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Life Cycle Assessment of Swedish Lamb Production

Version 2

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Summary

Background
There is a rising awareness of the environmental impacts related to a rapidly growing global production and consumption of animal products. Life Cycle Assessment (LCA) has become the major method to assess the environmental performance of livestock production. This study is the first LCA of Swedish lamb meat production, analysing some of the most important environmental effects from the production.

The consumption of lamb meat represents a very small, but increasing share of the Swedish meat consumption. The rise in consumption is to a large extent matched by increasing imports, but the production of Swedish lamb meat is growing as well. Swedish sheep production is diverse, with large variations across farms in important production parameters such as growth rates, grazing periods and feeding regimes. All these aspects influence the results of an environmental assessment of the production.

Scope and method
Life cycle assessment (LCA) methodology was used to assess the environmental impact from lamb production. Impact categories analysed were climate change, eutrophication, acidification, photochemical ozone creation, ozone depletion and use of primary energy, pesticides, land, phosphorus and potassium. Nitrogen balances were also calculated for the farms in the study.

The assessment was based on data from 10 sheep farms, of which 3 had conventional indoor lamb breeding (winter lambing) and 3 had conventional outdoor lamb breeding (spring lambing) and 4 were organic (with outdoor lamb breeding or mixed). The inventories were made during 2008.

Economic allocation was used to distribute the environmental burden between meat (lamb and mutton) and hides; 62 % of the environmental burden was allocated to meat. The functional unit used in the study was *one kg carcass weight lamb meat after transport to retail distribution centre*. Farm nitrogen balances were analysed both per kg carcass weight and per hectare.

Results and discussion

Results as an average from the ten farms are given for each impact category in Table I.

Table I. Results from life cycle assessment of Swedish lamb production. Average from ten farms. Functional unit: 1 kg carcass weight after transport to retail distribution centre.

	Enteric fermen tation	Manure	Home-grown feed	Diesel & electri-city	Pur-chased feed	Post farm	Total, mean
Land use, m^2			115		3		118
Primary energy use, MJ			7	16	10	5	36
Use of pesticides, g a.i.			0.11		0.40		0.52
GHG emissions, kg CO_2-e	9	2	3	1	1	0	16
Contribution to eutrophication, g PO_4-e	0	20	45	1	6	0.1	72
Contribution to acidification, kg SO_2-e		0.09	0.02	0.01	0.01	0.00	0.12
Photochemical ozone creation, g C_2H_4-e	2.5	0.03	0.01	0.04	0.05	0.01	2.6
Ozone depletion, mg CHC11			0.00	0.10	0.04	0.01	0.16

For greenhouse gas emissions, methane from enteric fermentation was the main contributor, representing more than 50 % of the total characterised emissions. Also nitrous oxide from manure handling and cultivation of feed were important. Growth rate and mortality are production parameters of great importance to the carbon footprint of lamb meat since emissions of methane and nitrous oxide from the rumen and the excretions represent the dominant share of total emissions.

Nitrogen leaching from feed cultivation was the main contributor to the emissions of eutrophying substances from lamb production. Ammonia from manure was another important source to these emissions. Ammonia was also the most important contributor to the emissions of acidifying substances.

Substantial differences between organic and conventional systems were found for energy use and farm nitrogen balances. Use of pesticides and mineral phosphorus and potassium in feed production was analysed for conventional systems only (being zero for organic production). For the organic systems, energy use was half as high per kg meat compared to the conventional systems. This was explained by i) the higher average use of concentrates in the conventional indoor breeding and ii) the use of synthetic fertilisers in conventional systems (the production of fertilisers involves high energy use). Nitrogen surplus per hectare was considerably higher for the conventional farms in the study than for the organic. The discrepancy was smaller when analysed per kg meat, but still conventional farms had a larger surplus of nitrogen.

The production parameters at the studied farms are close to the Swedish average in most aspects, but the farms in this study tend to be slightly higher in growth rates and carcass weight efficiency (kg carcass weight per kg live weight), which in extensive ruminant production such as Swedish lamb production typically leads to lower environmental burden per kg carcass weight.

Possibilities to reduce the environmental impact from lamb production
The results are determined by the balance between environmental burdens from inputs and emissions from the production on the one hand, and the amount of outputs such as meat and hides on the other. To improve the environmental standard of the production, inputs, on-farm emissions and outputs have to be addressed.

Examples of production improvements to increase the meat output:

- Reduced mortality
- Increased fecundity
- Increased growth rates

Examples of actions to reduce inputs of resources and emissions:

- Use roughage fodder of good quality
- Avoid soy in feed
- Minimize the feed losses and the over-use of feed
- Minimize the nutrient losses from manure
- Do not use over-optimal amounts of fertilisers or manure in feed production

Additional information
This study was funded by Stiftelsen Lantbruksforskning (Swedish Farmers' Foundation for Agricultural Research).

CONTENTS

1 Introduction

There is a rising awareness of the environmental impacts related to a rapidly growing global production and consumption of animal products. Life Cycle Assessment (LCA) has become the major methods to assess the environmental performance of livestock production. Results from LCA research and consultancy work are used in the industry, by policy makers and recently also by consumers. This study is the first LCA of Swedish lamb meat production, analysing some of the environmental effects from the production. The outcome from the study has been used in the development of criteria for climate certification of lamb production.

The consumption of lamb meat represents a very small share of the Swedish meat consumption, only 1.4 % in 2009, which means 1.2 kg meat per capita and year, compared to a total of 83 kg meat from livestock (carcass weight) (Jordbruksverket, 2011). However, lamb meat consumption is increasing, both in real terms and as a share of the total meat consumption per capita in Sweden. The rise is to a large extent matched by increasing imports, but the production of Swedish lamb meat is growing as well.

Swedish sheep production is very diverse with variations in slaughter time, slaughter age, growth rate, number of lambs per ewe and year, length of stable period, feeding, share of feed produced on the farm, area and quality of land used for grazing and use of hides. All these aspects influence the results of an environmental assessment of the production.

The production is economically based on three main sources of income: meat, hides and agri-environmental payment schemes (financed by the state of Sweden and the EU). The proportions of these sources of income vary greatly between farms. Meat is produced from both lambs and adult sheep, but the economic value of lamb meat is much higher than for mutton.

This research project was funded by Stiftelsen Lantbruksforskning (Swedish Farmers' Foundation for Agricultural Research). Several persons have been a great help in the work and we would like to thank the following persons:

Special thanks to the ten farmers sharing data and information on the production. Magnus Jönsson, Agnus Konsult, and Anna Törnfelt, LRF Konsult did all the inventory work and were central actors for selecting inventory farms. Magnus Jönsson and Anna Törnfelt were also parts of the reference group, where also Erica Lindberg, Federation of Swedish Farmers (LRF), and Mie Meiner, Swedish University of Agricultural Sciences (SLU), were included.

Carin Clason, Växa Halland, helped in the calculations of methane emissions from enteric fermentation.

Several members of staff at Scan assisted with data on slaughter, packaging and transports. Scan, Donnia Skinn and Tranås Skinnberedning helped with data on hides.

1.1 Definitions and glossary

Definitions

English	Definition[1]	Swedish
Agri-environmental payment	Payment to farmers who make actions in order to improve the environmental outcome from the production on the farm, financed by the EU and the Swedish government.	miljöersättning
Arable land	Land in crop rotation, including cropland and temporary grassland	åkermark
Carbon sequestration	Sequestration of carbon in soil. C is stored as organic matter and makes the soil a carbon sink.	kolinlagring
Pasture	Land used for grazing, either permanent or temporary.	betesmark
Semi-natural grassland	Permanent grassland used for grazing. No ploughing occurs, nor application of pesticides or fertilizers.	naturbetesmark
Single farm payment	Payment to all agricultural land to compensate for low prices on food, financed by the EU.	gårdsstöd
Temporary grassland	Grassland used primarily for forage for silage or hay production (and sometimes for post harvest grazing) with varying share of N-fixing species (0-75 % at the farms studied), included in a crop rotation. In this study, the age of temporary grasslands varied from 3-16 years .	slåttervall
Temporary grazings	Like temporary grassland, but used for grazing only.	betesvall

Acronyms

Acronym	English	Swedish
a.i.	active ingredient (in pesticides)	aktiv substans
BMF	bone free meat	benfritt kött
CW	carcass weight	slaktvikt
dm	dry matter	torrsubstans
GHG	green house gases	växthusgaser
ha	hectare	hektar
LW	live weight	levandevikt
RDC	regional distribution centre	regionalt grossistlager

Chemical Formulas and elements

Formula	English	Swedish
CH_4	methane	metan
CO_2	carbon dioxide	koldioxid
K	potassium	kalium
N	nitrogen	kväve
NH_3	ammonia	ammoniak
N_2O	nitrous oxide	lustgas
P	phosphorous	fosfor
PO_4^{3-}	phosphate	fosfat
SO_2	sulphur dioxide	svaveldioxid

[1] Definitions are valid specifically for this study and should not be considered established for general use.

2 Goal and scope definition

2.1 Goal and purpose of the study

The goal of this study was to perform a life cycle assessment (LCA) of lamb meat production based on data from contemporary sheep farms in Sweden.

The purpose was to gain increased knowledge on the environmental impacts of Swedish production of lamb meat. This included knowledge on variation in environmental impact resulting from different production systems, e.g. whether the lambs are raised mainly in stable with use of concentrate feed or mainly outdoors with grazing as the predominant feeding system. Both organic and conventional production were studied. In addition, the study was aimed to identify potential ways to environmentally improve Swedish sheep production.

2.2 Scope of the study

The study dealt with all the phases of sheep production, from the production of inputs for feed production, to the transport of meat to regional distribution centre (RDC). Transports of inputs and outputs are included. The material flows are shown in Figure 2.1.

2.2.1 Inventory

Production data were collected from ten sheep farms for the year 2008. The farms differed in size and type of production. More information on the farms is given in section 1. The data inventory sheet used is presented in Appendix 1.

2.2.2 Delimitations

Waste handling of by products regarded as waste (e.g. wool) was not included in the study, since it was assumed that its influence on the results would be negligible.

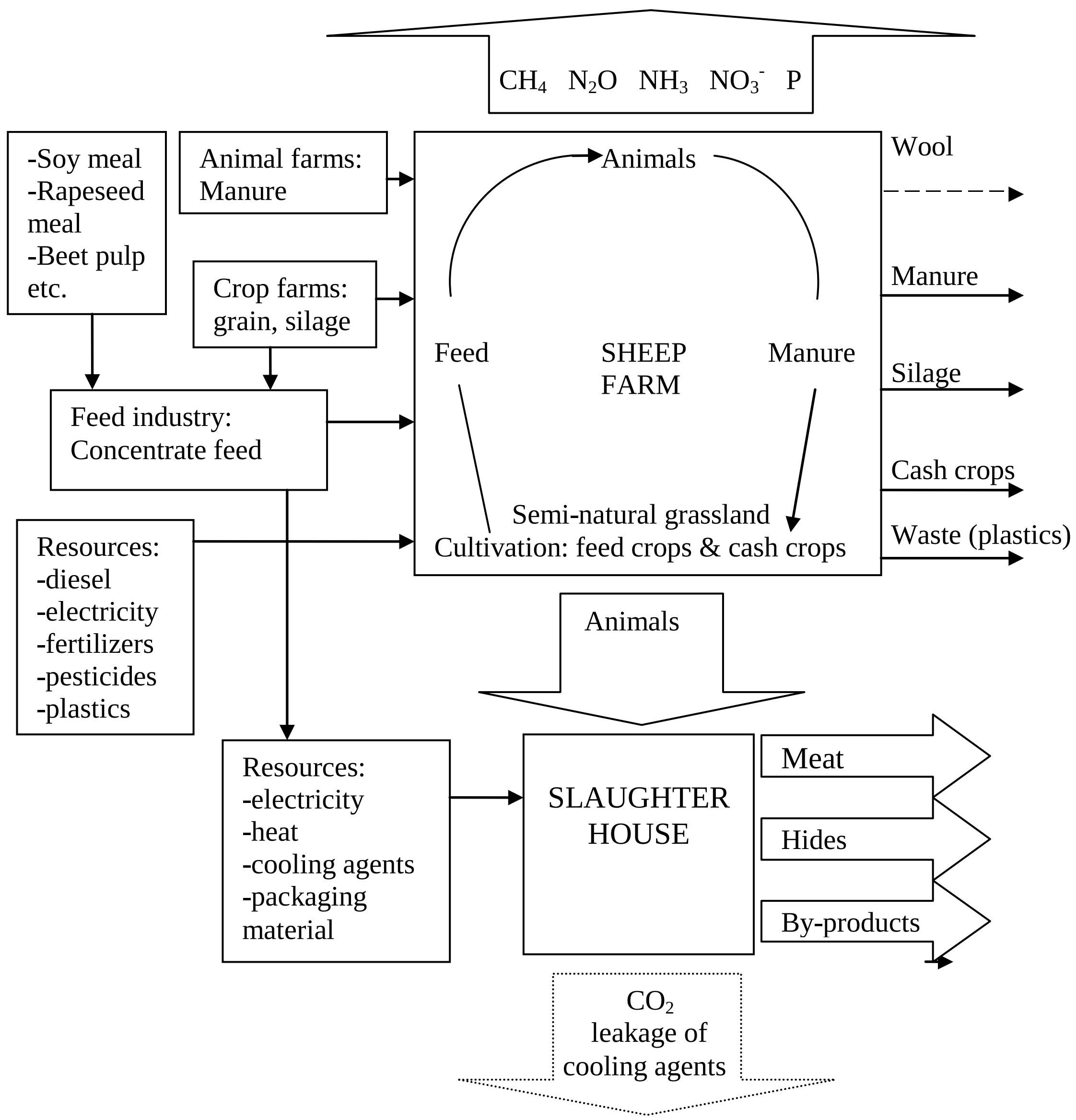

Figure 2.1. Flow diagram for production of lamb meat. Dotted arrows represent cut off flows. Transports are included in the study.

2.3 Functional unit

The functional unit (FU) used in the study was *one kg carcass weight (CW) lamb meat after transport to retail distribution centre (RDC).*

Nitrogen balances were calculated both per hectare (for the farms as a whole, including cash crops) and per kg carcass weight (CW). These balances were calculated not for the whole farms, but for flows relevant for meat production only.

2.4 Co-product handling

The studied farms were specialized on lamb production and had no other livestock than sheep on the farm. Sheep production results in meat from lamb and mutton, hides, wool, manure and some minor animal by-products. The economic value of these minor animal by-products, such as entrails, was assumed to be zero. Manure is often used and re-circulated on the sheep farm, and is dealt with separately below (section 2.4.4).

2.4.1 Mutton meat

Mass allocation was used to split the environmental impact between lamb and mutton meat. This complies with ISO standard 140 41, due to which allocation, if needed, should preferably be based on the physical relationship between the co-products. Also, the inventory results provide a very weak basis for finding the right proportions between these two meat categories on the farms. Therefore, a partitioning other than by mass allocation would introduce large uncertainties to the study.[2]

2.4.2 Hides and wool

A hide from a lamb or a sheep is quite a unique product, lacking an evident substitute and therefore system expansion was not considered possible. Allocation on a physical basis between meat, hides and wool was excluded due to the very different characteristics of these three products. Therefore, economic allocation was considered as the most reasonable way to distribute the environmental burden between meat, hides and wool.

Wool has generally a low or no economic value for Swedish sheep farmers. Four of the studied farms regarded the wool as a waste and six farms sold it as a by-product, but at a very low price. Here we assumed the economic value of wool to be zero.

The economic value of hides depends on sheep breeds and slaughter season, beside the quality of the hides. The price of meat from lambs and mutton also varies over the year. Therefore, the economic relation between hides and meat is not constant all year round. Hides are generally economically more valuable in relation to meat at farms where slaughter takes place during autumn in comparison with farms that send their animals to slaughter during the first half of the year. Here, the meat allocation factor is calculated from the average economic value of the total Swedish production of meat and hides during one year. The allocation factor used is 62 % for meat and 38 % for hides. The basis for this calculation is presented in Appendix 2.

Payment for organic meat is higher than for conventional, but the allocation factor is the same for both systems. Different allocation factors for the two systems would probably hide relevant differences derived from the difference in production methods, why we choose to use the same factor.

[2] The large flows (buying and selling) of young and adult animals to and from the farms and the recalculations of these flows in order to simulate constant stock sizes make it difficult to find some normal proportion between mutton and lamb meat on the farms studied. There are also large variations between farms.

2.4.3 Partitioning of crop and forage production on the farm

Several farms produced arable crops for sale. Use of manure, fertilisers and pesticides were inventoried per crop at each farm while data on diesel were given as a total for each farm. Diesel use for cash crops was calculated according to Flysjö et al (2008), and then subtracted from the farm´s total diesel use, to provide input data for diesel use in the sheep system.

Many farms had roughage fodder in excess and sold some of this, mostly silage. Inputs and emissions from this fodder were excluded from the studied sheep system.

2.4.4 Manure

Manure was regarded as a waste from sheep production. This means that when manure was exported from the sheep production system (i.e. sold or used for sale crops), the entire environmental burden from sheep keeping was still allocated to the lamb production, and nothing to the crop receiving sheep manure. Emissions from application were fully allocated to the receiving crop.

2.4.5 Provision of straw

Straw was used as bedding material on all farms. All resource use and emissions from cereal cultivation were allocated to the grain. For straw, only bailing and transport were included in the analysis of lamb meat.

2.5 Environmental impacts considered

The environmental impact categories considered in this study are listed in Table 1.

Table 1. Impact categories included in the study.

Impact category	Specification/Main substances emitted per impact
Energy	Use of primary energy
Land	Use of land for feed production, on- farm and bought-in feed
Other resources	Use of mineral P and K as fertilizers
Pesticide use	Use of pesticides in terms of amounts of active ingredients
Climate change	Potential emissions of CO_2, CH_4 and N_2O
Eutrophication	Potential emissions of NO_3^-, NH_3, NO_x and P
Acidification	Potential emissions of NH_3, NO_x and SO_2
Photochemical ozone creation potential	Potential emissions of CH_4, other hydrocarbons and fossil CO.
Ozone layer depletion potential	Potential emissions of hydrocarbon-halogen compounds

2.6 Methods

The LCA calculation programme SimaPro7 was used for this study (PRé Consultants, 2007). The programme includes the database Ecoinvent (2007), which was used to find data not given by the inventory results or elsewhere in the study.

