SIK-rapport
Nr 728 2004

Life Cycle Inventory of 23 Dairy Farms in South-Western Sweden

Christel Cederberg

Anna Flysjö

SIK-rapport
Nr 728 2004

Life Cycle Inventory of 23 Dairy Farms in South-Western Sweden

Christel Cederberg
Anna Flysjö

SR 728

ISBN 91-7290-237-X

Summary

In this study, data on resource use and emissions for dairy farms in south-western Sweden were collected and analysed with Life Cycle Assessment (LCA) methodology. The purpose of the study was to gain increased knowledge of the environmental impact of today´s milk production and of the variations between farms regarding resource use and emissions.

Data were collected from 23 dairy farms in the Halland and Västra Götlands regions. The farms were divided into three groups:

1) Conventional high (Conv High); producing >7 500 kg ECM/ha (nine farms)
2) Conventional medium (Conv Med); producing < 7 500 kg ECM/ha (eight farms)
3) Organic (six farms)

Data on concentrate feed production were upgraded from earlier work by collating statistics and information from different feed and food industries.

All the studied farms participated in the advisory programme "Greppa Näringen" and had detailed information on feed and fertiliser consumption. In addition to this, data on use of diesel, electricity, pesticides and plastic were collected at the farms. For ammonia, nitrate, nitrous oxide and methane, different emission models were used in order to infer the losses.

The functional unit (reference unit) in the study was "one kg of energy corrected milk" at the farmgate. Emissions of ammonia and nitrate, as well as pesticide use, were also evaluated per hectare of arable land at the farms. The systems analysed included all phases in the life cycle of fertilisers, feed products, diesel, pesticides and plastics. Transport steps were also taken into account. Buildings, machinery and medicines were not included. Allocation between milk and meat was done on an economic basis, distributing 90 % of the impact to milk and 10 % to the meat. Economic allocation was also used in the Life Cycle Inventory (LCI) of concentrate feed.

In the LCIs of the 23 dairy farms, the results were presented as use of resources (energy, nutrients and land), use of pesticides, emissions of greenhouse gases, emissions of nutrifying and acidifying substances. The LCI results were statistically analysed in oneway ANOVA to establish the results that showed the least significant difference between the three farm groups.

There was no significant difference in the use of energy resources between the two conventional groups. The overall energy use was significantly lower for the organic farm group in comparison with the conventional groups, and it was the total lower use of fossil fuels that explained this difference between the production systems. The use of non-renewable resources for nutrient supply (phosphorous and potassium) was also significantly lower for the organic group.

The yearly land use for producing one kg milk was significantly higher for the organic group, for the land use types arable land, as well as natural grazing meadows. Information on land transformation, which is relevant in the production of protein crops, was not possible to obtain in the inventory work.

The pesticide use was 71 – 81 mg active substance per kg milk for the two conventional farm groups and there was no significant difference between these groups. In the organic group, average pesticide use was 7.8 mg active substance per kg milk and was caused by the conventional feed ingredients in the purchased organic feed.

The variation of greenhouse gas emissions from the 23 dairy farms were large and varied between 760 – 1260 g CO_2-equivalents/milk for the conventional farms and 730 – 1110 g CO_2-equivalents/kg milk for the organic farms. There was no statistical difference in the total emissions of greenhouse gases between the three farm groups.

The calculated ammonia and nitrous oxide emissions per hectare of arable land were largest in the conventional group with high milk production per hectare; this was an effect of the higher livestock density in this group. When these emissions were calculated per kg milk, the intensive group no longer had the highest emissions per unit of product. Due to uncertainties in the model calculations and large variations between the farms, there were small or no statistical differences in the emissions of reactive nitrogen per kg milk between the farm groups.

The farms´ N-surplus was calculated according to the farm-gate method and it was 166 kg N/ha for the intensive conventional group, 122 kg N/ha for the medium conventional group and 66 kg N/ha for the organic group. The organic group had significantly lower N-surplus than the conventional farms, but there was no statistical difference in the N-surplus between the two conventional groups.

Although LCI data were collected from 23 dairy farms in an area with uniform and favourable conditions for milk production, the results showed large variations between the farms. Better knowledge of these variations and their cause can be of good help in “benchmarking” and environmental improvement work at dairy farms. Seventeen conventional farms participated in the study and they were divided into two groups according to their area-based milk production. There were only small or not statistically significant differences in resource use and emissions between the two conventional groups.

Clear differences were seen between the conventional and organic farm groups. The organic farms had significantly lower use of fossil energy, phosphorous and pesticides, but significantly larger land use. There was no difference in the emissions of greenhouse gases between the two production forms. The average N-surplus was lower at the organic farms but there was no statistically significant difference between the farm groups in the area-based nitrate leaching. The calculated area-based ammonia emissions followed primarily the livestock density and not the production system.

Table of contents

1 Introduction

The Swedish environmental policy is summarised in 15 environmental quality goals. Agriculture and food production are of great importance for several of the goals, and reducing emissions of reactive nitrogen from the food sector is a key factor for succeeding in the work. Increased knowledge among farmers is one measure for reaching the goals and an advisory programme has been launched by the government in co-operation with the farmers´ organisations. The programme "Greppa Näringen" aims at improving the whole farm´s N-management by offering advisory services from different fields of expertise (animal feeding, crop production, buildings). Also, in the Swedish research programme MAT 21 (FOOD 21), emphasis is put on whole farm management by system analysis of different farming systems. In the synthesis work of FOOD 21, scenario methodology is used to present solution for future agriculture production.

In this study, data on resource use and emissions were collected from several dairy farms in south west Sweden and analysed with Life Cycle Assessment methodology (CEN 1997). So far, there has been a lack of well documented data of this kind in Sweden, describing the environmental impact of farms and variations between them. Earlier data on concentrate feed production were updated in this study and a database for feed products was established. The results will be used to develop environmental performance indicators for dairy farms and give reference values for today´s production. The results will also be used when constructing future scenarios for sustainable milk production. The work of developing environmental indicators and future scenarios will in the near future be presented in other reports.

This research project was financed by Stiftelsen Lantbruksforskning (Swedish Farmer´s Foundation for Agricultural Research) and MAT 21. The project manager was Svensk Mjölk (Swedish Dairy Association). Several persons have been to a great help in the work and Svensk Mjölk would like to thank the following persons:

Veronica Carlsson did all the inventory work at the dairy farms and processed the farm data. Jan Bertilsson, Institution for animal feeding, Sveriges Lantbruksuniversitet, assisted in the supervising of Veronica and helped with the statistical analysis.

At SIK, Britta Nilsson, Viveca Reimers and Berit Mattsson participated in the work of upgrading the database of feed products, and Jennifer Davis reviewed the English.

Personnel at the dairy advisory service: Hans-Erik Andersson, Skara Semin, Anders Bengtsson, Södra Älvsborgs husdjur and Carin Clason, Hallands Husdjur, helped us to contact and select dairy farms for the inventory of farm data.

Several members of staff at Svenska Lantmännen assisted with data on concentrate feed production, special thanks to Christina Nyemad and Gustav Kämpe. Birgit Landquist, Danisco Sugar and Per-Johan Herland, Karlshamn, were also very helpful in this work.

Finally, Svensk Mjölk wants to convey its thanks to Stiftelsen Lantbruksforskning och MAT 21 for financing this study.

2 Goal and scope definition

2.1 Goal and purpose of the study

The goal of this study was to perform a life cycle inventory (LCI) of milk production based on data from contemporary dairy farms, conventional as well as organic, in Sweden.

The purpose of the study was to gain increased knowledge of the environmental impact of today´s milk production and of the variations between different farm types in regard to resource use and emissions. The results will be used when testing and developing environmental performance indicators for dairy farms and as reference data in research work on scenarios for future milk production in Sweden. The conventional farms were grouped according to their milk production per hectare arable land, to investigate the importance of area-intensity in dairy production. Organic farms also participated in the study.

2.2 Scope of the study

The study dealt with all the phases of milk production as shown in Figure 2.1 including production of materials and energy used. Transport steps were also taken into account.

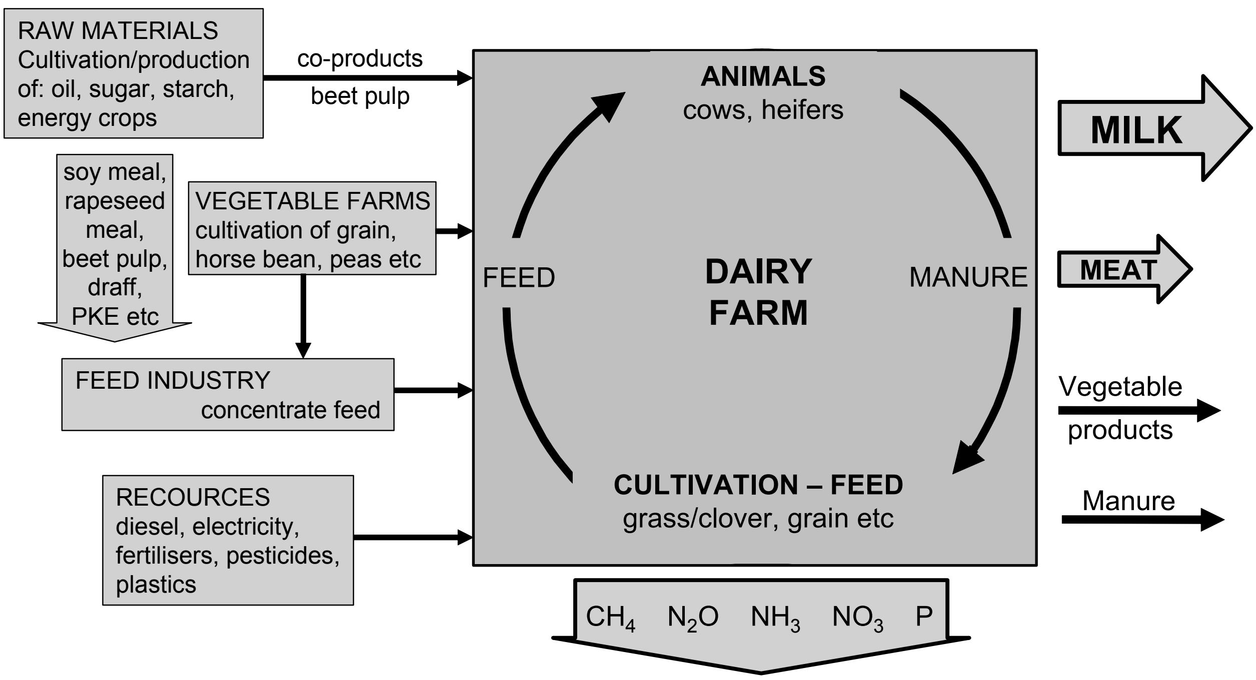

Figure 2.1 A flow diagram for farm production of milk

2.2.1 Descriptions of the three groups of dairy farms

Data for the production year 2001/2002 were collected from 23 dairy farms in the west of Sweden. This region is important for Swedish milk production, and due to its wet climate, there are good potentials for producing grass/clover. The farms were divided into three groups:

1. Conventional High (Conv High). The farms produced (delivered) more than 7 500 kg ECM milk per hectare of arable land. Nine farms in the group.
2. Conventional medium (Conv Med). The farms produced (delivered) less than 7 500 kg ECM per hectare of arable land. Eight farms in the group.
3. Organic (Org). The farms in the group produced milk according to organic principles and used the label KRAV[1]. Six farms in the group.

2.2.2 Delimitations

Production of farm buildings and farm machinery was excluded in the study.

The production, use and emissions from medicine use were excluded in the study due to lack of knowledge of the environmental impact from medicine residues in the ecosystems.

Production of seed was not included in analysis of the dairy farms but was included in the database for feed products.

The production and use of pesticides were included but no toxic assessment of the pesticides was performed.

Washing detergents, disinfectants and silage agents were excluded.

2.3 Functional units

The functional unit (FU) in the study was *"one kg of energy-corrected milk (ECM) at the farm gate".*

Emissions of ammonia and nitrate are the source of local as well as regional environmental impact. The concentrations of these emissions are therefore of interest and consequently the impacts of these emissions were also referred to the functional unit "one hectare of arable land at the dairy farm". Pesticide use was also assessed per hectare of arable land at the dairy farms.

2.4 Allocations

The selected dairy farms were all specialised on milk production and had no other livestock production at the farms. By this selection, some allocation problems were avoided, e.g. the electricity use in the farm houses were only due to the milk production. However, despite this ambition, there were still allocation situations in the study.

[1] KRAV is the Swedish labelling system for organic production

2.4.1 Milk and meat

Although the farms studied were pure dairy farms, there are meat production due to slaughter cows and bull calves. According to the market prices in 2002, 90 % of the income is due to milk and 10 % to meat (Rietz, pers comm., 2003). The allocation between milk and meat was thus 90 % / 10 %.

2.4.2 Concentrate feed

In the production of concentrate feed, co-products from the food industry are important raw materials. Economic allocation was used when dividing the environmental burden between the main products and co-products (se further section 3.4)

2.4.3 Vegetable products at the farms

Nine of the 23 dairy farms under study sold vegetable products (mainly surplus grain). The resource use and calculated emissions for the cultivation of these exported crops were deducted for these crops, thus avoiding allocation. When farmyard manure was used in the vegetable crops for sale, only emissions due to spreading was allocated to the sale crop. Since it was mainly smaller share of the dairy farms´ crop production that was sold, all use of Glyphosate was allocated to the milk production (mainly used when breaking the leys).

2.5 Environmental impacts considered

The environmental impact categories considered in the study are listed in Table 2.1

Tabel 2.1 Environmental impacts considered in the study

Impact category	Substance
Resources	Finite energy
	Infinite energy
	Non-energy
Energy	Secondary energy (fossile, electricity, renewable)
Land	Land use and type of land
Toxicity	Pesticide use
Climate change	CO^2, CH_4, N_2O
Eutrophication	NO_3-, NH_3, NOx, P
Acidification	NH_3, NOx, SO_2

2.6 Data gaps

Smaller volumes of feed ingredients (MgO, vitamins) were excluded. In the purchased organic feed, maize gluten meal was an ingredient. There were earlier data available for this high-protein ingredient but they were considered uncertain due to many allocation situations in its production. Therefore data for conventional soymeal was used instead of maize gluten meal in LCI calculations of the organic concentrate feed (see further section 3.4).

3 Inventory analysis

3.1 Three farm groups

Data on milk production, resource use and emissions were collected from 23 dairy farms in the south west of Sweden. The farms were grouped into three groups:

4) Conventional high (Conv High); producing >7 500 kg ECM/ha (nine farms)
5) Conventional medium (Conv Med); producing < 7 500 kg ECM/ha (eight farms)
6) Organic (six farms)

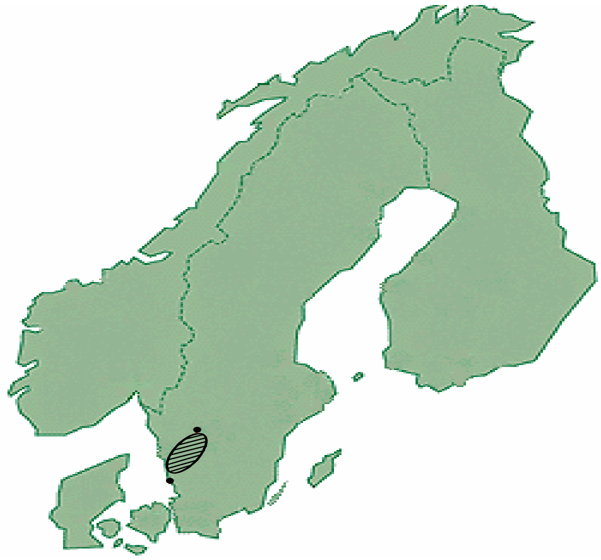

Figure 3.1 The studied dairy farms were situated in an agricultural area in south western Sweden where conditions for milk production are favourable.

Table 3.1 gives some basic data on the farms. The livestock density[2] is calculated according to the National Board of Agriculture (JBV 1998). The two groups Conv Med and Org were very similar in terms of livestock density and milk production per hectare but the farms in group Conv Med were larger, in land area as well as number of dairy cows. The farms in Conv High had a significantly higher milk production per hectare than the other two groups. On average, the organic group had more natural grazing meadows at their farms.

[2] One livestock unit (LU) corresponds to one dairy cow including one calf up to one month, or six calves aged between one and six months, or three heifers older than six months.

