Methane emissions from Swedish sheep production

Helena Allard

Supervisors: Mie Meiner, LBT, SLU, Alnarp and Erica Lindberg, LRF

Examiner: Jan Bertilsson, HUV, SLU,

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ABSTRACT

The quantity of methane emissions from sheep depend on several factors, for example, the composition of the diet, feed quality, the age of the animals, time of the day and maybe also breed and sex. A comprising literature review was made about which factors that affect the size of emissions. In addition, a questionnaire was sent to two farms, one with a more intensive production system and another with a more extensive system. Inventories of the two farms were made; the rest of the data needed to conduct the study was taken from literature and other sources. Meat produced at the more intensive farm caused emissions of 0.4 kg of methane per kg of bone free meat and the more extensive farm caused emissions of 0.9 kg methane per kg of bone free meat. The higher emissions on the extensive farm were probably caused by the longer raising period of the lambs and the inclusion of more roughage in the diet of the ewes and lambs.

SAMMANFATTNING

Storleken på utsläppen från fårens fodersmältning beror på flera faktorer, t.ex. foderstatens sammansättning, foderkvaliteten, djurens ålder, vilken tid på dygnet det är och kanske också ras och kön. En omfattande litterstursökning om vilka faktorer som påverkar metanutsläppen från får gjordes för denna studie. Dessutom utfördes en enkätundersökning via e-post där två gårdar deltog, en med intensiv vårlammsproduktion och en med extensiv höstlammsproduktion, med de flesta data om djurproduktionen som behövdes för att räkna ut metanutsläppen per kg kött. Ett frågeformulär som skickades per e-post användes för datainsamlingen. Resterande data som behövdes för uträkningarna togs från litteratur och andra källor. Utsläppen blev 0,4 kg metan per kg benfritt kött på gården med vårlammsproduktion och 0.9 kg metan per kg benfritt kött på gården med höstlammsproduktion. De högre utsläppen från den senare gården berodde antagligen på en längre uppfödningstid av lammen och en högre andel grovfoder i tackornas fodersstater.

OBJECTIVES

The aim of this study was to investigate which factors that influence methane emissions from sheep production and to compare the size of emissions from two different common production systems in Sweden.

INTRODUCTION

Agriculture in Sweden causes 13 % of the total greenhouse gas emissions in Sweden and 8431 000 tons CO_2-equvivalents of emissions, 21 % of the emissions from agriculture come from the livestock sector (Naturvårdsverket, 2009). Methane is only one of the greenhouse gases emitted from animal production; carbon dioxide and nitrous oxide are two big contributors to climate change as well. Methane is produced through enteric fermentation and from manure. The gas is rich in combustion energy, 54.4 MJ/kg of gas. Nitrous oxide produced and emitted to the atmosphere from crop land when nitrogen is cycled is accounting for the greatest part of the emissions in agriculture (LRF, 2008). The amount emitted depends on the nitrogen content in the soil and if there is oxygen free conditions, the more oxygen that flows through the soil, the less nitrous oxide form (Greppa näringen, 2009). Carbon dioxide from organic soils and burning of fossil fuels are also big sources of greenhouse gas emissions on a farm. When manure is stored at the farm, both methane and nitrous oxide are released. Mineral fertilizer production contributes to the total emissions, but new techniques in the production have made this more environmentally friendly (LRF, 2008). The contribution of the different agricultural sectors to the total impact on climate change of agriculture can be seen in Figure 1.

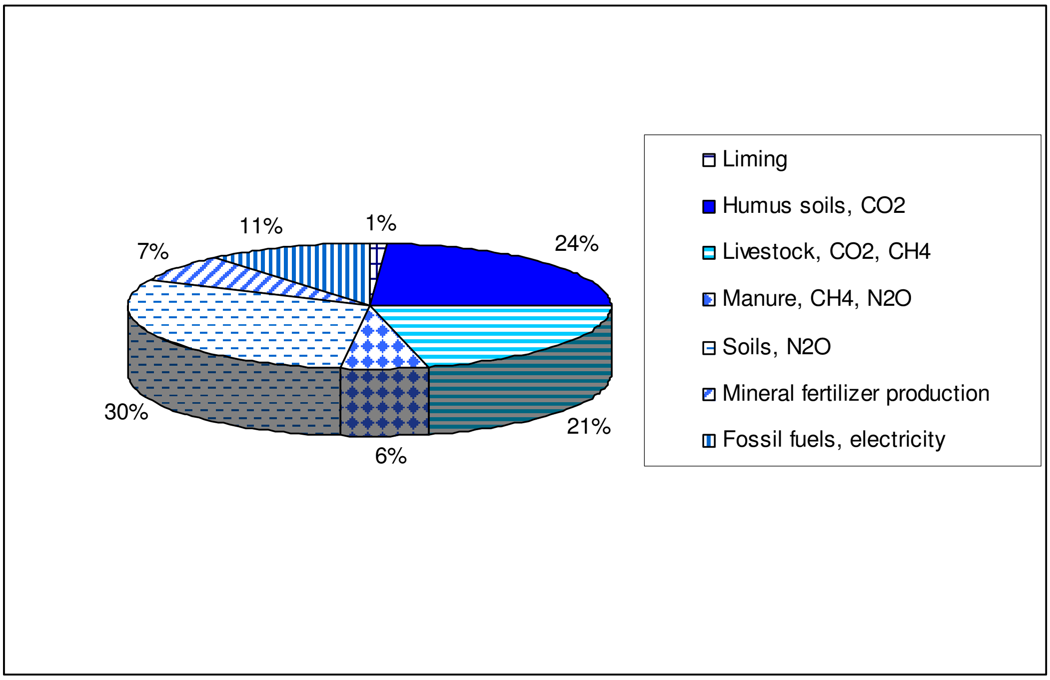

Figure 1. The contribution of different sectors to the total greenhouse gas emissions from agriculture (LRF, 2008).

Sheep are ruminants which mean that they can digest fibre which can not be utilized by monogastric animals like for example pigs or humans. Fibre is broken down to volatile fatty acids in the rumen of sheep, and these fatty acids are the primary energy source for ruminants. In the process, where these acids are produced, the greenhouse gas methane is produced. In monogastric animals, only very small amounts of methane are released from the digestion of feed (McDonald et al., 2002). Ruminants have the ability to extract nutrition from feed we can not utilize in any other way, for example grass from land with poor soils.

Meat from both chicken and pig cause less emissions of greenhouse gases than meat from ruminants per kg of meat, especially chickens are effective feed converters (Cederberg & Darelius, 2000; Cederberg & Darelius, 2001; Cederberg & Nilsson, 2004; Widheden et al., 2001) (See Figure 2 for calculated amounts of greenhouse gases emitted per kg of meat from different animals). But the feed of monogastric animals mainly consist of grain and protein sources like soya and rape seed, feed that can be used as food directly or which has to be cultivated on land suitable for food crops for human consumption. The soya used in Sweden is imported and cause great emissions in South America when forests are devastated to make room for the expanding soya fields. The crop can also be used for human consumption directly; this could be another reason to exclude it from the diets of our production animals. Grain can also be utilised as food for humans, and means a large loss in energy if it is fed to pigs and their meat is consumed by humans as food in place of the grain.

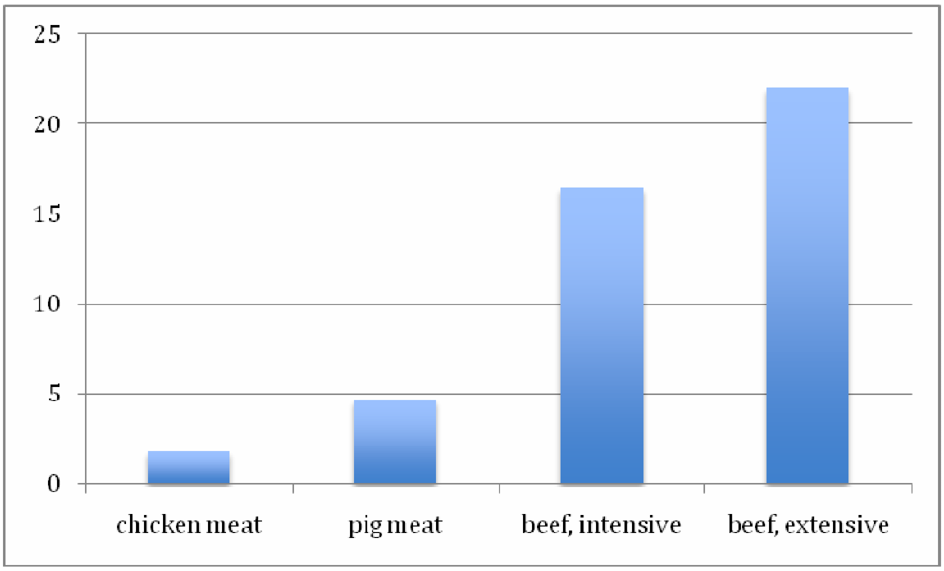

Figure 2. Kg of CO_2- equivalents emitted per kg of product, N_2O, CH_4 and CO_2 are considered. Emissions from feed production and manure handling included (Cederberg & Darelius, 2000; Cederberg & Darelius, 2001; Cederberg & Nilsson, 2004; Widheden et al., 2001).

The Swedes ate 1.0 kg of sheep meat per person in 2006, 6 000 tons were imported 2007 and the value of this was 264 million Swedish kronor and 200 tons were exported of a value of 9 million kronor. The consumption of sheep meat has increased since at least

1990 (Jordbruksverket, 2008b), see Figure 3. About 60 % of the lamb meat we eat is imported. The greatest part of it comes from New Zeeland and Ireland (Andréasson & Sundelöf, 2006). There is in other words, room for an extended Swedish sheep enterprise, the import of meat could in that case be decreased.

In year 2008, there were 251 484 ewes and rams in Sweden and 8 186 holdings with sheep. The number of animals has increased every year since at least 2005 but the number of holdings has varied, imposing that each enterprise is getting bigger (Jordbruksverket, 2008a).

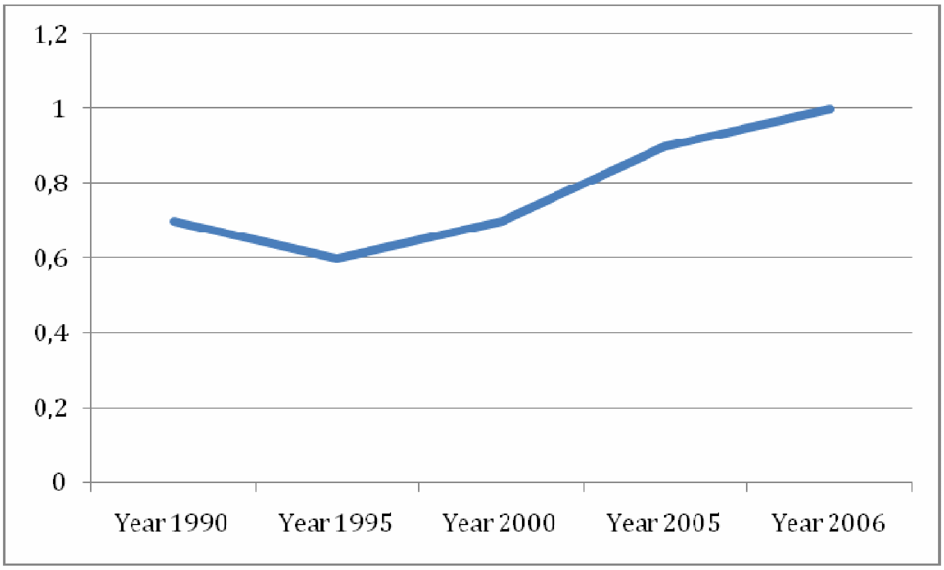

Figure 3. Kg of lamb meat consumed per person in Sweden different years (Jordbruksverket, 2008b).