For the impact categories climate change, acidification, eutrophication and photochemical ozone creation potential, the method CML (Guinée et al, 2002) was used, though updated with the GWP100 characterisation factors from IPCC (2007). For primary energy use, the CED (cumulative energy demand) method was used (Frischknecht et al, 2003). For ozone layer depletion potential, the EDIP2003 method was used (Hauschild and Potting, 2003).

2.7 Data gaps

One farm uses a mixture of 60% straw and 40% peat as bedding material. No data on production of peat for this purpose were found and thus this production was excluded from the analysis. But the transport of the peat was included. Peat as bedding material is known to reduce ammonia emissions from the housing of animals. But since no data were found on the magnitude of this possible reduction in lamb production, the emission factor for manure in stable is the same for all farms.

For minor feed ingredients on organic farms where data were missing, slightly adapted data on conventional feed were used.

3 Inventory analysis

Data for the production in 2008 were collected from 10 sheep farms in the south of Sweden. Five of the farms were located on the island of Gotland, three in the county of Skåne and two in the county of Västra Götaland (Figur 3.1). Three production systems were studied and the farms were chosen to give a view of these systems:

I. Conventional lamb production, slaughter period March-June. In this production system, lambs are raised indoors and slaughtered before the grazing season. This system is referred to as ***conv indoor*** in the report. Three farms constitute this category.

II. Conventional lamb production, slaughter period July-December. In this production system, lambs are raised outdoors and mostly slaughtered by the end of the grazing season. This system is referred to as ***conv outdoor*** in the report. Three farms constitute this category.

III. Organic lamb production. Two of these farms had slaughter period in the latter half of the year, while two had early as well as late slaughter period. This system is referred to as ***organic*** in the report. Four farms constitute this category.

Figur 3.1. Sweden and its counties. The farms inventoried for this study were located in the counties I (Gotlands län), M (Skåne län) and O (Västra Götalands län) (www.skl.se).

Some basic data on the farms are given in Table 2.

Table 2. General data on the sheep farms inventoried, average and minimum/maximum values for each category. Cash crop land included.

	Mean, conv. indoor (I)	Range	Mean, conv. outdoor (II)	Range	Mean, organic (III)	Range
Total arable land (cash crop land included), ha/farm	63	30-120	54	3-120	39	15-57
No of ewes to stable 2007	211	141-360	204	67-353	133	30-325
Ewes/ha total arable land	3.7	3.0-4.7	10	2.9-22	9.7	2.0-33
Arable land for feed production, ha/farm	19	10-35	36	3-76	32	19-57
… of which ley	18	9-35	36	3-76	30	13-55
grain	1.2	0-3.5	0	-	0.5	0-2
other crops	0	-	0	-	1.9	0-7.5
Semi-natural grassland, ha/farm	85	10-235	51	20-107	17	0-57

Data collected for this study put light on the striking heterogeneity among sheep farms. The variations are only partly a result of the different ways of production here called categories I-III. As shown in Table 2, the categories overlap widely when it comes to basic farm data. In this chapter, all aspects are given as mean values for organic and conventional farms, separately.

Data on transports of living animals from farm to slaughter house were collected from both the farmers and from two animal-transporting companies, see section 3.4.3.

Data on slaughter and packaging were collected from a large meat processing company in Sweden, see sections 3.3.1 and 3.3.2.

3.1 Animal production

3.1.1 Meat production and animal numbers

Herd sizes differed between years for most of the farms. Also, for some farms the time from the first lambing to the last slaughter exceeded 12 months, which was a problem when analysing production of one single year. These circumstances were adjusted for as follows:

- Sold adults were considered retained on the farm. Sold lambs were considered slaughtered, if not compensated for by purchased lambs. The numbers of replacement lambs were adjusted to equal the number of dead and slaughtered adults. To keep the total number of lambs intact, the numbers of slaughtered lambs were changed when the numbers of replacement lambs were recalculated. Table 3 gives an example of these recalculations.

Table 3. An example of handling of herd dynamics in the calculation of outputs from meat production. Inputs are not recalculated.

	Inventory result	Comment	Adjusted result
Ewes to stable 2007	353		353
Rams	14		14
Lambs born and surviving 2008	608		608
...of which replacement lambs	71	To replace the dead and slaughtered adults 102 are required.	102
IN			
Bought adult animals	0		0
Bought lambs	0		0
OUT			
Sold adults	43	Considered kept	43
Sold lambs	30	These are counted as replacement lambs.	0
Dead adults	11		11
Slaughtered adults	91		91
Slaughtered lambs	507	One lamb is counted as a replacement lamb.	506

- Lambs born in 2007 and slaughtered in January-March 2008: Meat from these lambs was not included in the total amount of meat of 2008.[3]
- On one farm, some lambs born in spring 2008 are slaughtered in January-March 2009. Meat from these lambs was included in the total amount of meat of 2008. Feed consumed during 2009 by these animals was not included, but emissions from enteric fermentation and from manure were. Energy for transport to slaughter of those slaughtered in 2009 was included.

After all these adjustments were made, the meat outcome was recalculated, and the result of this is given in Table 4.

[3] Feed belonging to these animals was subtracted from the total, as were emissions from enteric fermentation and from manure. Energy for transport to slaughter of these lambs was not included.

Table 4. Production of mutton and lamb meat after adjustments.

	Mean, conventional	Range	Mean, organic	Range
Total meat, kg CW/(ewe*yr)	31	19-40	31	28-39

The outcome from the farms in terms of meat from sheep and lambs is related to how many surviving lambs each ewe gives birth to, and to the mortality rate among adult animals. The number of rams also influence, but to a smaller extent. In Table 5, these data are listed for conventional and organic farms.

Table 5. Relations between the number of ewes, rams and lamb, and mortality rate for adult animals. Note that the figures concern one single year.

	Mean, conventional	Range	Mean, organic	Range
Lambs born and surviving per ewe	1.5	1.0-1.9	1.6	1.4-1.9
Mortality rate, adults	0.07	0.00-0.17	0.03	0.01-0.04
Ewes per ram	31	22-40	20	10-24

3.1.2 Feed consumption

Roughage fodder dominated the feed intake, as silage, hay or grazing. As a complement, some grain and/or protein feed was used (see Table 2). The organic farms used less concentrate feed than the conventional ones. Grazing on arable land (temporary grazings) was done to a larger extent on organic farms while the conventional farms used more grazing of semi-natural grasslands. However, the variation in land used for grazing is very large across farms, within the same production system.

The amount of feed was not adjusted when the numbers of animals slaughtered were recalculated (see section 3.1.1), except for lambs born in 2007 which were slaughtered in spring 2008 – feed for these animals was not included in the 2008 records.

Table 6. Total feed consumption of ewes, rams and lambs, distributed on the number of ewes. Grazed feed is presented as area only (excluding grazed fields which were also harvested). Feed waste was included.

	Mean, conventional	Range	Mean, organic	Range
Roughage fodder, kg dry matter (dm)/ewe and year[4]	415	130-590	348	250-540
Grain, kg/ewe and year	94	29-212	38	17-62
Concentrates, kg/ewe and year	64	31-117	13	3-21
Semi-natural grassland, m^2/ewe and year	4047	280-16 700	683	0-1 800
Temporary grazings, m^2/ewe and year	9	0-53	770	0-1 700

[4] Harvested feed only.

3.1.3 Manure production and emissions

Deep beddings

Deep bedding with straw was the manure handling system on all farms. One farm had a small share of sawdust in addition, and another farm close to half of the bedding material as peat. Sawdust was regarded as a locally produced by-product without environmental burden. Ammonia emissions were assumed to be the same as from deep beddings based on straw and manure only. No data were found on production of peat as a bedding material or on the potential carbon dioxide emissions from peat decaying as a result of its use as bedding material. This was a data gap, but a distance of 200 km was assumed for the transport of peat to the farm. A mixture of peat in bedding is known to reduce the ammonia emissions from manure, but this reduction was not taken into account due to lack of data.[5]

Manure production

Manure production was calculated from reference data shown in Table 7.

Table 7. Monthly manure production (volume and mass) for adult sheep, including straw as bedding material per one ewe with 1.8 lambs.

Manure volume per month and sheep, m3	0.14
Manure mass per month and sheep, kg	70

Source: Stank in Mind, 2009

Manure production was calculated for the herd for the year 2008. Manure from lamb until 6 months were included in the ewe´s production. Lambs dying prematurely were not included. Lambs 6-9 months old were assumed to produce 25% less excreta than the adults. From the age of 9 months, the lambs were assumed to produce as much excreta as an adult sheep (an ewe with 1.8 lambs per year). Manure production only included the stable period. Excreta dropped at grazing were calculated separately.

One organic farm raised the animals outdoors on semi natural grasslands all year round, but wintertime the animals also had indoor access. On this farm, 25 % of the winter manure was assumed to be dropped indoors. On two organic and one conventional outdoor farm, the animals had winter access to an out-door sheepfold, and for those farms, 75 % of the winter manure was assumed to be dropped indoors.

Adjustments of animal numbers presented in section 3.1.1 were taken into account when calculating emissions of nitrogen and methane from manure.

In Table 8, estimates of indoor manure production are shown. The organic farms have on average lower manure production in stable due to longer grazing periods compared to the conventional farms.

[5] Experiments in pig production have resulted in 40% potential reduction of ammonia emissions when adding peat (60%) to the straw bedding – see http://www.greppa.nu/uppslagsboken/naringistallet/svinproduktion/bristandestallteknik/atgader/djupstrogodsel.4.1c0ae76117773233f7800018714.html

Table 8. Manure production for farms inventoried, total and per ewe, as mean values for conventional indoor, conventional outdoor and organic farms.

	Mean, conv.	Range	Mean, org.	Range
Manure produced at stable, ton /(ewe*yr)	0.41	0.29-0.51	0.33	0.12-0.50

Data on production of nutrients in manure are shown in Table 9, including 1.8 lambs per ewe.

Table 9. Total nutrient production in sheep excreta, representing one ewe and 1.8 lambs per year.

Nutrient production in excreta	kg per yr and head (1 ewe with 1.8 lambs)
Nitrogen, N	14
Phosphorous, P	1.5
Potassium, K	19

Source: Stank in Mind, 2009

Emissions of nitrogen compounds and methane from manure

There are a several steps between excretion and uptake by crops where nitrogen (N) in manure is lost, see Figure 3.1. Emissions of N to the air are mainly in the shape of ammonia, but small amounts are lost as nitrous oxide (direct emissions of N_2O). When dropped at pasture or applied to crops, some of the nutrients in manure are available for plant uptake but there will also be some N leaching, as nitrate (NO_3^-). Nitrogen lost as either ammonia or nitrate may transform into N_2O and give rise to so-called indirect emissions of N_2O.

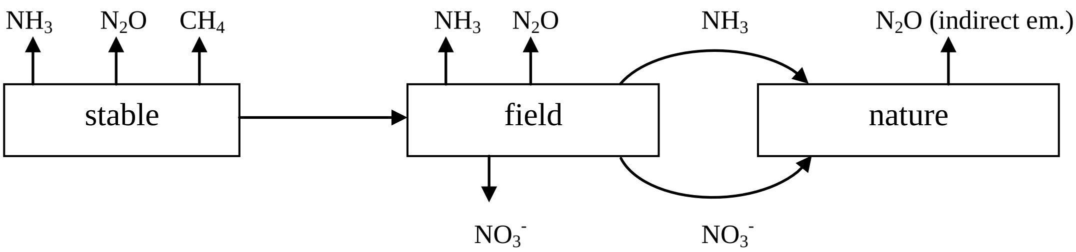

Figure 3.1. Schematic description of N losses from manure. Nitrogen is lost in the shape of ammonia from manure in the stable and from application of manure. There are also losses of nitrate from the soil to groundwater and surface water. Nitrous oxide is lost from the stable, from the field (calculated as a function of N application and N in crop residues). Some of the N lost as NH_3 and NO_3^- is also transformed into N_2O after deposition (indirect emissions of N_2O).

Table 3.8 presents N flows and emissions considered when calculating losses of NH_3 and N_2O from manure in houses and storages. Used emissions factors are 25 % of the total nitrogen in manure lost as ammonia in housing and storing and 1 % as direct N_2O. The emission factor used for indirect N_2O from ammonia was 0.01 kg N_2O-N per emitted kg NH_3-N.

Table 10. Calculated emissions of ammonia and nitrous oxide from manure during housing and storing, and resulting content of nitrogen before application. Assuming that 10 % of the total N content is in the shape of ammonia, the content of NH3-N in manure before application is 1.3 kg per ton manure.

N-content in manure before losses, kg N-tot/ton manure	17
NH_3-N losses, housing and storing (25 %), kg NH_3-N/ton manure	4.2
N_2O-N losses, direct emissions, housing and storing (1 %), kg N_2O-N/ton manure	0.15[6]
N_2O-N losses, indirect emissions, housing and storing (1 % of NH_3-N), kg N_2O-N/ton manure	0.04
Total N content after housing and storing losses, kg N-tot/ton manure	13

Source: Stank in Mind, 2009 and IPCC 2006

Table 11 shows the assumed emission factors used for estimating NH_3 and N_2O losses from excreta dropped during grazing.

Table 11. Emission factors for ammonia and nitrous oxide, animal excretions outdoors.

Emission from excretions on pasture	Part of total N in excreta
NH_3-N	8 %
N_2O-N (direct emissions)	1 %
N_2O (indirect emissions)	1 % of NH3-N lost and 0.75 % of NO_3^--N lost

Sources:
http://www.greppa.nu/uppslagsboken/naringistallet/mjolkproduktion/forlusterpabetet/fakta/kvavelackage (2009) and IPCC (2006)

Exports and imports of manure

The sheep manure not used in cultivation of feed to the animals was considered exported, irrespective of whether this were to another farm or to cash crops at the sheep farm. When manure was exported from the sheep system, manure emissions from housing and storing were included in the sheep production, while manure transports and emissions from use and spreading were not. Manure export was more frequent from the conventional farms than from the organic ones, as shown in Table 12.

Table 12. Manure exported from the system (to cash crops at the same farm, or to other farms)

	Mean, conv.	Range	Mean, org.	Range
Share of manure exported	0.57	0-1.0	0.43	0-1.0
Exported manure, ton/ewe	0.31	0-0.58	0.14	0-0.42
Exported manure, ton/ha feed production	3.20	0-6.9	0.78	0-2.4

Some of the farms studied imported manure. Manure imported to the sheep farms used in fodder cultivation was regarded as a waste from another animal production. All emissions from the use of manure (e.g. ammonia, nitrous oxide and nitrate) were allocated to the fodder crop where the manure was spread, as was the transport of the manure to the importing sheep farm.

[6] The losses of N_2O-N calculated from the remaining N content. Half of the NH_3 losses is subtracted from the original total before calculating the N_2O losses, which means that the ammonia losses are assumed to be linear in time and simultaneous to the N_2O losses.

Methane emissions from manure
Methane emissions take place from manure excreted both in stable and at pasture. The IPCC guidelines (IPCC 2006) specifies the methane emission for sheep to 0.19 kg CH_4 per animal and year (Tier 1), and this emission factor is used for both indoor and outdoor manure. This was adapted to the lambs' age, assuming a linear increase from 0 to 0.19 kg CH_4 per animal and year during their first year.

3.1.4 Methane emissions from enteric fermentation

Methane (CH_4) emissions due to enteric fermentation were calculated with a model which considers live weight, slaughter age, growth rate and feed digestibility, see further Appendix 3. Calculations considered the herd´s composition and were made for each farm. Average emissions for the production systems studied are shown in Table 13. Adjustments of animal numbers presented in section 3.1.1 were taken into account when calculating methane emissions from enteric fermentation.

Table 13. Calculated emissions of methane from enteric fermentation in the different production systems. For rams, the same background data are used for all farms.

	Mean, conv. indoor	**Range**	**Mean, conv. outdoor**	**Range**	**Mean, org.**	**Range**
Lambs for slaughter, kg CH_4/(animal*lifetime)	2.5	2.2-3.0	4.1	3.5-4.5	3.5	2.7-4.6
Ewes, kg CH_4/(animal*yr)	12.5	11.5-13.2	11.2	10.3-11.5	11.9	11.5-12.0
Rams, kg CH_4/(animal*yr)	11.5	-	11.5	-	11.5	-

3.2 On-farm feed production

3.2.1 On-farm land use

All farms produce forage fodder and one farm also purchased silage as a complement to its own production. Four farms produce other feed crops, mostly grain. Table 14 lists the land area on the farms used for feed production.

Table 14. Areas for on-farm feed production, as mean values for conventional and organic farms in the study. One conventional farm has very large areas of semi-natural grassland in relation to herd size. Inventory mean values are presented both as including (n=6) and as excluding (n=5) this farm. Area used for production of feed to be sold is not included.

	Mean, conv. (n=6)	Range	Mean, conv. (n=5)	Range	Mean, organic (n=4)	Range
Semi-natural grassland, ha	68	10-235	34	10-107	17	0-57
Temporary grassland and temporary grazings, ha	27	3-76	30	3-76	30	13-55
Grain, ha	0.6	0-3.5	0.7	0-3.5	0.5	0-2
Other feed crops, ha	0	-	0	-	1.9	0-7.5
Total, arable land used for feed production, ha	28	3-76	31	3-76	32	19-57
Total (including semi-natural grassland), ha	96	23-245	66	23-136	49	20-114

3.2.2 Inputs of fertilisers and imported manure in feed production

Average use of synthetic fertilisers on the conventional farms is shown in Table 15. In addition to the fertilizers, two of those farms imported slurry for use on grassland (10-20 ton slurry per ha). The organic farms used no fertilizers, but one of them imported slurry for application of 20 ton per ha to some of the grassland on the farm.

Table 15. Average fertiliser rates to temporary grassland, temporary grazings and cereals on the conventional farms.