Table 3.1 General data on the dairy farms, average and minimum/maximum values (in brackets) for each group

	Conv High (9)	Conv Med (8)	Org (6)
Dairy cows/farm	65 (28-120)	57 (30 – 115)	39 (30 – 50)
Arable land, ha/farm	70 (30 – 163)	90 (43 – 139)	63 (35 – 87)
Livestock density, LU/ha	1.2 (1 – 1.4)	0.8 (0.5 – 1)	0.9 (0.5 – 1.3)
Milk production[1], kg ECM/ha arable land	9 460 (7 550 – 14 480)	5 360 (3 070 – 7 050)	5 100 (4 170 – 7 003)
Natural meadows, ha/farm	11 (0 – 30)	10 (0 – 25)	19 (2 – 52)

[1] milk production is delivered milk (sold from the farm)

3.2 Animal production

3.2.1 Milk production

All the farms were connected to the official milk recording program and the milk yields according to these measurements (year 2001/2002) are shown in Table 3.2. The nine farms in the Conv High group (producing more 7 500 kg ECM/ha) also had the highest milk production per cow. The Conv Med and the Org groups had similar milk yields according to the milk recording program, although the variation within the Org group was must larger. The average amount of delivered (sold) milk per cow (milk production) was approximately 800 kg lower than the milk recording statistics. This is a normal deviation and is due to milk for calf feeding, reduced milk delivery due to quarantine for veterinary treatments etc. For the organic farms, the average deviation between milk yield and milk delivery per cow was approximately 1 700 kg milk/cow or twice as high as the conventional farms. One explanation for this can be that organic farms feed their calves with fresh milk in contrast to conventional farms where it is common that a purchased milk substitute are used for the calves.

Table 3.2 Milk production at the dairy farms, average and minimum/maximum values for each group

	Conv High (9)	Conv Med (8)	Org (6)
Milk yield according to the milking record, kg ECM/cow*yr	10 100 (9 000 – 11 600)	9 130 (8 260 – 10 400)	9 400 (7 510 – 11 180)
Delivered milk, kg ECM/cow*yr	9 240 (7 440 – 11 500)	8 340 (7 420 – 9 030)	7 690 (6 160 – 9 030)

3.2.2 Feed consumption

Data on the consumption of fodder produced at the farms were collected indirectly, i.e. as use of diesel, plastics, fertiliser and calculations of emissions connected to the production of the fodder crops that consisted mainly of grass/clover silage and grains. Data on the amount of purchased feed were based on each farm´s economics account. Background data on the production of purchased feed are further presented in section 3.4. Table 3.3 shows the types of feed purchased by the farms and the share of the feed products within each group. Protein concentrate feed is a fodder that contains no grains and has rapeseed meal and soy meal as the basic protein feed ingredients. Protein concentrate is used as a complement to grain when the cows are in their highest lactation. Mixed concentrate feed contains approximately 45 %

grains and by-products from the mill industry, beet fibers and protein feed mainly as soymeal and rapeseed meal. Mixed concentrate feed is often used as the sole concentrate feed complementing roughage fodder.

Table 3.3 Share (%) of farms within each group that purchased feed of different types

	Conv High (9)	Conv Med (8)	Org (6)
Protein concentrate feed	100	100	83
Mixed concentrate feed	67	88	67
Calf feed	44	50	0
Mineral feed	78	75	83
By-products from the sugar industry	67	88	17
Grain	44	50	87
Roughage fodder	11	25	33
Others	0	25[1]	17[2]

[1] co-products from beer and juice industry
[2] horse beans

In Table 3.4, the average use of purchased feed per dairy cow in the three farm groups is shown. The cows in the group Conv High had the biggest average use of purchased feed which is an effect of higher yielding cows as well as less area per cow at the farms, which leads to a higher need for purchased fodder. The farms in the organic group purchased more grain per cow; this is probably a price effect, organic concentrate feed from the feed industry is relatively expensive, and the organic farms probably buy grain directly from other organic farms. The average purchase of minerals per cow was highest in the Org group; since less mixed concentrate feed was used in this group, the organic farmers complement with minerals separately.

Table 3.4 Average use of purchased feed in the three farm groups

	Conv High kg/cow*yr	Conv Med kg/cow*yr	Org kg/cow*yr
Protein concentrate feed	1 622	1 362	590
Mixed concentrate feed	601	401	294
Co-products sugar industry[1]	276	223	88
Grain	421	242	445
Minerals	31	28	40

[1] dried beet-pulp and super-pressed pulp, expressed as kg dry matter

As can be seen in Table 3.3 and 3.4, all the conventional farms imported protein concentrate feed in rather large amounts. Some of the farms also used smaller amounts of soy meal separately as a protein complement, this is included in the average figure in Table 3.4.

On average, the organic farms had a use of protein concentrate feed that was more than half of that of the conventional farms. Despite the fact that the farms in the Conv Med group had a larger land area per cow than the farms in the Conv High group (see Table 3.1), several of the farms in this group purchased a mixed concentrate feed (including grains). Some of the farms in the Conv Med group purchased grain separately from neighbouring farms. Co-products from the sugar industry were purchased by a majority of the conventional farms and dried beet-pulp was also an ingredient in the feed concentrates (see further section 3.4). Grains were purchased by the organic farms at a higher degree than by the conventional farms.

3.2.3 Manure production

In the inventory analysis, data on the strategy for grazing at the farms and the number of grazing days were collected. One important consequence of whether the manure is dropped outdoors or indoors in the cow house, is the size of the emissions of greenhouse gases and ammonia. The length of the grazing period of the replacement animals was very similar for all farms while it varied significantly for the dairy cows. As can be seen in Table 3.5, fully 40 % of the manure from the replacement heifers was produced in the grasslands, and this animal category was held outdoors approximately between 5.5 – 6 months. The organic farms were to a higher degree using grass as the main feed during the summer period. A common grazing strategy in the group Conv High was keeping and feeding the cows indoors during the night and grazing them six to eight hours during daytime from May to September. The organic cows grazed outdoors night and day except for about five hours during the milking when high-lactating cows in the organic group were fed with extra concentrate feed.

Table 3.5 Average share of manure distribution (%) between different manure handling systems

Animal category	Grazing	Solid manure	Slurry	Deep litter
Dairy cows				
Conv High (9)	16	40	44	0
Conv Med (8)	24	17	61	0
Org (6)	36	32	32	0
Replacement				
Conv High (9)	43	2	28	26
Conv Med (8)	39	12	31	18
Org (6)	45	21	1	33

As can be seen in Table 3.5, the manure handling systems for the dairy cows was similar when comparing the groups Conv High and Org, while slurry was more used in the group Conv Med. None of the investigated farms used deep litter for their dairy cows, which in contrast was a commonly used manure system for the replacement heifers, especially at the organic farms. The replacement animals on the conventional farms were to a higher degree held on slurry in comparison with the organic farms.

Data on nitrogen production in manure is important when calculating the emissions of ammonia and nitrous oxide. Data on the N excreted per animal for different animal categories and production levels were based on standards from the computer program STANK 4.11 (JBV 2003a), which is software used in the advisory service for calculating nutrient flows and N losses at farms (Table 3.6).

Table 3.6 Annual total N-excretion for the animal categories/production levels

Animal category	Kg N, total excreted per year
Calf, 0-2 month	2.9[1]
Younger heifer, 2 – 12 month	22
Older heifer, 12-24 month	47
Dairy cow, 6 000 kg ECM/year	100
Dairy cow, 8 000 kg ECM/year	117
Dairy cow, 10 000 kg ECM/year	139

[1] Data according to Dansk Jordbruksforskning, 2000 (all others STANK 4.11)

3.2.4 Emissions of ammonia

Ammonia is lost in the housing system, during the grazing period, when manure is stored and when the manure is spread (see Figure 3.2). The emission factors used for calculating the losses are presented in Appendix 1.

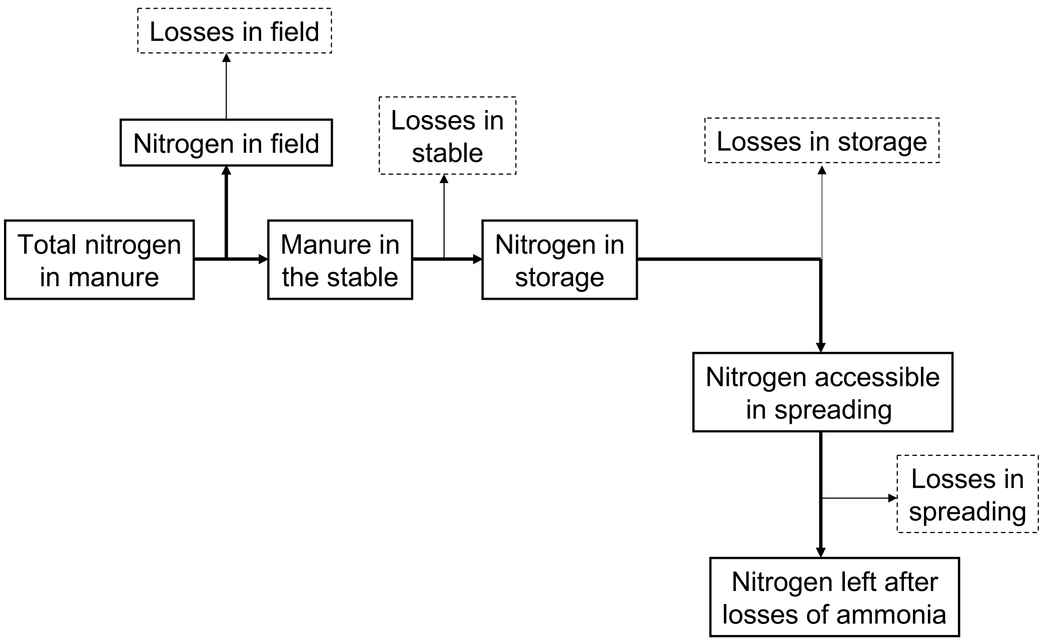

Figure 3.2 Losses of ammonia in different stages

In tied-up stables, the manure is deposited on a smaller surface, and thus has a lower emission factor than in the free-going systems. According to Stank 4.11 (JBV 2003a), the emissions are high from cattle houses with deep litter manure. The emission factor for the grazing period is also used as an emission factor in the Swedish inventory statistics.

3.2.5 Emissions of nitrous oxide

No emissions of nitrous oxide were calculated in the housing since the slurry and solid manure/urine were transported to the storage on a daily basis. Deep litter in the stable was considered as stored manure. Emission factors (EF) for nitrous oxide were chosen according to IPCC updated guidelines (IPCC 2000).

Table 3.7 Emission factors for nitrous oxide during storage and grazing period

	Kg N_2O-N/kg N in manure[1]
Slurry	0.001
Solid manure, deep litter	0.02
Manure dropped in grazing periods	0.02

[1] After deducting ammonia losses

For estimations of indirect N_2O emissions due to the deposit of ammonium, IPCC gives the EF of 0.01 kg N_2O-N/kg NH_4-N deposited; this factor was used for the emitted ammonia in housing, storing and grazing.

3.2.6 Emissions of methane

Methane is a by-product of microbial breakdown of carbohydrates (mainly cellulose) in the digestive tracts of herbivores. This process, called enteric fermentation, is influenced by the production level, feed consumption level and type of feed. The default values that are given by IPCC (1996) are based on milk yields lower than those recorded in contemporary Swedish milk production, and therefore a relation according to Kirchgessner *et al* (1991) was used to calculate the methane emissions due to enteric fermentation:

CH_4-emission (g/dag) = 55 + 4.5 x (kg milk/cow*day) + 1.2 x (metabolic weight)

Metabolic weight = (live weight) $^{0.75}$

When calculating the emission factors for different milk yield levels (Table 3.8), it was assumed that the lactation period was on average 305 days and the dry period 60 days. It was also presumed that there was an “over-feeding” with 10 % of energy which leads to a slight increase of the emissions. According to the Swedish Dairy Association, there is an average of 7 % of “over-feeding” at Swedish milk farms.

For the replacement animals, an average emission factor of 50 kg CH_4/animal*yr was used which is the Swedish EPA emission factor for cattle other than cows (NV 2002).

Table 3.8 Calculated emission factors for methane due to enteric fermentation, dairy cows

Milk yield, kg ECM/cow*yr	Emission of methane, kg CH4/cow*yr	Milk yield, kg ECM/cow*yr	Emission of methane, kg CH4/cow*yr
7 500	118	10 000	130
8 000	120	10 500	132
8 500	122	11 000	135
9 000	125	11 500	138
9 500	128		

The emission of methane from manure storage was calculated according to IPCC (1997):

Emissions of CH_4 = VS * Bo * 0.67 kg/m^3 * MCF

Data for the yearly production of manure for different animal categories and production levels were according to STANK 4.11 (JBV 2003a). Volatile solid (VS) was calculated as 87 % of the dry matter in the manure (Dustan 2002). In Table 3.9, the VS production used is shown. The variation of VS-production is due to the production level and type of manure. In systems with solid manure, more straw is used and here the manure production is higher. Thus, some methane production is calculated from the straw as well as from the manure.

Table 3.9 Production of VS (volatile solids)

Animal category	Kg VS/head*yr
Dairy cow	1 700 – 2 100
Young heifer, 2-12 month	330 – 400
Older heifer, 12 – 24 month	720 – 840
Calf, 0 – 2 month	26

Bo is the methane generation potential: 0.24 l CH_4/kg VS for cows and 0.17 l CH_4/kg VS for replacement heifers.

MCF is the methane conversion factor. For slurry in cold climates, IPCC (1997) suggested MCF to be 10 %. In the revised guidelines (IPCC 2000), MCF for slurry was significantly increased, up to 39 %. Dustan (2002) argues that, based on Danish long-term measurements and calculations, the MCF for cattle and swine slurry should be around 10 %. The Swedish EPA uses 10 % in their country inventory calculations and this emission factor is also used in this study (NV 2002). According to IPCC (2000), MCF for solid manure is 1 %, manure dropped at grazing 1 % and for deep litter manure 39 %. With the data on how manure was divided between grazing period and different manure systems (see Table 3.5), emission factors were calculated based on the conditions on each separate farm. Table 3.10 shows the magnitude of the calculated emission factors. The manure systems for dairy cows were solid (or semi-solid) manure or slurry, at the conventional as well as the organic farms. Slurry generates significantly more CH_4-emissions than solid manure. The emissions from the storage of the manure were lower on the organic farms with slurry, due to longer grazing periods leading to a larger share of the manure production being dropped outdoors (MCF 1 % for this manure). The manure systems for the heifers were very diversified at the inventoried farms. One farm could have a mixture of solid, slurry and deep litter with different age categories of the heifers in different manure systems. The lowest emission factors for replacement animals were from farms with solid manure, the highest from farms with deep litter. Generally, deep litter systems were more commonly used for the heifers at the organic farms.

Table 3.10 Variation in calculated emission factors for methane emission from manure storage

	Solid manure, dairy cows, kg CH_4/head*yr	Slurry, dairy cows, kg CH_4/head*yr	All manure types Replacement heifers, kg CH_4/head*yr
Conventional farms	2.9 – 3.4	19 – 25	1.7 – 19
Organic farms	2 – 2.8	13.5 – 15.6	1.7 – 17.5

Finally, the average calculated emission factors for enteric fermentation and manure storing for the three groups are shown in Table 3.11.

Table 3.11 Calculated emission factors for methane, average for the three farm groups

	Enteric fermentation Kg CH_4/cow*yr	Enteric fermentation Kg CH_4/heifer*yr	Manure storing Kg CH_4/cow*yr	Manure storing KgCH_4/heifer*yr
Conv High	130	50	13.6	9.2
Conv Med	126	50	17.4	6.7
Org	127	50	8.4	9.6

3.2.7 Use of electricity

The annual use of electricity at the farms was calculated as an average of the consumption over three years: 2000, 2001 and 2002. The data on electricity at farms normally also includes household electricity. The standard electricity consumption is 5 900 kWh/year for household consumption (kitchen, lightning etc) and 14 500 kWh/year when electricity is used for heating[3]. Electricity used privately was deducted from the farms´ total electricity consumption. Table 3.12 shows the average electricity use in the farm groups, the average electricity use per dairy cow was higher at the organic farms.