Natural pastures and other grasslands are important parts of the Swedish landscape, both for the biodiversity it promotes, and for recreational causes. If the land was not grazed by ruminants, it would eventually turn into forest. A varied agricultural landscape is one of the environmental objectives adopted in 2005 by the Swedish Parliament. Having varying environments in a landscape favours biological diversity which is important for functioning eco systems and conservation of different genotypes for the future. Holdings with grazing animals are needed if we want to conserve these landscapes. Especially more extensive systems, for example sheep production systems where the lambs are slaughtered in autumn crave large areas of pastures.

The Parliament has as an objective to increase the land area used as natural pastures or meadows in Sweden by the year 2020. The biological diversity of all agricultural land should also be favoured by the right cultivation practices (Miljömål, 2009). Keeping grazing animals contributes to this objective and if the area of natural pastures is to be increased in size, the number of animals held on pasture also has to increase.

Rather new research has shown that natural pastures can be at least as effective carbon sinks as forest land, one hectare of grassland can store 0,29 ± 0,25 tons of carbon dioxide and forest can store 0,35 ± 0,26 t/ha. Some studies show that carbon accumulates in pastures 10-100 years while others claim that this the accumulation continues until the soil is being ploughed or similar (Jordbruksverket, 2008c). Therefore this carbon binding effect should be accounted for when emissions from systems with grazing animals are being analysed considering their climate impact.

There has not been any research so far about the greenhouse gas emissions from Swedish sheep production. Several different production systems with cattle have been evaluated in this aspect and also pig and chicken production systems but not a single one with sheep. When the debate about climate impact from meat started, the sheep enterprise could not give any answers about the emissions that lamb meat caused. There is therefore a great need of Life Cycle Analyses where both more intensive and extensive systems are evaluated. In year 2010, Swedish Institute for Food and Biotechnology (SIK) will publish an analysis where all emissions from a number of sheep farms are included. In this report, only the methane emissions from sheep enterprises are being estimated. This gas is probably the major contributor of the greenhouse gases in sheep production systems to climate change and therefore these emissions are important to predict.

MATERIALS AND METHODS

A questionnaire was sent to two farmers who have two different production systems. Questions about number of animals, feeding, pasture, manure handling and skin use were asked. See Appendix 1 for the questionnaire used in this study.

$$\mathbf{EF_{feed\ 1} = 17.4 - 0.062DCE - 1.70L}$$

$EF_{feed\ 1}$ = emission factor**,** percentage of digestible energy in the diet lost as methane

DCE = digestibility coefficient of energy in the feed. Can be expressed as the digestibility coefficient of organic matter minus 2 percentage points (Cederberg & Darelius, 2000).

L = feeding level expressed as a multiple of the energy required for maintenance

The amounts of feed used at the farms were divided by the number of ewes and lambs. At Farm Intensive, LammFor 300 was used only for the lambs and Unik 52 and barley only for the ewes, making it easy to calculate different energy intakes for these two categories of animals. At Farm Extensive, the feedstuff Sund Ängsull was used for both ewes and lambs, the amounts eaten by the different categories of animals were known.

The digestibility coefficients of energy in the feedstuffs LammFor 300, Sund Ängsull and Unik 52 were calculated by the percentage contents of the ingredients and their digestibility coefficients of energy, which were taken from "Fodertabeller för idisslare 2003" (Spörndly, 2003). The digestibility coefficient of the feedstuff Unik 52 was later used for all three feedstuffs, because of lacking data about the two others. But similar ingredients were used in all three, and therefore the coefficient should be somewhat similar to the one for barley.

From the metabolisable energy content, the digestible energy content of all feedstuffs could be calculated. For conversion of metabolisable energy to digestible energy for all feedstuffs except barley, the metabolisable energy was divided with 0.82 (Bertilsson, pers. message, 2009). Barley contains 15 MJ digestible energy per kg (Spörndly, 2003).

The maintenance requirement for a lamb at a weight of 30 kg is around 5 MJ a day. At farm Extensive, the lambs were on pasture and the pasture intake was therefore unknown. The lambs' energy intakes were instead estimated by using a normal growth rate for Gotlandic Pelt lambs, 250 g/day and their energy requirements at different weights to accomplish this growth. The age at slaughter was estimated to six months based on the facts given from Farm Extensive.

The ewes at Farm Intensive were on pasture six months per year and fed inside the other 6 months. For the 6 months in the barn, a common digestibility coefficient of energy was calculated for the three feedstuffs used in the diet, silage, barley and the feedstuff Unik 52. The energy intake was calculated and divided with 9.6 MJ, the maintenance requirements of a 70 kg sheep which is a normal weight for ewes. On pasture, the feeding level was set to just meet the maintenance requirements because of the lack of production at this time. The ewes at farm Extensive were grazing about 7 months per year. When on pasture, the energy intake was estimated as 28.6 MJ per day. The value was taken from Fodertabeller för idisslare 2003 for a lactating ewe with 2 lambs. During wintertime, they were fed inside and the amounts of silage and Sund Ängsull were known, making it possible to calculate true energy intakes.

The values of L and DCE for both lambs and ewes at the two farms were then used in the equation of Lindgren (1980) and the percentage of the digestible energy lost as methane was calculated.

The emissions of lambs, the number of lambs born and raised per ewe at the two farms, were added to the emissions of a ewe. This value was divided with the number of lambs and the emissions were allocated to meat, intestines and skins. Consideration was taken to a regeneration percentage of 15 % at the both farms (Sjödin et al., 2007). Then, by using the figures of the percentage of meat on a carcass and kg of meat from the lambs, the emissions of methane per kg of bone free meat could be calculated. The carcass weight was known at Farm Intensive, but at farm Extensive, a mean figure from Swedish Meats was used.

Brief descriptions of the farms

Farm Intensive

The farm is situated in Skåne, Sweden and is owned by Magnus Jönsson. Year 2008, he was breeding 132 ewes, some of them were Finnish landrace and others were “Sveafår”. The lambs slaughtered were born during 6 weeks with start during Christmas 2007 and slaughtered in the end of March- June. The lambs were not let out on pasture. The estimated mean age at slaughter was 3 months, based on the data given by the farm. A number of 1.97 lambs per ewe were born and raised. The mean carcass weight was 19.4 kg. The generation percentage was 15 %. The sheep were out on pasture from the last week in April to the last of November. From the middle of October and during the winter the ewes were fed silage, barley and Unik 52. They ate 234 kg dry matter of silage, 83.5 kg of barley and 45.5 kg of Unik 52. The lambs ate 67.2 kg of LammFor 300 each during their life time. The manure was handled as deep litter and spread on the field in autumn.

Farm Extensive

The farm is situated in Skåne, Sweden, and is owned by Annika and Mikael Pettersson. In year 2008, they had 130 ewes of the breed Gotlandic Pelt and 30 ewes of the breed “Sveafår” (a mixture of different breeds). The lambs were born in March/April and were slaughtered from September to December. The age at slaughter was estimated to 6 months based on the information given by the farm. They raised 235 lambs. Because of lack of data, the figure for lambs born was taken from Elitlamm for the breed Gotlandic Pelt and the figure for carcass weight was taken from the mean weight of lamb carcasses at Swedish Meats, 18.6 kg. The animals were held on pasture from the beginning of May until the middle of December. From the 1st of November and during the winter the sheep got silage and the concentrate mixture Sund Ängsull. Each ewe consumed about 365 kg dry matter of silage and 53.5 kg of Sund Ängsull per year. The lambs consumed about 10 kg of Sund Ängsull during their life time. The generation percentage was estimated as 15 %, as it is a normal figure in Swedish sheep production. The manure was handled as deep litter and spread on the field in autumn. See Appendices 1 and 2 for questionnaires and full info in Swedish about the farms.

RESULTS

Literature review

Methane emissions from sheep

Herbivorous animals are able to convert cellulose and hemicelluloses to energy in opposite of monogastric animals. Microorganisms in the rumen ferment the fibres and produce volatile fatty acids, which are then used as an energy source for the host animal. The volatile fatty acids produced are; propionic acid (CH_3CH_2COOH), acetic acid (CH_3COOH) and butyric acid ($CH_3CH_2CH_2COOH$). The formation of these acids either requires or produces hydrogen and this hydrogen together with carbon dioxide form the gas methane, CH_4. The production of propionic acid requires hydrogen and the formation of acetate and butyrate produces hydrogen. In a diet, rich in starch, propionic acid is largely produced and in a diet, rich in fibre, acetic acid instead is produced to a greater extent (Nicholson & Sutton, 1969). Therefore, the methane emissions differs according to the animal's diet, a diet rich in roughage gives rise to higher emissions than a diet rich in concentrates (Johnson & Johnson, 1995). The absolute main part gas produced is lost through eructation, only to a small extent it is absorbed by the blood through the ruminal wall and then exhaled via the lungs (Blaxter & Czerkawski, 1966).

Pelchen & Peters (1998) made an overview of methane emissions from sheep including 1337 observations from 89 in vivo-studies. The calculated mean methane yield of all observations was 7.22 % CH_4 of the gross energy contents; the mean values for growing sheep and adult sheep did not differ in this review. In the guidelines from IPCC (2006) for calculating methane emissions from enteric fermentation in ruminants, mean values of methane yield for both growing sheep and adults are listed. Adult sheep are said to have a loss of gross energy as methane of 6.5 % and growing sheep, 4.5 % CH_4 of the gross energy. These figures are collected from the references Lassey et al. (1997), Judd et al. (1999) and Ulyatt et al. (2002a, 2002b, 2005) also used in this literature overview. All these four studies were conducted in New Zealand and the sheep were grazing and not given any extra feed such as concentrates or silages. The studies cover a range of different types of pastures; dry ones with poor nutritive value as well as good perennial ryegrass/white clover pastures. Methane is not only just affecting the climate negatively, energy that could be retained for maintenance or growth in the animal is also lost (Czerkawski & Breckenridge, 1975).

Feeding

The type and the amounts of feedstuffs used in sheep production have big impact on methane emissions. The digestibility of feeds and the proportions of concentrates and roughage in the diet are for example important factors to consider when calculating the emissions.

Feeding practices in Sweden

The energy and protein requirement varies during different stages in the life of lambs, ewes and rams. The example in Figure 4 illustrates the nutritional need of a ewe weighing 75 kg at different stages in her pregnancy and lactation.

	Hay/silage/pasture (kg DM)	Concentrates lambs slaughtered in spring (kg)	Concentrates lambs slaughtered in autumn (kg)
Dry ewes	1		
Early pregnancy	1-1.5		
6 weeks before birth (1-2 lambs)	1.2	0.2	0.2
6 weeks before birth (3-4 lambs)	1.2	0.4	0.4
2 weeks before birth (1 lambs)	1.2	0.2	0.2
2 weeks before birth (2 lambs)		0.8	0.5
2 weeks before birth (3-4 lambs)	Free access	0.5- 1.2	0.9 or pasture
Lactation (1 lamb)	Free access	1.5	1 or pasture
Lactation (2 lambs)	Free access	2	1.5 or pasture
Lactation (>3 lambs)	Free access	2.5	2 or pasture

Figure 4. Example of diets for ewes at different production stages in life and in different production systems. The hay/silage/pasture in this example contains 10 MJ metabolisable energy and 70 g AAT The concentrate contains 11.4 MJ metabolisable energy and 100 g AAT (Fag, 2005).

The energy concentration in the total feed ration should be 11-12 MJ for a high producing ewe and at least 50 % of the total dry matter should consist of roughage for a functional rumen. In production systems where lambs are slaughtered in spring, a ewe consumes about 244 kg dry matter of silage and 79 kg dry matter of concentrates (Andréasson & Sundelöf, 2006).

Lambs slaughtered in spring are sometimes weaned abruptly at 8-10 weeks and lambs slaughtered in autumn at three months. The diet mainly consists of milk during the first weeks of life but the lambs are at this time also often fed concentrates and roughage *ad libitum* in a separate space (Fag, 2005). At the age of 5 weeks, the diets of lambs, which are raised in early spring, consist mostly of concentrates. During its life, a lamb consumes about 30 kg of concentrates and 20 kg dry matter of silage (Andréasson & Sundelöf, 2006). The energy content in the total feed ration should be 11-12 MJ/kg for growing lambs (Fag, 2005).

