kriterier. Exempel på de kriterier som anges är markomställning, biologisk mångfald och minskade växthusgasemissioner. Det senare innebär krav på att utsläppen ska minska med minst 35%. I det fall att inte kriterierna uppfylls kan drivmedlet inte tillgodoräknas mot de nationella målen för biodrivmedel och inte heller åtnjuta finansiellt stöd.

Beträffande växthusgasemissioner kan producenter, i stället för att göra egna omfattande beräkningar, använda sig av de, för varje produktionsmetod, föreslagna typvärden som anges i förslagets Bilaga IV. Detta förutsätter dock att medlemsstaten har kunnat visa att emissionerna kan förväntas vara lägre än dessa värden.

Enligt artikel 17.2 i förslaget ska medlemsstaterna senast den 31 mars 2010 till EU-kommissionen överlämna en rapport som beskriver regionala typvärden för utsläpp från odlingen av biodrivmedel och andra biovätskor. Redovisning ska ske på minst NUTS 2-nivå och även innehålla en beskrivning av beräkningsmetod och använda datakällor. Några av de faktorer som ska tas i beaktande i beräkningarna är markegenskaperna, klimatet och förväntad avkastning.

På regeringens vägnar

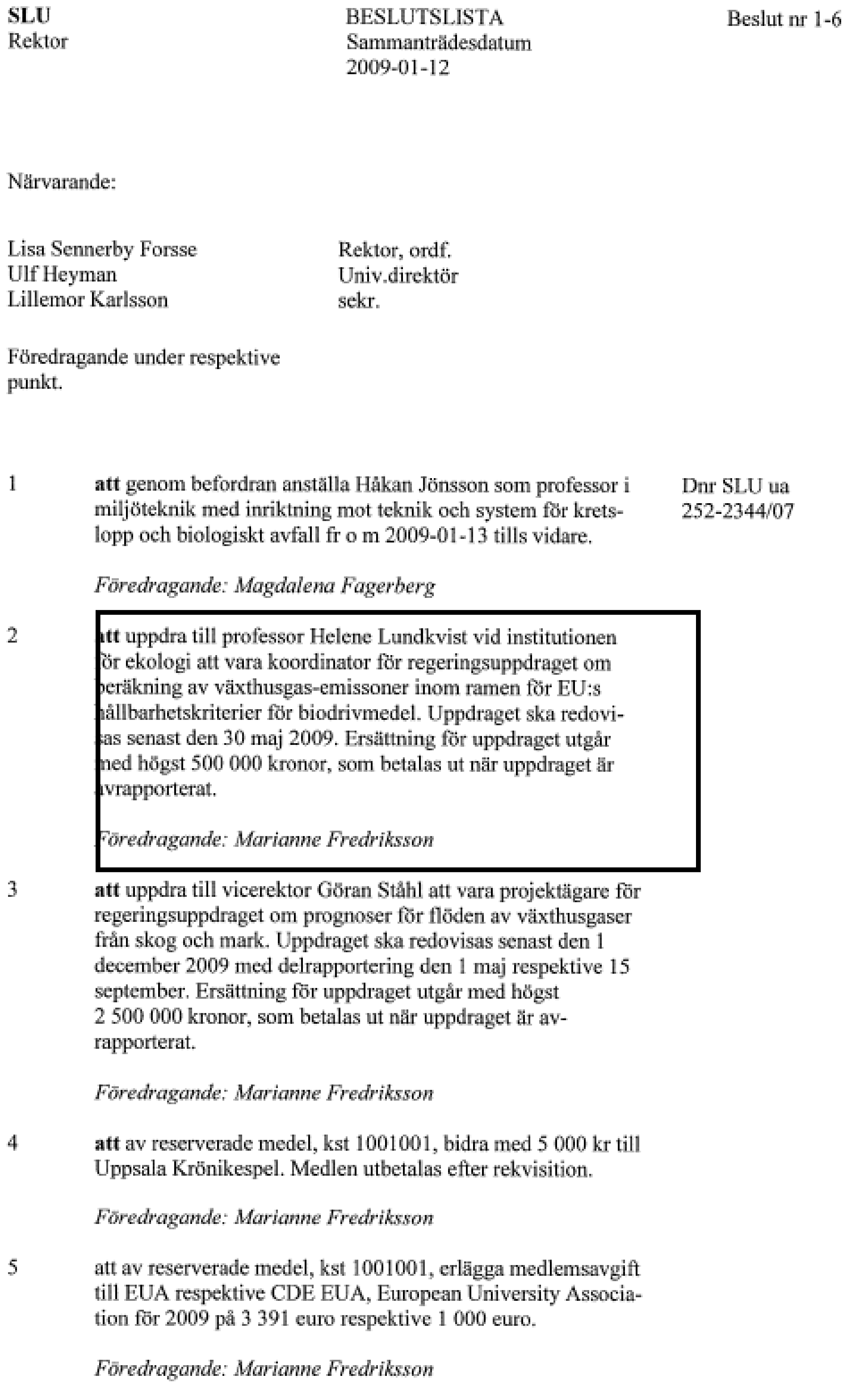
Eskil Erlandsson

Fredrik von Unge

Kopia till

Finansdepartementet
Näringsdepartementet
Miljödepartementet
Riksdagens miljö- och jordbruksutskott

Appendix 2



SLU
Rektor

BESLUTSLISTA
Sammanträdesdatum
2009-01-12

Beslut nr 1-6

Närvarande:

Lisa Sennerby Forsse	Rektor, ordf.
Ulf Heyman	Univ.direktör
Lillemor Karlsson	sekr.

Föredragande under respektive punkt.

1 **att** genom befordran anställa Håkan Jönsson som professor i miljöteknik med inriktning mot teknik och system för kretslopp och biologiskt avfall fr o m 2009-01-13 tills vidare. Dnr SLU ua 252-2344/07