Table 3.12 Average annual electricity consumption in the three farm groups

	Conv High (9)	Conv Med (8)	Org (6)
Electricity consumption, kWh per dairy cow including replacement animal	1 290	1 220	1 600

3.3 Crop production

3.3.1 Land use for farm- produced fodder

The arable land used for fodder production was recorded at the farms and the land use was divided for different crops. Table 3.13 shows the arable land area used yearly for the fodder production at the farms, distributed per cow (and its replacement heifer). The group Conv High (producing more than 7 500 kg milk/ha) had an average area of 0.93 ha/cow for fodder

[3] Average house hold data for electricity use was based on data from SCB (www.scb.se), The Swedish Statistics Institute

production at the farm. This is far lower than the group Conv Med and Org and can be due to that this farm group buys more feed from outside the farm, has higher yields in crop production and/or has a better feed efficiency (higher milk production per cow).

Table 3.13 Average yearly land use for fodder production at the dairy farms

Crop	Conv high Ha/cow+replacement	Conv Med Ha/cow+replacement	Org Ha/cow+replacement
Ley (grassland)	0.60	0.81	0.92
Maize	0.03	0.02	0
Other roughage	0.01	0.02	0.06
Grains	0.29	0.45	0.41
Leguminous	0	0	0.10
Total arable land	0.93 (0.72-1.1)	1.3 (0.92-2)	1.49 (1-2.4)

The groups Conv Med and Org had a rather similar land use pattern, but the organic farms had in average more grassland per cow. Table 3.14 shows the average distribution of the crops that were grown at the invented farms.

Table 3.14 Distribution (average) of crops grown at the arable land of the dairy farms

Crop	Conv High Share of arable land, %	Conv Med Share of arable land, %	Org Share of arable land,%
Ley, grassland	59	50.5	62
Maize	3	1	0
Other roughage	1	1	5
Grains	32	36	27
Rapeseed	0	1	0
Leguminous	0	0	2
Set-aside	5	10.5	4
Total	100	100	100
Exported area	5 (0-35)	9 (0-34)	0

In the group Conv High, leys and grains was grown on 90 % of the farms´ arable land. Four out of nine farms in this group exported vegetable products, at one farm as much as 35 % of the farm´s arable land was used for specialised seed production and all concentrated feed was imported to the farm. However, most commonly in this group was that all the farm´s area (except set-aside land) was used for fodder production.

In the group Conv Med, in average 86 % of the arable land at the farms was used for growing cereals and leys. Five farms out of eight in this group exported surplus vegetable crops, mostly grain.

Finally, in the organic group, almost 90 % of the land use was grassland and grains. None of the six farms in this group exported any vegetable crops, all crop production was used as fodder and the farms only sold animal products.

3.3.2 Diesel use

The data on diesel consumption at the farms for the fodder production, manure handling and animal production were collected. Data on the purchases of diesel at the farms were collected for three years (2000 – 2002) and an average yearly use was calculated from these data. All the studied farms used, in varying degree, contractor services, e.g spreading slurry, baling straws etc. Data were also collected for these services and by using standard values for different machine operations, the diesel consumption for the services connected to fodder production and manure spreading was calculated. In some cases, the farms did smaller contractor work at other farms and this diesel was deducted as was the diesel used in vegetable crops that were sold from the farm. In Carlsson (2003), the standard values for diesel use in different machine operations are presented. Table 3.15 shows the average total diesel use in the three farm groups. The variation was big within the groups, but the group Conv High had the highest average use of diesel per hectare. One explanation for this can be that this farm group had more manure to handle and spread per hectare and that the grazing period was shorter in this group.

Table 3.15 Yearly average diesel use and variation in the three farms groups

	Conv High	Conv Med	Org
Average diesel use for fodder production and animal production, liter/ha fodder crops	134 (62 – 191)	101 (77-122)	107 (64-144)

Data on emissions from diesel use in tractors and harvest machines were based on Lindgren *et al* (2002), see Table 3.16.

Table 3.16 Emissions from diesel combustion tractors

Emission	Gram per MJ diesel
CO	0.07967
CO_2	75
HC	0.0237
NOx	0.9102
SO_2	0.019

3.3.3 Pesticide use

In Table 3.17, the average use of pesticides in the fodder crops is shown. Fungicides and insecticides were used to a very low extent in the farms´ fodder production. Glyphosate (used when breaking the leys) was the most frequently used pesticide, corresponding to 35 % of the total pesticide in the group Conv Med and 70 % in Conv High. Data on pesticide production was according to Green (1997).

Table 3.17 Pesticide use in fodder crops at the farms

	Conv High, gram active substance/ha	Conv Med, gram active substance/ha	Org, gram active substance/ha
Pesticides, average use and variation in fodder crops at the farm	200 (0 – 450)	236 (0 – 700)	0

3.3.4 Manure and fertiliser use

With standard values from the database in STANK 4.11 (JBV 2003a), the manure production at the farms was calculated. Table 3.18 shows the average manure production used at the farms.

Table 3.18 Manure use at the farms

	Conv High (9 farms)	Conv Med (8 farms)	Org (6 farms)
Manure, kg dry matter/ha*year	2 070	1 200	1 330

Standard values for dry matter content in different manure categories were used: slurry 8 %, solid manure 16 % and deep litter 25 %. The organic farms had more deep litter manure and this is the reason for a higher dry matter production per hectare in this group compared to the group Conv Med. Conv High had the highest livestock density, and thus the highest manure rate.

The average use of synthetic fertilisers in the fodder crops at the conventional farms is shown in Table 3.19. The use of fertiliser was slightly lower at the farms in Conv High which is probably an effect of the higher supply of manure in this farm group. No synthetic fertilisers were used at the organic farms.

Table 3.19 Use of fertilisers in the fodder crops at the conventional farms

		Conv High	(9 farms)		Conv Med	(8 farms)
	Kg N/ha	Kg P/ha	Kg K/ha	Kg N/ha	Kg P/ha	Kg K/ha
Average use of fertilisers	76	1	2	80	3	8
Variation	6 – 103	0 – 4	0 – 13	22 – 102	0 – 7	0 - 22

Data on resource use and emissions from fertiliser production were taken from to Davis and Haglund (1999), important parameters are shown in Table 3.20

Table 3.20 Energy use and emission of CO_2 and N_2O from fertiliser production

	Per kg nitrogen	Per kg phosphorous
Energy use, MJ/kg	41.8	30.6
Emission,		
CO_2, g/kg	2 950	3 080
N_2O, g/kg	14.6	0.287

3.3.5 Use of plastic

Data on the use of plastic for silage were collected. The average use in the groups is shown in Table 3.21. Data for production of polyeten was taken from APME (1994). It was assumed that the plastic was recovered for energy production (district heating) after use at the dairy farms (Sundqvist 1999).

Table 3.21 Average use of plastic at the farms

	Conv High	Conv Med	Org
Kg plastics/ha fodder crops at the farm	8.2	9.7	13.8

It was more common with silage in bales than in silos at the organic farms which is an explanation for the higher use in this farm group.

3.3.6 Nutrient balances

All the studied farms were participating in the advisory programme "Greppa Näringen" and in this advisory programme, nutrient balances according to the farm-gate principle are calculated for the farms. In Table 3.22, the average nitrogen balance for the three farm groups is presented. The balances are calculated for arable land at the farms (the area for grazing meadows are not included).

Table 3.22 Nitrogen balance (average) for the three farm groups (farm-gate method)

	Conv High (9 farms)	Conv Med (8 farms)	Org (6 farms)
Input *(kg N/ha)*			
Fertilisers	91 (57 – 115)	74 (11-111)	5[1] (0-30)
Purchased feed	96 (66-148)	56 (32-100)	41 (18-86)
N-fixation	34 (15-57)	25 (15-41)	53 (38-64)
Atmospheric N-deposition	8 (4-12)	8 (4-11)	8 (5-10)
Others	3 (1-8)	1 (0-2)	4 (5-10)
Total input	**232** (177-334)	**164** (112-202)	**111** (70-164)
Output *(kg N/ha)*			
Milk	48 (37-67)	28 (17-38)	28 (17-41)
Meat	7 (4-13)	4 (2-5)	4 (2-6)
Vegetable products	5 (0-22)	9 (0-35)	0
Manure	6 (0-45)	1 (0-2)	0
Total output	**66** (45-125)	**42** (31-74)	**32** (20-46)
Surplus (kg N/ha)	**166** (129-209)	**122** (80-159)	**79** (48-123)

[1] One of the organic farms imported manure

Conv High had on average a higher input of nitrogen in fertilisers and feed than the group Conv Med, but also a significantly larger output of nitrogen in the products milk and meat.

The overall farm N-surplus was lower at the organic farms and the difference to the two other groups was statistically significant. The difference in N surplus between the two conventional groups was not statistically significant.

The N-fixation was, as expected, highest in the organic group. The higher nitrogen fixation in the group Conv High compared to Conv Med is probably a consequence of a larger share of leys (with clover/grass) of the total farm area (see Table 3.14).

3.3.7 Emissions of nitrogen and phosphorous

Emissions of reactive nitrogen compounds are a source of several important environmental impacts from animal production (e.g. eutrophication, climate change, acidification). The nitrogen flows of the farms were inventoried closely and nitrogen emissions were calculated with information on management of crops, manure, soil preparation etc on each separate farm.

Ammonia emissions

Calculations for ammonia emissions from cow houses, manure storing and grazing were described in section 3.2.4. Data were collected on manure-spreading practice (e.g. time, technique) and the ammonia emissions were calculated with the help of emission factors used in the computer program STANK (JBV 2003a), and also in the national inventory statistics (Karlsson & Rodhe, 2002). The emission factors are summarised in Appendix 1.

Nitrate emissions

The nitrate leaching was calculated with an empirical model used in the computer program STANK (Aronsson & Torstensson, 2002). In this model, a number of factors are considered that are important for the size of the leaching, e.g: soil type, average yearly precipitation, total manure application in the crop rotation (average manure rate as tonne dry manure/ha), crop, point of time for soil preparation in the autumn, point of time for manure application and over-optimal N-fertiliser rate. The leaching in the single field (as kg NO_3-N/ha) is calculated as:

(Base-leaching x Crop factor x Soil preparation factor) + factor for manure application + factor for over-optimal N-fertilising

All data needed for calculating the nitrate leaching were collected for each single field at the farms. From this data, an area-weighted leaching was calculated for each of the 23 farms.

Nitrous oxide emissions

Methods for calculating emissions of nitrous oxide (N_2O) during the grazing period and storing of manure were discussed in section 3.2.5. For calculating emissions of N_2O from the agricultural soils due to N-application from fertilising, emission factors from IPCC (1997) were used.

Table 3.23 Emission factors for N_2O as direct emission from agricultural soils

Nitrogen input	Kg N2O-N/kg N
Synthetic fertilisers	0.0125
Manure	0.0125
N-fixation in crops	0.0125

N_2O-losses from manure and fertilisers were calculated after ammonia losses were deducted. N_2O-losses due to N-fixation in the crops were calculated with data for symbiotic nitrogen fixation in the clover/leys and peas/horse-beans that was recorded when the farms´ nutrient balances were set up.

Indirect emissions due to losses of ammonia and nitrate were also calculating according to IPCC (2000) (Table 3.24)

Table 3.24 Emission factors for indirect emission of N_2O

	Kg N_2O-N/kg N deposited or leached
Deposit (NH_3-N)	0.01
Leached (NO_3-N)	0.025

Phosphorous

The loss of phosphorous from Swedish arable land varies and there are no models available for calculating emissions from separate farms today. A reasonable average for P-losses is 0.3 kg P/ha*yr (Kyllmar *et al*., 1995) and this was used for all farms in the study.

3.4 Concentrate feed production

3.4.1 Concentrate feed products

The most frequently used raw materials in concentrate for cattle are grains, soy meal, rapeseed meal and beet pulp (JBV 2004). Two major feed product types are used in Swedish milk production: protein concentrate feed and mixed concentrate feed. Protein concentrate feed is used as a complement to grain and most often purchased by dairy farms that grow their own grain or purchase it directly from a neighbouring farm.

Mixed protein feed contains approximately 40 % cereals, fibres and around 30 % protein ingredients. This feed type is mainly used by dairy farms that do not have any own production of grain. There are a number of different feed products within these two groups but grain, soymeal, rapeseed meal and beetpulp are without exception the major ingredients. When collecting data on the purchased feed at the 23 dairy farms, a larger number of different concentrate feed products were found. Therefore, a standard feed recipe for the two major concentrate feed products was put together with data from Lantmännens feed industry in Lidköping and Falkenberg (Nyemad, C. pers comm. 2003). These standard feed compositions represent the most sold products from feed industry that sell feed products to more than 25 % of the Swedish dairy farms. In Appendix 2, the compositions of these standard concentrate feed are shown.

Protein concentrate feed for conventional farms (normally used by around 1 500 kg per cow*yr) contains more than 25 % of Expro® which is a heat-treated rapeseed meal with a higher protein value for cattle than ordinary hexane-extracted rapeseed meal. The soymeal part is slightly more than 20 %, a smaller part of the soymeal is heat-treated (soy-pass). The third big ingredient in this feed type is beet-pulp which provides fibre and balance the proteins.

The recipes for protein concentrate feed for organic farms can differ more, due to more variations in the supply of raw material. Since 5 % of the feed is allowed to be conventionally produced, the standard feed type contains conventional maize gluten meal and fats. Due to problems finding data on production of maize gluten meal, data for conventional soymeal was used in the inventory (the two feeds both have a high protein content).

The mixed concentrate feed for the conventional farms contains cereals and co-products from mill, approximately 45 %. Other ingredients are protein and fibres. The mixed concentrate feed produced for organic dairy farm contains relatively more grain and domestically produced protein in the form of rapeseed cake and horse-beans (Appendix 2).

The energy use for grinding, mixing and pelleting cattle concentrate feed in the Swedish feed industry is 374 MJ/tonne feed of which 50 % is natural gas and 50 % is electricity (Cederberg, 1998; Tietz, F pers comm. 2003). The transport of the concentrate feed products from the feed industry to the dairy farms were calculated as an average of 115 km according to data from the Lantmännen feed industry (Lundström, S. pers comm., 2004). Data on resource use and emissions in the production of the raw materials are presented in the following section. In Appendix 3, all transport data for the raw materials are summarized.

3.4.2 Conventional grain

In the mixed concentrate feed, about 40 % of the mass is grains. The feed industry in Lidköping buys grain in the region of Västra Götaland, and data for cultivation in this area was according to regional economic calculations (SLU 2004).

Table 3.25 Yields and use of seed, fertilisers and diesel in cultivation of cereals for feed production in the region of Västra Götaland

	Barley	Wheat	Triticale
Yield, kg/ha	4 600	6 100	5 000
Seed, kg/ha	180	190	180
Fertiliser-N, kg/ha	72	112	80
Fertiliser-P, kg/ha	14	18	15
Fertiliser-K, kg/ha	3	11	5
Diesel, l/ha	80	80	80
Drying, 18 % to 14 %, MJ/kg	0.3	0.3	0.3
Drying, electricity Kwh/kg	0.014	0.014	0.014

Data on pesticide use in grain cultivation are taken from SLU (2004) and JBV (2004).

Table 3.26 Use of pesticides in grain production, Västra Götland

	Wheat, share of area treated	Wheat, average dose, g/ha	Barley. Share of area treated	Barley, average dose, g/ha	Triticale, share of area treated	Triticale, average dose, g/ha
Weed	1.0	114	1.0	6	1.0	775
Glyphosate	0.2	216	0.2	216	0.2	216
Fungicides	0.7	314	0.25	112	0.25	112
Insecticides	0.5	6.2	0.3	30	0.25	3
Total		650		364		1830

Emissions of nitrogen and phosphorous were calculated according to the models described in section 3.3.7.

Table 3.27 Emissions of N and P in grain production, Västra Götaland

	Barely	Wheat	Triticale
Kg NO_3-N/ha	23	23	25
Kg NH_3-N/ha	0.7	1.1	0.8
Kg N_2O-N/ha	0.9	1.4	1
Kg P/ha	0.3	0.3	0.3
Indirect emission, N_2O-N, kg/ha	0.58	0.59	0.63

3.4.3 Organic grain and horse beans

Data for cultivation of organic wheat, oats and horse beans were collected from regional economic calculations for organic farming (SLU 2004). The three crops are assumed to be cultivated in a crop rotation, se Table 3.28 for yields and manure.

Table 3.28 Crop rotation and yield for production of fodder crops

Crop	Yield, kg/ha	Fertiliser
Oats	3 000	20 t/ha cattle manure
Green manure	0	
Sugar beets	37 000	
Peas	2 600	
Winter wheat	3 215	20 t/ha cattle manure
Horse beans	2 600	none

The yields are estimated to be 60 % of conventional yields for grain and 80 % of conventional yields for horse beans. Green manure leads to an extra land use for the whole crop rotation and emissions of nitrous oxide and ammonia. Since this green manure is cultivated to fertilise the most valuable crop in the rotation namely sugar beets, these impacts were allocated to the beet crop. The use of diesel was calculated at 93 l/ha for oats and wheat and 83 l/ha for horse beans. The drying of the crops reduces the water content to 14 % from 18 %, using the same energy sources as for conventional grain.