Lammfor 300, which is a specially formulated feed for growing lambs from Lantmännen, is a common feedstuff and contains 27.9 % barley, 18.1 % heat treated rape seed meal, 5.8 % maize meal, 5.8 % oat, 10.0 % dried distiller´s grain, 5.0 % wheat middlings, 2.0 % sugar beat molasses, 1.2 % wheat, 8.6 % sugar beet mass, 4.1 % soya meal, 6.8 % malt sprouts, 2.0 % common salt and 2.0 % calcium carbonate. Lammfor 300 has an energy content of 12.7 MJ per kg dry matter and the climate impact of the product has been calculated to 412 g CO_2-equivalents per kg (Hellberg, pers. message, 2009).

Feed formulated for growing calves is also widely used for lambs and soybean meal, betfor and grain are also fed in different combinations to lambs (Fag, 2005). A typical feed from Lantmännen, Unik 52, used for cattle consists of 25 % barley, 18 % wheat, 11 % palm kernel expeller, 10 % rape seed meal, 9 % soya bean meal, 9 % sugar beet fibre, 7 % heat treated rape seed meal, 5 % wheat bran, 2 % melass and 2 % of fats. The energy content is 14 MJ/kg. The climate impact of this product has been calculated to 550 g CO_2-equivalents per kg of matter (Flysjö et al., 2008). The climate impact of a mixed legumes and grass silage conserved in big bales has been calculated to 280 g CO_2-equivalents per kg dry matter and if the same feed is conserved as hay, the climate impact has been estimated to 250 g CO_2-equivalents (Flysjö et al., 2008). The exact contents vary between batches and of the market prices of the different feedstuff included.

Lambs slaughtered in spring grow from 300 to 600 g per day, depending on breed and feeding (Andréasson & Sundelöf, 2006). Lambs slaughtered in autumn are grazing after weaning and do not need any supplementing concentrates the first period. But as the pasture looses in nutritional value, supplementing feed as early harvested silage or concentrates can be needed. Growth rates of 250- 350 g per day are good rates for lambs slaughtered in autumn (Sjödin et al., 2007).

Viklund (2009) has made recommendations based on Swedish trials with lambs slaughtered in winter together with French nutritional recommendations for lambs. In the trials, diets consisting of large parts of roughage were given to lambs, and the energy concentration of the diets was around 11 MJ/kg. Diets with energy concentrations exceeding this can be given in less quantity. According to the author, a lamb weighing 20 kg and growing 300 g per day needs 8.5 MJ. Needs for other growth rates and weights than these can be seen in Figure 5 and eventual adjustments for these figures in Figure 6. Depending on feeding system, feed wastage of at least 5 % could be added to diets of both ewes and lambs (Viklund, 2009).

Weight Interval	Growth						
	100	150	200	250	300	350	400
12.5- 17.4	5.7	5.8	5.9	6.0	6.1		
17.5- 22.4	7.1	7.3	7.6	8.0	8.5		
22.5- 27.4	8.3	8.8	9.4	10.2	10.5	10.7	
27.5- 32.4	9.3	10.3	11.1	12.1	12.7	13.1	13.3
32.5- 37.4	10.5	11.6	12.9	14.0	14.9	15.9	16.2
37.5- 42.4	12.0	13.0	14.1	15.1	15.8		
42.5- 47.4	13.4	14.4	15.5	16.7	17.5		
47.4- 52.4	14.8	15.8	16.9	18.3	19.2		

Figure 5. Energy expressed as MJ needed per day of lambs at different weights in kg and growth rates in g (Viklund, 2009).

Gender and breed	Adjustment
Ram lambs	None
Crossings	No adjustment
Meat breeds	Plus 10 % for growth rates 100-300 g/day for weights 17.5- 22.4 kg
	Minus 5 % for growth rates 100-300 g/day for weights 22.5-52.4 kg
Ewe lambs	
Crossings	Plus 15 % for growth rates 100-300 g/day for weights 12.5- 22.4 kg
	Plus 4 % for growth rates 100-300 g/day for weights 22.5- 52.4 kg
Meat breeds	Plus 23 % for growth rates 100-350 g/day for weights 17.5- 22.4 kg
	Minus 4 % for growth rates 100-350 g/day for weights 27.5- 52.4 kg

Figure 6. Eventual adjustments to the energy needs in Figure 7. Crossings are land races X meat breeds. (Viklund, 2009).

Ratios concentrates: roughage in the diet

Digestibilities of feeds usually increase when the amount of concentrates in the diet increases (Nicholson & Sutton, 1969). As the digestibility of a feed increases, as a rule, the percentage of gross energy released as methane also increases (Lindgren, 1980). A drop in ruminal pH can also be seen and the ratio acetate: propionate is lowered. Methanogens, which are responsible for the production of methane in the rumen, are sensitive to acid environments and therefore their function is inhibited when the pH drops. This results in lower methane emissions in a diet rich in concentrates (Russell, 1998).

In a study done by Chandramoni et al. (2000), twelve sheep were divided into three groups, all receiving different ratios of concentrates and roughage in their diet. Group 1 was given 8 % concentrate and the rest roughage in their diet, group 2, 50 % concentrate and 50 % roughage and group 3 was offered 70 % concentrates and 30 % roughage. The workers could then measure that the digestibility of the feed ration given to group 1 was significantly lower than of the other diets, but the digestibility of crude fibre was higher. Methane loss as percentage of gross energy increased with increasing amounts of roughage in the diet, but more concentrate than 50 % in the diet only had a small reductive effect on the emissions. Christophersen et al. (2008) saw a decrease of 16 % in methane emissions when sheep were fed 70 % grain in their diet compared to when they were given 35 % grain.

Not all studies on sheep show decreases in methane emissions as the inclusion of concentrates in the diet increases. Moss & Givens (2002) noticed that the amount of energy lost as methane as percent of gross energy increased when the proportion of grass silage in a diet also containing soya bean meal decreased. The four diets were designed to be isoenergetic and the proportion of silage was 100 %, 75 %, 50 % and 25 %. When expressed as litre methane per day the emissions first increased and then decreased with more soy bean meal in the diet. Kelly & Thomas (1978) compared diets including different amounts of grass silage and barley. They found that a diet with 2 500 g dry matter silage and 400 g of barley resulted in methane emissions of 7.4 % of the total gross energy intake and a diet with 2500 g silage and 200 g barley caused 6.7 % CH_4 loss of the gross energy content. These results show that the methane emissions descending from a diet not always can be predicted based on the proportions of feedstuffs included.

Digestibility of feeds

Pelchen & Peters (1998) saw, when comparing 89 references from literature concerning methane emissions from sheep that an increasing intake of digestible energy, crude fibre and N-free extracts also increased the amount of CH_4 emitted. On the other hand, an increasing intake of crude protein and a higher energy density of the diet decreased the emissions. Increasing digestibilities of rations heighten the methane emissions, but at digestibilities above around 72 % the increasing effect on the emissions faded out. As the digestibility of a feed increases, the amount energy available to the animal also increases, and therefore the methane emitted per kg of production for example growth decreases. Therefore, increased digestibilities of diets often mean less methane emissions per unit of production.

Type of roughage

Legumes often give rise to increased feed intakes and they have higher digestibilities than grass. In a study where CH_4 emissions were calculated using equations but not directly measured, higher rates could be seen for grass hay than legume hay (Mirzaei-Aghsaghali et al., 2008).

Fine grinding and pelleting of roughages will speed up the passage rate through the gut, the feed will then be less digested and therefore also methane emissions decrease (Johnson & Ward, 1996).

Level of feeding

The digestibility of a feed usually decreases when the feeding level increases (Margan et al., 1982). Feeding level is defined as the amount of feed consumed, divided with the feed requirements for maintenance. In an experiment done by Nicholson & Sutton (1969) the same types of feed were fed to several sheep but in diets with varying degrees of covering the maintenance requirements. The feed was given covering 0.9, 1.7 and 2.3 of the requirements and the proportions energy lost as methane of gross energy were 10.8 %, 9.3 % and 8.2 %. Pelchen & Peters (1998) also found that higher levels of feeding decreased the percentage of gross energy lost as methane, supporting the results.

Methane production (g/day) increases but methane yield (% of gross energy) decreases with an increasing feeding level. The amount of methane increases because of the higher energy intake, but the percentage of gross energy lost as methane produced decreases, as less of the energy contained in the feed is available for digestion at high feeding levels. The percentage of energy of the total gross energy content which can be utilized by the animal decreases. Therefore the percentage energy lost as methane of the total gross energy also decreases. This change in emissions is smaller for feeds of lower quality, which have lower digestibilities (Blaxter & Clapperton, 1965).

Fat supplementation

Fat supplementation of diets suppresses methane production, both for cattle and sheep. This decrease can be attributed to that some fatty acids can provide an alternative metabolic hydrogen acceptor to reduction of CO_2 instead of CH_4. But fat can also suppress the fermentability of feeds and therefore is the methane production also suppressed (Johnson & Johnson, 1995).

Methane emissions from sheep on pasture

Emissions from grazing livestock can be hard to predict, the exact feed intake is hard to estimate and the nutritional value of the pasture differs within the season. Several studies with grazing sheep have though been conducted. Lassey et al. (1997) measured the emissions from 50 grazing sheep in New Zealand with the ERUCT technique. The pasture was a typical improved one with mostly perennial ryegrass and white clover. As seen in Figure 7, they calculated the mean value of methane emissions to 4.57 % of the total gross energy intake.

Study	Number of sheep	Pasture (DM digestibility)	CH_4 production (g/day)	CH_4 yield (%)
Lassey et al., 1997	50	Perennial ryegrass/white clover (75.3)	18.9 +/-0.8	4.57 +/-0.11
Ulyatt et al., 2002a	12	Kikuyu grass, (61.2)	15.6 +/-0.92	6.3 +/-0.36
Ulyatt et al., 2002a	12	Kikuyu grass, (64.1)	4.4 +/-0.92	1.9 +/-0.36
Judd et al., 1999	55	Ryegrass/white clover (81.2)	19.4 +/-4.2	3.6 +/-0.8
Ulyatt et al., 2005	12	Ballantrae Perennial ryegrass/browntop/white clover (79.7)	19.3 +/-5.4	4.1 +/-0.9
	12	Aorangi Perennial ryegrass/white clover (81.4)	21.9 +/-3.7	3.9 +/-0.7
	12	Poukawa Dead matter (54.0)	21.4 +/-2.0	5.3 +/-0.5
	12	Springston Browntop/cocksfoot (73.2)	35.2 +/-8.7	6.3 +/-1.2
	12	Sep perennial ryegrass/white clover (82.0)	30.6 +/-2.26	6.1 +/-0.4
Ulyatt et al., 2002b	12	Nov perennial ryegrass/white clover (75.5)	33.2 +/-2.26	6.9 +/-0.4
	12	Mar perennial ryegrass/white clover (74.5)	27.0 +/-2.26	6.1 +/-0.4
	12	Jul perennial ryegrass/white clover (82.0)	27.9 +/2.26	4.6 +/-0.4

Figure 7. Methane production and methane yield of sheep from different studies.

Ulyatt et al. (2002a) compared methane emissions from sheep and cattle grazing the same pasture in New Zealand two different years, 1997 and 1999. In 1997, the same CH_4 yield could be found for both cattle and sheep. The pasture in year 1999 had a better nutritional value compared to the one in 1997 and the emissions were lowered for both species of animals, but the reduction was clearer marked in the sheep. The authors suggested that the extra low values in 1999 could be a result of the pasture containing compounds that could inhibit methanogenic bacteria, and not only of the pasture's better quality. Kikuyu grass is a subtropical C4-plant and these often have a lower digestibility than C3-plants, resulting in higher CH_4 emissions from rumen fermentation, thereby also the lower digestibilities compared to the other pastures seen in Figure 9 (Ulyatt et al., 2002a).