Fertiliser	Mean fertiliser rate, kg/ha	Range, kg/ha
Nitrogen, N	77	10-136
Phosphorous, P	6.7*	0-14
Potatissium, K	38*	0-118

*Two of the farms had no application of P and K fertilizers.

3.2.3 Field losses of nitrogen and phosphorus

Ammonia (NH_3) losses from manure application depend on e.g. technique for application and weather conditions. These losses were calculated specifically for each farm, using specific emission factors provided by the Stank in Mind database (Jordbruksverket, 2009). Since there is a great variation in method for manure application, an average value is of little interest. Instead, Table 16 presents the range for the assumed ammonia losses from application of sheep manure and other, respectively. Emission factor for NH_3 emissions from fertilizers is presented in the same table.

Table 16. Emissions of ammonia and nitrous oxide to air from soil and from application of fertilizers and manure.

	Ammonia lost in application, % of NH_3-N	Ammonia lost in application, % of N-tot
Sheep manure	20-30	2-3
Other manure	25-50	20-30
Fertilisers		2

Sources: Stank in Mind (2009) and IPCC (2006).

Direct N_2O emissions from soil were calculated according to the IPCC guidelines (IPCC 2006), with the emission factor 0.01 kg N2O-N per kg N applied (fertiliser, manure, crop residues). N in crop residues was calculated according to IPPC (2006). Indirect N_2O emissions from former emissions of NH_3 were also calculated according to the IPCC guidelines (2006), assuming that 1 % of the emitted NH_3-N is further emitted as N_2O-N.

Leaching of nitrate from arable land was estimated for every single crop on all farms with the national leaching model (Jordbruksverket, 2009), and adjusted with average leaching data for different crops and regions (Naturvårdsverket, 2008), see further section 3.2.4. In Table 17, the estimated average N-leakage for arable land is shown. The relatively low numbers reflects the fact that a large share of the land used in sheep production is grassland.

Table 17. Estimated N-leaching (kg N/ha) from feed production on arable land on conventional and organic farms. On farms producing different feed crops, a weighted average leakage was calculated before calculating the mean figure of all farms.

	Mean, conv.	Range	Mean, org.	Range
N leaching from arable land, kg NO_3^--N/ha	18	10-26	11	4-18

Data on leakage of nitrate (NO_3^-) from semi-natural grassland are missing, and there are only a few studies made on low intensity temporary grassland/grazings. These studies report levels of N leakage of about 5 kg per ha or even less (Johnsson & Hoffman, 1996; Cederberg& Nilsson, 2004). Based on this, we assume that the N leakage was 2 kg NO_3^--N per ha for semi-natural grassland carrying less than 5 ewes per ha (as an average for one farm) and 4 kg NO_3^--N per ha for land carrying 5 or more ewes per ha. From all temporary grazings, the leakage of nitrate was assumed to be 4 kg NO3-N/ha.

Emissions of N_2O from crop residues were assumed to be the same as for other temporary grassland, since the grazing was assumed to be part of the crop rotation in the same way as for the mowed ley.

When calculating N_2O emissions from crop residues, temporary grazings were treated as cut temporary grasslands. Harvest of straw was not accounted for when calculating N_2O emissions from crop residues in grain cultivation, it was assumed that all straw became crop residues to soil, and this was also done for whole-crop. This means that in reality in the normal case, less crop residues were left on the ground than accounted for in this study. According to the emission models used, more crop residues mean higher N_2O emissions. Thus, direct N_2O emissions from crop residues are slightly over-estimated.

The national average losses of phosphorus from arable land in Sweden are 0.52 kg P per hectare and year (Naturvårdsverket, 2008). This was assumed to be the losses for all fields of arable land in the study. The P losses from semi-natural grasslands were assumed to be zero.

3.2.4 Nitrogen balances

A nitrogen (N) balance shows the relation of N-input to the farm with purchased feed, fertilizers, imported manure, bedding material, fixation by leguminous plants and deposition from air on the one hand and output of N with animal and vegetable products and exported manure (so-called farm-gate balance) on the other. [7] The balance gives a picture of the N surplus (or deficiency) on the farm.[8] A surplus consists of *i)* losses to atmosphere as ammonia (NH_3), nitrous oxide (N_2O) and nitrogen gas (N_2), and *ii)* losses to water, mostly as nitrate (NO_3^-) and *iii)* N incorporated in soil organic matter. The different fates of the surplus N result in various environmental effects. A farm-gate N-balance does not give information on the environmental consequences of the surplus, but it serves as a useful indicator on the potential of possible effects. Here, balances were calculated both per hectare (farm-gate) and per kg meat.

Per hectare: N flows for the whole farm are included (i.e. not only flows related to sheep and lamb production) and calculated per hectare of arable land. For the five farms that raised lambs on semi-natural grassland, separate N balances were made for these grassland areas.

Per kg meat: Only nitrogen flows linked to the sheep and lamb production are included. Arable land and semi-natural grassland are not separated. Allocation of the flows is made, and 62 % of the flows are attributed to the meat. The results are presented per kg carcass weight.

Balances per hectare of arable land
Farm-gate N balances were calculated in the Stank in Mind software (Jordbruksverket, 2009), which contains database information on nitrogen content in fertilizers, manure, feed, bedding material, crops and living animals etc. Deep litter manure from the sheep was mostly used in grain cultivation on the farms in this study. On farms without grain production, the sheep manure was used in production of forage, mostly when renewing grasslands. Some farms imported manure, which was mostly slurry to be used on temporary grasslands[9].

N balances for organic and conventional farms are shown in Table 18. For one of the conventional farms, the balances shows a nitrogen deficit of 17 kg N/ha. This farm sold a considerable amount of grass silage and the amount of N exported is uncertain. The balances for the conventional farms are therefore presented as an average excluding this farm.

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[7] Seeds are not included in the balances calculated here, since they generally represent but a small share of the total N input.
[8] There is a possibility of N outputs exceeding N inputs if there is a stock of N in soil.
[9] Imported solid pig manure was used in grain on one farm and poultry manure in rapeseed on one. Four farms imported manure. Three of those were conventional.

Table 18. Farm-gate N-balances for conventional and organic farms, per hectare. N surplus and N efficiency are calculated as mean values from single farm surpluses and efficiencies. If you instead calculate N surplus and N efficiency from the mean values of the table, the result will be different.

	Mean, conv. farms (n=5)*	Range	Mean, org. farms (n=3)**	Range
Arable land, ha	64	3-120	32	15-50
Input, kg N/ha				
Purchased feed	40	5-146	3	2-5
Fertilizers	79	6-149	0	
Imported manure	9.8	0-19	8	0-24
Imported bedding material	2.3	0-9	1	1.0-1.4
Atmospheric N deposition	7.4	6-11	7	6-9
N fixation, biological	24	0-69	31	13-50
Total input, kg N/ha	**163**	**43-206**	**50**	**26-82**
Output, kg N/ha				
Animal products***	11	6-29	4	3-5
Exported manure	0.2	0-0.8	0	
Vegetable products	33	0-97	7	0-9
Total output, kg N/ha	**44**	**7-105**	**11**	**4-18**
Surplus, kg N/ha	**119**	**29-222**	**39**	**14-65**
N-efficiency	**0.27**	**0.05-0.51**	**0.25**	**0.09-0.45**

*) One conventional farm excluded with negative N-surplus, probably caused by uncertain data on exported N in sold grass silage
**) One organic farm, where the calculated losses exceed the surplus N (possibly due to over-estimated losses or under-estimated inputs), was excluded from the mean value.
***) Including growth on semi-natural grasslands, without considering N deposition, N fixation or manure excretion on this land.

The conventional farms have an average N surplus per hectare, which is more than double that on the organic farms, due to the input of synthetic fertilisers and considerably higher input of purchased feed and manure. Outputs of N in meat as well as crops and roughage fodder are also higher on conventional farms, as a consequence of both more intense production and larger areas of cash crops. The N efficiency per hectare varies widely between farms, partly because of variation in self-sufficiency on the farms (low self-sufficiency often gives a higher N efficiency), and no clear difference can be seen between the two systems.

Results from farm-gate N-balances for a large number of pig, dairy and cattle farms located in the south of Sweden are shown in Table 19 (Jordbruksverket, 2008). The farm category “cattle” includes farms with beef production from cattle (no milk) and their production system is similar to the lamb production studied here. The average input of N in fertilisers and purchased feed on the cattle farms are in the same range as the conventional sheep farms in this study, as is the final N-surplus, approximately 100 kg N/ha.

Table 19. Farm-gate N balances for pig, dairy and cattle farms in the Swedish advisory program Greppa Näringen ("Focus on nutrients"). The balances are made after some years' participation in the advisory program. A few farms are organic, but most of them conventional.

	Pigs n= 109	Dairy n= 701	Cattle n= 50
Input, kg N/ha			
Purchased feed	90	73	32
Fertilisers	102	87	84
Imported manure	9.3	2.6	9.0
Bedding material	0	2.0	2.1
Live animals	7.6	0.5	2.3
Atmospheric N deposition	8.5	8.8	8.6
N fixation leguminous	2.3	22	14
Total input	**220**	**197**	**153**
Output, kg N/Ha			
Animal products	50	38	14
Exported manure	9.8	7.7	1.9
Vegetable products	79	24	43
Total output kg N/ha	**139**	**69**	**59**
Surplus, kg N/ha	**81**	**128**	**95**
Efficiency (output N /input N)	**0.63**	**0.35**	**0.39**

Source: Jordbruksverket (2008)

In a recent survey, Wivstad et al (2009) compared nutrient balances from organic and conventional cattle farms from the database of the advisory programme Greppa Näringen (Focus on nutrients). They found that the organic cattle farms had lower inputs of purchased feed, used a higher proportion of the farm´s land for forage production and had a lower surplus of nitrogen per hectare. N-efficiency (output N/input N) was higher for conventional farms (Table 20). The lower N-surplus combined with a lower N-efficiency for organic farms reflects the lower production intensity per hectare on organic farms – the surplus of nitrogen is "diluted" to a larger land area than in conventional production. This is similar to the situation found on the organic and conventional sheep farms of this study (compare Table 3.15).

Table 20. Farm-gate N balances for cattle farms in the Swedish advisory programme Greppa Näringen ("Focus on nutrients") with conventional and organic farming.

	Conventional cattle n= 267	Organic cattle n= 93
Input, kg N/ha		
Purchased feed	25	8
Fertilizers and manure	93	14
N fixation leguminous	14	45
Other inputs	16	21
Total input	148	88
Total output pre losses, kg N/ha	51	22
Surplus, kg N/ha	97	63
Efficiency (output N/input N)	0.34	0.26

Source: Wivstad et al (2009)

Calculated N losses per hectare

N leaching from crop cultivation was calculated with the leaching model in the Stank in Mind (Jordbruksverket, 2009). With this model, the calculated leakage from grassland was found to be unreasonably high, compared to regional averages for the soil types in question as reported by Naturvårdsverket (2008). This was especially the case for almost permanent grasslands (renewed with larger intervals than five years) and with low fertiliser rates, which was the case for many farms in the study. Therefore, the Stank in Mind results for grasslands' leaching were adjusted with regional average N-leaching data for grassland according to figures from the Swedish EPA (Naturvårdsverket 2008).

In **Table *21***, an overview of the estimates of losses of reactive N is shown. As expected from the farm-gate balance, conventional farms have higher area-based N-losses. The reason is the more extensive use of land on organic farms, with lower inputs of N, which results in lower N emissions to air and water per hectare.

The area-based estimate of reactive N was compared with the N-surplus (Table 3.15). Approximately 40 % of the N-surplus were found as N-losses on the conventional as opposed to approx. 50 % on the organic farms. The discrepancy between surplus and calculated losses can be explained by N lost in denitrification (as N_2) and N immobilization in soil (increasing humus content). However, it is also most likely that some of the emissions were underestimated in the models used, giving a good example of the difficulty to estimate N-emissions in sheep production with many parameters not known (e.g. feed intake, excretion on pasture, etc), and with emission rates unsatisfyingly studied.

Table 21. Calculated losses of reactive N in relation to farms' arable land, average kg N/ha.

	Mean, conv. farms (n=5)	Range	Mean, org. farms (n=3)*	Range
Housing and storage, kg NH_3-N/ha	15	5-45	3.9	3-4
Housing and storage, kg N_2O-N/ha	0.6	0.2-1.7	0.1	0.1-0.2
Grazing, kg NH_3-N/ha	1.2	0.5-2.8	1.3	1.0-2.3
Direct N_2O grazing, kg N_2O -N/ha	0.2	0.06-0.3	0.2	0.1-0.3
Manure application, kg NH_3-N/ha	4.5	2-9	1.4	0.3-2.7
Leaching, kg NO_3-N/ha	22	12-26	9.6	4-17
Direct N_2O, fertiliser/manure, kg N_2O -N/ha	1.7	0.3-3	0.4	0.2-0.4
Total losses of reactive N, kg N/ha	45	20-81	16.9	11-26
Share of farm-gate N-surplus found as lost reactive N	36 %	27-69 %	51 %	38-76 %

*) One farm, where the calculated losses exceed the surplus N (possibly due to over-estimated losses or under-estimated inputs), was excluded from the mean value.

N balances on semi-natural grassland, per hectare

Nitrogen balances were calculated for semi-natural grasslands on the five farms[10] where lambs were born in late spring and then raised on these grasslands (Table 22). Here, the lambs receive all feed from the grassland, directly as grass or indirectly through the ewes´ milk. Supplementary feed and feeding for final fattening was used in small amounts on some farms and was not taken into account.[11]

Nitrogen accumulating in the biomass of growing lambs during the grazing period origins either from temporary grasslands/grazings or from semi-natural permanent grasslands. The proportions of these sources were determined from the areas of each and the length of the grazing period on the two types of grassland. The live weight at birth of the lambs was assumed to be 4 kg, and slaughter live weight ranged from 42.5 to 48 kg, based on data from the farms.

The share of leguminous plants in the semi-natural grasslands is unknown. Symbiotic N- fixation on these lands was assumed to be 10 kg N/ha for all farms. Excreta from the grazing sheep was assumed to be distributed to temporary grasslands/grazings and semi-natural grassland in the same proportions as the nitrogen accumulation in the sheep biomass.

Semi-natural grasslands are managed similarly on conventional and organic farms. Table 22 shows an N-balance for this land-use type with no distinction between the two production systems.

[10] These farms were found in the systems conventional outdoor and organic farms.
[11] Supplementary feed during the grazing period was used on three of the five farms included in Table 22.

Table 22. N balance for semi-natural grassland. Average from five farms with outdoor breeding of lambs.

	Mean (n=5)	Range
Atmospheric N-deposition kg N/ha	7	6-11
Symbiotic N-fixation (general assumption), kg N/ha	10	-
TOTAL Input kg N/ha	17	16-21
Emissions from excreta*, kg N/ha	4	1-12
Leaching, kg NO3-N/ha	3	2-4
N uptake in growing animals, kg N/ha	7	2-12
TOTAL Output kg N/ha	14	4-22
Surplus/deficit kg N/ha	5	-6-15

*ammonia and nitrous oxide

Balances per kg carcass weight

As in the comparison on land basis, the nitrogen surplus per kg carcass weight (CW) was lower for the organic farms, but the relative difference between the organic and conventional farms was smaller than when comparing area-based N-surplus. This again puts light on the more extensive land use on organic farms (Table 3.20, compare with Table 3.15). Average N efficiency per kg CW seems to be lower on organic farms, but looking at the single farms, we see a great overlap between the two systems. The number of farms is too small to draw any conclusions in this respect.

Table 23. N balances per kg carcass weight (CW). Only N-flows relevant for sheep production are included.

	Mean, conv. farms (n=6)	Range	Mean, org. farms (n=3)***	Range
Inputs, kg N/kg CW				
Purchased feed	0.09	0.03-0.18	0.03	0.02-0.05
Synthetic fertilisers	0.15	0.04-0.32	0	0
Imported manure	0.02	0-0.07	0.03	0-0.10
Imported bedding material	0.01	0-0.03	0.01	0.01-0.02
Atmospheric N-deposition, cropland and semi-natural grassland*	0.14	0.02-0.38	0.10	0.04-0.15
Symbiotic N-fxation, cropland and semi-natural grassland*	0.21	0.004-0.62	0.22	0.12-0.30
Total nitrogen input, kg N/kg CW	0.61	0.24-1.3	0.39	0.31-0.45
Outputs, kg N/kg CW				
Animal products**	0.04	0.03-0.04	0.04	0.03-0.04
Exported manure	0.10	0-0.31	0.02	0-0.06
Totalt nitrogen output, before any losses, kg N/kg CW	0.09	0.04-0.13	0.06	0.04-0.10
Surplus, kg N/kg CW	0.52	0.30-1.2	0.33	0.28-0.42
N efficiency	0.20	0.03-0.39	0.15	0.08-0.25

*) The large area of semi-natural grassland of one conventional farm increases the average. If that farm were excluded, the figures on deposition and fixation of N would be the same for conventional and organic farms.

**) Dead animals not sent to slaughter were included here, which makes the variation between farms.
***) One farm, where the calculated losses exceed the surplus N (possibly due to over-estimated losses or under-estimated inputs), was excluded from the mean value.

Calculated N losses per kg CW

Table 24 shows the calculated losses of reactive N per kg CW as average values for conventional and organic farms in the study. The calculated N emissions were at the same level for both categories. The main reasons why the conventional farms came better off in this comparison than per ha are i) that there was no dilution effect from the extensive land use on organic farms in the comparison per kg CW and ii) that the N losses per ha are lower on feed producing area than on cash crop area on conventional farms (due to higher N leakage from cash crop fields).

A higher proportion of the lamb excreta were dropped indoors in indoor lamb production than in outdoor breeding, which could imply higher emissions from manure in stables and during storage. However, since manure emissions from lambs up to the age of 6 months are included in the emissions from the ewes, this cannot be seen in the calculations of manure emissions (the separation of indoor and outdoor excretions is not made specifically for lambs) up to six months.

Table 24. Calculated losses of reactive N in relation to output of meat, average kg N/kg CW.