The nitrogen emissions due to leaching and application of manure were calculated with models presented in section 3.3.7. Table 3.29 gives an overview of the calculated losses.

Table 3.29 Emissions of N and P in organic grain and horse bean cultivation

	Oats	Winterwheat	Horse beans
Kg NO_3-N/ha	16	35	30
Kg NH_3-N/ha	4.5	6	0
Kg N_2O-N/ha (direct)	1.2	1.2	1
Kg N_2O-N/ha (indirect)	0.44	0.94	0.75
Kg P/ha	0.3	0.3	0.3

All transports are according to Appendix 3.

3.4.4 Conventional rapeseed meal

Rapeseed meal occurs in two forms in the concentrate feed; as heat-treated ExPro® from the Swedish crusher Karlshamn, and imported hexane-extracted meal from Germany. The heat-treatment makes protein in the feed more valuable for cattles. The rapeseed for the production of ExPro® originates from Sweden (40 %) and Germany (60 %) (Herland P-J, pers. comm., 2003).

Out of the Swedish production of rapeseed , 60 % comes from winter rapeseed and 40 % from spring rapeseed. The average yields were in 2002, 2 900 kg/ha for winter rapeseed and 2 100 kg/ha for spring rapeseed (JBV 2003b). Data used for rapeseed cultivation in this study were a weighted average of the two forms. Table 3.30 shows production data for the cultivation.

Table 3.30 Data on rapeseed cultivation (Skåne, Västra Götaland)

Input	Winter rape seed	Spring rape seed
Seed, kg/ha	6.5	10
Fertiliser-N, kg/ha	195	119
Fertiliser-P, kg/ha	18	16
Fertiliser-K, kg/ha	34	30
Diesel, kg/ha	86	83

Source: Hushållningssällskapet (2003), Törner L. pers comm

Winter rapeseed is dried from 10.8 % water content to 9 % and from 14 % to 9 % for spring rapeseed (Hushållningssällskapen 2003). Data on average use of pesticides in rapeseed cultivation were taken from agricultural statistics and Svensk Raps (JBV 2003c; Biärsjö, pers comm. 2004).

Table 3.31 Use of pesticides in rapeseed cultivation (Skåne, Västra Götaland)

Treatment	Winter rape Act subst Dos/ha	Winter rape Share of area treated	Winter rape Average dose	Spring rape Act subst Dose/ha	Spring rape Share of area treated	Spring rape Average dose
Weed	Metazaklor, 1000 g/ha	0.83	830	Metazaklor, 300 g/ha	0.32	96
				Cyanazin, 400 g/ha	0.22	88
Fungicide	Iprodion, 640 g/ha	0.16	102			
Insecticide	Deltametrin, 10 g/ha	0.55	5.5	Deltametrin, 12.5	0.82	10.2
Total, gram act.sub/ha			938			195

Emissions of N from the cultivation of rapeseed were calculated according to the same models as described in section 3.3.8.

Table 3.32 Emissions of N and P in Swedish rapeseed cultivation

Emission	Winter rapeseed	Spring rapeseed
NO_3-N, kg/ha	36	30
NH_3-N, kg/ha	2	1.2
N_2O-N, kg N/ha1	2.4	1.5
Phosphorous, kg P/ha	0.3	0.3

The German rapeseed used was presumed to originate from the north of Germany. According to different materials from UFOP[4] the use of fertilisers was estimated at 200 kg N/ha, 30 kg P/ha and 100 kg K/ha German winter rapeseed. The diesel use was estimated at 90 l/ha. According to an article of Jonsson (1996), the use of pesticides in German rapeseed cultivation is 1.5 l/ha herbicides, 0.8 l/ha fungicides and 0.27 l/ha insecticides. Using the same active substances as in Swedish winter rapeseed production (Table 3.31), this gives an active dose of approximately 960 g/ha in winter rapeseed.

In the extraction of rapeseed meal the exchange is approximately 56 % meal and 41 % oil (Herland, PJ pers comm. 2003). The price allocation was based on world market prices 2001/02.

[4] UFOP Union zur Förderung von Oel-und Proteinpflanzen e.V.

Table 3.33 Mass-and price distribution between oil and meal

Products	Mass, %	Price, %
Oil	41	72
Meal	56	28

Price according to Oil World (2003)

Total energy consumption for the extraction is approximately 918 MJ/tonne rapeseed in the Karlshamn crusher, all data and emissions connected to this process is described by Cederberg (1998).

Transports of German and Swedish rapeseed and the rapeseed meal are described in Appendix 3. In the production of Expro®, 40 % of the rapeseed was of Swedish origin and it was estimated that half of this was transported from central Sweden by boat and the other half from southern Sweden by lorry (Herland, P J, pers comm. 2003).

3.4.5 Organic rapeseed cake

The organic rapeseed cake in the organic concentrate feed is produced in a small feed industry in the south west of Sweden. Since hexane extraction is not permitted in organic feed, no chemicals are applied in the extraction.

The dominant part of the rapeseed cultivation for this feed ingredient is in the region of Västra Götalands. The yield of conventional winter rapeseed is 3 200 kg/ha in this region and the yield level for organic rapeseed was calculated as 2 000 kg/ha (60 % of conventional). The rapeseed was assumed to be cultivated with an application of 15 t/ha cattle slurry in the autumn and 20 t/ha cattle slurry in the spring. The diesel consumption is estimated as higher than for conventional rapeseed due to two manure applications; 100 l/ha. Drying of the seeds reduces the water content to 9 % from 10.8 %, using the same energy data as for conventional rapeseed. Emissions of N and P from the cultivation were calculated with the same methods as described in section 3.3.7. (see Table 3.34).

Table 3.34 Emissions of N and P in organic rapeseed cultivation

Emission	Organic winter rapeseed
Kg NO_3-N/ha	37
Kg NH_3-N/ha	5.5
Kg N_2O-N/ha (direct)	1.5
Kg N_2O-N/ha (indirect)	0.98
Kg P/ha	0.3

The energy use in the small feed industry (Slöinge Lantmän) when extracting the rapeseed was 65 kWh electricity per tonne rapeseed and the exchange rate was 33 % oil and 67 % rapeseed cake (Sönnerstedt, J. pers comm. 2002). The oil is sold as an organic food product. The prices fluctuate for the cake as well as the oil but a reasonable price allocation between the two products were estimated as 50 %/50 % (Sönnerstedt, J. pers comm. 2002).

3.4.6 Soymeal

The soy meal is imported from Brazil and the dominant part comes from the state Mato Grosso (Kämpe, G. pers comm.). In this region there is a fast expansion of soybean production and new arable land is taken into production by reclamation of the savannas "Cerrados". The yield level of soybeans in Brazil is today approximately 2 500 kg/ha.

Data on fertiliser, diesel use etc were collected from economic calculations for soybean cultivations from the website of AgBrazil[5] , where information is given on the conditions for soybean cropping in this part of Brazil. These data have been compared with data collected from Embrapa in earlier studies (Cederberg, 1998). Cultivation data are shown in Table 3.35.

The soybean is a leguminous and only minor amount or no nitrogen fertilisers at all are applied. The symbiotic nitrogen fixation varies between 60 – 168 kg N/ha, in optimal irrigated conditions up to 244 kg N/ha and a reasonable average is 132 kg N/ha (FAO 1994)

Table 3.35 Use of diesel, fertilisers and lime in soybean cropping in the Cerrados

	kg/ha	litre/ha
Seed	50	
Fertiliser, N	8	
Fertiliser, P	31	
Fertiliser, K	57	
Lime	50	
Diesel		65

The use of pesticides in soybean cultivation is extensive. Depending whether the soybean is cultivated in a conventional soil tilling system or in a no-till system, different strategies for weed application are used. The herbicide application according to Table 3.36 is an average of conventional and no-till cropping (www.agbrazil.com). Insecticides are normally applied at least twice per soybean crop and toxic products like monocrotofos and endosulfan are used (Cederberg, 1998). The doses presented in Table 3.36 have been checked against recommendations from Embrapa (2002)[6]

[5] www.agbrazil.com

[6] www.cnpso.embrapa.br

Table 3.36 **Estimated average pesticide use in soybean cropping.**

	active substance	dose, g/ha
Herbicides	Glyphosate	540
	2,4-D	250
	Cletodim	36
	Lactofen	48
	Oxasulfuron	22
	Trifuraline	380
	Imazaquin	70
Insecticides	Monocrotofos	160
	Profenofos	75
Fungicides	Difenoconazole	50

Data on leaching of nitrogen and phosphorous have not been possible to collect. To calculate the leaching of nitrate, a field balance was established. A yield of 3 000 kg/ha soybeans requires 230 kg N/ha and 192 kg N/ha is removed in the soybean harvest (FAO 1994). According to Castro & Logan (1991) soybean cultivation does not increase organic matter in the soil and the difference of 36 kg N/ha is assumed to leach. Soil erosion in soybeans can be significant; Klink (1995) reports on soil losses in the order of tonnes per hectare. Due to much higher losses of soil in Brazil it is assumed that phosphorous losses are ten times higher than in Sweden, corresponding to 3 kg P/ha*yr.

The emission of nitrous oxide is calculated to be 1.25 % of applied N in fertilisers and symbiotic N-fixation (IPCC 1997). Losses of N and P are summarised in Table 3.37

Table 3.37 **Estimated emissions of nitrogen and phosphorous in soybean cultivation**

Emission	kg/ha
Nitrate, NO_3-N	36
Nitrous oxide, N_2O-N	1.7
Phosphorous, P	3

When the soybean is extracted, the exchange is 80 % meal and 17 % oil. Price allocation is based on average world market prices during October 2001 – September 2002. The basis for the allocations is given in Table 3.38.

Table 3.38 **Mass and price relations of soy meal and oil**

Products	Mass ratio*, %	World market price**, $/tonne	Price ratio, %
Meal	80	190	68
Oil	17	412	32

* Mass according to Boulder (1985)

** Price according to Oil World (2003)

Data on extraction of soybeans were presented by Cederberg (1998) and they are based on modern extraction industries with new technique. The dominant energy source for this industry in Brazil is wood for steam production and hydropower (Cederberg, 1998).

Today, approximately 75 % of the imported soy meal in Sweden comes from the Cerrado region in Mato Grosso and 25 % from the coastal region in the south of Brazil (Kämpe G. pers comm. 2003). Transports of soymeal in Brazil can be with train, truck or boat on the Amazonas. An estimated average transport scenario according to data from the Swedish feed industry is presented in Appendix 3.

A minor share of the soymeal used in the concentrate feed was soypass, a heat-treated soymeal with a very high feeding value. The soybeans are cultivated in Brazil but the extraction and heat-treatment take place in the Dutch feed industry. Due to difficulties to collect data for this specialised soymeal product, all the soymeal used in the concentrate feed were assumed to follow the cultivation and extraction as described above.

Organic soybeans

In the organic feed some organic soybean from South America (not extracted) was included. No data were available for this crop. The following assumptions were made for the input data: The yield level was 1 800 kg/ha (70 % of conventional). No fertilisers or pesticides were applied. The diesel use was increased by 50 % compared to conventional amounting to 100 l/ha. The emissions were estimated to 36 kg NO_3-N/ha, 1.5 kg P/ha and 1.25 kg N_2O-N/ha. Transports are summarised in Appendix 3.

3.4.7 Co-products from the sugar industry

The two co-products from sugar production, beet pulp and molasses, are important ingredients in feed production for dairy cows. The average sugar beet yield in Sweden is about 46 t/ha, the dry-matter content in sugar beets is 24 –25 %, thus approximately 11 tonnes of products are generated from one hectare of sugar beets (Table 3.39).

Table 3.39 Products from sugar beet cultivation

Products from one hectare of sugar beets, kg/ha	
Sugar:	7 500
Dried beet pulp (DM):	2 143
Molasses (DM):	1 071
Total:	10 714

Data on the cultivation of an average hectare of sugar beets are shown in Table 3.40. The source of this data is Danisco Sugar and the base is yearly collected information on cultivation practices from all the sugarbeet farmers (Landqvist, B pers comm. 2003).

Table 3.40 Resource use and emissions from an average hectare of sugar beets

Resource/emission	
Fertiliser-N, kg/ha	106
Fertiliser-P, kg/ha	16
Fertiliser-K, kg/ha	44
Manure, kg N/ha	14
Use of pesticides, gram act.subst/ha	2 740
NO_3-N, kg N/ha	22.5
NH_3-N, kg N/ha	2.4 (10 % manure-N, 1 % fertiliser-N)
P, kg P/ha	0.3
N_2O-N, kg/ha	1.5

Mass and price distribution between sugar and the fodder co-products is shown in Table 3.41. Price allocation was used when distributing the resource use and emissions from the cultivation between the sugar and the co-products.

Table 3.41 Distribution of mass and price for different products from sugar beet cultvation

Products	Mass-relation, %	Price-relation, %
Sugar	70	85
Beet-pulp	20	15
Molasses	10	5

Drying of beet-pulp (final feed product with 90 % DM) has an energy cost of 6.06 MJ/kg. In the Swedish sugar industry the energy sources are 86 % natural gas and 14 % oil for drying. According to Danisco Sugar the prime energy sources for drying are oil and coal in Denmark (Landqvist, B. pers. comm., 2003). For the imported beet-pulp in the concentrate feed, the same cultivation data as the Swedish ones were assumed, but the drying of the beet pulp was assumed to be done with the energy sources coal (50 %) and oil (50 %).

Due to the high costs of energy for drying the pulp, there is a transition from handling the beet pulp by drying to conserving it by a silage process. The product super-pressed pulp is pressed and mixed with smaller amounts of molasses. It has a DM content of 25 – 27 % and is transported directly to the dairy farms (not via the feed industry). The energy cost for handling the super pressed pulp at the sugar industry is 0.064 l diesel/t product with 25 % DM (Landquist B., pers comm. 2003). The product is transported with lorries to the dairy farms.

All transports accounted for in the production of beet pulp, molasses and super-pressed pulp are according to Appendix 3.

Organic super-pressed pulp

One of the organic dairy farms purchased organic super pressed pulp from the sugar industry. There are some organic sugar beet cultivations in the south of Sweden and data on the cropping were estimated from growers´ experience. The yield was estimated at 37 tonne sugar beets/ha (80 % of conventional). No fertilisers or pesticides were used, 3 t/ha broiler manure was applied in the spring before sowing. Use of diesel was 220 l/ha (10 % higher than conventional), and the emissions were estimated at 23 kg NO_3-N/ha, 2 kg NH_3-N/ha, 1.5 kg N_2O-N/ha and 0.3 kg P/ha.

3.4.8 Co-products from the mill industry

Wheat bran is a co-product from the mill industry and a large mill is situated in the province of Östergötland (Mjölby). The wheat was cultivated according to the quality label "Svenskt Sigill"[7] and ground at Mjölby. Data for this cultivation were collected in the project "LCA of seven food items" (LRF 2002). The wheat was a mixture of spring and winter wheat cultivated at relative high yields. Data from the mill in Mjölby are given in to Table 3.42 and collected from Stadig *et al* (2001).

Table 3.42 Inventory data from the mill in Mjölby

	Consumption/Emission
Electricity, GJ_{el}/t wheat	3.985
Oil (EO1), MJ/t wheat	302.6
Water, m^3/t wheat	0.71
Waste, kg/t wheat	39

When the wheat is ground, 72 % of the mass is wheat-flour and there are two feed co-products: wheat-bran and wheat feed-flour. The allocation is according to Stadig *et al* (2001).

Table 3.43 Mass and price relation of wheat-flour and its feed co-products

Products	Mass ratio, %	Price ratio, %
Wheat-flour	72	91
Wheat-bran	17	4
Wheat feed-flour	11	5

3.4.9 Co-products from ethanol industry

Draff ("Agrodrank" or Distillers waste) is a co-product from the ethanol industry in Norrköping where wheat is the raw material for producing the biofuel ethanol (E100). Data for the cultivation of wheat was described earlier in section 3.4.2. The wheat is transported 100 km from the farm to the ethanol industry.