Judd et al. (1999) made measurements of methane emitted from sheep grazing a pasture, which was located near the pasture Lassey et al. used in their study in 1997. They found values in the normal range for grazing sheep and the authors explained their somewhat higher values than Lassey et al. (1997) found with a greater standing dry matter on their pasture and seasonal variations.

Ulyatt et al. (2005) compared four pastures, which would represent four different seasonal variations in nutritional quality of the grasslands in New Zealand. The pasture in Ballantrae represented southern North Island summer moist hill country, the grasslands in Aorangi represented good quality perennial ryegrass/white clover dominant pasture in the locus Manawatu, the pasture in Poukawa represented severe late summer drought pasture in Hawke's Bay and the place Springston represented after drought conditions in Canterbury. Young wethers were used in all experiments except the one in Springston where mature ewes were used. The study was conducted over the years 1997-1999 and variations in the weather sometimes made the conditions somewhat unusual for the season for all cases except Poukawa, resulting in higher feeding values than normal in some cases. The mature ewes grazing in Springston had the highest emissions, which could be explained by the fact that mature sheep probably cause higher CH_4 emissions than younger sheep. But the method used for measurements was not the same as for the other sheep in the study and therefore the results should not be directly compared to each other. The higher emissions for the Poukawa sheep than the Aorangi and Ballantrae sheep could be explained by the lower digestibility of the dead matter grazed at Poukawa. The values for the Aorangi and Ballantrae sheep were similar to those found by Lassey et al. (1997).

Ulyatt et al. (2002b) studied the impact of seasonal variations on methane emissions using a perennial ryegrass/white clover pasture in New Zealand and found the highest emissions of methane from sheep grazing in November. This is in accord with the low feeding value of pastures in New Zealand at this time of the year, but the authors found no explanation to the low values in July. They concluded that seasonal variation in the chemical composition of pastures had little importance in this study for the rate of methane emitted. They could also see that cows and sheep had about the same efficiency of utilizing the feed. They saw that the emissions from grazing dairy cows and grazing ewes were about the same expressed in g CH_4/kg digestible dry matter intake with values of 26.6 and 25.2 for cows and sheep respectively.

Murray et al. (2001) could see that sheep grazing on a pasture with both clover and perennial ryegrass had significantly higher emissions of methane, than sheep grazing only grass which received fertilizer. But as the digestibilities of the feeds were not included in the calculations this could mean that per unit of production such as growth or lactation, the emissions measured from the sheep grazing clover could be of another value. Clover pastures often have better digestibilities than grass pastures (Spörndly, 2003). Therefore the total amount methane emitted may be higher for a certain intake of gross energy but not of digestible energy intake.

Age differences

In newborn lambs, the size of rumen is small in relation to the abomasum, but it soon starts to develop in to a functional fermentation chamber as the lamb starts to eat solid feed (Oh et al., 1972). Ruminal development consists of changes in mass, volume, surface area, establishment of a microbial flora and papillary development. The rumen epithelium in a newborn ruminant is smooth with no prominent papillae (Gilliland et al., 1962). The main function of rumen papillae is to enlarge the absorptive surface for volatile fatty acids of the rumen wall (Soveri & Nieminen, 2007). Volatile fatty acids become the main source of energy instead of fats and sugars when the diet later on changes from milk to solid feeds (Hamada et al., 1976). Several bacterial species colonise the rumen immediately after birth and they prepare a biotope which is suite to ferment lignocellulosic feeds (Fonty et al., 1991).

As long as the diet only consists of milk, the feed shunts directly to the abomasum without passing the rumen and consequently no development of the rumen occurs (Baldwin, 2000). In studies where milk has been administered in to the rumen, tissue growth has been seen to be stimulated (Tamate et al., 1962). In a trial, calves were fed a diet consisting of either, just milk, hay or grain, or a diet with hay and grain together. The four different stomach compartments of the milk fed calves did not increase in size in proportion to other organs, but only grew in relation to the increased body size. The animals receiving hay had the greatest rumen capacity; this effect was probably due to the greater bulk of hay (Warner et al., 1956). Non fermenting substances such as wood shavings have also been seen to have this effect on rumen muscular growth (Tamate et al., 1962). Grain showed to be as effective as hay for tissue growth and forestomach papillae development (Warner et al., 1956).

Papillae development has been seen in several studies to be stimulated to a greater extent by a diet consisting of concentrates than one with roughage. Volatile fatty acids are released faster from diets containing more easily fermentable carbohydrates such as concentrates and the presence of these acids is an important factor for the papillae development (Stobo et al., 1966; Gilliland et al., 1962) and mucosal growth (Hamada et al., 1975), especially the volatile fatty acids butyrate and propionate (Stobo et al., 1965; Gilliland et al., 1962). Rumen papillae have been seen to almost disappear when calves change from a diet of roughage and concentrates to one with only milk (Stobo et al., 1965).

Lambs have been seen to crave roughage as soon as the rumen starts to develop and lambs without access to silage or hay can even start to eat from the bedding material (Poe et al., 1971). Coarse material has shown not to be the main contributor to rumen development; calves just fed grain also have an extensive development. Considering that grain contains about 7 % of the crude fibre of that in roughage, another explanation than the introduction of coarse material is needed for the development of the forestomach. All feed passing the rumen is attacked by microorganisms, resulting in release of different chemical compounds which could be the main contributors (Warner et al., 2002).

The tissue weight of the ruminoreticulum increases in proportion of the total tissue weight of the stomach from 31 % at birth to 75 % at 8 weeks of age. In calves, the rumen has reached its final size and position by the age of 8-9 months, but already at 3 months of age the rumen is almost the same size as in adults (Warner et al., 2002).

In 8 and 10 week old lambs, most of the fermentation occurs in the rumen. In 3 weeks old lambs the concentration of volatile fatty acids is higher in the colon than in the rumen, but at 4 weeks of age the ruminal concentrations of the fatty acids are higher. The concentration of volatile fatty acids in the rumen in calves has been found to reach adult levels at 6 weeks of age in animals fed a high-roughage diet and at 7-8 weeks for a high-concentrate diet (Stobo et al., 1965). The presence of these acids implies that fermentation of cellulose rich material occurs.

At 21 weeks of age, lambs are considered to have the same ability to digest components in feeds as adult animals. Three phases can be distinguished in the development of the ruminal fermentation in sheep; nonruminant from birth to 3 weeks, transition state from 3 weeks to 8 weeks and ruminant from 8 weeks (Oh et al., 1972). Calves have not been successfully weaned before the age of 3 weeks; it seems therefore to be a critical age-period for a great intake of solid food. Probably there is a critical age limit for lambs as well (Hamada et al., 1975).

The mother ewe and type of feed are large contributors to the type of composition of the ruminal flora in young ruminants. Maybe genotype and other environmental factors also take part in the process (Yañez-Ruiz et al., 2008). Methanogens in the rumen become present 3-4 days after birth in lambs (Fonty et al., 1987). The population of cellulose-splitting microorganisms in the rumen of calves have reached adult proportions by the age of about 9 weeks (Stobo et al., 1965).

Faichney et al. (1999) had 12 lambs isolated from two days of age to see if the isolation could suppress the colonization of methanogens in the ruminal flora. The lambs were divided into two groups, the animals in the first group were given ruminal fluid obtained from a grown sheep and the second group did not receive any ruminal fluid. After 6-10 weeks, samples of their ruminal fluids were taken and the first group had a normal ruminal flora but the fluid from the second group contained virtually no protozoa and a uniform bacterial population. The second group lost less energy as methane expressed as % of gross energy but the digestibility of energy was also less. However, the lower amounts of energy lost as methane could compensate for the lower digestibility.

In an experiment done by Yañez-Ruiz et al. (2008) the effect of diet on the composition of the bacterial population in newborn lambs was investigated. Lambs were divided into two groups, each with 20 lambs. They were fed either hay, or hay and concentrate together. The group fed only hay emitted more methane per kg dry matter than the group fed hay and concentrates, the rumens of the hay fed animals also contained more methanogens in total numbers. However, this difference seemed to disappear when the lambs later were held together and fed the same feed. This shows that the ruminal flora not definitely form when the animal is newborn.

Graham (1980) found that the digestibility of feeds and efficiency of feed utilization increased with age in growing lambs. Weston & Morgan (1979) also saw that some values of parameters in feed utilization changed with age. Lambs at 15, 24 and 40 weeks of age were fed dried clover and then various digestibility parameters were measured. The digestibility of crude protein increased by 10 % from the age of 15 weeks to 40 weeks but the digestibility of organic matter and cell wall constituents decreased by 1.8 %. No change in the rate of production of volatile fatty acids per unit of feed intake or rate of absorption of volatile fatty acids could be seen. Neither any change in rate of flow of digested food through the stomach could be seen. Rates of methane emissions were not measured.

In the New Zealand inventory, sheep younger than one year are considered to have 14- 28 % less gross energy loss as methane than sheep older than one year (New Zealand national inventory, 2007). In the IPCC guidelines for national greenhouse gas inventories, sheep younger than one year are considered to have a 4.5 % ± 1.0 loss of gross energy as methane and sheep older than one year to have 6.5 % ± 1.0 loss. Lambs consuming only milk are not considered to be responsible for any emissions (IPCC, 2006).

Knight et al. (2008) measured the methane emitted from lambs at the ages of 13, 17, 25 and 35 weeks. They compared this with emissions from adult sheep, all of the animals were fed fresh pasture. They found a bit lower emissions from lambs aged 13, 17 and 35 weeks than adults, but the difference was too small to be significant. In another study, Swainson et al. (2008) found lower methane yields from grazing red deer stags younger than one year than adult deer. In a study with Simmental and Angus calves methane emissions were measured at 1, 4, 7 and 10 months. The emissions per kg body weight gain did not change with age (Estermann et al., 2002).

Diurnal fluctuations

There are diurnal fluctuations in the rates of methane emissions by sheep. The production of methane tends to follow feeding patterns and the production usually peaks when a period of ruminating starts (Lockyer, 1997; Lockyer & Champion, 2001; Clapperton & Czerkawski, 1969). The emissions are at a maximum when the rumen is filled to a maximum and the emissions continue as long as there is fibrous material left in the rumen (Lockyer & Champion, 2001).

Sheep graze mostly during daylight and eating activity peaks early in the morning and four hours before sunset (Penning et al., 1991). In a study from Lockyer & Champion (2001), methane emissions from sheep were measured to see how grazing behaviour affected the rates of emissions. They could clearly see that the times of ruminating were accompanied by the highest amounts of methane emitted. The emissions increased during the day to reach a peak at sunset. There was a clearly linear correlation between eating and ruminating time and methane emissions. The frequency of eating behaviour could explain 12.4 % of the diurnal variations in the emissions. Lockyer (1997) could also see a diurnal pattern of methane emissions with the rates increasing during the day with a peak around sunset and then decreasing thereafter, reaching a minimum at dawn.

Judd et al. (1999) measured that the highest amounts of methane were emitted in the early hours of morning and in the afternoon. This corresponded well with the sheep's eating behaviour; they grazed most during the 3 hours after sunrise (6.30 a.m. to 9.30 a.m.) and 3 hours before sunset (2.30 p.m. to 5.30 p.m.). The authors stressed that the fluxes in emissions also could be a result of meteorological conditions, together with the behaviour of the sheep. In another study by Murray et al. (2001) strong diurnal patterns also could be seen. Peak emissions occurred between 3 p.m. and 5 p.m. and then they gradually fell until 8 a.m. when they started to rise again.

Differences between sexes

Knight et al. (2008) saw that male lambs produced 8 % more methane per kg of dry matter than female lambs, despite the fact that their live weight and dry matter intake were about the same. The authors stressed that no conclusions about this matter could be drawn from these findings, especially when no other studies before this could show such differences. They suggested that hormones maybe could influence the microbial fermentation, but also that further studies had to be made to be able to say if sex could have an impact on methane emissions.