	Mean, conv. farms (n=6)	Range	Mean, org. farms (n=3)*	Range
Leaching, kg NO3-N/kg CW	0.09	0.004-0.17	0.08	0.04-0.13
Housing and storage, kg NH_3-N/kg CW	0.05	0.03-0.07	0.04	0.03-0.05
Dir N_2O emission, grazing kg N_2O-N/kg CW	0.002	0.001-0.002	0.002	0.001-0.002
Manure application kg NH3-N/kg CW	0.007	0.002-0.011	0.007	0.002-0.01
Direct N_2O emissions fertiliser/manure kg N_2O-N/kg CW	0.005	0.002-0.011	0.005	0.003-0.009
Total emissions reactive N, kg N/kg CW	0.15	0.06-0.27	0.13	0.10-0.17
Unexplained surplus (surplus other than calc. losses of reactive N), kg N/kg CW	0.37	0.13-0.36	0.20	0.12-0.29
Share of N-surplus found as reactive N emissions	46 %	7-98 %	42 %	30-59 %

*) One farm, where the calculated losses exceed the surplus N (possibly due to over-estimated losses or under-estimated inputs), was excluded from the mean value.

3.2.5 Inputs of plastics in feed and straw production

Silage, as round bales, was the most frequent form of roughage fodder used on the farms. For the production of this silage, considerable amounts of plastics were used.

The weight of silage plastics was assumed to be 0.06 kg per layer for large, round bales and 0.08 kg per layer for square bales. For bales with a weight of 210 kg dm and eight layers of plastic, this makes 3.0 kg plastic per ton dm silage. The plastic used was assumed to be low density poly-ethylene (LDPE).

One farm imported part of the silage used to feed the sheep. It was assumed that the bales’ weight was 600 kg and that the dry matter (dm) content was 35 per cent, which makes 210 kg dm per bale (Greppa Näringen 1).

3.2.6 Pesticides

On the organic farms and on two of the conventional farms, no pesticides were used in the on-farm feed production. None of the farms studied used insecticides in feed production during 2008, but four farms used herbicides and one farm also used fungicides. Use of glyphosate after temporary grassland/grazings was allocated to the grass (and thus not to the following crop). The use of herbicides in feed production, as an average from the four conventional farms that used it, was 97 g active ingredient per ha, ranging from 2 to 278.

3.2.7 Energy input

Diesel and electricity constituted the energy input to the farms. Data on the on-farm use of diesel and electricity differ a lot between farms, partly due to variation in the home-grown feed share and ways of production, and partly because of uncertainties when it comes to what activities the data actually represent.

The diesel used on the farms was assumed to be “miljöklass (MK) 1” (the environmentally best quality of fossil diesel in Sweden), with 35.3 MJ/l (ÅF, 1983). Many of the farms imported feed, straw, manure or silage from nearby farms. For these transports, a tractor with a trailer was assumed to be used. The distance between the farms is assumed to be 2 km, and the loading capacity was assumed to be used in one direction only. Further details are given in Appendix 4. When the straw was produced on the farm, the diesel used for baling and collecting the straw was included. When straw was purchased from another farm, only diesel for transporting the straw was added. The effect of this inconsistency on the total diesel consumption for keeping the animals is very small, and the effect on the final results was therefore assumed to be negligible. Fuel consumption for baling of straw was assumed to be the same as for silage (round bales), 2.8 l diesel per ton dm (Flysjö et al, 2008). The straw yield was assumed to be 2 tons dm per hectare, and the dm content 0.82 (Börjesson, 2004).

Many farms sold forage and crops, and the handling of in- and outputs of these products is explained in section 2.4. Some farms hired services in the feed production, such as pressing of silage. These activities consumed diesel, and the level of consumption was calculated from data listed in Flysjö et al (2008). One farmer sold snow-clearing services with unknown diesel consumption. This farm was not included in the mean value of diesel consumption. For impact categories others than energy use, an average from other farms’ usage of diesel per kg CW was used for this farm.

Electricity was used for lighting of the stables, fences and drying of grain for feed. Most farmers did not heat the sheep stables. They distributed the feed without using electricity, i.e. by hand or with the help of tractor. The inventory data are, however, incomplete on this point. To trace the origins of the variation in consumption of electricity, one would need more information on the farms than could easily be provided.

In Table 25 the average use of diesel and electricity is given.

Table 25. Average use of diesel and electricity for animal keeping and feed production on farm.

	Mean conv. (n=5)	Range	Mean org. (n=4)	Range
Diesel use for feed production and animal keeping, MJ/ewe	356	106-699	461	183-829
Electricity use, kWh/ewe	39	2-76	19	9-28
Electricity use, MJ/ewe	139	6-272	69	33-100
Total electricity + diesel, MJ/ewe	534	112-929	550	217-930

3.3 Purchased feed to the farm

All farms in this study used both home-grown and purchased feed for the sheep. All farms purchased concentrate/protein feed and one farmer bought silage in addition. Some of the farms studied purchase concentrate mixes, sometimes including grain. In other cases, feed grain was either grown on the farm or purchased from another farmer in the neighbourhood. In Table 26 the purchased feed ingredients are listed.

Table 26. Average amounts of purchased feed ingredients on the conventional and organic farms. Typical compositions of the feed mixes used was assumed (Lantmännen and Svenska foder, personal communication 2009).

	Mean conv. (n=5)	Range	Mean org. (n=4)	Range
Grain, kg/ewe	66	29-118	23	0-56
Sugar beet co-products, kg/ewe	25	9-42	1	0-1
Peas/beans (raw or processed), kg/ewe	10	3-30	12	3-21
Grain ethanol co-products, kg/ewe	5	1-11	0	0
Rape seed co-products, kg/ewe	25	10-52	0	0

Data on conventional feed production was found in Flysjö et al (2008). As the EU regulated that organic sheep production should be based on 100 % organic feed from the year 2008, it was assumed that exclusively organic feed was used on the organic farms. Data on organic feed ingredients used were taken from the unpublished SIK internal feed library. These data are based on the conventional feed data, but adapted with regard to yields and to the use of fertilisers, manure and pesticides.

Data on organic lucerne meal (Sw. *grönmjöl*) production were missing, and therefore data on conventional lucerne meal were slightly adapted in order to represent organic production. Mineral fertilizers were assumed to be substituted by slurry from milk production, while pesticides were simply excluded, but no adaption of the yield was made. Lucerne meal was a minor feed ingredient on the organic farms, and the effect on the results from these assumptions is negligible.

3.4 Post farm activities

3.4.1 Slaughter

Swedish lamb and sheep are normally slaughtered at large abattoirs, where lamb meat is but a small part of the total produce. There is one dominating slaughter and meat processing company in Sweden, performing 80% of the Swedish lamb slaughter (www.scan.se). Data were collected from this company's holding in Linköping, where sheep as well as other livestock are slaughtered.

A lamb carcass consists of 76.2 per cent bone free meat and 23.8 % bone (Scan, 2010). For adult animals, the bone proportion could be higher, but since the amount of meat from adults is small, lamb meat-bone proportions are used for all meat.

In 2008, the total energy use per ton meat production (all animals) at the Linköping abattoir was 1 200 MJ. The proportions of different energy sources were: 55% electricity, 24% district heating and 21% district steam. Data on energy use cannot be separated for different meat categories. For lamb meat, about 80 per cent of the meat leaves the abattoir as whole meat, including bones. The resulting 20 per cent is cut to consumer size – some bone free, and some including bones. The further calculations are made assuming all meat sold as whole meat, including bones.

The cooling agents used were mainly ammonia and brine. Since we lack further specification on the cooling system, no environmental effects other than energy use are calculated from cooling of meat.

3.4.2 Packaging

Data on packaging sizes and amounts of packaging material were based on Scan, 2010. Whole meat was packaged in vacuum plastic pouches containing approx. 2 kg meat. The plastic for the packaging weighed 50 g, which makes 25 g per kg meat. Consumer meat was packaged in smaller vacuum plastic pouches, which contained 0.2-1.5 kg meat with varying amounts of bone included. As a simplification, all consumer packages were assumed to contain 0.8 kg meat. The packaging weighed about 8 g, which makes 10 g per kg meat.

There were no inventory data on what kind of plastics was used for the packaging. Laminates with layers of different plastic types are often used for meat products, but here the plastic was assumed to consist of low density polyethylene (LDPE) only, as a simplification.

No secondary packaging was included.

3.4.3 Transports

From farm to slaughter house
Slaughter transports of sheep and lamb by lorry always include animals from different farms since lamb and sheep are small animals and most Swedish sheep farms are small.

On the island of Gotland, where the sheep farm density is high, the slaughter transport may include sheep only (Ronny Molins Transporter AB, 2010). On the mainland, the sheep often are transported on the upper store of the lorry, while the bottom is filled with cattle (Scan, 2010). Each stop at a farm takes time, and the legislation limits the time for the slaughter transport (including stops) to 8 hours. As a result of this, slaughter transports are only partly filled.

We assumed the transports of sheep to slaughter to be performed by a lorry with a maximum load capacity of 20 tons. After the last stop, the lorry was assumed to be filled with 10 ton animals, which corresponds to 16 cattle and 15 lambs. The distance from farm to abattoir was assumed to be 40 km, which was the average from the 10 farms inventoried for this study. The transport was modelled as an 80 km trip, where the lorry is empty half of the way and loaded with 10 tons the other half. The emissions from these transports were calculated based on data from NTM (2010).

From slaughter house to RDC
The modelled distance for transports from slaughter house to regional distribution centre (RDC) was 200 km. The transport was chilled and performed with a lorry carrying 90 per cent of its maximum load. The emissions from these transports were calculated based on data from Ecoinvent Centre (2007).

4 Impact assessment

The three lamb production systems presented in chapter 3 – conventional indoor, conventional outdoor and organic production – widely overlapped in their basic farm data (see Table 2). The same is true for most environmental impacts from the farms' meat production. Since the variation within the systems was large, while the differences between them were often smaller, the systems were not considered generally usable in the reporting of the results of this study. Therefore, the results are mostly presented as one common average value and the range among all ten farms. In some cases, substantial differences between conventional and organic farms were found, and then the results are presented for these two systems separately.

For each impact category, the results were split on sub-groups, to better illustrate which parts of the life cycle have the greatest influence on the results. The sub-groups were defined as follows:

Diesel and electricity	Use of diesel and electricity at the farm for feed production, manure handling and stables
Enteric fermentation	Enteric fermentation from the sheep (figures adjusted to simulate constant herd sizes in a year-to-year perspective).
Manure: housing and pasture	Emissions from manure at stable (including potential storing elsewhere before application) and manure excreted by animals on pasture.
On-farm feed production	Transport (if any) of and field losses from manure used in feed production, production of, transport of and field losses from fertilizers, production and transport of pesticides and production, transport and recycling of silage plastics.
Purchased feed	Production and transport of purchased feed such as concentrate, grain and forage, plus pressing and transport of straw for the deep beddings.
Post-farm activities	Transport of the animals to slaughter, energy use at slaughter house, packaging and transport to regional distribution centre.

4.1 Use of resources

4.1.1 Phosphorus and potassium in fertilisers

Regulations on organic production restrict the use of mineral phosphorus (P) and potassium (K) in fodder crop production to a few special fertiliser products, and none of the organic farms used such fertilisers in feed production. It was assumed that no mineral fertilisers were used to produce feed imported to the organic farms. Most of the conventional farms used mineral P and K in the on-farm feed production, and it was assumed that these fertilisers had also been used in the production of feed purchased by the conventional farms (Table 27 and Table 28).

Table 27. Use of phosphorus as fertiliser in feed production (on-farm and purchased); average for the conventional farms.

	Mean, conventional	Range
On-farm feed production, kg P/kg CW	0.028	0-0.10
Purchased feed, kg P/kg CW	0.009	0.003-0.013
Total use of fertilizer P, kg P/kg CW	0.037	0.008-0.11

Table 28. Use of potassium as fertilizer in feed production (on-farm and purchased); average for the conventional farms.

	Mean, conventional	Range
On-farm feed production, kg K/kg CW	0.12	0-0.29
Bought-in feed, kg K/kg CW	0.15	0.019-0.34
Total use of fertilizer K, kg K/kg CW	0.26	0.025-0.63

4.1.2 Land

There was a remarkable variation in land use among the farms inventoried. Only land use for production of feed for the sheep was included[12]. The land use is separated into two main categories: grassland (permanent and temporary) and annual feed crops. The first category represents use of land at the sheep farm (though for one farm, some neighbour land producing silage was included). The other category includes land used on the farms and land for production of purchased feed.

The total average land use for producing lamb meat for all ten farms was 118 m^2 per kg CW and year. Excluding one conventional farm with exceptionally large areas of semi-natural grassland, the average (n=9) was 88 m^2 per kg CW and year. For conventional production (including all six farms), average total land use was 147 m^2 per kg CW and year (see Figure 4.1). Excluding the farm with the large areas of semi-natural grassland, the average (n=5) was 98 m^2. The average total land use in organic production was 75 m^2 per kg CW and year. It was the use of semi-natural grasslands that made the total average land use higher in the conventional production system. The average use of arable land in the organic production system was twice as high as in the conventional production system, due to a larger use of temporary grasslands, but the variation between farms was large. Grasslands (temporary plus semi-natural) dominate the land use in both systems.

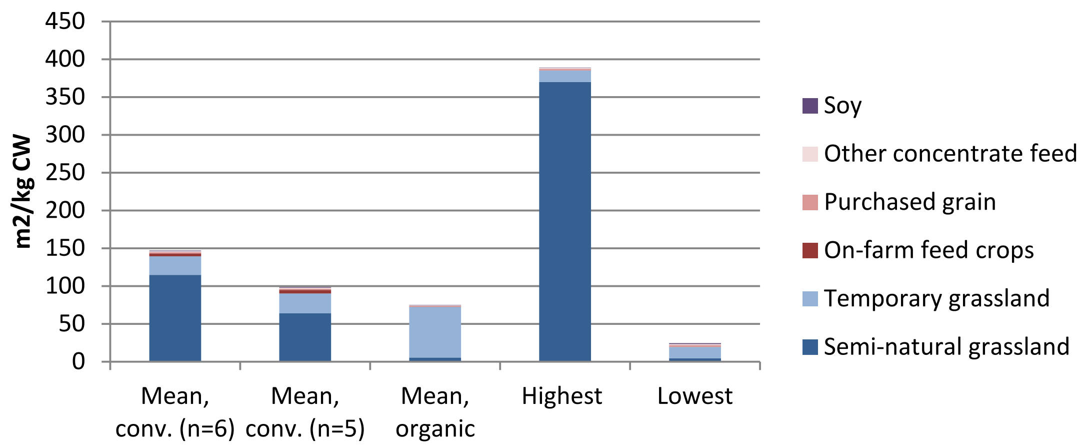


Figure 4.1. Yearly land use for feed production in the different production systems. One conventional farm had exceptionally large area of semi-natural grassland. This farm is represented by the "highest"-column. The average for conventional farms was calculated both including (n=6) and excluding (n=5) this farm.

Grasslands

There was a great variation in the use of semi-natural grasslands across farms in this study (Figure 4.2). A possible cause for this could be found in the general nature of semi-natural grasslands. In general, there is a great variation in this land type concerning amount and quality of grass production, which is due to history, stoniness, presence of trees and bushes, density of animals, climate, the nature of the soil etc. On top of this, semi-natural grasslands are in some cases "surplus land", i.e. land not strictly

[12] For farms also producing feed for sale, the total area for production of feed for the own animals was calculated as the percentage of the feed mass used for the own animals.

needed for feed production. But when available, semi-natural grassland is still often utilised for grazing for the sake of tradition, preservation of biodiversity and beauty, or because it is part of an EU agri-environmental payment scheme.

There was a also a large variation across farms in how intensively the temporary grasslands (i.e. grass on arable land) were managed in terms of fertiliser rates, yields, clover content, time period before renewal etc. This, combined with different feeding strategies and variations in use of semi-natural grasslands, explains the variation between farms in general. More specific, the organic farms had a larger use of temporary grasslands, and there are two main reasons for this: a) organic production is to a greater extent based on forage feed and b) organic ley production on the farms inventoried is more extensive, with lower input of N per ha and smaller yields.

One farm produced whole crop silage and feed turnip. These were annual forage crops and therefore hard to fit in the categories used here, but the area of this production was included in the temporary grassland area.

Semi-natural grasslands represented large areas on some farms, while non-existing on others. Farms without semi-natural grasslands seem to compensate for this by having more temporary grasslands.

The yearly total average use of grasslands in the conventional system (based on six farms) was 139 m^2 per kg CW (Figure 4.2). Excluding one farm with exceptionally large areas of semi-natural grassland, the average (n=5) was 90 m^2 per kg CW and year. The average total use of grasslands in the organic system was 72 m^2 per kg CW and year. Considering use of temporary grassland only, we find that conventional production uses less than half as much of this kind of land as organic (25 compared to 67 m^2 per kg CW and year) [13].

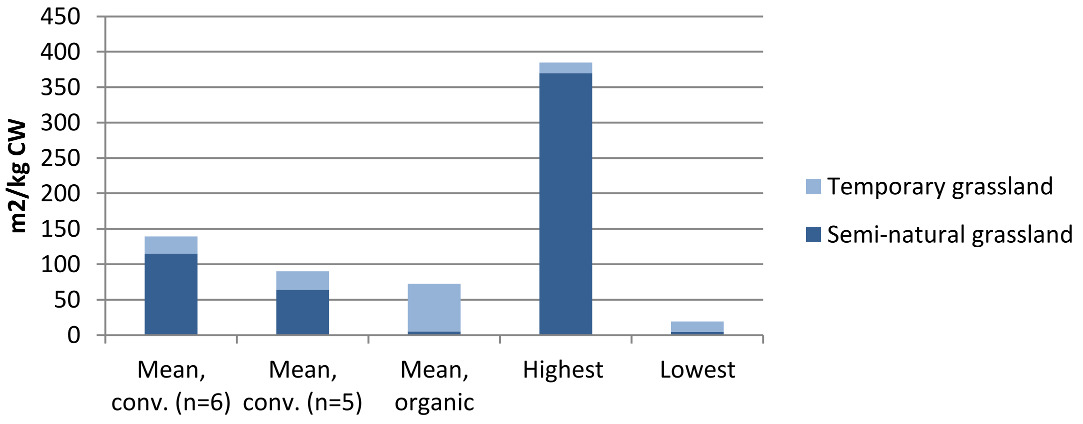


Figure 4.2. Yearly average use of land for grazing and silage production in the different production systems. One conventional farm had exceptionally large areas of semi-natural grassland. The average for conventional farms was calculated both including (n=6) and excluding (n=5) this farm.