[7] www.svensktsigill.com

The requirement is 2.65 kg wheat for the production of one litre of ethanol; the production is well described at the website www.agroetanol.se. Co-products in the production of 1 litre of ethanol are 0.85 kg fodder where 0.8 kg is dried draff (90 % DM) and 0.05 is a wet product. The dried product ("Agrodrank") is sold to the feed industry and mixed in feed concentrates for pigs and cattle. In the production, 0.7 kg carbon dioxide per litre ethanol is also produced. Today, this CO_2 is emitted. Mass-and price distribution between the products is shown in Table 3.44.

Table 3.44 Mass and price relations of ethanol and its fodder co-products

Product	Mass-relations. %	Price-relations, %
Ethanol	54	84
Fodder	46	16

The energy consumption in the ethanol industry is 4.5 kg steam/l ethanol (16 bar pressure, 205 C), corresponding to an enthalpy of 2.8 MJ/t. Source for the steam is a power heat station based on biomass fuels. Of the total energy use, 15 % is electricity produced from renewables (Beckman, B pers comm. 2003).

In the process, enzymes and sulfur acid are used, but since "Agrodrank" only is included in minor amounts in the protein concentrate feed, these were excluded.

3.4.10 Grass pellets (conventional and organic)

Since dried grass pellets from Denmark is only included in minor amounts in conventional concentrate feed, data from Swedish production were used. In the grass drying plant of Genevad (southwest of Sweden), grass/clover/luzern are dried from 30 % DM to 90 % DM. Drying one tonne of grass pellets (90 % DM) requires 0.33 tonne coal and 107 kWh electricity (Cederberg & Nilsson, 2004).

The grass pellets from Denmark were assumed to yield 8 000 kg dry matter/ha grass pellets with a fertiliser rate of 150 kg N/ha, 15 kg P/ha and 80 kg K/ha. The average yearly use of diesel for a three-year ley was assumed to be 70 l/ha and symbiotic N-fixation estimated at 55 kg N/ha. Nitrogen emissions were estimated at 29 kg NO_3-N/ha and 2.6 kg N_2O-N/ha.

The lucerne pellets in the organic feed were cultivated on heavy clay soil and no fertilisers were applied. The yield was 8 000 kg DM/ha lucerne pellets and average use of diesel 70 l/ha. N-fixation is calculated at 250 kg N/ha. Nitrogen emissions were estimated at 29 kg NO_3-N/ha and 3.1 kg N_2O-N/ha.

Transports of grass pellets are given in Appendix 3.

3.4.11 Feed fats

Data on production of vegetable feed fats came from a report on fodder fat production (Wallén *et al*, 2000). Two different products were the dominating fats in the concentrate feed. Standard feed fat was made up by 55 % rapeseed fat acid, 37 % palm fat acid and 8 % soy fat acid and lime feed fat composed by 85 % palm fat acid and 15 % calcium hydroxide.

3.4.12 Palm kernel expels

Data on cultivation of palm oil came from an LCA of vegetable oil production (Stadig *et al* 2000). Palm kernel expels is a relatively small (by mass and price) by-product from palm oil production and in the economic allocation only 2.7 % of the environmental impact from palm oil production was allocated to this feed ingredient. The major impacts caused by this feed component are caused by the long transports from the south-east of Asia which are presented in Appendix 3.

3.4.13 Mineral feed

The average content of the mineral feed was monocalciumphosphate (35%), lime (30%), salt (17 %) and MgO (10 %). The remaining 8 % are excluded due to data gaps. Data for the production of the most important raw materials in minerals (lime and phosphoric acid) were according to Davis & Haglund (1999). Data on final production (mixing etc) of mineral feed production came from the feed company Lactamin (Nordholm B., pers comm. 2003).The total energy consumption (including transports) to produce one kilo of minerals were 1.8 MJ electricity, 0.69 MJ natural gas, 1.2 MJ heavy fuel oil and 1.6 MJ diesel.

3.4.14 Others

Calf feed

In conventional milk production, calves are rather frequently fed with a milk substitute during the first ten weeks. Data on calf feed were collected from Cederberg (1998). The average energy use when producing one kg of calf feed was 2.19 MJ electricity, 4.17 MJ natural gas, 4.36 MJ light fuel oil, 1.07 MJ heavy fuel oil, 0.79 MJ diesel and 0.04 MJ wood chips.

Draff pellets

One of the conventional farms purchased draff pellets which is a co-product from the brewery process. No environmental burden of the brewery process was allocated to the feed product. The draff feed product is transported from the brewery to a drying plant. Before drying, the draff is pressed to reduce the water content, from about 50 % DM to 75 % DM. Then the draff is dried to 90% DM and pressed into pellets. The drying requires 0.5 MJ light fuel oil per kg draff pellets which was allocated to the feed (Blomqvist, J pers comm. 2003). The draff pellets are then transported directly to the milk farm (see Appendix 3).

Citrus pulp

Citrus pellets are a co-product from production of juice and this was used on one of the conventional farms. This product has a zero value and takes none of the environmental burden. No drying of the product was done. The juice pellets are transported directly from the juice factory to the milk farm (see Appendix 3).

Roughage fodder

Two of the organic farms and three of the conventional farms purchased minor amounts (3.5 – 25 tonnes) of roughage fodder as silage bales from neighbouring farms. Estimated resources use for this cultivation is shown in Table 3.45 and 3.46. Yield level in conventional silage was 7 500 kg DM/ha.

Table 3.45 Estimation of resource use and emissions in purchased conventional silage

Use of resources	Per ha	Estimated emissions	Per ha
Fertiliser-N, kg	140	NO_3-N, kg	21
Fertiliser-P, kg	15	NH_3-N, kg	1.4
Fertiliser-K, kg	80	N_2O-N, kg	2.2
Diesel, l	60	P, kg	0.3

The yield level in purchased organic silage was estimated as 6 000 kg DM/ha (80 % of conventional).

Table 3.46 Estimation of resource use and emissions in purchased organic silage

Use of resources	Per ha	Estimated emissions	Per ha
Slurry, tonne	20	NO_3-N, kg	21
Urine, tonne	20	NH_3-N, kg	10
		N_2O-N, kg	2.1
Diesel, l	82	P, kg	0.3

According to data from a contractor, the use of plastics was estimated at 1.4 kg/bale and each bale was assumed to contain 200 kg DM silage.

4 Results from the Life Cycle Inventory

The results from the Life Cycle Inventory of the 23 dairy farms were statistically analysed in oneway ANOVA with SAS (SAS Inst. Inc.) and the least significant differences at $p<0.05$ were established. The total results were used to form a LCI database for today´s milk production in Sweden. In Appendix 4, the most important results from the inventory are summarised, as average values and minimum and maximum value for each farm group.

4.1 Resource use

Table 4.1 shows the average use of the most important non-renewable energy resources for the three groups of dairy farms. FU is short for Functional Unit (one kg of ECM).

Table 4.1 Use of non-renewable energy resources in g/FU. Least square means and (se)

	Conventional High, n=9	Conventional Medium, n=8	Organic, n=6	P-value	Least significant difference
Crude oil	33.2 (1.86)	34 (1.97)	26.2 (2.28)	0.27	6.35
Natural gas	12.98 (0.76)	15.14 (0.81)	4.20 (0.93)	<0.0001	2.60
Coal	16.24 (1.28)	14.20 (1.36)	11.29 (1.57)	0.08	4.37
Lignite	2.11 (0.11)	2.34 (0.12)	1.05 (0.14)	<0.0001	0.38
Uranium	0.0022 (0.00018)	0.0023 (0.0002)	0.0028 (0.0002)	0.08	0.00057

There was no significant difference in the use of energy resources between the two conventional farm groups. The use of natural gas and lignite was significantly lower for the milk production in the organic group. The use of uranium (for electricity production) was lower for the group Conv High than the Org group.

Table 4.2 Use of renewable energy resources in g or MJ/FU. Least square means and (se)

	Conventional High, n=9	Conventional Medium, n=8	Organic, n=6	P-value	Least significant difference
Biomass, g	1.42 (0.11)	1.44 (0.12)	1.90 (0.14)	0.03	0.38
Hydropower, MJ	0.25 (0.03)	0.28 (0.03)	0.36 (0.04)	0.07	0.1
Windpower, MJ	0.00057 (0.000047)	0.00058 (0.000049)	0.00077 (0.000057)	0.03	0.00015

The use of renewable energy resources was mostly due to Swedish electricity production for which hydropower is a significant base. Windpower is still a very small contributor to electricity production. Similar to the use of uranium, the use of hydropower was significantly lower for the group Conv High in comparison with group Org.

Table 4.3 **Use of non-energy resources in g/FU. Least square means and (se)**

	Conventional High, n=9	Conventional Medium, n=8	Organic, n=6	P-value	Least significant difference
Phosphorous	1.33 (0.17)	1.90 (0.15)	0.80 (0.20)	0.001	0.54
Potassium	3.04 (0.22)	3.24 (0.24)	0.28 (0.27)	<0.0001	0.76

The use of phosphorous and potassium for producing one kg of milk was significantly lower for the organic group. Mineral feed was the main origin for the phosphorous input for the organic dairy farms while a mixture of feed and fertilisers used in the production of purchased feed was the source for the phosphorous on the conventional farms. Probably due to a higher milk yield per cow in the group Conv High (higher feed efficiency) the phosphorous use was lower than for the group Conv Med.

4.2 Use of energy

The use of energy is presented as secondary energy, i.e. as energy used in the production process.

Table 4.4 **Use of secondary energy in MJ/FU. Least square means and (se)**

	Conventional High, n=9	Conventional Medium, n=8	Organic, n=6	P-value	Least significant difference
Fossile energy	1.97 (0.10)	2.09 (0.10)	1.35 (0.12)	0.0004	0.33
Electricity	0.58 (0.04)	0.60 (0.05)	0.74 (0.05)	0.07	0.15
Renewable	0.037 (0.0034)	0.039 (0.0037)	0.011	0.0002	
Total energy	2.59 (0.12)	2.73 (0.13)	2.10 (0.15)	0.02	0.42

The total energy use was significantly lower for the organic farms while the difference between the two conventional groups was not statistically different. It is the lower use of fossile energy in organic milk production that explains this difference between the two production forms.

4.3 Land use

The land occupation for the production of feed was divided into arable land (at the farm and outside the dairy farm for purchased feed) and natural grazing meadows.

Table 4.5 **Land occupation (arable land and natural grazing meadows) in m^2year/FU. Least square means and (se).**

	Conventional High, n=9	Conventional Medium, n=8	Organic, n=6	P-value	Least significant difference
Arable land at the dairy farm	0.91	1.34	1.76		
Feed products outside the dairy farm	0.45	0.40	0.60		
Natural grazing meadows	0.18	0.18	0.57		
Total land use	1.54 (0.18)	1.92 (0.19)	2.93 (0.22)	0.0005	0.61

The group Conv High had the lowest land use; although, the difference was not statistically significant when comparing with Conv Med. This could be an effect of higher yields of feed at the farms in Conv High but also of the higher milk production per cow (higher feed efficiency). The total land use for producing one litre of milk in organic production was significantly larger than in conventional production.

4.4 Pesticide use

The average use of pesticides in the fodder production corresponded to on average 71 – 81 mg active substance per FU for the conventional farms. The use of pesticides in organic milk production was very low and caused by the conventional feed ingredients in the conventional ingredients in the purchased feed on the organic dairy farms.

Table 4.6 **Pesticide use, mg active substance/FU. Least square means and (se).**

	Conventional High, n=9	Conventional Medium, n=8	Organic, n=6	P-value	Least significant difference
Herbicides	63.3	71.9	6.83		
Fungicides	4.11	4.88	0		
Insecticides	4.0	4.5	1.17		
Total	71.3 (8.86)	81.1 (9.4)	7.8 (1.08)	0.00001	29.73

4.5 Emissions of greenhouse gases

The organic farms had significantly lower emissions of CO_2 per kg milk than the conventional farms which was explained by the lower use of fossile fuels in this production system (Table 4.7). The group Conv High had the lowest emissions of methane per kg milk which was due to a high milk production per cow in this group; the difference was however not statistically significant and there was a large variation between the farms for this emission. The dominant part of the output of methane was due to enteric fermentation; the CH_4 output from the manure handling was 11 – 12 % of the total emission for the conventional farms and 9 % for the organic farms. The group Conv high had the lowest emissions of N_2O of the groups.

Table 4.7 Emissions of greenhouse gases g/FU. Least square mean and (se)

	Conventional High, n=9	Conventional Medium, n=8	Organic, n=6	P-value	Least significant difference
CO_2	167.67 (8.61)	172.63 (9.14)	120.48 (10.55)	0.003	28.77
CH_4	19.70 (1.0)	22.36 (1.07)	22.92 (1.23)	0.10	3.31
N_2O	1.02 (0.07)	1.27 (0.08)	1.09 (0.09)	0.06	0.21

In Table 4.8, the greenhouse gases are weighted into CO_2-equivalents by the factors of CO_2 = 1 CO_2-equivalent, CH_4 = 21 CO_2-equivalents and N_2O = 310 CO_2-equivalents. The higher production per cow in group Conv High compared to Conv Med leads to a lower emission of greenhouse gases per kg milk for this group which is high in intensify, per cow as well as per hectare of land. There was no statistically significant difference in total output of greenhouse gases between conventional and organic milk production.

Table 4.8 Total greenhouse gas emissions, g CO2-eqiuvalents/FU. Least square means and (se).

	Conventional High, n=9	Conventional Medium, n=8	Organic, n=6	P-value	Least significant difference
CO_2-equivalents	896.22 (38.38)	1037.31 (41.74)	938.49 (48.2)	0.06	128.75

4.6 Emissions of reactive nitrogen at the farm level

In the inventory analysis, farm practices, conditions such as soil type etc were registered on the single field level. By using the models suggested by the Swedish Board of Agriculture, emissions of nitrate and ammonia were calculated as was the losses of nitrous oxide with emission factors from the IPCC. Table 4.9 shows the results from the model calculations and they include all the arable land at the dairy farms.

Table 4.9 Calculated N-losses and N-surplus, kg N/ha. Least square means and (se).

	Conventional High, n=9	Conventional Medium, n=8	Organic, n=6	p-value	Least significant difference
NH_3-N, ammonia-N	39 (3)	23 (3)	25 (4)	0.0022	9.77
NO_3-N, nitrate-N	32 (3)	27 (3)	26 (4)	0.9076	10.4
N_2O-N, nitrous oxide	4.7 (0.3)	3.6 (0.3)	3.2 (0.3)	0.004	0.88
Total calculated N-losses	76	54	54		
N-surplus (farm-gate)	161 (14)	122 (3)	80 (16)	0.0048	44.6
Share of N-surplus found in emission calculations	0.47	0.45	0.68		

The group Conv High had significantly higher emissions of ammonia and nitrous oxide per hectare compared to the other two groups and this was most likely an effect of the higher livestock density in this group. The calculated losses of nitrate per hectare of arable land showed no statistical differences between the three groups. The total N-surplus of the farms was calculated according to the farm-gate method. The organic farms had significantly lower N-surplus than the conventional farms, but there was no statistical significant difference in the N-surplus between the two conventional groups (Table 4.9).

Less than 50 % of the farm-gate balance N-surplus was found as calculated losses of reactive nitrogen at the conventional farms. The difference can be due to an increase of soil nitrogen, denitrification or underestimated calculations of emitted reactive nitrogen. A larger share (68 %) of the N-surplus was found as N-losses at the organic farms (Table 4.9). The nutrient balance is more uncertain for organic dairy farms since N input through symbiotic N-fixation can be difficult to rightly estimate. Therefore, the input of N might have been underestimated on the organic farms. However, it can also be that the models for calculating N losses are not fully adapted for organic production systems.

4.7 Emissions of acidifying substances in the life cycle

The emission of acidifying substances in the life cycle of milk production was dominated by ammonia (Table 4.10). The organic group had significantly lower out put of SO_2 due to less sea transports of concentrate feed. The organic group had the highest ammonia emissions per kg milk; the difference was however not statistically significant.

Table 4.10 Emissions of acidifying substances, g/FU. Least square means and (se)

	Conventional High, n=9	Conventional Medium, n=8	Organic, n=6	P-value	Least significant difference
NH_3	4.65 (0.34)	4.44 (0.37)	5.63 (0.43)	0.11	1.16
NOx	1.27 (0.06)	1.3 (0.06)	1.07 (0.09)	0.17	0.25
SO_2	0.60 (0.036)	0.58 (0.039)	0.30 (0.045)	0.0001	0.122

4.8 Emissions of nutrifying substances in the life cycle

Finally, in Table 4.11, the inventory results and the statistical analysis for the emissions of nutrifying substances are shown. When calculating emissions of ammonia and nitrate against the product one kg milk, the relation between the farm groups differs from when calculating the emissions per hectare of arable land at the dairy farms (see Table 4.9). The lower milk production per cow and larger land use per kg milk in organic production are very important factors for the results shown in Table 4.11; namely that the organic group had the highest emissions of nitrate and ammonia per functional unit. As earlier discussed, there were differences in the share of the farms´ nitrogen surplus found as reactive nitrogen in the emission calculations, and it is possible that the organic farms were treated unfairly in the calculations.