Machmüller & Clark (2006) found that emissions from male and female sheep were best predicted by different measures for each sex. The emissions from female sheep could be best predicted by neutral detergent fibre intake, estimated dry matter intake and the emissions from male sheep depended mostly on the same two factors but also metabolic live weight.

Breeds and eventual breed differences

Swedish sheep are divided into three breed groups; pelt sheep, land races and meat breeds. The Gotlandic pelt, which is a pelt sheep, is the most common breed. Finnish land race, Texel is a common breed in Sweden as well. Dorset and Finnish land race are easier to get in heat earlier months than October, which is when the natural mating season starts. Therefore ewes of these breeds are common in production systems where the lambs are slaughtered in spring. Often they are mated with rams of heavier meat breeds such as Texel, Oxford Down, East Friesian dairy sheep or Suffolk to get faster growing lambs with a better body confirmation. The Gotlandic pelt sheep is instead a common breed in production systems where the lambs grow slower and often are slaughtered in autumn (Fag, 2005). Weights and growth rates for different breeds can be seen in Figure 8.

Breed of ewe	60 days	Growth	110 days	Growth
Dorset Horn X Finnish landrace	21.2	0.3	34.9	0.28
Suffolk	20.3	0.25	32.1	0.21
Texel	22.8	0.3	37	0.26
Texel-Finnish landrace	20.8	0.27	33.5	0.25
Finnish landrace	18.3	0.25	30.3	0.21
Gotlandic Pelt	19.4	0.25	31.4	0.2
All	20.1	0.27	32.9	0.23

Figure 8. Weights and daily growth rates of different sheep breeds in kg (Elitlamm, 2009).

Margan et al. (1982) found small differences in rumen mean retention times, rumen digested feed content and organic matter and fibre digestion between lambs of the breeds Dorset Horn and Corriedale with higher values for the Dorset Horn lambs. These parameters could affect the size of methane emissions from the different breeds. The authors clearly stated that further trials concerning breed differences had to be made to enable conclusions about the subject. No studies concerning differences in emissions of Swedish sheep breeds have been done.

Number of lambs per ewe

The more lambs born and raised per ewe, the less methane is produced per lamb by the ewe. Therefore, the number of lambs per ewe is an important factor to consider when calculating emissions from sheep farms. In Sweden, breed differences in this aspect exist, but this alone should not be the reason for choosing a specific breed in a herd, the type of breed should instead primarily be adapted to the production system used. See Figure 9 for the number of lambs born and raised per ewe depending on the breed.

	Dorset Horn-Finnish landrace	Shropshire	Suffolk	Texel	Finnish landrace	Gotlandic Pelt	All
Number of ewes	1636	114	384	2778	5983	17576	48102
Lambs born	3230	185	621	4290	13692	31450	88133
Born per ewe	1.97	1.62	1.62	1.54	2.29	1.79	1.83
Raised per ewe (Percentage raised of all born)	1.84 (93 %)	1.56 (96 %)	1.48 (92 %)	1.42 (92 %)	2.03 (88 %)	1.68 (94 %)	1.69 (92 %)

Figure 9. Number of lambs born and raised per ewe of different breeds (Elitlamm, 2009).

Individual differences in the size of emissions

Differences in methane emissions between individual sheep exist. These differences are often results of differing genotypes. Pinares-Patiño et al. (2003a) concluded that animal factors such as rumen outflow rate and the pool size of organic matter in the rumen had a big impact on the amount of feed needed for maintenance. The variation between sheep accounted for, in their study, 70 % of the variation in CH_4 production (g/day) and 62 % of the CH_4 yield (% of gross energy). The differences in methane yield were best explained by rumen fractional outflow, organic matter intake and the molar % of butyrate in the rumen. The variation in methane production was best explained by rumen organic matter pool and the molar % of butyrate. If the rumen organic matter pool is big, it enables the feed to be retained in the rumen for a longer time, allowing it to be fermented to a greater extent. More methane is therefore being produced. A high rumen fractional outflow shortens the time the feed is exposed to microbial fermentation and as a consequence, less methane is produced. Acetate and butyrate formation are the major sources of H_2 for use in methanogenesis, making the concentration of butyrate an important factor. All these parameters mentioned here often differ between individual animals and therefore cause individual differences in methane emissions.

In a study done by Lassey et al. (1997), differences in methane production and yield were found which could not be explained by feed or any other environmental factor. Eight sheep of the total herd of 50 animals were identified as low or high emitters by measuring their methane emissions, four in each category. The both groups had similar feed intakes but emitted 16.0 ± 0.7 g and 22.5 ± 0.6 g CH_4 respectively; the authors could not explain this difference.

Pinares-Patiño et al. (2003a) found that CH_4 production was positively correlated to organic matter intake, organic matter pool size in the rumen and to what extent rumen was filled. CH_4 yield was negatively correlated to particular rumen fractional outflow and buffering capacity of rumen fluid. The methane yield was positively related to apparent mean retention times in the rumen and the digestibility of cellulose (cellulose is the most methanogenic carbohydrate).

In a study where the persistence of variation of methane emissions between sheep was measured, the four low-emitters and four high-emitters chosen kept their rankings throughout the experiment. The sheep were grazing perennial ryegrass and white clover pasture in New Zealand under generous herbage allowances. The mean values of methane yield and methane production were 3.75 % and 28.8 g for the low-emitters and 5.15 % and 35.5 g for the high emitters. During the experimental period, the low-emitters gained more live weight than the high-emitters, suggesting that the low-emitters retained a greater portion of the gross energy as body energy (Pinares- Patiño et al., 2003b).

Judd et al. (1999) also found a high inter-animal variability in CH_4 emissions in their experiment with sheep grazing abundant pasture. The rates were consistent from individual animals over time.

Methane measurement techniques

There are several methods for measuring methane emissions from ruminants. The ERUCT technique is a rather new one and is widely used in experiments conducted today. A permeation tube containing the gas sulfur hexafluoride (SF_6) is placed in the animal's rumen some days before an experimental period starts. The animal wears an evacuated canister around the neck, and through a tubing system the air from around the nasal cavity is collected. The air collected is from breathing of the animal, eructation and from the surroundings. Small known amounts of SF_6 are continuously released from the permeation tube, the ratio of SF_6 and CH_4 can then be seen and the amount of eructed CH_4 is calculated using equations. The background emissions of methane are also recorded using a separate canister, and can then be withdrawn from the calculated emissions from the animal (McGinn et al., 2006).

Using a respiration chamber to collect gas is another way of calculating the total emissions of methane from an animal. The animal is confined in the chamber with controlled airflows and the contents of air going in and out are registered. The amounts of methane going in can then be subtracted from the amounts going out of the chamber and the total emissions from the animal can be calculated (McGinn et al., 2006).

Emissions measured from grazing animals can also be calculated using a rather simple method where a plastic tunnel is placed over a confined area of a pasture where sheep are grazing. Air is blown through the tunnel and the concentrations of methane in in-going and out-going air are recorded. The tunnel can easily be removed and placed over other patches of pastures (Murray et al., 1999).

Judd et al. (1999) compared emission rates from sheep using both the ERUCT technique and micrometeorlogical measurements. When using the ERUCT method, the mean value was 39.0± 9.6 mg per day and m^2 and when using micrometeorlogical methods, the median and mean value were 41 and 46 mg per day and m^2. All these values were satisfyingly consistent with each other. Leuning et al. (1999) also compared the ERUCT technique and meteorlogical methods and got values of 11.7 ± 2.5 g and 13.0 g methane per day respectively, the both values highly comparable with each other.

Blümmel et al. (2005) found that emissions from sheep measured in open-circuit respiration chambers corresponded well with values calculated from a simple in vitro gas procedure, where the CH_4 emissions from the substrate fed can be measured.

Pinares-Patiño et al. (2008) compared the ERUCT technique with calorimetry measurements, using sheep, and found non-significant differences between the two methods in one trial and significant differences in another. But they suggested that the differences were probably a result of mishandling the equipment used in the study. The results, the authors said, supports earlier results comparing the same methods but with cattle, concluding that the both methods are accurate and only small differences in rates exist.

Murray et al. (1999) made measurements of methane emissions from sheep using both a respiration chamber and a polytunnel system. They found that animals in the polytunnel system produced consistently lower values than the ones in the respiration chamber. Recovery tests showed that the both systems showed correct amounts of methane released. The workers suggested that ambient temperatures and differing animal behaviour and not the equipment caused the differences in emissions. The results were in line with other previous studies showing that emissions from polytunnel systems often were lower than from respiration chambers. Respiration chambers could be suitable for measuring emissions from housed animals and polytunnel systems for animals that are mostly out-doors.

Methane emissions from cattle

According to IPCC:s guidelines for enteric methane emissions, all cattle except them raised in feed-lots, loose 6.5 +/- 1.0 % of the gross energy in their feed as methane. Johnson & Johnson (1995) saw methane yields that varied from 3.5 % to 6.5 %, depending on the type of feeding. Crutzen et al. (1986) found that methane losses from range cows were 7.5 % of gross energy intake and in another study; Gibbs and Johnson (1994) got the value 6.0 % of the gross energy lost as CH_4 for the same category of cattle. Johnson and Ward (1996) mentioned the value 6.0 % CH_4 of the gross energy for all categories of cattle except calves in Western Europe. Johnson et al. (1993) wrote that concerning cattle, energy lost as methane in percentage of gross energy, could vary from 2 to 12 %, depending on various circumstances.

As with sheep, when the daily feed intake of cattle increases the percentage gross energy lost as methane decreases. Diets which are rich in grains lower methane emissions. In U.S. feedlots where cattle are fed at least 90 % concentrates in their diets, losses are about 2 % to 3 % of gross energy (Johnson & Johnson, 1995). Kirkpatrick et al. (1997) compared three different diets; one with highly digestible silage, another with silage with low digestibility supplemented with some concentrates and a third with highly digestible silage and concentrates. These diets were fed at two levels of energy intake; concentrates was added to all diets to accomplish the higher energy contents. The third diet with good silage and concentrates caused the lowest emissions for both feeding levels; the other two were not differing from each other in this matter. Ellis et al. (2007) found in a review of various studies that the amount neutral detergent fibre eaten by beef cattle per day was the best single predictor of methane production.

Mean annual emissions per head of cattle in Germany have been calculated to 52 kg CH_4 for the age group 6-12 months and 60 kg for the age group 12-24 months (Flessa et al., 2002).

Cederberg & Darelius (2000) and Cederberg & Nilsson (2004) have made Life Cycle Analyses of Swedish beef cattle production systems and have found values of 16-22 kg CO_2-eqvivualents per kg of bone free meat. The higher values are for more extensive systems where the mother animals are used only for raising the calves and not for milk production, similar to extensive sheep production. Methane accounted for about 13 kg of the 20 kg of CO_2-eqvivalents per kg of meat in one of the extensive systems (Cederberg & Nilsson, 2004) and 16 kg of a total of 22 kg CO_2-eqvivalents in the other (Cederberg & Darelius, 2000). About 9 kg of 16 kg CO_2-eqvivalents per kg of meat originated from methane in an intensive system under study (Cederberg & Nilsson, 2004).

Blaxter & Clapperton (1965) stated that cattle and sheep given seven different diets had no significant differences in emissions of methane.

Estimation of methane emissions from enteric fermentation

Lindgren (1980) estimated the energy loss as methane in diets of sheep as the result of the equation:

$$\mathbf{EF_{feed\ 1} = 17.4 - 0.062DCE - 1.70L}$$

$EF_{feed\ 1}$ = emission factor**,** percentage of digestible energy in the diet lost as methane

DCE = digestibility coefficient of energy in the feed. It can also be expressed as the digestibility coefficient of organic matter minus 2 percentage points (Cederberg & Darelius, 2000)

L = feeding level expressed as a multiple of the energy required for maintenance

In diets consisting only of roughage and fed at maintenance level, the value 11.3 % of gross energy lost as methane can be used. But at any other feeding level above that, the equation above should be used. The equation is based on 2 500 measurements of methane emissions from both sheep and cattle in several countries (Lindgren, 1980).