Föredragande: Magdalena Fagerberg

2 **att** uppdra till professor Helene Lundkvist vid institutionen för ekologi att vara koordinator för regeringsuppdraget om beräkning av växthusgas-emissoner inom ramen för EU:s hållbarhetskriterier för biodrivmedel. Uppdraget ska redovisas senast den 30 maj 2009. Ersättning för uppdraget utgår med högst 500 000 kronor, som betalas ut när uppdraget är avrapporterat.

Föredragande: Marianne Fredriksson

3 **att** uppdra till vicerektor Göran Ståhl att vara projektägare för regeringsuppdraget om prognoser för flöden av växthusgaser från skog och mark. Uppdraget ska redovisas senast den 1 december 2009 med delrapportering den 1 maj respektive 15 september. Ersättning för uppdraget utgår med högst 2 500 000 kronor, som betalas ut när uppdraget är avrapporterat.

Föredragande: Marianne Fredriksson

4 **att** av reserverade medel, kst 1001001, bidra med 5 000 kr till Uppsala Krönikespel. Medlen utbetalas efter rekvisition.

Föredragande: Marianne Fredriksson

5 att av reserverade medel, kst 1001001, erlägga medlemsavgift till EUA respektive CDE EUA, European University Association för 2009 på 3 391 euro respektive 1 000 euro.

Föredragande: Marianne Fredriksson

Appendix 3

Subject: Tilläggsuppgifter RES art. 19.2 Jo2009/1718
Date: Thursday, October 14, 2010 1:54 PM
From: anette.madsen@agriculture.ministry.se
To: Helene Lundkvist <Helene.Lundkvist@ekol.slu.se>
Cc: <lars.olsson@agriculture.ministry.se>, <registrator@agriculture.ministry.se>, <sven-olov.ericson@enterprise.ministry.se>

Hej Helene, **Dnr. Jo2009/1718**

Nedan följer en uppräkning av det som behöver göras i form av en komplettering till det tidigare uppdraget om beräkning av växthusgasemissioner inom ramen för EU:s hållbarhetskriterier för biodrivmedel.