[13] Use of temporary grassland in conventional production: 24 m^2 per kg CW and year based on six farms and 26 m^2 per kg CW and year based on five farms.

Grain and concentrates
The organic farms use less land for production of grain and concentrate feed, because of the smaller proportion of these ingredients in the feed on these farms. Two conventional farms had lower yields than what was assumed for purchased grain, and also more grain in the feed ration than the other farms in this study. Both these aspects contributed to a high grain and concentrate land use for these farms, and increased the average for the conventional farms substantially. But even if these farms were to be excluded from the conventional average, land use for production of grain and concentrate feed would still be lower on the organic farms.

The average land use for production of grain and concentrate in the conventional system (based on six farms) was 7.7 m^2 per kg CW and year (Figure 4.3), which was three times higher than in the organic system (which was 2.6 m^2 per kg CW and year, based on four farms).

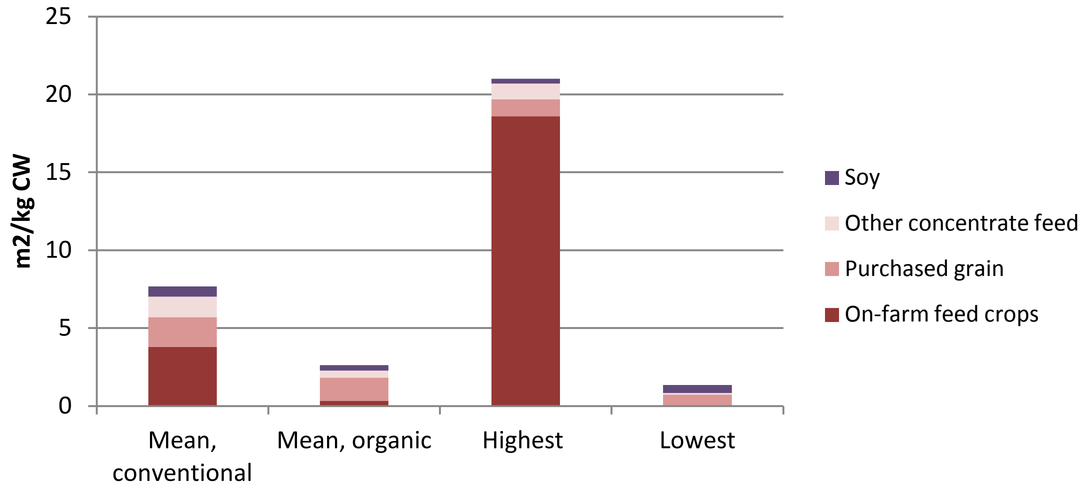


Figure 4.3. Land use for the production of grain and concentrate in the different production systems. There was a great variation between farms in the proportions of grain and concentrate in the feed rations. Yields per hectare also varied a lot. Some farms produced grain for feed, which is shown as "on-farm feed crops". Some farms imported grain, and all farms imported some concentrate feed.

4.1.3 Energy

Use of primary energy in lamb production varied between farms. The total average from all ten farms was 36 MJ/kg CW, but there was a substantial difference between the organic and conventional farms. As an average 44 MJ/FU was used in the conventional production, which was almost double that in the organic production (Figure 4.4). For the conventional farms, purchased feed represented the largest share of energy use, while this source was of little significance on the organic farms. One reason for this was that three of the conventional farms bred the lambs indoors with high growth rates which require high concentrate feed input. Also the use of synthetic fertiliser in feed production explains the higher energy use in conventional production.

The main contributor to the energy use in the organic production system is the use of diesel, which is higher than in the conventional system. This is explained by a higher use of roughage feed and (on average) lower silage yields per hectare, which leads to larger areas of temporary grassland in the organic system being object to tractor driving.

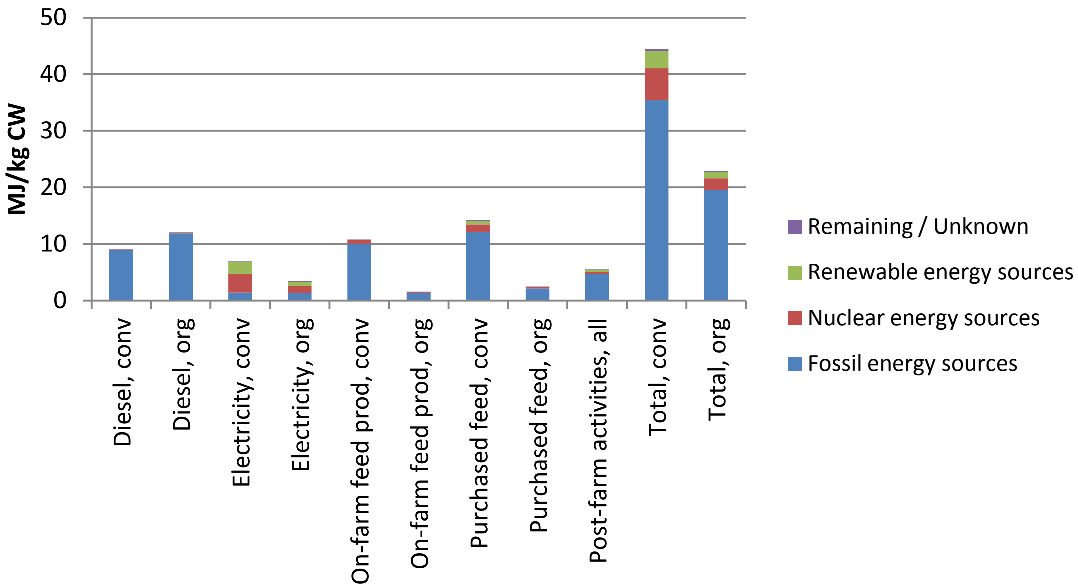


Figure 4.4. Primary energy use, as mean values for conventional and organic production.

4.2 Use of pesticides

No toxicity assessment was made. Instead, use of pesticides is presented as a toxicity indicator.

Pesticide use in conventional production is shown in Figure 4.5. The EU regulation on organic production requires 100% organically produced feed to sheep. Therefore, there was no pesticide use in the organic lamb production.

On the conventional farms no insecticides and very little of fungicides were used during the year studied. Four out of six the conventional farms used herbicides. The low pesticide use in feed produced at the farm is principally a result of the low need in grasslands. As seen in Figure 4.5, the pesticide used in lamb meat´s lifecycle is very much found outside the sheep farm, in the cultivation of crops for concentrate feed.

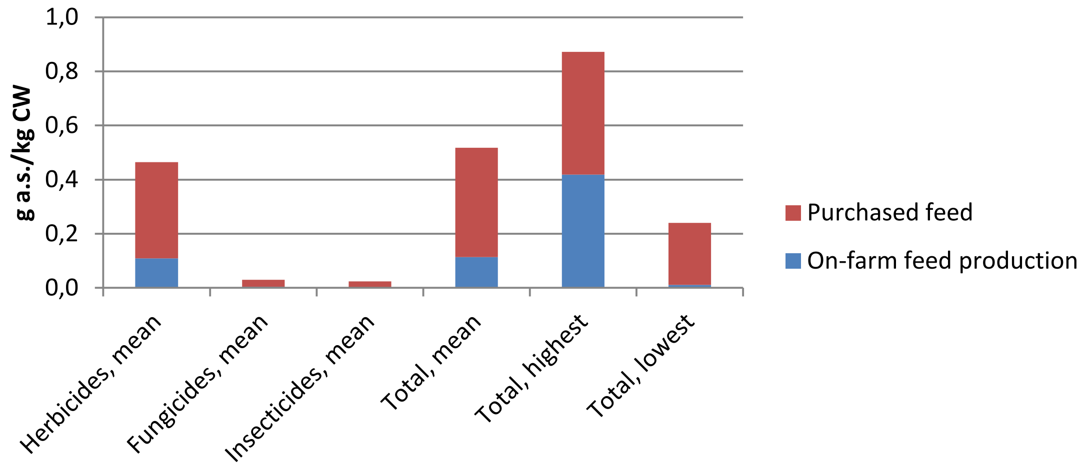


Figure 4.5. Pesticide use in on-farm feed production and purchased feed, as active ingredient (a.i.) in herbicides, fungicides and insecticides. Mean values calculated from six conventional farms.

4.3 Climate Change

Characterisation factors for climate change comply with IPCC (2007), see Table 4.4

Table 29. Characterisation indexes for the main substances contributing to greenhouse gas emissions from sheep production.

Substance	Kg CO2-equivalents (CO2e) per kg
Carbon dioxide, CO_2	1
Nitrous oxide, N_2O	298
Methane, CH_4	25

As an average of the 10 studied farms, the life-cycle GHG emissions were 16 kg CO_2-eq per FU (Figure 4.6). The variation around this mean value was large, ranging from 11 – 25 kg CO_2-eq/FU. There was no clear difference between conventional and organic production, neither in total GHG emissions nor in proportions of main contributing aspects. Two of the conventional farms with outdoor production had remarkably high GHG-emissions, but the third conventional outdoor farm had very low emissions. From this study, it is obvious that the management on the individual farm has a higher impact on the carbon footprint of lamb meat than the system affiliation.

Growth rate and mortality are production parameters of great importance to the carbon footprint of lamb meat since CH_4 and N_2O emissions from the rumen and excretions represent the dominant share of total emissions. Methane from enteric fermentation is the main contributor, contributing to more than 50 % of the total characterised emissions. Also nitrous oxide from manure handling and cultivation of feed are very important.

Nitrous oxide emissions varied between the farms and this was explained by the differences in nitrogen surplus (see also section 3.2.4). This variation suggests that there are potentials for improvements in the provision of nitrogen to the crops.

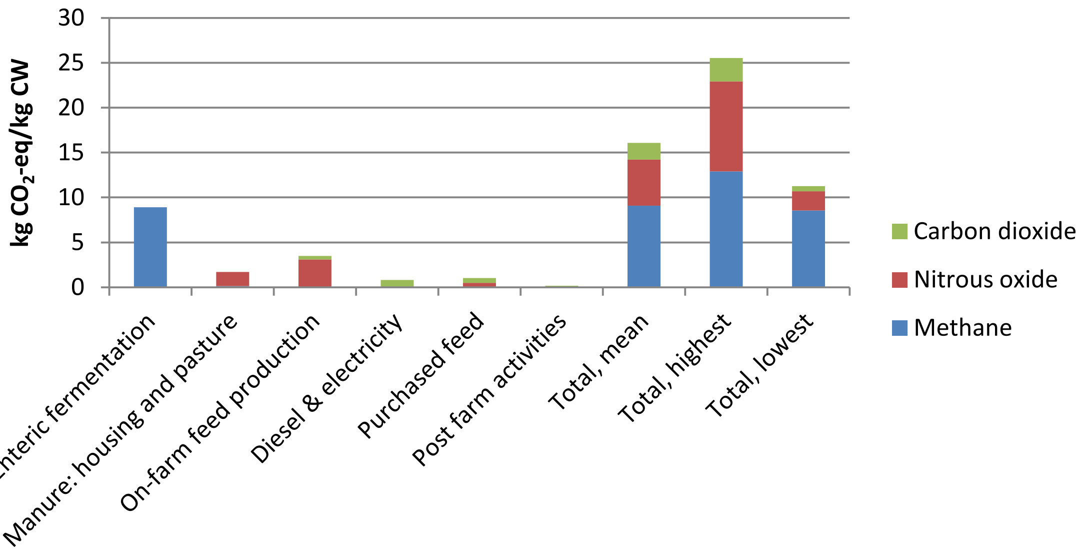


Figure 4.6. Greenhouse gas emission in the life-cycle of lamb meat, average value for all farms studied.

4.4 Eutrophication

The potential emissions of eutrophying substances are presented as PO_4^{3-}-equivalents. Characterisation indexes (Guinée et al, 2002) are listed in Table 30.

Table 30. Characterisation indexes for the main substances contributing to eutrophying emissions from sheep production.

Substance	Characterisation factor, kg PO_4^{3-}-eq/kg
Phosphorus, P	3.06
Ammonia, NH_3	0.35
Nitrate, NO_3^-	0.10

As an average for all ten farms, the potential contribution to eutrophication was 72 g PO_4^{3-}-eq per FU (Figure 4.7). There was no clear difference between organic and conventional production, therefore results of the production systems are not shown separately. The variation between farms was remarkably large, ranging from 35 to 130 g PO_4^{3-}-eq per FU.

N leaching from feed cultivation on the sheep farm is the most important contributor to eutrophication in the lamb meat life cycle. Ammonia from manure is also important. The deep bedding system used by all farms means relatively high emissions of this reactive N. Other parts of the life cycle are of minor importance to the eutrophication potential of lamb meat.

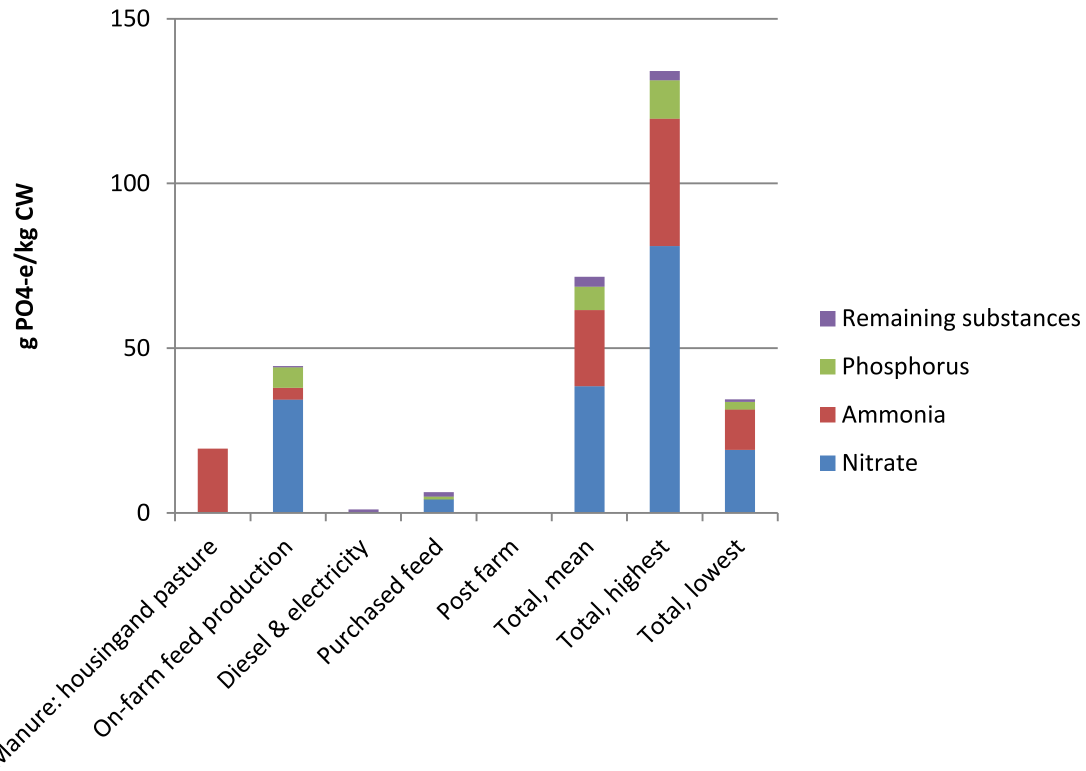


Figure 4.7. Potential eutrophication (max scenario) in the life cycle of lamb meat, average for all farms studied.

4.5 Acidification

The potential emissions of acidifying substances are presented as SO_2-equivalents. Characterisation indexes (Guinée et al, 2002) are listed in Table 31.

Table 31. Characterisation indexes for the main substances contributing to acidifying emissions from sheep production.

Substance	Characterisation factor, kg SO_2-eq/kg
Sulfur oxides, SO_x	1.2
Sulfur dioxide, SO_2	1.2
Nitrogen oxides, NO_x	0.5
Nitrogen dioxide, NO_2	0.5
Ammonia, NH_3	1.6

As an average for all farms, the potential contribution to acidification was 0.12 kg SO_2-equivalents per FU (Figure 4.8). There was no clear difference between organic and conventional production, therefore results for the two production systems are not shown separately. Ammonia (NH_3) was the dominating acidifying substance, and emissions from manure in stable and storing were the main sources. Deep bedding systems, where straw and manure successively builds a high, warm bed where the animals reside, give rise to high emissions of ammonia.

When the excreta are dropped outdoors on pasture, NH_3 emissions are lower than in the stable due to infiltration into the soil and lower temperature. The grazing season for sheep is approximately six months. On four of the farms inventoried the sheep are outdoors part of the time during the winter as well.[14]

Ammonia emissions from on-farm feed production vary considerably between the farms. The extent of on-farm feed production, use of fertilizers and manure, and time for application of the latter are important for the size of the emissions.

[14] There is a lack of information on the emissions from outdoor manure wintertime, so here it was assumed that the emissions are the same as summertime, which means lower emissions for farms where the sheep have outdoor access all the year round. During the winter, the sheep do not use as large areas, since they have little or nothing to graze. Therefore, the manure dropped by the animals is more concentrated around the feeding places. If the soil is frozen, or if the fold has a cement floor, there may be puddles of urine, which increases the probability of ammonia emissions. On the other hand, the low temperature wintertime could lead to lower emissions. None of this, however, was taken into account because of the uncertainties.