Table 4.11 Emissions of nutrifying substances, g/FU. Least square means and (se).

	Conventional High, n=9	Conventional Medium, n=8	Organic, n=6	P-value	Least significant difference
NO_3	17.47 (3.03)	21.80 (2.96	27.57 (3.79)	0.11	9.63
NH_3 (air)	4.65 (0.34)	4.44 (0.37)	5.63 (0.43)	0.11	1.16
NOx (air)	1.27 (0.06)	1.30 (0.06)	1.07 (0.09)	0.17	0.18
Total P (water)	0.09	0.10	0.09		

The calculated losses for phosphorous (P) are very uncertain. Due to the complex processes of P movements and losses from agricultural soils, there is no Swedish model available for estimating P-leaching under different fertiliser rates, soil types etc. Therefore an average area-based value for P-leaching was used for all farms. P losses from soybean cultivation in the tropics were estimated from data reporting big soil erosion losses from the crop. The LCI results for phosphorous emissions must therefore be interpreted very carefully.

5 Discussion

Use of energy and resources for energy

In this LCI, buildings and machinery were excluded. According to Swiss studies, the building infrastructure is of special relevance for energy use in milk and meat production. Erzinger *et al* (2004) investigated the importance of building constructions in LCAs of milk and pig meat production and for the impact categories energy use and human toxicity, buildings were found to be highly relevant. The construction of animal housing made up for 25 % of total energy cost in milk production. Consequently, energy use is underestimated in this study but since there was no significant difference in the buildings between the farm groups, it is reasonable to assume that the relative position between the three groups for the energy use per kg ECM was not affected by the exclusion of buildings.

The average energy use for producing milk according to organic principles was approximately 20 % lower than in conventional production. Lower energy use in organic milk production has been reported by Danish, German and earlier Swedish studies (e.g. Halberg 1999, Haas et al. 2001, Cederberg & Mattson 2000). The omission of synthetic fertilisers and reduced input of concentrate feed in organic milk production are the main reasons for this discrepancy.

The difference in energy use between the two conventional groups (having medium and high milk production per hectare) was very small and it was not possible to draw the conclusion that a greater milk intensity, per hectare as well as per cow, would lead to lower or higher use of energy resources.

Approximately 35 % of the energy use in the conventional milk production was due to direct energy use at the dairy farms as diesel and electricity use. Purchased concentrate feed was the largest indirect energy source, corresponding to 50 – 60 % of the overall energy use (buildings and machinery excluded). The key factor when improving energy use in milk production is a careful control of the use of concentrate feed: avoiding over-feeding, adapting the concentrate feed after the lactation curve, improving silage quality to reduce the need of concentrates, and probably also questioning high milk production per cow when it is based on a high share of protein concentrates in the total feed ratio.

Land use

Land use is probably the most important resource to assess in environmental analysis of food production. Impact assessment is not yet fully developed for this impact category (Lindeijer et al. 2002), but there are agreements that in an LCI a distinction should be made between land occupation and land transformation.

Land occupation was divided between arable land and natural grazing meadows (see Table 4.5) and the term includes the surface as well as the duration (m^2*yr). Since the 1920s, two millions hectares of meadows and pastures in Sweden have been reduced to some 450 000 hectares due to forest plantation. To preserve the rich biodiversity that is connected to this land use, there is a political goal of preserving the remaining meadows and pastureland. A large use of natural grazing meadows is thus considered as a positive environmental impact in

Swedish food production.

Arable land for the feed production was divided between land at the dairy farm and arable land for feed production outside the farm (Table 4.5). On average, two thirds of the total arable land occupation was at the dairy farms in the group Conv High, and approximately 75 % at the dairy farms in the groups Conv Med and Org. The land occupation in Europe for outside farm feed production was mainly grain cultivated in the west of Sweden and rapeseed and sugar co-products cultivated in Sweden and in the Baltic region. The land occupation in South America for outside farm feed production was almost exclusively soybeans.

Due to lack of data, the aspect of land transformation could not be accounted for in this LCI. In Europe, very little land is transformed into new agricultural land but in South America the land use pattern in agriculture changes continously. It was not possible to get data whether the soymeal in the concentrate feed originated from traditional agricultural land in Brazil or newly transformed savannas/forestland. Soybean cropping in Argentine and Brazil has gone through a very strong expansion during the last two decades (Bickel & Dros 2003, Pengue 2004) and it is therefore likely that some of the land occupation for producing milk in Sweden also have led to a land transformation due to the use of soymeal in the concentrate feed. This land transformation has probably contributed to degradation of biodiversity.

Pesticide use

The average pesticide use at the dairy farms was 200 and 236 gram active substance per hectare of arable land in the groups Conv High and Conv Med respectively. This is significantly lower than the use in Swedish agriculture as a whole, where the average use has been approximately 400 gram active substance per hectare arable land in the period 1996-2001 (KEMI 2002). The main pesticide use in the life cycle of milk occurred outside the dairy farms and for the group Conv High, as much as 74 % of the total use was due to pesticide applications in the crops providing raw materials for the concentrate feed production. It is obvious that most of the risks connected with pesticide use in the milk production chain take place outside the dairy farms and focus should be put on the feed industry´s responsibility. Only by setting up standards on cultivation practices for their suppliers of raw materials, can pesticide use and risks in the dairy chain be reduced.

The organic farms had on average a small use of pesticides which was caused by the allowed maximum limit of 5 % conventionally produced feed (Table 4.6). This is likely to change to zero in the coming year since the exception for using conventional feed ingredients in the EC standard for organic production[8] will be repealed.

Greenhouse gas emissions

There was no statistical difference in the total emissions of greenhouses gases (GHGs) between the three farm groups, although there was a tendency that the groups Conv High and Org showed better results (Table 4.8). The pattern of GHG emissions differed between these

[8] EEG 2092/91

two groups. The focus on high milk production per cow in the group Conv High led to lower CH_4 emission per kg milk but larger emissions of CO_2 due to higher input of feed and fertilisers. The less intense milk production in the organic group resulted in higher CH_4 emissions per kg milk but reduced CO_2 output which was a consequence of the lower use of fossil energy. Similar conditions were found by Ledgard *et al* (2004) who compared dairy production in New Zealand based on all year-around-grazing with high-input milk production in Sweden. The total GHG emissions per kg milk were in the same magnitude for the two countries but the contributions of the separate GHGs varied due to differences in the production system.

The variation of GHG emissions from the 23 dairy farms was large and varied between 760 – 1260 g CO_2-equivalents/kg ECM for the conventional farms and 730 – 1110 g CO_2-equivalent/kg ECM for the organic farms. It should be kept in mind that there is a significant uncertainty in the emission factors for the biogenic GHGs methane (CH_4) and nitrous oxide (N_2O). In the newly revised guidelines of IPCC, factors for CH_4 emissions due to manure management have been altered (IPCC 1997; 2000). According to the new factors, the methane conversion factor (MCF) for slurry has increased from 10 % to 39 % in cold climates. Danish studies have however shown that a MCF of 10 % is a more reasonable factor in Nordic conditions and this lower MCF was used in this report. This means relatively low estimates of CH_4 from the farms with slurry as the dominating manure handling system. The slurry storing from a high-yielding cow with only a short grazing period is estimated to emit 24 kg CH_4/cow*yr in this study; had the MCF of 39 % been used, the emission had been estimated at over 90 kg CH_4/cow*yr which would have been a significant increase. Also the MCF for deep litter has been increased in the revised guidelines (IPCC 2000). Deep litter was to a rather higher extent used for the replacement heifers in the groups Conv High and Org, and this manure handling system has recently increased in Sweden because of concerns of animal welfare. Deep litter contributed to a relatively high CH_4 emission from the heifers in these two groups (Table 3.11).

It is obvious that it is difficult to describe an “optimal” milk production system from a greenhouse gas perspective. Intensity per cow, fertiliser and feed use and manure management are important parameters. There are still difficulties in correctly estimating biogenic emissions from the dairy production chain, and great care must be taken when comparing different production systems.

Ammonia emissions

The emissions of ammonia (NH_3) were largest per hectare in the group Conv High but when calculated per kg milk (*i.e.* the functional unit), the NH_3 emissions were in the same magnitude as the group Conv Med. This result was an effect of the higher livestock density in Conv High combined with a higher milk production per cow in the intensive group.

Ammonia can be the cause of regional as well as local environmental impacts. NH_3 can be deposited dry close to the source, and Danish investigations indicate that depending on the structure of the vegetation, 20 – 60 % of NH_3 can be dry deposited within a radius of two kilometres from the source (Asman, 1998). To evaluate the potential local impact of NH_3 emissions, results from LCAs using only the product as functional unit are therefore insufficient. An effective milk production can emit low NH_3 per unit of milk, but due to a high livestock density, the emission per hectare still can be so high that the local environment is damaged. The concentration of the emissions per area unit must also be accounted for and Haas *et al*. (2000) have suggested that local effects should be expressed as impacts per hectare while global effects should be expressed as impacts per kg product.

Calculating ammonia emissions correctly is a difficult task due to the big variation in feeding strategies, techniques for storing manure, spreading techniques and also influence of temperature and precipitation. The NH_3 emissions of the organic farms in this study were probably overestimated in relation to those from the conventional farms. The Swedish emission factors for storing and spreading of solid manure and deep litter are higher than corresponding Danish factors (Hutchings *et al*. 2001; Karlsson & Rodhe 2002). The organic farms had to a higher extent solid/deep litter manure systems and thus got relatively high emissions. Had Danish emission factors been used in this study, the organic farms would have had lower NH_3 emissions. Also NH_3 emissions during the grazing period can have been overestimated at the organic farms. The emission factor 8 % of total N excreted was used and it originates from EMEP/CORINAIR (McInnes 1996) and is also used in the national inventory of Swedish ammonia emissions. However, Misselbrook *et al.* (2000) point out that NH_3 emissions from grazing animals are known to be related to inorganic N input to the grassland and they use a relationship based on the rate of N-fertilising when calculating ammonia emissions from grazing animals in UK agriculture. Ledgard *et al*. (1999) showed that ammonia losses were very low from grassland-based dairy systems with no input of fertilisers. The organic farms in this study had much longer grazing periods for the cows on non-fertilised grassland compared with the conventional farms and the heifers grazed to a high extent on natural grass-meadows with low nitrogen content. The LCI results for ammonia are uncertain due to some of the emission factors today used in Sweden and this can be one explanation for the difference between organic and conventional farms in the share of total N-surplus found as calculated losses of reactive N (Table 4.9).

Nitrate leaching

The calculated nitrate leaching was relatively similar at the farms (Table 4.9) and varied between 20 – 49 kg NO_3-N/ha at the conventional farms and 23 – 30 kg NO_3-N/ha at the organic farms. There was no statistical difference in the area-based nitrate losses between the groups.

The relatively similar nitrate leaching per hectare leads to that the size of the land use is an important factor for the size of nitrate emissions per kg ECM (functional unit). The nitrate leaching per kg fodder produced at the organic farms was probably larger than at the conventional farms due to lower yields (larger land use). Feed intensity (*i.e.* kg feed per produced=delivered kg milk) is also important. Since feed consumption at the farms was not measured in this study, no conclusion can be drawn on this factor. However, the group Conv High seemed to have a high output per kg input of feed and the average production (delivered milk) per cow was very high in this group (Table 3.2).

Also the composition of the concentrate feed had an influence of the calculated nitrate emission per kg ECM (Appendix 2). The feed ingredients in conventional concentrates are based on co-products from oil/starch/sugar products, and the nitrate leaching from these crops are divided through the allocation procedure between the main product and the co-products. In the organic concentrates, more grain, grain legumes and dried grass pellets were used and less co-products from the food industry. Thus, nitrate leaching from these ingredients were allocated to the feed product only. Although the farms in the group Org imported less concentrates than the group Conv Med, approximately 25 % of the nitrate emissions in the life cycle occurred outside the farm boundary for both farm groups. This can mainly be explained by the differences in the composition of concentrate feed (less co-products in organic concentrates).

Final conclusions

In this study, LCI data were collected from 23 dairy farms in an area with uniform and favourable conditions for milk production. The farms participated, in varying degree, in an advisory service for feeding and crop production. Despite these pre-requisites, the results showed large variations between the farms. Better knowledge of these variations and their cause can be of good help in "benchmarking" and environmental improvement work at dairy farms. However, due to the large differences in preconditions for milk production in Sweden, similar data sets should be inventoried and assessed for the central and northern parts of Sweden.

The 17 conventional farms were divided into two groups according to their area-based milk intensity. One hypothesis was that a higher milk production per hectare would lead to larger inputs of feed to the dairy farm which would increase the resource use. This was not the case for the farms investigated in this study and there were small or no statistical differences in resource use and emissions between the two conventional groups. The farm group with a high milk production per hectare also had high milk production per cow so there was a tendency that this group generally scored better on resource use in milk production.

Clear differences were seen between conventional and organic farms. The organic dairy farms had lower use of fossil energy resources and phosphorous and potassium in their milk production. Pesticide use and thereby risks were also significantly lower in the organic production. Land occupation was significantly larger for the organic dairy production. There was no statistical difference in the greenhouse gas emissions from milk production between the two production forms. The average N-surplus was lower at the organic farms but there was no statistical difference between the farm groups in the area-based nitrate leaching. The calculated area-based ammonia emissions, primarily followed the livestock density and not the production form.

Two types of strategies for reducing environmental impact in milk production can be perceived in this study. The first one is to aim for a high production per cow and use the input resources as efficiently as possible. In this strategy, emissions and resource use can be lowered per kg milk and, provided that the livestock density is not to high, N-surplus and N-losses per hectare can be held at an acceptable level. This strategy is prioritised when the land resource is limited. The other strategy is extensive production, for example production according to organic principles. Limited or no input of fertilisers and feed decreases the use of non-renewable resources and the area-based nitrogen surplus can be relatively low. This strategy is interesting for dairy farms that have sufficient areas of land for a large home-based fodder production.

6 References

APME. 1994. Eco-profiles of the European polymer industry. Report 6: Polyvinyl Chloride. APME-Association of plastics manufacturers in Europe.

Aronsson H & Torstensson G. 2003. Teknisk beskrivning av utlakningsberäkning i kalkylprogrammet STANK (Description of the leaching calculations in the computer program STANK). www.sjv.se (mark/växt/miljö)

Asman W A H. 1998. Factors influencing local dry deposition of gases with special references to ammonia. Atmospheric Env. 32: 415-421.

Bickel U & Dros J M. 2003. The impacts of Soybean Cultivation on Brazilian Ecosystems. Three Case Studies commissioned by the WWF Forest Conversion Initiative. www.wwf.ch/images/progneut/upload/Impacts_of_soybean.pdf/

Boulder R (ed). 1985. World Soybean Research Conference III. Col. Westview 1985.

Carlsson V. 2003. Kväveförluster och energianvändning på mjölkgårdar I västra Sverige (Nitrogen losses and energy use on dairy farms in western Sweden). Examensarbete 192. Institutionen för husdjurens utfodring och vård. Sveriges Lantbruksuniversitet, Uppsala, Sweden.

Castro C F & Logan T J. 1991. Liming effects on the stability and erodobility of some Brazilian oxisols. American Journal of Soil Science Society 55:1407-1433.

CEN. 1997. Environmental management – Life cycle assessment – Prinicples and framework, EN ISO 14040. European Committee for Standardisation, Brussels Belgium.

Cederberg C. 1998. Life Cycle Assessment of Milk Production – a comparison of conventional and organic farming. SIK-Report 643. SIK, The Swedish Institute for Food and Biotechnology, Göteborg, Sweden.

Cederberg C & Mattsson B. 2000. Life cycle assessment of milk production – a comparison of conventional and organic farming. Journal of Cleaner Production 8:49-60.

Cederberg C & Nilsson B. 2004. Miljösystemanalys av ekologiskt griskött (Environmental system analysis of organic pig meat). SIK-rapprt 717. SIK, Institutet för livsmedel och bioteknik, Göteborg, Sweden

Dansk Jordbruksforskning. 2000. Kväve, fosfor och kalium i husdjursgödsel (Nitrogen, phosphorus and potassium in manure). Rapport 36. Foulum. Denmark.