- Rapporten behöver kompletteras med beräkningar på hur odlingen i Sverige (i berörda län) av grödorna **vete, sockerbeta (beta + blast), majs, havre, råg, vall, halm (balpressning och fälttransporter) och rörflen** påverkar utsläppen av växthusgaser.
- För sockerbeta, majs, halm, vallgröda och rörflen behövs en beräkning som omfattar produktion av **biogas med hela grödan rom råvara.**
- För vete, råg och havre behövs en beräkning som omfattar produktion av **etanol**. För vete kan beräkningen ske gemensamt för vår- och höstvete.

Beräkningarna ska göras i enlighet med artikel 19.2 i RES-direktivet och den tidigare rapportens beräkningar och omfatta aktuella län.

Kompletteringen bör vara Jordbrukdepartementet tillhanda i engelsk version senast den 23 november 2010.

I mån av tid föreslår vi att referensgruppen aktiveras t.ex genom elektronisk form.

Återkom gärna så fort som möjligt med en uppskattning av medel som ni bedömer kommer att gå åt för att fullfölja denna komplettering.

Självklart är du välkommen att kontakta mig när som helst för ytterligare frågor kring dessa tillägg. För frågor av mer teknisk karaktär hänvisas till direktkontakt med S-O.

Bästa hälsningar
Anette

Anette Madsen
Deputy Director
Ministry of Agriculture
Skogs- och lantbruksenheten/Agriculture and Forestry Division
Direct no: +46 8 405 11 29
Fax: +46 8 24 95 46
Mobile: +46 70 547 46 38

Appendix 4

European Commission

EU Pilot

16/08/2010

File ref n°:	1325/10/ENER
Member State:	SE
Commission service:	ENER
Issue area:	Energy/Electricity produced from renewable energy sources
File nature:	Own Initiative / Commission

Contact person Commission service:	Ms SCHNEIDER Anne
Contact person Member State:	Ms PETKOVSKA Katerina

File history

- **04/08/2010:** Draft file created by Energy / SCHNEIDER Anne
- **10/08/2010:** File submitted to Member State in EU PILOT database - Energy / SCHNEIDER Anne

File status

- **File status:** Awaiting acceptance by Member State

Title:

- Submission to the Commission of the report required by Article 19 (2) of Directive 2009/28/EC on the promotion of the use of energy from renewable sources (1)

Issue Description:

- **Commission service language:** We are writing to you with respect to the report you submitted under Article 19(2) of Directive 2009/28/EC for which we would like to thank you. However, we have now reviewed the report and it appears that some further elements are needed to comply with the requirements set out in the Directive. The following point needs further clarifications:

  •The report introduces a reference case which is not according to IPCC Tier1 methodology, where the "background" emissions are already deducted (see footnote 7 of chapter 11 of the IPCC guidelines for National GHG inventories). The revision of the report shall exclude the subtraction of a reference when IPCC Tier1 methodology is applied.

  The Commission is of the view that the quality of the report could be further improved if the following points were taken into account:
  • The calculations include crop drying, which shall be excluded in the "cultivation step".
  • The report includes 5% biofuel in machinery which is not according to the methodology.
  • The fertilizer is assumed to be produced with catalytic cleaning giving emissions of only 2.9 kg vs. 6.8 for average EU fertilizer in 2003. This shift is significant for the results and more evidence could be provided to justify the lower emissions value.

- Swedish soil contains more organic carbon than average EU soil. Relevant JRC data shows that there are regions in Sweden with a large share of organic soils used for agriculture. Please provide a discussion on how the high soil organic carbon content may affect emissions from cultivation.
- The inclusion of GHG emissions values for biogas from manure is not necessary, as this is considered waste, and thus bears no emissions from the point of collection.

In the light of the above, we would be grateful if you could ask the competent authorities to respond to the above mentioned points at your earliest convenience and not later than 6 weeks of receipt of this letter.
Once this time-limit has expired and if the Commission considers that your Government has failed to fully fulfil its obligations under Article 19(2) of the Directive 2009/28/EC, it may issue a Letter a Formal Notice pursuant to Article 258 TFUE. The Commission may also ask for additional information to be submitted in relation to this report.

(1) OJ L140/16, 5.6.2009