IPCC have different guidelines for calculating methane emissions from sheep depending on the information available. Tier 1 is the simplest method, using a standard amount of methane emitted per animal, the value is depending on if it is a developed or developing country. The figure for developing countries is 5 kg CH_4 per head and year for a 45 kg sheep and the figure for developed countries is 8 kg CH_4 per head and year for a 65 kg sheep. These figures are also recommended by the Swedish Environmental Protection Agency (Naturvårdsverket, 2002) to be used in national emission inventories. The Tier 2 method can be used when more information about feed and animals are available. For the Tier 2 method is an equation used, which can be seen right below and which includes a methane conversion factor and the gross energy intake of the animal it concerns. The methane conversion factor used in the equation is only based on data from grazing sheep in New Zealand. The fact that the composition of diets differs in sheep production all over the world is not therefore not fully considered when calculating the emissions. The equation estimates the amount of methane emitted per head and year.

$$\mathbf{EF_{feed\ 2} = (GE * (Y_m/100) *365)/55.65}$$

$EF_{feed\ 2}$ = emission factor, kg of methane emitted per head and year

Y_m = methane conversion factor, set to 4.5 +/- 1.0% of the gross energy lost as CH_4 for lambs under 1 year of age and 6.5 +/- 1% of the gross energy lost as CH_4 for older sheep. The lower value is used when the feed is of poor quality and the high value is used for highly metabolisable feeds. For most feeds, though, the median value can be used

GE = gross energy intake of the animal. Can be calculated by either measuring the amounts of feed consumed by the animal and the energy content of the feed ration or by growth and other performance such as producing milk and wool

In Tier 2, lowered feed digestibilities because of higher feeding levels are not considered. No concerns are paid to genotype or breed variations, or diet chemical composition. Nor the impact of heat or cold stress on maintenance requirements is considered. Neither, variation in ruminal microbial population or particle passage and digestion kinetics. Both Tier 1 and Tier 2 are suitable for calculating emissions from sheep according to the IPCC (IPCC, 2006).

Blaxter & Clapperton made an equation in year 1965 based on several experiments with both sheep and cattle. The percentage energy emitted as methane from an animal depends in this case on the digestibility of a feedstuff and the level of feeding.

$$\mathbf{EF_{feed\ 3} = 1.30 + 0.112D - L\ (2.37 - 0.050D)}$$

$EF_{feed\ 3}$= emission factor, percentage of energy in the diet emitted as methane

D = digestibility of feed

L = level of feeding expressed as a multiple of maintenance requirements

Methane emissions from manure storage

Animal manure is an important source of greenhouse gas emissions, where CH_4 is of big importance. The amount of gas produced depends on many factors, such as animal species, diet, temperature at storage, the solidity of wastes, storage duration, bedding content, water content and if a natural cover or crust can be formed on the manure during storage (Massé et al., 2008). Liquid manure gives greater emissions than solid manure. Methanogenesis in manure is inhibited by low moisture content and oxygen availability (Loyon et al., 2008; Dinuccio et al., 2008). When manure is deposited on rangelands or mixed with bedding material and such, less methane is formed (IPCC, 2006). Pig slurry has a greater biodegradability than cattle manure and therefore gives rise to higher emissions (Van der Meer, 2008). Loyon et al. (2008) also found that pig slurry gave rise to higher emissions than cattle slurry, both in summer and winter temperatures. Globally, pig manure stands for 38 % of the total methane emissions coming from manure from all domestic animals (Johnson & Ward, 1996) Sheep wastes has been found to be a larger source of methane emissions than cattle waste. Jain et al. (1981) found that cellulose in sheep manure was more easily degradable than cellulose in cattle waste and per kg of manure 45.2 and 28.0 litres of gas were produced respectively. In a study by Massé et al. (2008), dairy cows were given two different diets, one with a low energy concentration containing large amounts of dry hay and another with a higher energy concentration. The amounts of methane emitted from the manure in both summer- and winter temperatures were measured and compared. The methane emitted from the manure of the cows fed the diet containing hay was only 3 % at 10 °C and 54 % at 20 °C of the gas emitted from other manure of the cows fed the energy-rich diet.

The Swedish Environmental Protection Agency, Naturvårdsverket, states that information of methane emissions from manure in conditions seen in Sweden is lacking. Therefore exact predictions of emissions are impossible to make.

Slaughter

An effective production with a maximal number of kg meat produced per kg of feed lowers the emissions of greenhouse gases from farms. With an optimal age at slaughter and good carcass characteristics, this can be achieved.

In a study concerning several hundreds of farms in Sweden, the median age of lambs slaughtered in autumn was 181 days and lambs slaughtered in summer had a mean living length of 172 days. Animals slaughtered in winter and spring lived 221 days and 129 days, respectively (Elitlamm, 2009), see Figure 10.

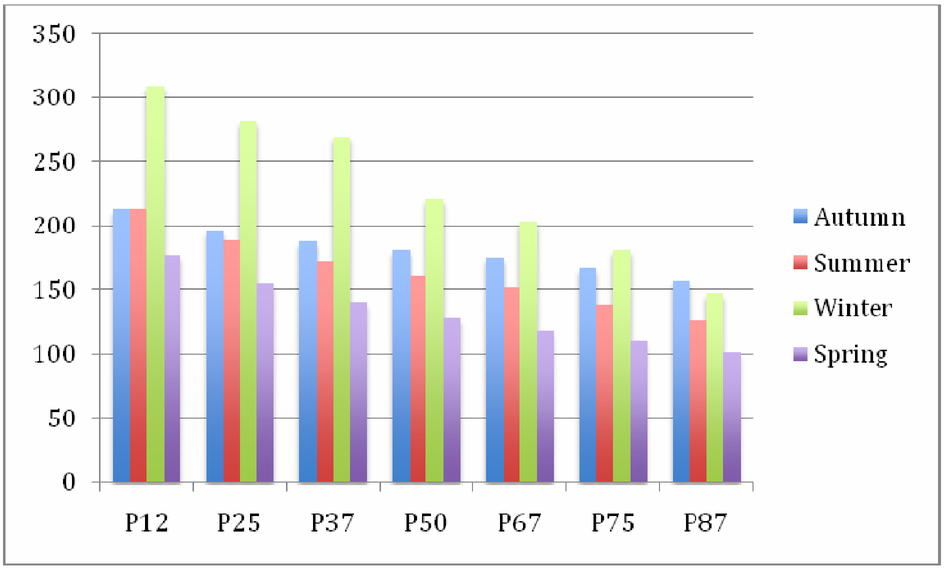

Figure 10. Age in days of lambs at slaughter in different production systems. Elitlamm, 2009.

Lambs slaughtered at Swedish Meats had, in the beginning of 2009, a mean carcass weight of 18.6 kg and are rated as R- as a mean in the EUROP scale and as 2+ in fat (Svensson, pers. message, 2009). The EUROP scale is used in the EU as a way of judging carcasses. E means extremely swelling muscles and animals rated as P has very little musculature. The fat scale ranges from 1 up to 5 where 1 is hardly no fat on the carcass and 5 is a thick layer of fat covering the body. There are also + and – for each class, making 15 different grades available to use. The mean figure R- for lambs at Swedish Meats means swelling, well developed muscles in the EUROP scale and 2+ in the fat scale means small to average amounts of fat (Svensson, pers. message 2009). High fat contents can cause severe economical losses for the farmer. A lamb which is slaughtered in spring with a value of 4– can give 45 % less income than if the fat content is at an optimum of the carcass when it is delivered to the slaughter house (Andréasson & Sundelöf, 2006).

The slaughter ratio for lambs slaughtered in December-April is 40-42 %, for lambs slaughtered in April-June it is 45-50 % and for lambs slaughtered in June-November it is 38-40 % of (Svensson, pers. message, 2009). The higher value of lambs slaughtered in December- April is a result of the lambs being younger at slaughter. The rumens are then not fully developed and therefore the intestines uptake a smaller part of the whole body (Andréasson & Sundelöf, 2006). In general, carcasses from female lambs have around 2 % more meat than them from male lambs. A percentage of 85.6 of a carcass of a lamb is meat, the rest is fat and bones (Svensson, pers. message 2009).

Lambs that have better scores in the EUROP scale and fat-scale also often have a higher percentage of meat on their bodies. Heavy meat breeds have around 1 to 1.5 % more meat than lighter breeds as Gotlandic pelt sheep if they are slaughtered at the best time.

The economic value for the intestines collected at the slaughterhouse is accounting for 2 % of the whole economic value of the carcass (Svensson, pers. message, 2009). In earlier studies concerning cattle, the economic value for intestines and hides have been set to 10 % of the whole carcass (Cederberg & Darelius, 2000; Cederberg & Nilsson, 2004), but this value should not be used for sheep, as sheep farmers get less paid for the skins by the slaughter houses (Meiner, pers. message, 2009).

Ewes and breeding rams transported to slaughter have practically no economical value for the farmer. In year 2008, the mean weight of the carcasses of these animals was 28.5 kg and the scaling in the EUROP-scale was O+. Fat was estimated as a 3 in the fat-scale. Just as for lambs, the skin and organs from rams and sheep are utilized at the slaughter house

Breeding

Ewes reach their puberty at 5-8 months of age and rams at 4-6 months, but there are large breed differences. Ewes and rams are then ready to be mated and the gestation period is in average 145 days but can vary from 142 to 148 days (Fag, 2005). The earlier the animals can be bred, the less methane they emit before they start to produce, and less gas is produced per kg of meat produced per ewe or ram. A generation percentage for ewes of 15- 20 % is normal for Swedish herds (Fag, 2005)

Wool and pelts

A sheep produces about two kg of wool per year, but it varies greatly between breeds. Wool is nowadays not a profitable business unless the wool is prepared by the farmer himself and sold as handicraft, or if the wool comes from a breed with more coveted wool (Fag, 2005). More wool is being produced than used in Sweden. Therefore no economic value is allotted to the wool in this study. Skins that are prepared today mostly come from Gotlandic pelt sheep (Meiner, pers. message, 2009). The payment varies with season of the year, quality of the skin and slaughterhouse (Fag, 2005). Week 7, year 2009, a skin was 2.3 % of the whole price paid for an average lamb to the farmer by Swedish Meats if sold at slaughter (Swedish Meats, 2009). The amount paid for the skins varies with season (Meiner, pers. message, 2009).