Davis J & Haglund C. 1999. Life Cycle Inventory (LCI) of fertiliser production – fertilisers used in Sweden and western Europe. SIK-Report 654. SIK, The Swedish Institute for food and Biotechnology, Göteborg, Sweden

Dustan A. 2002. Review of methane and nitrous oxide emission factors for manure management in cold climates. JTI-rapport 299. Institutet för jordbruks - och miljöteknik, JTI, Uppsala, Sweden

Embrapa 2002. Sistemas de Producao1. ISSN 1677-8499. www.cnpso.embrapa.br

Erzinger S, Dux D, Zimmerman A, Badertscher Fawaz R. 2004. LCA of animal products from different housing system in Switzerland. In: Proceedings of 4th International Conference on Life Cycle Assessment in the Agri-Food sector, p 55-63. DIAS report no. 61. Danish Institute of Agricultural Sciences, Tjele, Denmark. ISSN 1397-9892.

FAO 1994. Tropical Soybean. Brazilian Agriculture Research Embrapa-CNPSo. Plant Production and Protection Series No 27. FAO. Rome. ISSN 0259-2525

Green M B. 1997. Energy in Pesticide Manufacture, Distribution and Use. In: Z R Helsel (ed.) Energy in Plant Nutrition and Pest Control. Elsevier, Amsterdam, p. 165-177.

Haas G, Wetterich F, Geier U. 2000. Life cycle assessment framework in agriculture on farm level. Int. J. Life Cycle Assess. 5 (6): 345-348.

Haas G, Wetterich F, Köpke U. 2001. Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. Agriculture, Ecosystems and Environment 83:43-53.

Halberg N. 1999. Indicators of resource use and environmental impact for use in a decision aid for Danish livestock farmers. Agriculture, Ecosystems and Environment 76:17-30.

Hushållningssällskapen. 2003. Produktionsgrenskalkyler 2002. Hushållningssällskapen I Skåne och Halland, Borgeby/Kristianstad, Sweden.

Hutchings N J, Sommer S G, Andersen J M, Asman W A H. 2001. A detailed ammonia emission inventory for Denmark. Atmospheric Environment 35: 1959 – 1968.

IPCC 1997. Revised 1996 IPCC Guidelines for the National Greenhouse Gas Inventories. The Reference Manual (Volume 3). www.ipcc.ch

IPCC. 2000. IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. www.ipcc.ch

Jonsson H. 1996. Världsmarknadspriset minskade bekämpningen (World market price reduced Pesticide Use). Article in Svensk Frötidning no 10, Alnarp, Sweden

JBV 1998. Förordning 1998:899 (Directive 1998:899). Jordbruksverket, Jönköping, Sweden.

JBV 2003a. STANK 4.11. Computer program for calculating nutrient flows and losses. Jordbruksverket, Jönköping, Sweden. www.sjv.se

JBV. 2003b. Hektarskördar och totalskördar 2002 (Yields in 2002). JO 16 SM 0301. Jordbruksverket, Jönköping, Sweden. www.sjv.se (statistik och fakta).

JBV. 2003c. Jordbruksstatistik årsbok (Annual agricultural statistics). Jordbruksverket, Jönköping, Sweden. www.sjv.se (statistik och fakta).

JBV. 2004. Jordbruksstatistik årsbok (Annual agricultural statistics). Jordbruksverket, Jönköping, Sweden www.sjv.se (statistik och fakta).

Karlsson S & Rodhe L. 2002. Översyn av Statistiska Centralbyråns beräkning av ammoniakavgången I jordbruket – emissionsfaktorer för ammoniak för lagring och spridning av stallgödsel. (Overview of calculations of ammonia losses from agricultre – emission factors for ammonia from storing and spreading of manure). JTI, Institutet för jordbruks- och miljöteknik, Uppsala, Sweden. www.jti.slu.se

KEMI. 2002. Försålda kvantiteter av bekämpningsmedel 2001 (Sold quantities of pesticides 2001). Kemikalieinspektionen, Solna, Sweden.

Kirchgessner M, Windisch W, Muller H L & Kreuzer M. 1991. Release of methane and carbon dioxide by dairy cattle. Agribiol. Res. 44:2-3

Klink C A, Macedo R H & Mueller CC. 1995. Bit by bit the Cerrado loses space. Eds: Alho C J R, Martins E D S. WWF Brasilia, DF, Brazil.

Kyllmar K et al. 1995. Avrinning och växtnäringsförluster från JRK:s stationsnät för agrohydrologiska året 1993/94 samt en långtidsöversikt. Ekohydrologi nr 38, avd för vattenvård, Sveriges Lantbruksunversitet, Uppsala, Sweden.

Ledgard S F, Penno J W, Sprosen M S. 1999. Nitrogen inputs and losses from clover/grass pastures grazed by dairy cows, as effected by nitrogen fertiliser application. Journal of Agricultural Science, Cambridge 132:215-225.

Ledgard S F, Finlayson J D, Pattersson M G, Carran R A, Wedderburn M E. 2004.Effects of intensification of dairy farming in New Zealand on whole system resource use efficiency and environmental emissions. In: Proceedings of 4th International Conference on Life Cycle Assessment in the Agri-Food sector, p 226-229, DIAS report no. 61. Danish Institute of Agricultural Sciences, Tjele, Denmark. ISSN 1397-9892.

Lindeijer E, Muller-Wenk R, Steen B. 2002. Impact Assessment of Resources and Land Use. In: (Udo de Haes et al, eds) Life-Cycle Impact Assessment: Striving towards Best Practice. Society of Environmental Toxicology and Chemistry (SETAC). ISBN 1-880611-54-6

Lindgren M, Pettersson O, Hansson P-A, Noréen O. 2002. Jordbruks-och anläggningsmaskiners motorbelastning och avgasemissioner samt metoder för att minska bränsleförbrukning och avgasemissioner. Rapport 308. JTI, Institutet för jordbruks-och miljöteknik, Uppsala, Sweden.

LRF. 2002. Maten och miljön – livscykelanalys av sju livsmedel (Food and the environment, Life Cycle Assessment of seven food products). Sigill Kvalitetssystem AB, LRF-Lantbrukarnas Riksförbund, Stockholm, Sweden.

McInnes G. (ed). 1996. Joint EMEP/CORINAIR Atmospheric Emission Inventory Guidebook, 1. European Environment Agency, Köpenhamn, Denmark

Misselbrook TH, Van der Weerden T J, Pain B F, Jarvis S C, Chambers B J, Smith K A, Phillips V R, Demmers T G M. 2000. Ammonia emission factors for UK agriculture. Atmospheric Environment 34: 871-880

NV. 2002. Utveckling av metodik för att kvantifiera jordbrukets utsläpp av växthusgaser (Development of methodology for quantifications of emissions of greenhouse gases in agriculture). Dnr: 108-356-01-Md. Naturvårdsverket (EPA), Stockholm, Sweden.

Oil World. 2003. Oil World No 22, vol 46, May 30th. Copyright by ISTA Mielke GmbH.

Pengue W A. 2004. *Soybean Production in Argentine.* In: Proceedings of 4th International Conference on Life Cycle Assessment in the Agri-Food sector, p 157-167. DIAS report no. 61. Danish Institute of Agricultural Sciences, Tjele, Denmark. ISSN 1397-9892.

SLU 2004. Områdeskalkyler 2004. Databas Agriwise. Sveriges Lantbruksuniversitet, Uppsala, Sweden.

Stadig M, Mattsson B & Wallen E. 2000. Livscykelanalys av vegetabiliska oljor (LCA of vegetable oils). Projektnummer UP-99-10384, SIK, Institutet för livsmedel och bioteknik, Göteborg, Sweden

Stadig M, Wallen E & Nilsson B. 2001. Livscykelanalys av hamburgerbröd (Life Cycle Assessment of hamburger bread). Projektnummer UP-00-10965, SIK, Institutet för livsmedel och bioteknik, Göteborg.

Wallén E, Stadig M & Mattsson B. 2000. LCA of feed fats (LCA of feed fats). Projektnummer UP-00-11173, SIK, Institutet för livsmedel och bioteknik, Göteborg, Sweden.

Websites

www.sjv.se

www.agbrazil.com

www.cnpso.embrapa.br

Personal communication

Beckman, Börje. 2003. Agroetanol AB. Norrköping

Biärsjö, Johan. 2003. Svensk Raps, Alnarp

Blomkvist, Jan. 2003. Bobergs Valltork, Borensberg.

Herland, Per-Johan. 2003. Karlshamns Crusher, Karlshamn.

Kämpe, Gustav. 2003. Svenska Lantmännen, Lidköping.

Landquist, Birgit. 2003. Danisco Sugar. Malmö.

Lundström, Staffan. 2003. Svenska Lantmännen, Umeå.

Nordholm, B. 2003. Lactamin, Svenska Lantmännen, Stockholm.

Nyemad, Christina. 2004. Svenska Lantmännen, Jönköping.

Rietz, Håkan. 2004. Svensk Mjölk (Swedish Dairy Association) Stockholm.

Sönnerstedt Johan. 2002. Slöinge Lantmän, Slöinge.

Tietz, Frank. 2003. Svenska Lantmännen, Falkenberg

Törner, Lars. 2003. Odling i Balans. Vallåkra

Appendix 1 Ammonia emissions

Table 1 Emissions factors for ammonia emissions from grazing, cow house, storage

	Type of manure	System	Technique	Cover	Factor (% of total-N)
Grazing					8%
House		Tie-up			4%
		Loose			7%
		Box, slatted floor			7%
		Deep litter			20%
Storage	Solid		solid floor	-	20%
	Semi-solid		solid floor	-	10%
	Slurry, no cover		filling from upside	-	6%
			filling from bottom	-	7%
	Slurry, with cover		filling from bottom	roof	1%
				natural crest	3%
				other	2%
			filling from upside	roof	1%
				natural crest	4%
				other	3%
	Urine, no cover		filling from upside	-	37%
			filling from bottom	-	40%
	Urine, with cover		filling from bottom	roof	5%
				natural crest	17%
				other	10%
			filling from upside	roof	5%
				natural crest	20%
				other	12%
	Deep litter		solid floor	-	30%

Table 2 Ammonia emission from commercial fertiliers

	Type	Factor (% of N)
Spread of commercial fertilisers	Containing NH4+	1%

Table 3 Emission factors for ammonia emission when spreading manure.

Time	Technique	Incorporation	Type of manure, % of total N		
			Solid+deep litter	Urine*	Slurry
February/March	Broadspread	Frosted soil	8%	40%	15%
	Trail hoses	-	-	30%	10%
Spring	Broadspread	At once	7%	8%	5%
		< 4 hours	14%	14%	7,5%
		5-24 hours	22%	20%	10%
		Ley	31%	35%	20%
		Grain	-	11%	10%
	Trail hoses	At once	-	7%	2,5%
		< 4 hours	-	14%	4%
		5-24 hours	-	20%	5%
		Ley	-	25%	15%
		Grain	-	10%	7,5%
	Shallow inject	Ley	-	8%	7,5%
Early summer/summer	Broad spread	Ley	40%	60%	35%
		Grain	-	10%	10%
	Trail hoses	Ley	-	40%	25%
		Grain	-	10%	3,5%
	Shallow inject	Ley	-	15%	15%
Early autumn (before 1st October)	Broadspread	At once	8,8%	15%	2,5%
		< 4 hours	15%	23%	9,0%
		5-24 hours	22%	30%	15%
		No incorp	31%	45%	35%
	Trail hoses	At once	-	10%	1,5%
		< 4 hours	-	18%	4,5%
		5-24 hours	-	25%	7,5%
		No incorp	-	30%	20%
Late autumn (after 1st October)	Broadspread	At once	4,4%	10%	2,5%
		< 4 hours	7%	15%	4,0%
		5-24 hours	9%	20%	5%
		No incorp	13%	25%	15%
	Trail hoses	At once	-	4%	1,5%
		< 4 hours	-	11%	2%
		5-24 hours	-	18%	2,5%
		No incorp	-	25%	7,5%

* % of NH4-N in urine

Appendix 2 Feed composition

Table 1 Protein concentrate feed (conventional farms)

Ingredient	% (mass)	Origin
Wheat bran	3	Swe
Dried draff	5	Swe
Rapeseed meal	2	Ger
Molasses	4	Swe 40 %, Baltic 60 %
Expro®	28	Swe 40 %, Ger 60 %
Soymeal, soypass	22	Brazil
Beet-pulp	18	Swe 20 %, 80 % Baltic
Palmkernelexpels	6	Malaysia
Grass pellets	3.6	Denmark
Lime	1	
MgO	0.1	
Fats	5.6	Diff oil crops

Table 2 Mixed concentrate feed (conventional farms)

Ingredient	% (mass)	Origin
Barley	25	Swe (region)
Winter wheat	5	Swe (region)
Triticale	9	Swe (region)
Wheat/oat bran	6	Swe
Rapeseed meal	13.5	Ger
Molasses	4	Swe 40 %, Baltic 60 %
Expro®	6	Swe 40 %, Ger 60 %
Soymeal, soypass	10	Brazil
Beet-pulp	8	Swe 20 %, 80 % Baltic
Palmkernelexpels	5	Malaysia
Grass pellets	3	Denmark
Lime	1	
Salt	0.6	
Fats	3	

Expro® = heat treated rapeseed meal

Table 3 Protein concentrate feed (organic farms)

Ingredient	% (mass)	Origin
Wheat	10	Swe-region (org)
Oats	3	Swe-region (org)
Rapeseed cake	15	Swe-region (org)
Horse-bean	20	Swe-region (org)
Soybean	15	South America (org)
Maize gluten meal	20	France (conv)
Luzern pellets	15	Swe (org)
Fats	4	(conv)
Minerals	2	
Vitamines	1	

Table 4 Mixed concentrate feed (organic farms)

Ingredient	% (mass)	Origin
Wheat	50	Swe-region (org)
Oats	7	Swe-region (org)
Rapeseed cake	7	Swe-region (org)
Horse bean	5	Swe-region (org)
Beet-pulp	2	Swe (conv)
Maize gluten meal	9	France (conv)
Luzern pellets	15	Swe (org)
Fat	2	conv
Molasses	1	conv
Minerals	2	

Appendix 3 Transports of feed products, fertilisers and plastics

Table 1 Transport data used in the study

Product	Distance	Mode of transport	MJ/tkm	km	share of product, %
CONVENTIONAL FEED					
Concentrate feed					
SOLID / UNIK / Protein mix	Feed industry – dairy farm	Medium truck (rural, 14/24 tons, full+empty return, Euro 2)	0,761	115	100
Soy meal	farm - crusher	Heavy truck MK1 (highway, 26/40 tons, full+empty return, Euro 0)	0,405	25	100
	crusher - Santos	Train, diesel MK3	0,23	1800	60
	crusher - Santos	Heavy truck (highway, 26/40 tons, 70%*, Euro 0)	0,59	1800	15
	crusher - Paranagua	Train, diesel MK3	0,23	500	20
	crusher - Paranagua	Heavy truck (highway, 26/40 tons, 70%*, Euro 0)	0,59	500	5
	Santos - Rotterdam	Freighter, large (>8000 dwt, 60%*)	0,202	10080	100
	Rotterdam – feed ind (Lidköping)	Freighter, small (<2000 dwt, 60%*)	0,396	1000	100
Wheat bran	Arable farm - mill	Medium truck MK1 (rural, 14/24 tons, 50%*, Euro 2)	1,76	50	100
	Mill – feed ind (Lidköping)	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	268	100
Beet pulp	Sugar beet farm-sugar ind	Diesel combustion, tractor; 28.8 MJ/ton sugarbeet			100
	Balticum – feed ind (Lidköping)	Freighter, small (<2000 dwt, 60%*)	0,396	1000	80
	Malmö – feed ind (Lidköping)	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	376	20
Heat threated rapeseed meal	Arable farm - grain store	Tractor, 10 tons (including empty return)	1,52	20	100
	Grain store - Karlshamn	Freighter, small (<2000 dwt, 60%*)	0,396	350	20
Expro®	Grain store - Karlshamn	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	150	20
	Grain store - Kiel	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	200	60
	Kiel - Karlshamn	Freighter, small (<2000 dwt, 60%*)	0,396	580	60
	Karlshamn – feed ind (Lidköping)	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	300	100
Grass pellets	Farm – drying plant	Diesel combustion, tractor; corresponding to 48 MJ/ton feed			100
	Drying plant - Aalborg	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	100	100
	Aalborg - Göteborg	Freighter, small (<2000 dwt, 60%*)	0,396	170	100
	Göteborg –feed ind (Lidköping)	Heavy truck MK1 (highway, 40/60 tons, 70%*, Euro 1)	0,54	130	100
Oat bran	Arable farm - mill	Medium truck MK1 (rural, 14/24 tons, 50%*, Euro 2)	1,76	50	100
	Mill – feed ind (Lidköping)	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	268	100