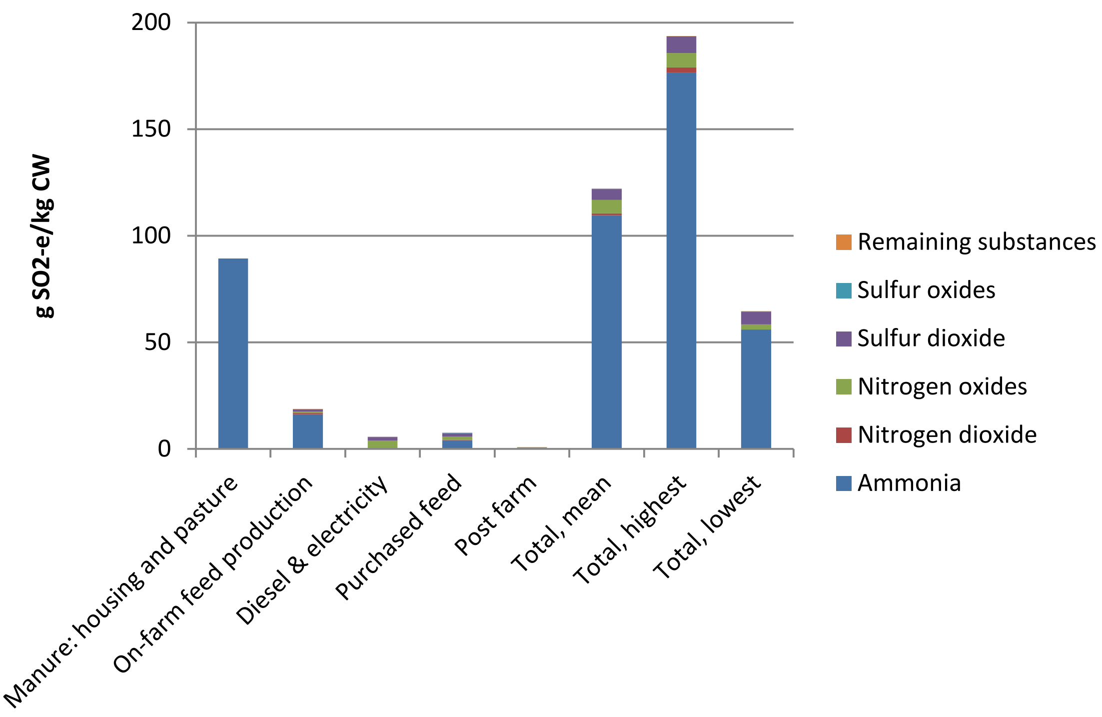


Figure 4.8. Potential acidification (max scenario) in the life cycle of lamb meat, average for all farms studied.

4.6 Photochemical Ozone Creation

The photochemical ozone creation potential is presented as emissions of C_2H_4-equivalents. Characterisation indexes are listed in Table 32 (Guinée et al, 2002).

Table 32. Characterisation indexes for the main substances contributing to photochemical ozone creation potential in sheep production.

Substance	Characterisation factor, kg C_2H_4 eq/kg
Benzene	0.4
Butane	0.5
Carbon monoxide, fossil	0.04
Ethane	0.1
Ethene	1
Heptane	0.5
Hexane	0.5
Methane	0.007
Pentane	0.3
Propane	0.5
Toluene	0.5

As an average for all farms, the contribution to photochemical ozone creation potential acidification was 2.6 g C_2H_4-equivalents per FU (Figure 4.9). There was no clear difference between organic and conventional production, therefore results for the two production systems are not shown separately. Methane (CH_4) was the dominating ozone creating substance emitted from the production, and emissions from enteric fermentation the main source, representing 90-95 % of the total.

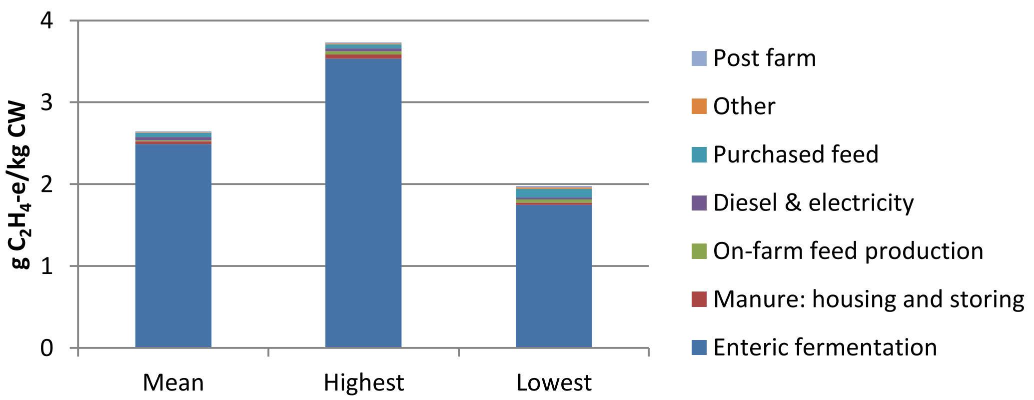


Figure 4.9. Potential photochemical ozone creation (max scenario) in the life cycle of lamb meat, average for all farms studied.

4.7 Ozone depletion

The photochemical ozone creation potential is presented as emissions of CFC11. Characterisation indexes are listed in Table 33.

Table 33. Characterisation indexes for the main substances contributing to ozone depletion potential in sheep production.

Substance	Characterisation factor, kg CFC11/kg
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	0.85
Methane, bromochlorodifluoro-, Halon 1211	5.1
Methane, bromotrifluoro-, Halon 1301	12
Methane, chlorodifluoro-, HCFC-22	0.04
Methane, tetrachloro-, CFC-10	1.2

As an average, the contribution to emissions of ozone depleting substances was 0.18 kg CFC11 per FU on the conventional farms and 0.14 kg CFC11 per FU on the organic farms (Figure 4.10). Emissions from the production of energy dominate the results. This includes energy as diesel and electricity used on the farm, and energy used for the production of inputs.

The organic farms had, on average, 24% lower emissions than the conventional ones. This was explained by the lower use of concentrate and the absence of mineral fertilisers.

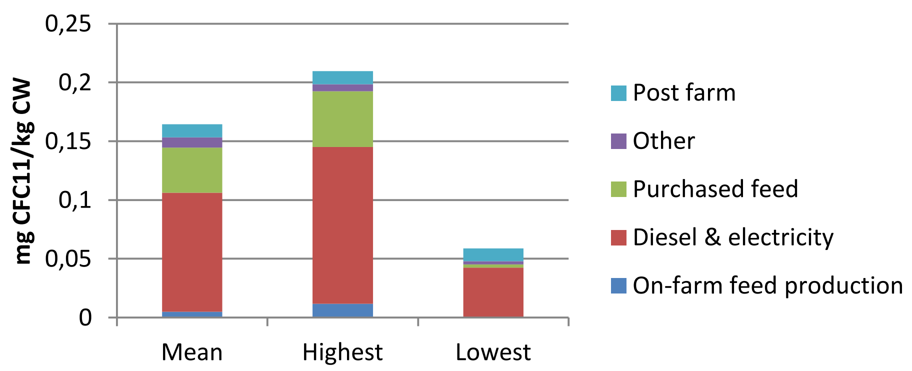


Figure 4.10. Potential ozone depletion (max scenario) in the life cycle of lamb meat, average for conventional and organic farms studied.

5 Discussion

In the early phases of this project, there was an ambition to analyse the variation between farms due to indoor or outdoor breeding of lambs and due to conventional or organic production. The number of farms was for several impact categories found to be too small to make such analyses. However, there were a few clear and important differences:

- The organic farms inventoried had a more extensive use of arable land (even if the conventional farms used more semi-natural grassland), which also influenced the nitrogen balance per hectare.
- The use of primary energy in the organic production systems was, on average, half as high as primary energy use in the conventional production systems.
- Pesticides and phosphorus and potassium as fertilisers were used in the conventional production systems, but not in the organic ones.

5.1 Representativeness

Emissions from the living animals through enteric fermentation and excretion dominate the environmental impact from sheep production. This makes the amount of meat produced on the farm per ewe crucial for the environmental outcome of the production. Therefore, the best way to investigate how well the results of this study represent Swedish production of sheep and lamb as a whole is to check key data for the production, e.g. slaughter age, carcass weight and number of lambs per ewe. Such key data are presented in **Table *34***.

Table 34. Comparison of key data for the farms in this study and national average.

	Average for farms in this study	Swedish average
Age by slaughter, indoor breeding, days	111	ca 130*
Age by slaughter, outdoor breeding, days	168	ca 190*
Age by slaughter, all, days	151	ca 170*
CW, kg	19.1	18.5
CW/LW	0.44	0.41
no lambs/ewe	1.6**	1.7***

*) estimate
**) lambs surviving until the age of slaughter
***) weaned lambs
Sources: Jordbruksverket (2009) and Allard & Wallman (2010)

We see that the studied farms are close to the Swedish average in most aspects, but are higher in growth rates and carcass weight efficiency (CW/LW). Higher growth rates and carcass weight efficiencies in extensive ruminant production such as Swedish lamb production typically leads to lower environmental burden per kg CW.

5.2 Uncertainties

A large share of the environmental burden from sheep production arises from emissions created by biological processes on the farms. For most of these emissions, such as methane from enteric fermentation, nitrous oxide from fields and ammonia emissions from manure, there are large uncertainties in the emission factors, and thus also in the results of this study. Even if incomplete and uncertain, the results of this study point out some important aspects for further research and improvements.

5.3 Results in relation to other studies

There are rather few LCA studies published on lamb production, compared to e.g. milk, but there are some recent results. Table 35 shows an overview of carbon footprint and LCA studies on lamb production in New Zealand, United Kingdom (UK), Norway and results from this study. Figures cannot be directly compared, as differences might be consequences of different methodology in the studies.

Even if the same methodology is used, uncertainties in emission factors and inventory data may hinder conclusions on what is the most environmentally efficient production. Flysjö et al (2011) have explored the consequences of using the highest and the lowest emission factors in the intervals specified by the IPCC for CH_4 from enteric fermentation and N_2O in a comparison of milk production in New Zealand and Sweden. The same methodology was used for the analyses of the two systems. Flysjö et al (2011) found that the potential differences between the two production systems, corresponding to approx. 15 % of the carbon footprint, were totally overshadowed by the EF uncertainties.

However, giving some key information in combination with the figures, our ambition is to give a view of this study in relation to previous studies.

Table 35. Results from this study compared to results from LCA:s made on lamb production in other countries.

	New Zealand A	**New Zealand B**	**United Kingdom**	**Norway**	**Sweden**
Reference	Ledgard et al (2010)	Defra (2008)	Defra (2008)	Møller & Vold (2008)	this study
FU	100 g meat (CW)	1 kg CW	1 kg CW	1 000 kg CW	1 kg CW
CW/LW	-	0.47	0.54	-	0.40-0.47
Production system	Outdoor breeding all year round	Outdoor breeding all year round	Part of the year indoors	Part of the year indoors	Part of the year indoors
Allocation (economic allocation used in all of the studies, if not specifically noted)	Lamb meat, mutton and wool. No factors presented.	Lamb meat 0.64, mutton 0.22 and wool 0.14.	Lamb meat 0.74, mutton 0.18, and wool 0.08.	Meat, hides, leather and wool. No factors presented.	Meat 0.62 and hides 0.38. (Mass allocation between lamb and mutton meat)
System boundaries	Cradle to retail gate	Cradle to farm gate	Cradle to farm gate	Cradle to grave	Cradle to RDC
Conversion factors used for GHG emissions	IPCC 2007	IPCC 2001	IPCC 2001	IPCC 2001	IPCC 2007
Carbon footprint, kg CO_2-eq per kg CW	19 (of which 4 post farm)	9.7	13.4	16 (of which ca 0.5 post farm)	16 (of which 0.2 post farm)
Eutrophication, kg PO_4-eq per kg CW	-	0.061	0.084	0.025	0.07
Acidification, kg SO_2-eq per kg CW	-	0.052	0.058	0.010	0.12
Land use, m^2/(kg CW*yr) [15]	-	50	90	-	88*
Primary energy use, MJ/kg CW	-	12.2	17.9	42	36

*) n=5; one farm with extremely large semi-natural grassland area per kg CW was excluded from the average.

The results from this study indicate higher environmental impacts from Swedish sheep production for energy use, greenhouse gas emissions and land use compared to lamb meat from NZ (study B) and UK. If the economic allocation would be used between lamb and mutton meat (as for NZ and UK lamb), the environmental impacts per kg CW would be even higher for the Swedish production (10-20 % higher).

The high impact results from Swedish lamb production are explained both by production system properties and by methods chosen for calculating emissions.

[15] In the original Defra (2008) study, the land use in UK lamb production is presented as 5 and 9 *m^2* per ton CW, respectively, which was a typographical error where it should be 5 and 9 *ha* per ton CW (Cranfield University, personal communication 2010).

Known major differences in production system properties:

- All farms inventoried for this study use deep beddings for the sheep at stable. The emissions of ammonia from these beddings are high. The high emissions of acidifying substances are a result of this. The ammonia emissions also add to the GHG emissions through indirect emissions of nitrous oxide and to the eutrophying emissions. The more time the sheep spend outdoors, the less ammonia is emitted from manure.
- Primary energy use is larger for the Norwegian and Swedish systems, partly because more of the production chain is included in these studies. However, the production system (organic as well as conventional) in Sweden with harvested instead of grazed feed half of the year requires higher energy input than the NZ production. Feed production (both purchased and on-farm, but except on-farm diesel consumption) represents almost half of the total energy use in the Swedish lamb production.
- Sweden has lower output of carcass weight per kg live weight compared to the UK and NZ (B) studies. This production parameter is important to the final results. It is also possible that the growth rate of Swedish lamb is lower, and that each ewe produces fewer lambs per year, but there is no information to prove this in the Defra (2009) study. A reasonable explanation for lower productivity in Swedish lamb production could be that the Swedish production is very small, almost considered as a niche product for Swedish agriculture with many extensive “hobby-farmers”. Research and development in production techniques, extension services etc have not focused on sheep production as in countries such as NZ and UK, where sheep production is a business of large importance to the agricultural economy.

Known major differences in ways of calculation:

- The use of the Lindgren equation instead of the IPCC method for calculation of enteric methane emissions adds to the results concerning GHG emission, see Appendix 3.

5.4 Methane estimates from enteric fermentation

Use of the IPCC method (Tier 2) instead of the Lindgren equation to calculate the enteric fermentation from lamb and sheep gives lower calculated emissions of enteric methane. As a sensitivity check, methane emissions were recalculated for two farms using the IPCC method.[16] One of the farms (here called farm 1) had very low enteric methane emissions, and the other very high (here called farm 2). The impact of calculation method for the two farms is shown in Table 36.

[16] Specifications for the calculations using the IPCC method: The assumed DE (digestible energy expressed as percentage of gross energy) is 70%. It is also assumed that the sheep graze on rather flat, lush temporary grasslands, which means lower methane emissions due to less energy expenses to acquire feed, compared to grazing in hilly semi-natural grasslands with low grass production. This assumption is made to put light on the possible maximum variation between the two ways of calculation.

Table 36. Reduction in calculated emissions of enteric methane and GHG when using the IPCC method compared to the Lindgren equation to calculate methane emissions from enteric fermentation. Farm 1 and 2 are farms inventoried for the study. Farm 1 is a farm with relatively low emissions of methane from enteric fermentation, and farm 2 is a farm with high methane emissions. GHG emissions other than methane from enteric fermentation are also higher for farm 2 than for farm 1.

	Farm 1	Farm 2
Reduction of enteric methane emissions	18 %	25 %
Reduction of total GHG emissions from the farm	8 %	13 %

5.5 Land use

Sweden has large areas of land suitable for grazing and/or production of hay and silage. At present, there is no lack of land for production of grazing animals; in fact the situation is partly the opposite. Conservationists are concerned that there are not enough animals to graze all semi-natural grasslands to preserve biodiversity. Since there is quite an abundance of grassland and little alternative production for this land, land use on Swedish sheep farms is often extensive.

Recent studies of Europe´s terrestrial carbon balance show that there is a significant sink in grasslands and forests while the croplands represent a carbon source to the atmosphere. The sequestration in grasslands is likely the result of high fine-root turnover and reduced carbon losses due to stabilization of organic matter by endomycorrhizal compounds (Schultze et al, 2009). In France, carbon sequestration in grasslands has been measured for different grasslands management and are typically in the range 200 to 500 kg C per ha and year (Sousanna et al, 2010). As an average for the whole European continent, Schultze and colleagues (2009) estimate the average carbon sink in the European grasslands at 560 kg C per ha and year while the croplands on average are a source corresponding to 100 kg C per ha and year. Carbon sinks in permanent pastures measured in Great Plains in North America are reported as 390±50 kg C per ha and year measured over a time period of 44 years on moderately grazed and non-fertilised pastures (2.6 hectare pasture per yearling steer) (Liebig et al, 2010).

Using an indirect method based on N-input in grassland and assuming constant C/N-ration in the soil, C-sequestration in Swedish semi-natural grasslands was calculated at 30 kg C per ha and year as an average (SJV 2010). Kätterer et al (2004) measured an average yearly C-sequestration of 400 kg C/ha and year when converting arable cropland to grassland in Uppland, Sweden.

Grassland is the overall dominating land use in Swedish sheep production with two types of land use: temporary grassland on arable land *(Swe: slåtter/betesvall på åker)* and semi-natural grassland *(Swe: naturbetesmark).* Both grassland types are promoted within the agri-environmental payment scheme, especially the semi-natural grasslands which are considered important for preserving biodiversity. Semi-natural grasslands are not ploughed and have lower productivity than arable land. Temporary grasslands are cultivated on approximately one third of the Swedish arable land and have a large variation in management methods. On the plains in the south where grain is the dominating crop, temporary grasslands are often used as short leys (two or three years) and included in crop rotations. In regions outside the most intense agricultural areas, temporary grasslands have longer duration. On many cattle and sheep farms, temporary grasslands represent a large share of total land use. This means that long cultivation cycles for the grasslands are combined with only short interruptions when the grasslands are ploughed and cultivated with annual crops. This management favours carbon sequestration (Soussanna et al., 2010).