CALCULATIONS OF METHANE EMISSIONS

Digestibility coefficient of energy (DCE) in the feedstuff Unik (percentage of inclusion of a ingredient and its digestibility coefficient of energy):

0.250*84+0.180*86+0.110*78+0.100*75+0.090*88+0.090*87+0.070*75+0.050*67+0.020*88= **78.5**

Farm Intensive

Lambs

132 ewes*1.97 lambs = 260

17 460 kg LammFor/ 260 lambs = 67.2 kg LammFor/lamb

67.2*12.7 MJ oms energy = 853.4 MJ

853.4 MJ/110 days = 7.8 MJ

12.7/0.82= 15.5 MJ digestible energy

67.2 kg*15.5 MJ digestible energy = 1041.6 MJ

1041.6 MJ/110 days = 9.5 MJ digestible energy/day

Maintenance requirement for a 30 kg sheep 5 MJ/day, 9.5 MJ/5 MJ = 1.9

L= 1.9*maintenance

$EF_{feed\ 1}$= 17.4 - 0.062DCE - 1.70L

17.4 - 0.062* 78.5 - 1.70*1.9 = 9.3, **9.3 % of digestible energy intake is loosed as methane**

0.093*9.5 MJ = 0.9, 0.9 MJ digestible energy lost as methane per day

0.9 MJ*110 days = 99 MJ per 110 days

99/54.4 (energy content per kg of CH_4) = **1.8 kg CH_4/lamb**

Ewes during winter

234 kg DM silage/ewe and 6 months= 1.3 kg/day, 1.3*10.9 MJ = 14.7 MJ metabolisable energy/day

11000 kg barley/132 ewes = 83.0 kg, 83.0 kg/180 days = 0.46 kg 0.46 kg*13.2 MJ = 6.1 MJ metabolisable energy/day

6000 kg Unik/132 ewes = 45.5 kg, 45.5 kg/180 days = 0.25 kg, 0.25 kg*14 MJ = 3.5 MJ metabolisable energy/day

14.7 MJ+ 6.1 MJ+ 3.5 MJ = 24.3 MJ metabolisable energy/day

Maintenance requirement for a 70 kg ewe is 9.6 MJ/day 24.3/9.6 = 2.5

L= 2.5*maintenance

DCE of the total diet of ewes:

234+ 83+ 45.5= 362.5 234/362.5= 0.65 83/362.5= 0.23

45.5/362.5= 0.12

0.65 silage * 0.70 + 0.23 barley * 0.84 + 0.12 LammFor * 0.78 = 0.74

$EF_{feed\ 1}$= 17.4 - 0.062DCE - 1.70L

17.4 - 0.062* 74 – 1.70*2.5 = 8.6, **8.6 % of digestible energy is lost as methane**

Grass silage: 10.9 MJ/0.82= 13.1 MJ digestible energy/kg

Barley: 15.0 MJ digestible energy/kg

Unik: 14.0 MJ/0.82= 17.1 MJ digestible energy/kg

0.65* 13.1 MJ+ 0.23* 15.0 MJ+ 0.12* 17.1 MJ= 14.0 MJ digestible energy/day and ewe

0.086* 14.0 MJ= 1.2 MJ 1.2* 180 days= 216 MJ in 6 months 216 MJ/54.4=

4.0 kg CH_4/ewe and 6 months

Ewes during summer

DCE in grass pasture: 76 % (Spörndly, 2003) **L= 1*maintenance requirements**

$EF_{feed\ 1}$= 17.4 - 0.062DCE - 1.70L

17.4- 0.062* 76- 1.70* 1= 11.0, **11.0 % of digestible energy is lost as methane**

9.6 MJ/0.82= 11.7 MJ digestible energy per day and ewe from pasture

0.11* 11.7 MJ= 1.3 MJ 1.3 MJ*180 days= 234.0 MJ in 6 months

234.0 MJ/54.4= **4.3 kg CH_4/ewe and 6 months**

Total

4.0+ 4.3=8.3 kg CH_4/ewe and year

8.3+ 1.97* 1.8= 11.8 kg CH_4 for 1.97 lambs per year,

1.97 lambs* 0.85= 1.7 lambs delivered to the slaughterhouse

11.8 kg/1.7 lambs= 6.9 kg CH_4 per lamb

2 % allocated to intestines and 2.3 % to pelt, 0.043* 6.9 kg= 0.3 kg

6.9 kg- 0.3 kg= 6.6 kg CH_4

A carcass at Karma Agro KB weighs 19.4 kg, 85.6 % on a carcass is bone free meat

6.6 kg/ (19.4 kg* 0.856) = **0.4 kg CH_4/kg bone free meat**

Farm Extensive

Lambs

10 kg Sund Ängsull/lamb and 6 months 10 kg* 12.8 MJ= 128 MJ

128 MJ/180 days= 0.7 MJ

Energy requirement for different live weights for growing 250 g per day:

6.0 MJ+8.0 MJ+10.2 MJ+12.1 MJ+14.0 MJ+15.1 MJ= 65.4 MJ 65.4 MJ/6= 10.9 MJ/day in average

0.7 MJ/10.9 MJ= 0.06 About 6 % of the lambs diet consist of Sund Ängsull

Maintenance requirement: 5 MJ/day 10.9 MJ/5 MJ= 2.2

L= 2.2*maintenance requirement

DCE in the diet of lambs: 0.94* 76+ 0.06* 78= 76.1

$EF_{feed\ 1}$= 17.4 - 0.062DCE - 1.70L

17.4- 0.062* 76.1- 1.70* 2.2= 8.9, **8.9 % of digestible energy is lost as methane**

10.9 MJ/0.82= 13.3 MJ digestible energy/day

0.089* 13.3= 1.2 MJ 1.2 MJ* 180 days= 216 MJ 216 MJ/54.4= **4.0 kg CH_4/lamb and 6 months**

Ewes during winter

8000 kg/150 ewes= 53 kg 53 kg* 12.8 MJ= 678.4 MJ

678.4 MJ/180 days= 3.8 MJ/day

365 kg silage/180 days= 2.0 kg 2.0 kg*10.5 MJ= 21.0 MJ/day

3.8 MJ+ 21.0 MJ= 24.8 MJ/day 24.8 MJ/9.6 MJ= 2.6

L=2.6* maintenance requirements

365 kg+ 53 kg= 418 kg feed 365 kg/418 kg= 0.87 87 % of the diet is silage

DCE of the total diet of ewes during winter:

0.87*70+ 0.13*78= 71.0

$EF_{feed\ 1}$= 17.4 - 0.062DCE - 1.70L

17.4- 0.062*71.0-1.70* 2.6= 8.6 %, **8.6 % of digestible energy is lost as methane**

Conversion to digestible energy: 24.8 MJ/0.82= 30.2 MJ digestible energy

0.086* 30.2 MJ= 2.6 MJ 2.6 MJ*180 days= 468 MJ 468 MJ/54.4= **8.6 kg**

CH_4/ewe and 6 months

Ewes during summer

Digestibility coefficient of energy in grass pasture: 76 % (Spörndly, 2003)

9.6 MJ+ 19 MJ= 28.6 MJ   28.6 MJ/9.6 MJ= 3   **L= 3*maintenance requirements**

$EF_{feed\ 1}$= 17.4 - 0.062DCE - 1.70L

17.4- 0.062*76- 1.70*3= 7.6, **7.6 % of digestible energy is lost as methane**

0.076* 28.6 MJ= 2.2 MJ   2.2 MJ*180 days= 396 MJ

396 MJ/54.4= **7.3 kg CH_4/ewe and 6 months**

Total

8.6 kg+ 7.3 kg= **15.9 kg CH_4/ewe and year**

15.9 kg+ 1.68 lambs born and raised per ewe* 4.0 kg= 22.6 kg CH_4 for 1.68 lambs

1.68 lambs* 0.85= 1.43 lambs transported to slaughter

22.6 kg/1.43 lambs= 15.8 kg CH_4 per lamb

0.043* 15.8 kg= 0.7 kg   15.8 kg- 0.7 kg= 15.1 kg

15.1 kg/ (18.6 kg* 0.856) = **0.9 kg CH_4/kg bone free meat**

DISCUSSION

Several studies have shown that methane losses are less from diets containing concentrates than diets with solely roughage. Concentrates are often given in diets to sheep in Sweden. The mean figure of 7.22 % of gross energy lost as methane (Pelchen & Peters, 1998), for sheep eating mostly roughage could therefore be a bit high for Swedish conditions. Especially for intensive production systems where lambs and sheep are fed high amounts of concentrates, this could be the case. IPCC recommend use of the methane yield (% of gross energy) 6.5 % for adult sheep when calculating methane emissions, but this figure is based only on data from studies with grazing sheep. Pasture is often of better nutritional quality than silage, but not as good as concentrates. This could mean that the figures from IPCC may be a bit high for most production systems in

Sweden during the periods when the diet consists of large parts of concentrates. IPCC recommends that the lower value of 6.5 % - 1.0 %, which equals 5.5 %, should be used for high energy feeds, maybe this figure is more accurate for use in Swedish production systems.

Feed is clearly a factor affecting the size of emissions, less digestible feeds give rise to higher emissions and more easily digestible feeds give rise to less. It seems like age also has effect on the size of emissions from sheep in some matter. As long as the lamb is milk fed, practically no methane is emitted from enteric fermentation, but as soon as the intake of solid feed starts, emissions occur. When the diet entirely consists of solid feeds such as concentrates and roughage, emissions expressed as percentage of gross energy are only slighter smaller for young animals than older ones. There seem not to be any big differences between the intakes of either roughage or concentrates for the development of the rumen, some other factor than fibre content in the diet seem to be more important in this matter.

In the guidelines of IPCC, milk fed lambs are considered to not give rise to any emissions and sheep younger than one year are supposed to emit lesser amounts than older ones. But according to Oh et al. (1972) lambs older than 9 weeks are considered to be almost fully developed as ruminants and other sources imply that the concentration of volatile fatty acids in the rumen and the microbial population reaches adult proportions earlier than one year of age. Therefore the age limit of one year, used in the equation of IPCC, seems to be a bit rough and high set, several values could be used for calculating emissions from lambs at differing ages. But as long as the exact levels of emissions from sheep at differing ages are not known, no other values could be recommended to use instead.

In the equation of Lindgren (1980), the age of the animal is not considered. As can be seen in the literature overview, the emissions from younger animals should be lower than from adult animals. But as the present study's objective is mainly to compare the emissions from two farms, and not to quantify the total methane emissions from sheep production, the figures are still useful.

High feeding levels, which are used in intensive Swedish production systems, give rise to lower methane yields than low feeding levels. But as less of the feed can be digested by the animal depending of the high passage rate, the animal produces less per energy unit in the feed. This may be of small importance when comparing the two different production systems in this study, because of the relatively good production that can be seen from lambs at pastures in Sweden

The equations of Lindgren (1980) and Blaxter and Clapperton (1965) both consider the digestibility of the ration given and level of feeding. Both equations are also based on studies from several countries, hence none of them can be said to surely reflect Swedish conditions. But the one from Lindgren is newer and based on more observations than the one from Blaxter and Clapperton, and therefore Lindgren´s equation may be more suitable to use when calculating emissions from Swedish production systems.

In the equation of IPCC, gross energy is used in the calculations, gross energy contents are pretty similar for highly digestible feeds, such as concentrates, and for less digestible, as hay for example. Therefore, if the equation from IPCC would be used in this study, the methane emissions from the animals at the two farms should be about the same. With the equation of Lindgren (1980), both feeding level and digestibilities of the diets are considered, making the values hopefully more precise. The equation of Lindgren (1980) is recommended by Berglund et. al, 2009.

The amount methane emitted by animals on pasture is hard to predict, because of the unknown feed intake and shifting nutritional value between and in pastures. In the studies reviewed in this paper, the methane yield varied between 1.9 +/- 0.36 and 6.9 +/- 0.4, depending of different botanical composition, season and climate. Sheep in Sweden are spending about half the year on pasture and therefore Swedish studies concerning the emissions from grazing sheep would be important to conduct.

Differences in emissions depending on sex and breed could exist, but should not be accounted for when calculating emissions from Swedish farms. It is too uncertain if such differences exist and if they should exist, the sizes of these are anyway unknown. Diurnal fluctuations in emissions are not necessary to include in estimates of emissions, but should be considered when true measurements are done.

In the aspect of emissions of methane, cattle and sheep seem to react similarly to different factors concerning diet. The emissions expressed in percentage of gross energy for cattle and sheep are similar and there are no reasons to think that emissions should differ between them if they were held in the same production systems. But as these systems often differ in Sweden, emissions surely differ as well, as they do between extensive and intensive systems with cattle.

Cattle are getting in their reproductive age later than sheep, and therefore methane is produced without producing any meat for a longer period before the first pregnancy by cattle than sheep. The gestation period is also longer, about 9 months for cattle in comparison with 145 days for sheep. Sheep are therefore much younger when they give birth to their first lamb than cattle are when they give birth to their first calf. But female cattle live and produce longer in average than ewes and therefore they maybe can compensate a part of the higher amounts of gas they emit than sheep before their first birth with larger quantities of meat produced. Beef produced from dairy production give rise to less emissions than beef produced from just plain beef production, sheep production in Sweden is more similar to the latter.