Lime	Hengelo - Rotterdam	Train, load-carrier	0,155	180	100
	Rotterdam - Lidköping	Freighter, small (<2000 dwt, 60%*)	0,396	1000	100
Barley	Arable farm - grain store	Tractor, 10 tons (including empty return)	1,52	10	100
	Grain store – feed ind (Lidköping)	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	150	100
Molasses	Sugar beet farm – sugar ind	Diesel combustion, tractor; 28.8 MJ/ton sugarbeet			100
	Balticum – feed ind (Lidköping)	Freighter, small (<2000 dwt, 60%*)	0,396	1000	60
	Malmö – feed ind (Lidköping)	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	376	40
Palm kernel expels	Plantation - crusher	Light truck (urban, 8,5/14 tons, 50%*, Before 1990)	2,41	25	100
	Crusher - harbour	Medium truck (rural, 14/24 tons, 50 %*, Euro 0)	1,71	150	100
	Malaysia - Rotterdam	Freighter, large (>8000 dwt, 60%*)	0,202	15500	100
	Rotterdam – feed ind (Lidköping)	Freighter, small (<2000 dwt, 60%*)	0,396	1000	100
Triticale	Arable farm - grain store	Tractor, 10 tons (including empty return)	1,52	10	100
	Grain store – feed ind (Lidköping)	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	150	100
Salt	Hengelo - Rotterdam	Train, load-carrier	0,155	180	100
	Rotterdam –feed ind (Lidköping)	Freighter, small (<2000 dwt, 60%*)	0,396	1000	100
Rapeseed meal (Germany)	Arable farm - grain store	Tractor, 10 tons (including empty return)	1,52	20	100
	Grain store - crusher	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	200	100
	Bremen – feed ind (Lidköping)	Freighter, small (<2000 dwt, 60%*)	0,396	860	100
Wheat	Arable farm - grain store	Tractor, 10 tons (including empty return)	1,52	10	100
	Grain store – feed ind (Lidköping)	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	150	100
Distiller's waste/AgroDrank	Arable farm – ethanol ind	Heavy truck MK1 (highway, 26/40 tons, full+empty return, Euro 2)	0,405	50	100
	Norrköping – feed ind (Lidköping)	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	235	100
Feed fats	Karlshamn – feed ind (Lidköping)	Heavy truck MK1 (highway, 40/60 tons, 70%*, Euro 1)	0,54	300	100
Feed products directly to conventional dairy farms					
Beet pulp (Betfor®)	Sugarbeet farm – sugar ind	Diesel combustion, tractor; 28.8 MJ/ton sugar beet			100
	Sugar ind – dairy farm	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	300	100
Citrus pulp	Juice ind – dairy farm	Medium truck (rural, 14/24 tons, full+empty return, Euro 2)	0,761	20	100
Draff pellets	Brewery – drying mill	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	300	100
	Drying mill – dairy farm	Medium truck (rural, 14/24 tons, full+empty return, Euro 2)	0,761	75	100
Silage	Neighbour farm – dairy farm	Diesel combustion, tractor; 28.8 MJ/ton DM			100
Winter wheat	Neighbour farm – dairy farm	Tractor, 10 tons (including empty return)	1,52	10	100

Barley	Neighbour farm – dairy farm	Tractor, 10 tons (including empty return)	1,52	10	100
Super pressed pulp	Sugar beet farm – sugar ind	Diesel combustion, tractor; 28.8 MJ/ton sugarbeet			100
	Sugar ind – dairy farm	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	300	100
Calf feed	Feed ind – dairy farm	Medium truck (rural, 14/24 tons, full+empty return, Euro 2)	0.761	115	100
ORGANIC FEED					
Concentrate feed					
SOLID / UNIK	Feed industry – dairy farm	Medium truck (rural, 14/24 tons, full+empty return, Euro 2)	0,761	115	100
Soy bean (org)	Field - harbour	Heavy truck (highway, 26/40 tons, 70%*, Euro 0)	0,59	300	100
	Santos - Rotterdam	Freighter, large (>8000 dwt, 60%*)	0,202	10080	100
	Rotterdam – feed ind	Freighter, small (<2000 dwt, 60%*)	0,369	1000	100
Grass pellets (org)	Arable farm – drying mill	Diesel combustion, tractor corresponding to 48 MJ/ton feed			100
	Drying mill – feed ind	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	300	100
Oats (org)	Arable - grain store	Tractor, 10 tons (including empty return)	1,52	10	100
	Grain store – feed ind	Heavy truck, MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	150	100
Rapeseed cake (org)	Arable farm – grain store	Tractor, 10 tons (including empty return)	1,52	10	100
	Grain store - crusher	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	300	100
	Crusher – feed ind	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	300	100
Wheat (org)	Arable farm - grain store	Tractor, 10 tons (including empty return)	1,52	10	100
	Grain store – feed ind	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	150	100
Field bean (org)	Arable farm – grain store	Tractor, 10 tons (including empty return)	1,52	10	100
	Grain store – feed ind	Heavy truck, MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	150	100
Beet fibre (conv)	Sugarbeet farm – sugar ind	Diesel combustion, tractor; 28.8 MJ/ton sugar beet			100
	Balticum – feed ind	Freighter, small (<2000 dwt, 60%*)	0,396	1000	80
	Malmö – feed ind	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	376	20
Molasses (conv)	Sugarbeet farm – sugar ind	Diesel combustion, tractor; 28.8 MJ/ton sugar beet			100
	Balticum – feed ind	Freighter, small (<2000 dwt, 60%*)	0,396	1000	60
	Malmö – feed ind	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	376	40

Soymeal (conv) (instead of maize gluten meal)	farm - crusher	Heavy truck MK1 (highway, 26/40 tons, full+empty return, Euro 0)	0,405	25	100
	crusher - Santos	Train, diesel MK3	0,23	1800	60
	crusher - Santos	Heavy truck (highway, 26/40 tons, 70%*, Euro 0)	0,59	1800	15
	crusher - Paranagua	Train, diesel MK3	0,23	500	20
	crusher - Paranagua	Heavy truck (highway, 26/40 tons, 70%*, Euro 0)	0,59	500	5
	Santos - Rotterdam	Freighter, large (>8000 dwt, 60%*)	0,202	10080	100
	Rotterdam – feed ind	Freighter, small (<2000 dwt, 60%*)	0,396	1000	100
Fodder fats (conv)	Karlshamn – feed ind	Heavy truck MK1 (highway, 40/60 tons, 70%*, Euro 1)	0,54	300	100
Feed products directly to organic dairy farms					
Winter wheat (org)	Neighbouring farm – dairy farm	Tractor, 10 tons (including empty return)	1,52	10	100
Barley (org)	Neighbouring farm – dairy farm	Tractor, 10 tons (including empty return)	1,52	10	100
Field bean (org)	Neighbouring farm – dairy farm	Tractor, 10 tons (including empty return)	1,52	10	100
Super pressed pulp	Sugarbeet farm – sugar ind	Diesel combustion, tractor; 28.8 MJ/ton sugar beet			100
	Sugar ind – dairy farm	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	300	100
Silage (org)	Neighbouring farm-dairy farm	Diesel combustion, tractor. 28.8 MJ/ton DM			100
Beet pulp (Betfor®) (conv)	Sugarbeet farm – sugar ind	Diesel combustion, tractor; 28.8 MJ/ton sugar beet			100
	Sugar ind – dairy farm	Heavy truck MK1 (highway, 26/40 tons, 70%*, Euro 2)	0,61	300	100
OTHER PRODUCTS					
Fertilisers	EU continent - Lidköping	Freighter, small (<2000 dwt, 60%*)	0,396	1010	50
	Köping - Lidköping	Heavy truck MK1 (highway, 26/40 tons, full+empty return, Euro 2)	0,405	220	50
	Lidköping – dairy farm	Heavy truck MK1 (highway, 26/40 tons, full+empty return, Euro 2)	0,405	100	100
Plastics	Production - harbour	Heavy truck (highway, 26/40 tons, 70%*, Euro 1)	0,59	894	100
	Harbour - filmning	RoRo ship (2000-30 000 dwt, 80%*)	0,324	200	100
	Filmning - harbour	RoRo ship (2000-30 000 dwt, 80%*)	0,324	1030	100
	Harbour – dairy farm	Heavy truck (highway, 26/40 tons, 70%*, Euro 1)	0,59	750	100
	Dairy farm – waste management	Medium truck (rural, 14/24 tons, 50%*, Euro 1)	1,71	18	100

* loadfactor of the vehicle

Appendix 4 Inventory results

Table 1 The average value for the inventory results and the maximum and minimum values.

kg per F.U.	Conventional, medium			Conventional, high			Organic		
	average	max	min	**average**	max	min	**average**	max	min
Non renewable resources, with energy									
Crude oil	**3,40E-02**	4,59E-02	2,90E-02	**3,32E-02**	4,26E-02	2,47E-02	**2,92E-02**	3,46E-02	2,25E-02
Crude oil, feedstock	**1,25E-09**	1,51E-09	7,63E-10	**1,45E-09**	2,28E-09	9,19E-10	**9,47E-10**	1,67E-09	4,94E-10
Hard Coal	**1,42E-02**	1,72E-02	9,07E-03	**1,62E-02**	2,48E-02	1,10E-02	**1,13E-02**	1,83E-02	6,59E-03
Lignite	**2,34E-03**	3,36E-03	1,84E-03	**2,11E-03**	2,46E-03	1,76E-03	**1,05E-03**	1,27E-03	7,61E-04
Natural gas	**1,51E-02**	1,97E-02	9,53E-03	**1,30E-02**	1,60E-02	1,02E-02	**4,20E-03**	5,59E-03	2,91E-03
Unspecified fuel, MJ	**3,74E-08**	5,31E-08	2,68E-08	**4,58E-08**	7,86E-08	2,63E-08	**3,67E-08**	6,33E-08	2,07E-08
Uranium	**2,27E-06**	2,88E-06	1,93E-06	**2,22E-06**	3,38E-06	1,39E-06	**2,82E-06**	4,01E-06	2,44E-06
Renewable resources, with energy									
Biomass	**1,43E-03**	1,85E-03	1,19E-03	**1,40E-03**	2,19E-03	8,52E-04	**1,88E-03**	2,68E-03	1,62E-03
Hydropower, MJ	**2,84E-01**	3,69E-01	2,40E-01	**2,80E-01**	4,33E-01	1,74E-01	**3,62E-01**	5,16E-01	3,09E-01
Windpower, MJ	**5,84E-04**	7,58E-04	4,88E-04	**5,73E-04**	9,00E-04	3,48E-04	**7,74E-04**	1,11E-03	6,67E-04
Wood	**2,05E-05**	2,84E-05	1,57E-05	**1,90E-05**	2,34E-05	1,34E-05	**2,31E-05**	2,67E-05	1,78E-05
Resources without energy									
Phosphorus (P)	**1,62E-03**	2,15E-03	1,22E-03	**1,32E-03**	1,72E-03	6,89E-04	**6,87E-04**	8,49E-04	4,73E-04
Potassium (K)	**3,24E-03**	4,46E-03	1,73E-03	**3,04E-03**	3,44E-03	1,66E-03	**2,84E-04**	4,34E-04	1,46E-04
Pesticide use									
Fungicides	***4,88E-06***	*1,10E-05*	*2,00E-06*	***4,11E-06***	*7,00E-06*	*2,00E-06*	***0,00E+00***	*0,00E+00*	*0,00E+00*
Herbicides	***7,19E-05***	*1,37E-04*	*2,60E-05*	***6,33E-05***	*8,20E-05*	*3,20E-05*	***6,83E-06***	*1,10E-05*	*4,00E-06*
Insecticides	***4,50E-06***	*1,10E-05*	*2,00E-06*	***4,00E-06***	*5,00E-06*	*3,00E-06*	***1,17E-06***	*2,00E-06*	*1,00E-06*
Totalt	**8,11E-05**	1,59E-04	3,10E-05	**7,13E-05**	9,30E-05	3,70E-05	**7,83E-06**	1,30E-05	4,00E-06

Landuse, m2*year									
Arable land on dairy farm	***1,34E+00***	*2,02E+00*	*9,69E-01*	***9,13E-01***	*1,12E+00*	*7,11E-01*	***1,76E+00***	*2,80E+00*	*1,15E+00*
Arable land for purchased feed (in Europe)	***2,38E-01***	*3,63E-01*	*1,57E-01*	***2,92E-01***	*5,81E-01*	*1,18E-01*	***5,30E-01***	*9,48E-01*	*2,29E-01*
Arable land for purchased feed (outside Europe)	***1,66E-01***	*3,26E-01*	*1,05E-01*	***1,58E-01***	*2,08E-01*	*1,34E-01*	***6,57E-02***	*1,22E-01*	*0,00E+00*
Total arable land	**1,74E+00**	2,43E+00	1,26E+00	**1,36E+00**	1,48E+00	1,20E+00	**2,36E+00**	3,44E+00	1,64E+00
Natural grazing meadow	***1,76E-01***	*5,85E-01*	*0,00E+00*	***1,81E-01***	*4,84E-01*	*0,00E+00*	***5,74E-01***	*1,34E+00*	*4,83E-02*
Total landuse	**1,92E+00**	3,01E+00	1,34E+00	**1,54E+00**	1,83E+00	1,20E+00	**2,93E+00**	3,99E+00	1,91E+00
Emissions to air									
CO_2	**1,73E-01**	2,29E-01	1,33E-01	**1,68E-01**	2,06E-01	1,27E-01	**1,20E-01**	1,51E-01	8,89E-02
CH_4	***2,48E-04***	*3,16E-04*	*1,86E-04*	***2,51E-04***	*3,73E-04*	*2,04E-04*	***2,03E-04***	*2,85E-04*	*1,37E-04*
CH_4, animal	***1,94E-02***	*2,13E-02*	*1,77E-02*	***1,72E-02***	*2,07E-02*	*1,42E-02*	***2,07E-02***	*2,69E-02*	*1,68E-02*
CH_4, manure	***2,67E-03***	*4,45E-03*	*5,04E-04*	***2,22E-03***	*4,87E-03*	*6,78E-04*	***2,06E-03***	*3,67E-03*	*4,65E-04*
CH_4 total	**2,24E-02**	2,59E-02	1,99E-02	**1,97E-02**	2,58E-02	1,57E-02	**2,29E-02**	2,89E-02	1,74E-02
N_2O	***2,17E-04***	*2,97E-04*	*1,07E-04*	***1,68E-04***	*2,22E-04*	*1,01E-04*	***1,16E-05***	*2,03E-05*	*5,77E-06*
N_2O, direct	***7,74E-04***	*1,08E-03*	*5,39E-04*	***6,15E-04***	*7,43E-04*	*4,60E-04*	***7,53E-04***	*9,61E-04*	*5,95E-04*
N_2O, indirect	***2,84E-04***	*4,01E-04*	*2,02E-04*	***2,32E-04***	*2,84E-04*	*1,67E-04*	***3,22E-04***	*4,42E-04*	*2,57E-04*
N_2O total	**1,27E-03**	1,68E-03	9,28E-04	**1,02E-03**	1,14E-03	8,46E-04	**1,09E-03**	1,41E-03	8,66E-04
NH_3	**4,44E-03**	5,92E-03	3,16E-03	**4,65E-03**	5,96E-03	2,34E-03	**5,63E-03**	7,58E-03	4,24E-03
NO_x	**1,30E-03**	1,91E-03	1,12E-03	**1,27E-03**	1,62E-03	9,49E-04	**1,07E-03**	1,29E-03	8,16E-04
SO_2	**5,80E-04**	8,34E-04	4,48E-04	**6,01E-04**	8,27E-04	4,97E-04	**3,01E-04**	4,22E-04	1,99E-04
Emissions to water									
NO_3	**2,49E-02**	3,51E-02	1,81E-02	**1,94E-02**	2,64E-02	1,40E-02	**2,89E-02**	4,08E-02	2,22E-02
P	**1,06E-04**	1,61E-04	7,85E-05	**9,08E-05**	1,06E-04	8,12E-05	**9,35E-05**	1,32E-04	7,70E-05