In this study, land use on the sheep farms was dominated by grasslands. Five out of ten farms had more than 90% of their arable land area as cut and/or grazed temporary grassland *(sve: slåtter/bete på åkermark)*. On three farms, temporary grasslands constituted 70-80% of the arable land. Only on one farm, temporary grassland had less than 30 % of the arable land. Time periods between renewals of the grasslands varied between 3 and 15 years on the farms in the study, but were mostly in the range 4-7 years. The high proportion of temporary grasslands with long duration and thus low frequency of ploughing means that the farms studied have good potentials for carbon sequestration.

Here, we have chosen not to include carbon sequestration in the results for lamb production. The main reason to this is that the amount of carbon sequestrated per uear is very uncertain, and there is yet no consensus in the LCA research community regarding what model to use. Therefore, we only present some examples of carbon sequestration for a discussion

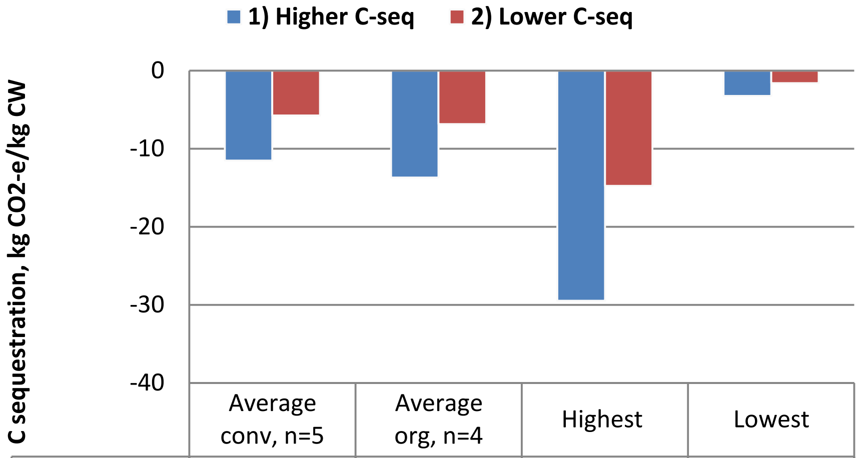
We did an estimate of the size of the carbon sequestration capacity in grasslands by testing values based on recent literature. Since the variation between literature sources is so large, we included two scenarios: 1) Higher and 2) Lower.

Table 37. Carbon sequestration capacity: 1) Higher and 2) Lower in grasslands. Estimates used in this study for calculating potential C sequestration from lamb production as an effect of land use.

Land use	1) Higher C seq, kg C/(ha*year)	2) Lower C seq, kg C/(ha*year)
Temporary grassland *(sve: slåtter/betesvall)*	500	250
Semi-natural grassland *(sve: naturbetesmark)*	300	150

In Figure 4.2, the yearly use of grassland for producing one kg CW lamb meat is shown. As an average for five conventional farms, the yearly land use was 90 m^2 grassland per kg CW of which 70% were semi-natural grasslands. Sheep production on the organic farms used, on average, 72 m^2 grassland per kg CW per year, of which only 7% were semi-natural. The difference in how temporary grassland versus semi-natural grassland was used in the two production forms is most likely much affected by how the agri-environmental payments are designed.

Based on the yearly use of different grassland types and the values for carbon sequestration in grasslands shown in Table 37, we calculated the potential carbon sequestration per kg CW lamb meat, see Figure 5.1. For farms from both production systems, scenario 1 (Higher) indicates a C sequestration in the grassland ecosystems corresponding to 12 kg CO_2/kg CW.[17] Using a C sink capacity according to Scenario 2 (Lower) gives a C sequestration potential corresponding to 6 kg CO_2/kg CW. This sequestration potential may be considered in relation to the average life-cycle GHG emissions (of CH_4, N_2O and fossil CO_2), calculated at 16 kg CO_2e/kg CW (see Figure 4.6).



	Average conv, n=5	Average org, n=4	Highest	Lowest
1) Higher C-seq	-11	-14	-29	-3
2) Lower C-seq	-6	-7	-15	-2

Figure 5.1. Estimated carbon sequestration in grasslands as a result of grassland use in sheep production, expressed as kg CO_2 per kg CW lamb meat. Average results for five conventional and four organic farms. The carbon sink potential is allocated between meat (62%) and hides (38%) in the same way as the environmental burdens of the sheep production. Negative values indicate a carbon uptake. Scenario 1 (Higher) and 2 (Lower) describe two alternatives for the C sequestration capacity (see Table 5.1 and text). "Highest" represents one conventional farm with a large area of semi-natural grassland used in sheep production. "Lowest" is a land-efficient conventional sheep farm with small areas of semi-natural grasslands.

One of the conventional farms in this study (not included in the conventional average in Figure 5.1) has very large extensive areas of semi-natural grassland. If we assume scenario 1 (Higher carbon sink potential, see Table 5.4) for this farm, this extensive land use means that almost 30 kg CO_2 per kg CW was sequestrated in the farm's grassland. One of the conventional farms (included in the conventional mean, called *Lowest* in Figure 5.1) has a yearly grassland use of only 19 m^2/kg CW (allocated) of which only a small share is semi-natural grassland. Assuming scenario 1 (Highest carbon sink potential) for this land implies a sequestration of only 3 kg CO_2 per kg CW on the farm. Obviously, there are large variations between sheep farms when it comes to the potential carbon sequestration in grasslands.

Sheep production in Sweden involves only small land areas for cultivation of grain and concentrate feed in relation to grassland. As an average for the conventional farms, grain and concentrates required approx. 8 m^2 per kg CW and year (allocated). Corresponding number for the organic farms was 3 m^2 per kg CW and year. Assuming that cropland producing grain and concentrate feedstuff generally is a carbon source (Schultze et al., 2009) the conventional production thus would have somewhat larger

[17] 62% allocated to meat.

emissions from this land use category. However, in comparison with the large areas of grasslands in both production systems and the grassland´s potential for carbon sequestration, the potential negative effects of the cropland are of minor importance.

5.6 Biodiversity

There are scientific problems in quantifying biodiversity. In addition, biodiversity is a local or regional environmental quality. This makes it badly fit for the LCA method, and therefore it is not included in the impact assessment of this study. However, biodiversity is a highly appreciated benefit from production of meat from grazing animals, especially when using semi-natural grasslands. When comparing LCA results on meat from different animals, one must not forget important environmental aspects not suited for the method. One way to include the benefits of biodiversity is to take into account the economic aspect of the public interest.

Biodiversity, but also an open, agricultural landscape, are public goods produced by sheep farms in addition to the material outcomes such as hides and meat. The production of public goods is encouraged economically by the Swedish state and the EU by means of agri-environmental payment schemes. Since these outcomes are specifically paid for, and important for the economy of Swedish sheep keepers as a whole, an economic allocation to public goods could be one way to quantify the benefits of biodiversity in relation to the environmental burden of the production in terms of climate change, eutrophication etc.

Based on the mean area per ewe of semi-natural grassland on the farms in the study and the current levels of agri-environmental payment for these lands (normal botanical values) in relation to the economic value of hides and meat, it was found that the support to semi-natural grasslands represent 0-62 per cent (average 19 %, leaving 50 % to meat and 31 % to hides) of the total gross income from the sheep production on the farms inventoried.[18] If agri-environmental payment to ley is also included, the allocation to public goods would range from 17 to 69 per cent (average 24 %, leaving 47 % to meat and 29 % to hides). Single farm payment is not included, because it is not considered a payment for public goods. The payments used in these calculations are the 2010 levels of support to semi-natural grasslands with normal botanical values and to ley in the south of Sweden. On a national level, the role of agri-environmental payment is probably even more important to the sheep farmer than what is shown by the calculations sketched here.

The purpose of this study was not to analyse the political instruments, and therefore the environmental burden of lamb production was allocated to the material outputs only. However, these rough calculations put the environmental benefits of the production in terms of biodiversity in economic relation to the environmental burdens of the production. It also tells us that the public payments for biodiversity and open landscape are by no means negligible as a driving force for sheep keeping in Sweden today.

[18] The economic value of hides and meat was not specifically calculated for each farm, but national mean figures were used.

5.7 Improvement potential

Since only one year is studied for this LCA, long-term management is not included, such as ewes' age at first birth and sustainable productivity over time.

The results are decided by the balance between environmental burdens from inputs and emissions from the production on the one hand and the amount of outputs such as meat and hides on the other. To improve the environmental standard of the production, both inputs, on-farm emissions and outputs have to be addressed.

Increasing outputs through reduced mortality, increased fecundity and improved productivity reduces the environmental impact for all impact categories, while actions to reduce the impact of inputs and reduce emissions from the production have more specific influence on the impact categories.

5.7.1 Reduced mortality, increased fecundity

In this study, there were large differences between farms concerning mortality and fecundity. Some of it may be explained by differences between sheep races and there are also differences between regions and years in presence of predators and disease occurrence. Nevertheless, possibilities to reduce mortality and increase fecundity should be examined when striving at lower environmental impact from Swedish lamb production. It is important that increased fecundity does not lead to higher lamb mortality or lower growth rates. Two lambs per ewe and year could be a general ambition (Allard & Wallman, 2010).

5.7.2 Productive animals

Slow-growing lambs and the keeping of more rams than necessary for covering reduces the productivity of the herd, and increases the environmental burden per kg meat produced. [19] Reducing the number of rams and choosing races with high growth rates are quite straight-forward actions that benefit the environment, but to increase the growth rate for a given race is a bit more complex. For slow-growing animals, a larger proportion of the total feed is used for maintenance (and less for growth) than for fast-growing. Slow growth also means long time with methane emissions before slaughter. To increase lamb growth, the amount and quality of feed as well as feed ingredients could be changed. When it comes to feed ingredients, the choice of ingredients should be made considering their environmental performance in relation to their effect on the growth and health of the lambs.

5.7.3 Feed

Feed is important for all impact categories studied in this report. Both home-grown feed and purchased have influence, but how much differs between impact categories.

[19] The ewes' age when first covered is not considered in the study, since it only looks upon the farms during one year. But it is still an important aspect of the productivity among the animals. Older ewes means more inputs used and more methane emissions before the ewes start to deliver lambs.

Roughage fodder
As general principles, the feed should be tasty and healthy and have a high digestibility to enhance a large consumption and a fast growth. Digestibility of roughage feed should be as high as possible, both for grazed and harvested feed. Roughage fodder with low digestibility results in larger losses of feed energy as methane. Lambs are often fed a large proportion of roughage feed (mostly through grazing), some grain and very little other concentrate. This makes the quality of the roughage even more important. To be able to optimise the feed from an environmental perspective, including growth rates, the farmer has to know the quality of the roughage, e.g. contents of energy and protein.

The quality of the grazed grasslands often falls off during late summer and early autumn. It is then hard to keep up the growth rates, and the carcass weight percentage of the live weight may be low because the rumen grows large when feed digestibility goes down. To overcome this, supplementary roughage feed could be served.

Use of manure and fertilisers
Large use of manure influences the results mainly for eutrophication and acidification, but may also lead to GHG emissions. To reduce the emissions of N and P as much as possible, it is important to apply the manure in the right time, to the right crop with the right equipment. What is right from these aspects differs between animals and between manure management systems.

Large use of fertilisers influences the use of primary energy, GHG emissions and eutrophication. Here, it is important not to apply larger amounts than necessary and to use fertilisers produced with as low N_2O emissions and energy use as possible, but also take into consideration the emissions from when applied to soil. Different types of N fertilisers differ in production techniques and in field emissions.

Concentrate feed
As mentioned above, the use of concentrates in Swedish sheep production is low. Nevertheless it is useful to choose concentrate ingredients with low environmental impacts, and avoid products with heavy environmental burdens, such as soy. Soy was included in all ready-made concentrate mixes used on the farms in this study, but the soy share varied considerably. By-products from the food industry on the other hand are often high in nutrients but low in environmental impact.

Waste and over-use of feed
Feed waste and over-use of feed were not included as separate aspects in this study, but are probably of importance for the overall contribution of feed to the environmental burden.

Grasslands
There are still large uncertainties considering the amount of carbon sequestrated per year in different types of grasslands, but it is likely that the amounts are not negligible. Semi-natural pastures and temporary grasslands are important parts of sheep production today and continued use of these grasslands is possibly favourable due to their carbon sink capacity, especially if the temporary grasslands are kept intact for a several years with high productivity and feed quality.

5.7.4 Manure management

All of the farms studied used deep beddings in the winter stable for the sheep. This system leads to large emissions of ammonia, compared to other manure management systems. Emissions of nitrous oxide and methane also occur because of the presence of both aerobe and anaerobe conditions in the bedding. Today there is no proper alternative for sheep to the deep bedding systems, from a practical and animal welfare perspective, but keeping the animals outdoors as long as possible could have a positive effect on the emissions.

5.7.5 Use of diesel and electricity

Use of diesel and electricity are important aspects of the production when it comes to primary energy use and ozone layer depletion potential. If it’s possible to shift from diesel-based solutions to equipment run by electricity, the use of primary energy would be reduced. Diesel use for field operations is highly dependent on soil type and what crop rotation is used, but also on farming practises, which is not analysed in the study.

6 List of appendices

1. Inventory form
2. Allocation calculation
3. Enteric fermentation and background data
4. Transports between farms
5. Results as tables

7 References

Allard, H.& Wallman, M. Utsläpp av växthusgaser vid produktion av lammkött. Underlag till klimatcertifiering. (Greenhouse gas emissions from production of lamb meat, in Swedish.) www.klimatmarkningen.se

Aronsson H, Stenberg M and Rydberg T. 2009. Kväve- och fosforutlakning från två växtföljder på lerjord med grön- och stubbträda. (Leakage of nitrogen and phosphorus from two crop rotations on clay soils including fallow. In Swedish.) Ekohydrologi 113. Swedish University of Agricultural Sciences (SLU). Uppsala. Sweden.

Börjesson P. 2004. Energianalys av drivmedel från spannmål och vall. (Energy analysis of transportation fuels from grain and ley crops, in Swedish). Report no 54. Department of Technology and Society. Environmental and Energy Systems Studies. Lund University. Lund. Sweden.

Cederberg, C. and Nilsson, B. 2004. Livscykelanalys (LCA) av ekologisk nötköttsproduktion i ranchdrift (Life cycle assessment (LCA) of ranch production of organic beef, in Swedish.) SIK Report no 718 2004. SIK – The Swedish Institute for Food and Biotechnology (Institutet för livsmedel och bioteknik). Göteborg. Sweden.

Defra. 2008. Comparative Life Cycle Assessment of Food Commodities Procured for UK Consumption through a Diversity of Supply Chains. Defra. UK.

Ecoinvent Centre (2007): Ecoinvent data v. 2.0. Ecoinvent Reports No. 1-25. Swiss Centre for Life Cycle Inventories. Dübendorf. Switzerland.

Flysjö A, Cederberg C and Strid I. 2008. LCA-databas för konventionella fodermedel – miljöpåverkan i samband med produktion: Version 1. (LCA database on conventional feed – environmental impacts in production: Version 1, in Swedish.) SIK-rapport nr 772 2008. SIK – The Swedish Institute for Food and Biotechnology (Institutet för livsmedel och bioteknik). Göteborg. Sweden.

Flysjö, A., Cederberg, C., Henriksson, M., Ledgard, S. (2011a), Aspects to consider for future sustainable milk production – critical choices affecting the carbon footprint of milk, Submitted paper (Journal of Cleaner Production)

Frischknecht R, Jungbluth N, et al. 2003. Implementation of Life Cycle Impact Assessment Methods. Final report ecoinvent 2000, Swiss Centre for LCI. Duebendorf, CH, www.ecoinvent.ch.

Greppa Näringen 1. Hjälpreda för beräkning av vallskörd. Praktiska råd från Greppa Näringen nr 12:1(Help for grass yield estimates. Practical advice from Focus on Nutrients, No 12:1, in Swedish.) www.greppa.nu

Guinée J, Goree M, Heijungs R, Huppes H, Kleijn R, de Koning A, van Oers L, Wegener Sleeswijk A, Suh S, Udo de Haes H, de Bruijn H, van Duin R and Huijbregts M. (2002), Handbook on Life Cycle Assessment, Operational guide to the ISO standards, Dordrecht:Kluwer Academic Publishers. Updated 2008.

M. Hauschild and Potting, J. 2003.Spatial differentiation in Life Cycle impact assessment - The EDIP2003 methodology. Institute for Product Development. Technical University of Denmark. Denmark.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4. Agriculture, Forestry and Other Land Use. Chapter 10: Emissions from livestock and manure management and Chapter 11: N_2O emissions from managed soils, and CO_2 emissions from lime and urea application http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

IPCC, 2007. Climate Change 2007 - The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press. Cambridge. United Kingdom. New York, NY. USA.

Johnsson H and Hoffman M. 1996. Normalutlakning av kväve från svensk åkermark 1985 och 1994. (Norm leakage of nitrogen from arable land in Sweden, in Swedish.) Ekohydrologi 39. Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden.

Jordbruksverket. 2008. Växtnäringsbalanser och kväveutlakning på gårdar i Greppa Näringen åren 2000-2006 (Nutrient balances and nitrogen leakage on farms in Focus on Nutrients 2000-2006). Report 2008:25. Jordbruksverket (Swedish Board of Agriculture). Jönköping. Sweden.

Jordbruksverket. 2009. Stank in Mind version 1.17. (Database and program for calculation of nitrogen losses from agriculture.) Jordbruksverket (Swedish Board of Agriculture). Jönköping. Sweden.

Jordbruksverket 2010. Inlagring av kol i betesmark. (Sequestration of carbon in grasslands, in Swedish.) Report No 2010:25. Jordbruksverket (Swedish Board of Agriculture). Jönköping. Sweden.

Jordbruksverket. 2011. Livsmedelskonsumtion och näringsinnehåll (Food consumption and nutrient contents). Statistical report No 2011:2. Jordbruksverket (Swedish Board of Agriculture). Jönköping. Sweden.

Ledgard S F, Lieffering M, McDevitt J, Boyes M and Kemp R. 2010. A Greenhouse Gas Footprint Study for Exported New Zealand Lamb. Report prepared for the Meat Industry Association, Balance Agri-Nutrients, Landcorp and MAF. AgResearch. New Zealand. www.agresearch.co.nz

Liebig M A, Gross J R, Kronberg S L, Phillips R L, Hanson J D. 2010. Grazing Managements Contributions to Net Global Warming Potential: A Long-Term Evaluation in the Northern Great Plains. J. Environ.Qual. 39:799-809.

Lindgren E. 1980. Skattning av energiförluster i metan och urin hos idisslare. En litteraturstudie. (Estimation of energy losses through methane and urine for ruminants, in Swedish.) Rapport 47. Avd. för husdjurens näringsfysiologi, Swedish University of Agricultural Sciences. Uppsala. Sweden.

Lindgren M, Pettersson O, Hansson P-A and Norén O. 2002. Jordbruks- och anläggningsmaskiners motorbelastning och avgasemissioner. (Engine load pattern and engine exhaust gas emissions from off-road vehicles and methods to reduce fuel-consumption and engine exhaust gas emissions, in Swedish). JTI – Swedish Institute of Agricultural and Environmental Engineering. Uppsala. Sweden.

Kätterer T, Andersson L, Andrén O, Persson J. 2008. Long-term impact of chronosequential land use change on soil carbon stocks on a Swedish farm. Nutr Cycl Agroecosyst 81:145-155.

Møller H and Vold M. 2008. Livsløpsvurdering av kjøttproduksjon i Norge. Versjon 2 (Life Cycle Assessment of Norwegian Meat Production, in Norwegian). Østfoldsforskning. Fredrikstad. Norge.

Naturvårdsverket. 2008. Läckage av näringsämnen från svensk åkermark (Leakage of plant nutrients from Swedish Arable Land, in Swedish). Rapport 5823. Naturvårdsverket (Swedish Environmental Protection Agency). Stockholm. Sweden.

Nätverket för transporter och miljö (NTM). 2010. (Network for transports and environment.) www.ntmcalc.se.

PRé Consultants bv. 2007. Amersfoort, Holland. www.pre.nl

Schulze E D et al. 2009. Importance of methane and nitrous oxide for Europe´s terrestrial greenhouse-gas balance. Nature GeoScience vol 2:842-850.

Soussana J F, Tallec T, Blanfort V. 2010. Mitigating the greenhouse gas balance of ruminant production systems through carbon sequestration in grasslands. Animal 4:334-350.

Spörndly R (ed) (2003). Fodertabeller för idisslare 2003 (Feed Tables for Ruminants 2003, in Swedish). Department of animal nutrition and management. Swedish University of Agricultural Sciences (SLU). Report 257. SLU. Uppsala. Sweden.

Viklund E. 2009. Lammens energibehov (Energy need of lambs, in Swedish). Nytt från institutionen för norrländs jordbruksvetenskap nr 1 2009. SLU. Umeå. Sweden.

ÅF. 1983. Energi- och miljöfakta. Energiinnehåll och densitet för bränslen. (Facts on energy and environment. Energy content and density of fuels, in Swedish). Database on the Internet, uppdated 2007-01-19. www.energiochmiljo.se.

Personal communication

Cranfield University, 2010: Dr Adrian Williams.

Lantmännen, 2010: Sven Hellberg.

Ronny Molins Transporter AB, 2010.

Scan, 2009: Elisabeth Svensson.

Scan, 2010: Elisabeth Svensson. Krister Svensson. Olof Osmark and Ola Willhammar.

Svenska foder, 2009: Camilla Knutstedt.

AB Tranås Skinnberedning, 2010.

Donnia Skinn AB, 2010.

Web pages

AB Tranås Skinnberedning. www.tranas-skinn.se

Donnia Skinn AB. www.donniaskinn.se

Jordbruksverket. www.sjv.se

Scan AB. www.scan.se

Sveriges kommuner och landsting. www.skl.se

Frågeformulär LCA lamm

Gård, brukare____

Adress____

Telefon____

1) Allmänna data om djuren

Antal installade tackor hösten 2007_________________ varav 2006 års lamm _____________

Antal slaktade lamm 2008________________________

Antal födda (inklusive dödfödda) lamm 2008________________________

Antal lamm som dött före ordinarie slakt 2008 (inklusive dödfödda) ________________________

Antal baggar 2008______________________

Antal döda vuxna djur 2008________________________

Andra djur__________________________________

Stallperiodens längd _____________________________ månader

Lammningsperiodens början ______________________ och slut ________________________

Levererade djur till liv

Djurslag	Antal	Medelvikt	Övrig kommentarer
Vuxna djur			
Lamm			

Förändrad produktion, beskriv kort om produktionen ändrats de senaste åren eller om data för 2008 är för likartad produktionsvolym som åren 2006
och 2007:

____

____

Kort beskrivning av gårdens stallar, inhysningssystem:

____

____

Kort beskrivning av foderstaten:

____

____

Kort beskrivning av utfodringssystem

____

____

2) Data om slakten

Levererad mängd kött från lamm ______________________ ton under 2008

Levererad mängd kött från får ______________________ ton under 2008

Vilket slakteri sköter slakten? ____

Bifoga gärna slaktdata från slakteriet. Om slaktdata inte kan ges, fyll i tabellen nedan.

Djurslag	Antal	Medelvikt (levandevikt)	Genomsnittlig ålder vid slakt	Övriga kommentarer
Lamm				
Tackor				
Baggar				

Vad händer med skinnet? ____

Vad händer med ullen? ____

Finns det andra biprodukter som tas om hand? ____

Tillvaratagna biprodukter

Produkt	Antal (st)/ Vikt (kg)	Förädlare	Slutprodukt
Skinn			
Ull			
Övrigt:			

Hur transporteras djuren till slakteriet (fordon och antal körningar)?

____

____

Vem sköter transporten? ____

Hur lång är transporten? ____

3) Data om grovfoder och bete

Hur mycket grovfoder äter
djuren?____

Har foderanalys gjorts? Bifoga i så fall gärna den.

Hur många vallskördar tas per år?

____

Hur lång liggtid har vallen i genomsnitt?
____

Hur hanteras ensilage (lagringssystem)?

____

____

Ts-halt i ensilage: ____

Beskriv hela maskinkedjan för ensilage fram till lager:

____

____

Används hö? Beskriv i så fall skördesystem ____

Vilka maskiner lejs in för grovfoderhantering?

____

____

Hur lång tid på säsongen betar fåren på vall på åkermark? ____________________________________

Hur stor är den betade vallarealen i genomsnitt under denna tid? _____________________________

Hur lång tid på säsongen betar fåren på naturbetesmark? _____________________________________

Hur stor är arealen naturbetesmark?____

Om naturbetesmark används, gödslas denna och i så fall med vad? ___________________________

Hur transporteras fåren till betesmarkerna?
____

Om fordon används, hur långt körs fåren?______________________ Hur många djur åt gången?
____

Transporteras vatten till betesmarkerna? _______

Hur? ____

Hur långt transporteras vattnet? ____________________________

Hur mycket vatten? ____________________________

4) Data om kraftfoder

Förbrukat kraftfoder (både inköpt och eget) på gården under 2008 (hämtas från växtnäringsbalans om sådan görs)

Fodermedel (produktnamn och leverantör/eget)	Mängd, kg	Vilka djurgrupper får fodret?	Kommentar

5) Allmänna data om växtodlingen

Gårdens åkerareal (inkl arrende)______________________________ha

Gårdens areal av naturbete (inkl arrende)______________________ha

Beskriv gårdens arrondering, ungefär hur stor andel av fälten ligger inom 2 km från

brukningscentrum:____

____

Om längre avstånd, hur långt?____________________________ För hur stor del av

marken?____

Har markkartering gjorts? Bifoga gärna en kopia i så fall. Om inte, beskriv ungefärligt fördelningen av jordarter och, i den mån det är känt, kalium- och
fosforstatus i marken:

____

____

Ungefärlig växtföljd:

____

____

När och hur sker jordbearbetning?

____

____

Grödfördelning, ungefärlig skördenivå och grödornas användning

Gröda	Areal, ha	Andel baljväxter i skörden, % i genomsnitt	Totalskörd exkl. bete, kg ts/ha	Varav hö, kg ts/ha (resten antas vara ensilage)	Använt till egna djur, kg ts	Säljs, kg ts
Vall						
Övriga grödor:						

6) Data om gödsling och kemisk bekämpning

Gödsling 2008

Gröda	Areal, ha	Stallgödsel giva, t/ha	Tidpunkt för stg-spridning (månad)	Handelsgödsel-medel	Handels-gödselgiva, kg/ha	Tidpunkt för hg-spridning (månad)	Nedbruk/myllning samt när efter spridning	Använda växtskyddsmedel (varumärke, typ)	Mängd vb alt. as (om uppgift saknas, ange l preparat)

Kommentar:

____

____

Hur bryts vallen?

____

Vid vilken tid på året sker vallbrottet?

____

Har ni djupströbädd?_________________________ Om nej, vad?____

Typ av strömedel: ____

Levereras från ____

Mängd strömedel per år: ____

Hur lagras gödseln? ____

Hur länge? ____

Uppskattning av hur mycket stallgödsel som produceras per år:

____

____

Avskiljs urin vid gödsellagringen? _____________ Är urinbehållaren täckt? _____________

Med vad? _____________________________________

Finns det aktuell stallgödselanalys? Bifoga den gärna i så fall.

Med vilken utrustning sprids stallgödseln?
____

Tillförs kalk på gården?_________ I vilken form? _____________________________
Hur ofta och hur mycket? ___________________________

7) Data om energianvändning

Årlig elförbrukning______________________________ kWh (medel 3 år)

Vad täcker denna

förbrukning:____

____

Ingår privatbostad? _____________Hur mycket energi står i så fall privatbostaden för?

____

Årlig dieselförbrukning______________________________ liter (medel 3 år)

Vad täcker denna förbrukning?

____

Ingår privat körning? __________Hur mycket diesel står i så fall denna körning för?

____

Årlig (2007) dieselförbrukning vid inköpta maskintjänster

Tjänst (t.ex. plöjning, rundbalsensilering, gödselspridning	Mängd (t.ex. ha, antal rundbalar, mängd spridd gödsel)	Kommentar (t ex beskriv att 200 ton flytgödsel har bandspridits och lång transportväg till fält)

Årlig (2007) dieselförbrukning för maskintjänster som gården har sålt

Tjänst (t.ex. plöjning, rundbalsensilering, gödselspridning	Mängd (t.ex. ha, antal rundbalar, mängd spridd gödsel)	Kommentar (t ex beskriv att 200 ton flytgödsel har bandspridits och lång transportväg till fält)

Förbrukning övrig energi (t ex olja för spannmålstork, uppvärmning)

____

____

8) Övriga data

Plast

Årlig plastanvändning för rundbalsensilering (ange som antal rundbalar och antal lager plast i balarna)

____

____

____

____

Lämnas plast till någon återvinning? ________________Hur mycket? ____________________ Var lämnas plasten?

____

Bekämpningsmedel

Har gården egen spruta? _____________ Typ av spruta: ____

Finns biobädd eller liknande (i så fall vad)?

____

Vilka grödor sprutades 2008; preparat och dos (anges även om tjänst köptes in)

Gröda	Preparat	Dos

Calculation of allocation factors for meat and hides from sheep production

Nearly all lambs and sheep in Sweden are slaughtered by Scan. Here, we have assumed that all lamb and mutton meat keeps medium quality, and that Scan's prices are valid for all slaughtered lamb and sheep. Lambs were assumed to have a carcass weight between 16.0 and 22.9 kg, and both lambs and ewes were assumed to belong to quality category O in Scan's system.

During 2009, 8 % of the slaughtered lambs were certified organic. No extra payment for organic quality was added, but the calculated total payments accords well with average payment examples for specific months (including organic lambs) given by Elisabeth Svensson (personal communication, 2010). There is no extra payment for adult organic sheep.

About 80% of the hides are sent to handicraft skin dressing, which gives a considerable income to the farmer. The remaining 20% of the hides are left to the slaughter house, either with a small payment or completely without. See Table a.

Table a. Incomes from meat and hides from sheep production for all Swedish sheep farmers during 2009, when 254 670 lambs and sheep were slaughtered in Sweden.

Farmers' total income from meat, 10^3 SEK	144 801
Farmers' total income from hides, exclusive product, 10^3 SEK	71 960
Farmers' total income from hides, industry, 10^3 SEK	15 060
Farmers' total income from hides, all, 10^3 SEK	87 020
Total income from meat and hides, 10^3 SEK	231 821

Sources: Spot prices on meat and hides (sw. "avräkningsnoteringar) from http://www.scan.se/, statistics on lamb and sheep slaughter from http://www.jordbruksverket.se/omjordbruksverket/statistik/animalieproduktion, price information on hides from http://www.tranas-skinn.se/ and http://www.donniaskinn.se/ and supplementary personal communication with AB Tranås Skinnberedning and Donnia skinn AB.

Allocation factor meat=

= total income from meat/total income from meat and hides= 144 801/231 821= 0.62

Calculations of methane emissions from enteric fermentation

Daily emissions of methane from enteric fermentation ($Meth_{EF}$) was calculated using an equation developed by Erik Lindgren (1980):

$$Meth_{EF}\text{ (kg)} = DE * mp / (100 * 55.65)$$

where
DE = digestible energy (MJ)
55.65 = constant to convert methane energy (MJ) content to methane mass (kg)
mp = percentage of DE lost as methane, calculated as

$$mp = 17.4 - 0.062 * DCE - 1.7 * L$$

where
DCE = digestibility coefficient for energy, expressed as a percentage, see Table a.

Table a. DCE estimates used in the study for different animal categories.

	DCE, digestibility coefficient of feed energy, %
indoor lambs	75
outdoor lambs	69
ewes	69
rams	69

L = feeding level (dimensionless), calculated as

$$L = (100 + \%\text{ over-feeding}) * \text{recommended energy intake} / (\text{maintenance energy requirements} * 100)$$

where
It was assumed that there was 10 % over-feeding of ewes and substitute lambs on all farms.
Recommended energy intake = metabolizable maintenance energy + metabolizable energy for growth/milk production/pregnancy, seen Table b-d.

Table b. Metabolisable energy for maintenance and growth at different weight intervals for intensively (indoor) and extensively (outdoor) bred lambs.

Weight kg	Mean metabolisable energy for maintenance, MJ/day	Mean metabolisable energy for growth, MJ/day		Total metabolisable energy, MJ/day	
	All lambs (conv. and org.)	Indoor lambs (conv)	Outdoor lambs (conv. and org.)	Indoor lambs (conv.)	Outdoor lambs (conv. and org.)
12-17	6	3	2	9	8
17-22	6	4	3	11	9
22-27	7	6	4	13	11
27-32	8	8	5	16	13
32-37	9	7	5	16	14
37-45	10	7	6	17	16

Table c. Metabolisable energy for maintenance, pregnancy and lactation for ewes in intensive and extensive production, respectively. Average live weight was 78 kg for an ewe in intensive production and 72 kg in the extensive system (when unknown, live weight was estimated at 75 kg in both systems). Over-feeding by 10% is included.

	Mean metabolisable energy for main-tenance, MJ/day	Mean metabolisable energy for lactation/ pregnancy, MJ/day		Total metabolisable energy, MJ/day	
	All ewes	Intensive	Extensive	Intensive	Extensive
Early pregnancy	11	5	5	16	15
Late pregnancy	11	10	9	21	20
At lambing and during lactation	11	21	16	32	27

Table d. Metabolisable energy for maintenance and covering for rams in both production systems. Live weight was assumed at 85 kg. Over-feeding by 10% is included.

	Mean metabolisable energy for main-tenance, MJ/day	Mean metabolisable energy for covering MJ/day	Total metabolisable energy, MJ/day
Normally	12	0	12
Covering period	12	7	19

Metabolizable energy in the feed to adult sheep was based on Spörndly (2003). Metabolizable energy in the feed to lamb was estimated from figures presented by Viklund (2009). The same level of energy intake for maintenance was assumed for all farms, but higher energy intake for growth was assumed for fast-growing lambs.

Further, the following assumptions were made, based on Spörndly (2003):

Metabolizable energy in forage	10.5 MJ/kg feed
Metabolizable energy in grain and concentrate	12 MJ/kg feed
Birth weight	4 kg
Lamb weight by weaning	12 kg
Weight at start of enteric methane emissions	12 kg
Linear growth of lambs from 4 kg to slaughter	
Share of digestible feed for lambs originating from forage	50% in indoor breeding (growth>300 g/d) 60% for outdoor breeding, up to 22 kg, then 100 %

Transports

Information on transports of inputs, animals and meat – distances and load factors/load for each transport.

Product	**Transport**	**Mode**	**Load factor/load (empty return not included)**	**Distance (one way), km**
Manure	From nearby farm to the sheep producer, empty return	Tractor with trailer	11 tons	2
Feed	From nearby farm to the sheep producer, empty return	Tractor with trailer	11 tons	2
Feed	From feed factory to the sheep producer	Lorry	70 %	150
Straw	From nearby farm to the sheep producer, empty return	Tractor with trailer	4 tons	2
Animals to slaughter	From farm to the slaughter house, empty return	Lorry, max. load 20 tons	90 %	40
Meat	Slaughter house to regional distribution center (RDC), chilled transport	Lorry, max. load 20 tons	90 %	200

Results

Results from life cycle assessment of Swedish lamb production. Average from ten farms. Functional unit: 1 kg carcass weight after transport to retail distribution centre.

	Enteric fermentation	Manure: housing and pasture	On-farm feed production	Diesel & electricity	Purchased feed	Post farm	Total, mean	Total, highest	Total, lowest
Land use, m^2			115		3		118	389	24
Primary energy use, MJ			7	16	10	5	36	58	8
Use of pesticides, g a.i.			0.11		0.40		0.52	0.87	0.24
GHG emissions, kg CO_2-e	9	2	3	1	1	0	16	26	11
Emissions of eutrophying substances, g PO_4-e	0	20	45	1	6	0.1	72	134	35
Emissions of acidiphying substances, kg SO_2-e		0.09	0.02	0.01	0.01	0.00	0.12	0.19	0.06
Photochemical ozone creation potential, g C_2H_4-e	2.5	0.03	0.01	0.04	0.05	0.01	2.6	3.7	2.0
Ozone depletion potential, mg CHC11			0.00	0.10	0.04	0.01	0.16	0.21	0.06

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