Both the ERUCT technique and respiration chambers seem like correct ways of measuring methane emissions by ruminants. But the ERUCT technique seems easier to use and the equipment are much easier to transport, making it possible to conduct studies at many varying places where to respiration chambers could not be transported. Polytunnel systems seem to be suitable for studies concerning grazing animals where other techniques are hard to use. Therefore it seems like all different ways of measuring methane emissions are suitable in at least some situations.

Rams were not included in the calculations because of lack of information of their feed intakes and their probably small contributions to the total emissions. Probably, the methane emitted by the rams is less than by the ewes; because of their lower demand on performance and thereby their lower feed intakes.

Some parameters have been overseen in this study because of the lack of real comprising data from the farms and difficulties concerning the calculations. One parameter which has not been taken in account is the time when the lambs are consuming mainly milk. During this time the methane emissions from the lambs should be negligible and therefore the total emissions from the lambs should be somewhat lower than they really are. The feed amount consumed at Farm Intensive should then still be the same per lamb, but during a shorter period, making the feeding level higher than what it is in the calculations. At Farm Extensive, the estimated pasture intake per day of the lambs should be correct. But in this study it is estimated that they eat just roughage at the time they only should consume milk in reality, which is a pretty long period, and therefore no emssions would occur at this time. This makes the total methane emissions in the calculations from the 7 months long raising period higher than they truly are.

The amount silage consumed at Farm Intensive was eaten by both ewes and lambs, but the silage consumption of the lambs was set to zero in the data given from the farm. Because of this assumption, the silage consumption of the ewes could be overestimated.

The lengths of the raising periods at the two farms are roughly estimated, due to lack of information of the exact age of every lamb in the herds at slaughter. This could affect the final values of emissions per kg of meat.

Where data was missing, for example the number of lambs born and raised per ewe, values from databases like Elitlamm or values from literature was used. More data was available from Farm Intensive than Farm Extensive, therefore more standard values were used in the calculations of emissions from the latter.

If totally correct, the methane emissions from ewes before they have their first lamb and emissions from rams should be included in the total emissions per kg of meat. But as the data available in this study is limited, such information has been excluded. But in other studies where there are more data available, these emissions should be included in the calculations.

Slaughter houses pay very little for ewes and skins, but if the farmers were paid more for these things, more of the methane emitted from the production could be economically allocated to these things. Maybe another method of allocation than economic allocation should be used, because of the high value of lamb skins. This would make the amount methane emitted per kg of meat less in the end than it is now.

Although too much data is lacking to really be able to say something about the exact quantities of methane emissions from Swedish sheep production, one could probably state that differences in methane emissions between the two farms in this study exist. The higher emissions from the extensive farm are probably a result of longer raising periods and larger quantities of roughage in the diet of both ewes and lambs. The ewes at Karma

Agro get more lambs than ewes of the breed Gotlandic Pelt usually do; the number of lambs per ewe is an important factor concerning the size of methane emissions.

The manure on both farms were stored and handled similarly, therefore there should not be large differences between the farms in the emissions from manure handling.

Methane is only one of the greenhouse gases emitted from sheep production and therefore the emissions are not converted to CO_2-eqvivalents in the results of this paper. Maybe in that case, there could be confusion if these values were compared with the total greenhouse gas emissions from cattle production or other production systems. But, if converted to CO_2-eqvivalents and the Global Warming Potential 25 is used for methane (Berglumd et al., 2009), one kg of bone free meat from the intensive system, Farm Intensive, should cause emissions of 10.0 kg CO_2-eqvivalents and meat from the extensive system, Farm Extensive, should cause 22.5 kg of CO_2-eqvivalents. Considering these amounts are emitted only from the enteric fermentation and not other sources of emissions which have great impact on the climate as well are included, one could probably assume that sheep production is cause of greater emissions than from most cattle production systems.

Sheep are common grazers on natural pastures in Sweden. Recent studies have shown that these grasslands work as carbon sinks and have about the same potential as forest in this matter (Jordbruksverket, 2008). This means that when animals grazing natural pastures, a reductive effect on the total climate impact from the system can be accounted for. Grazing animals also have a positive effect on biodiversity, another important environmental issue.

There could be ways to lower the emissions from Swedish sheep production. By letting the ewes have two litters a year, instead of one, the time when ewes are not producing could be shortened. The emissions could also be lowered by reducing the generation percentage and by increasing the productivity at the farms overall.

Consumers often get different facts about which type of meat is to prefer if concern is paid to the climate. If only considering the amount of greenhouse gases emitted, lamb and beef meat are surely not preferred before pig and chicken meat, but the positive effect on biodiversity and open landscapes can make sheep and cattle meat good choices for the environmentally friendly consumer.

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REFERENCES

Alcock, D., Hegarty, R. S. 2006. Effects of pasture improvement on productivity, gross margin and methane emissions of a grazing sheep enterprise. International Congress Series 1293. 103-106.

Andréasson, E., Sundelöf, J-A. 2006. Vårlammskompendium. Version 3. Swedish Meats.

Anderson, K. L., Nagaraja, T. G., Morrill, J. L., Avery, T. B., Galitzer, S. J., Boyer, J. E. 1987. Ruminal microbial development in conventionally or early-weaned calves. Journal of Animal Science, 64. Blaxter, K. L., Czerkawski, J. 1966. Modification of the methane production of the sheep by supplementation of its diet. Journal of the Science of Food and Agriculture 17. 417-421.

Baldwin, R. L. 2000. Sheep gastrointestinal development in response to different dietary treatments. Small Ruminant Research 35. 39-47.

Berglund, M., Cederberg, C., Clason, C., Henriksson, M., Törner, L. 2009. Jordbrukets klimatpåverkan – underlag för att beräkna växthusgasutsläpp på gårdsnivå och nulägesanalyser av exempelgårdar.

Bertilsson, J., SLU. Personal message, 2009-05-05.

Blaxter, K. L., Clapperton, J. L. 1965. Prediction of the amount of methane produced by ruminants. British Journal of Nutrition 19. 511-522.

Blaxter, K.L., Czerkawski, J. 1966. Modifications of the methane production of the sheep by supplementation of its diet. Journal of the science of food agriculture 17. 417-421.

Blümmel, M., Givens, D. I., Moss, A. R. 2005. Comparison of methane produced by straw fed sheep in open-circuit respiration with methane predicted by fermentation characteristics measured by an in vitro gas procedure. Animal Feed Science and Technology 123-124. 379-390.

Cederberg, C., Darelius, K. 2000. Livscykelanalys (LCA) av nötkött- en studie av olika produktionsformer. Naturresursforum. Landstinget Halland.

Cederberg, C., Darelius, K. 2001. Livscykelanalys (LCA) av griskött. Naturresursforum. Landstinget Halland.

Cederberg, C., Nilsson, B. 2004. Livscyeklanalys (LCA) av ekologisk nötköttsproduktion i ranchdrift. SIK-rapport 718.

Chandramoni, Jadhao, S. B. Tiwari, C. M., Khan, M. Y. 2000. Energy metabolism with particular refernce to methane production in Muzaffarnagari sheep fed rations varying in roughage to concentrate ratio. Animal Feed Science and Technology 83. 287-300.

Christophersen, C. T., Wright, A-D. G., Vercoe, P. E. 2008. In vitro methane emission and acetate:propionate ratio are decreased when artificial stimulation of the rumen wall is combined with increasing grain diets in sheep. Journal of Animal Science 86. 384-389.

Clapperton, J. L., Czerkawski, J. W. 1969. Methane production and soluble carbohydrates in the rumen of sheep in relation to the time of feeding and the effects of short-term intraruminal infusions of unsaturated fatty acids. British Journal of Nutrition 23. 813-826.

Crutzen, P. J., Aselmann, I., Seiler, W. 1986. Methane production by Domestic Animals, Wild Ruminants, Other Herbivourous Fauna and Humans. Tellus 38B, 271-284.

Czerkawski, J.W., Breckenridge, G. 1975. New inhibitors of methane production by rumen micro-organisms. Development and testing of inhibitors in vitro. British Journal of Nutrition 34. 429-446.

Dinuccio, E., Berg, W., Balsari, P. 2008. Gaseous emissions from the storage of untreated slurries and the fractions obtained after mechanical separation. Atmospheric Environment 42. 2448- 2459.

Elitlamm. 2009-02. Updated 2009-01-23. www.elitlamm.com

Ellis, J. L., Kebreab, E., Odongo, N. E., McBride, B. W., Okine, E. K., France, J. 2007. Prediction of Methane Production from Dairy and Beef Catlle. Journal of Dairy Science 90. 3456-3467.

Estermann, B. L., Sutter, F., Schlegel, P. O., Erdin, D., Wettstein, H. R., Kreuzer, M. 2002. Effect of calf age and dam breed on intake, energy expenditure, and excretion of nitrogen, phosphorus and methane of beef cows with calves. Journal of Animal Science 80. 1124-1134.

Fag, B. 2005. Lönsam lammproduktion. Hushållningssällskapet Jönköpings län.

Faichney, G. J., Graham, N. M., Walker, D. M. 1999. Rumen characteristics, methane emissions, and digestion in weaned lambs reared in isolation. Australian Journal of Agricultural Research 50. 1083-1089.

Flessa, H., Ruser, R., Dörsch, P., Kamp, T., Jimenez, M. A., Munch, J. C., Beese, F. 2002. Integrated evaluation of greenhouse gas emissions (CO_2, CH_4, N_2O) from two farming systems in southern Germany. Agriculture, Ecosystems and Environment 91. 175-189.

Flysjö, A., Cederberg, C., Strid, I. 2008. LCA-databas för konventionella fodermedel-miljöpåverkan i samband med produktion. SIK-rapport 772.

Fonty, G., Jouany, J. P., Chavarot, M., Bonnemoy, F., Gouet, P. 1991. Development of the rumen digestive functions in lambs placed in a sterile isolator a few days after birth. Reproduction Nutrition Development 31. 521- 528.

Fonty, G., Gouet, P., Jouany, J. P., Senaud, J. 1987. Establishment of the microflora and anaerobic fungi in the rumen of lambs. Journal of General Microbiology 133. 1835-1843.

Fonty, G., Jouany, J. P., Chavarot, M., Bonnemoy, F., Gouet, P. 1991. Development of the rumen digestive functions in lambs placed in a sterile isolator a few days after birth. Reproduction, nutrition, development 31. 521-528.

Fonty, G., Joblin, K., Chavarot, M., Roux, R., Naylor, G., Michallon, F. 2007. Establishment and development of ruminal hydrogenotrophs in methanogen-free lambs. Applied and Environmental Microbiology 73. 6391-6403.

Gibbs, M., Johnson, D. E. 1994. Methane Emissions from Digestive Processes of Livestock. International Anthropogenic Methane Emissions: Estimates for 1990, EPA 230R-93-010. 2-44.

Gilliland, R. L., Bush, L. J., Friend, J. D. 1962. Relation of ration composition to rumen development in early-weaned dairy calves with observations on ruminal parakeratosis. Journal of Dairy Science 45. 1211-1217.

Graham, N. McC. 1980. Variation in energy and nitrogen utilization by sheep between weaning and maturity. Australian Journal of Agricultural Research 31. 335-345.

Greppa näringen, 2009- 03. Updated 2008-02-11. www.greppa.nu

Hamada, T., Maeda, S., Kameoka, K. 1976. Factors influencing growth of rumen, liver, and other organs in kids weaned from milk replacers to solid food. Journal of Dairy Science 59. 1110-1118.

Hellberg, S., Lantmännen. Personal message 2009-02-21.

Hess, H. D., Beuret, R. A., Lötscher, M., Hindrichsen, I. K., Machmüller, A., Carulla, J. E. Lascano, C. E., Kreuzer, M. 2004. Ruminal fermentation, methanogenesis and nitrogen utilization of sheep receiving tropical grass-hay-concetrate diets offered with *Sapindus saponaria* fruits and *Cratylia argentea* foliage. Animal Science 79. 177-189.

IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, vol 4.

Jain, M. K., Singh, R., Tauro, P. 1981. Anaerobic digestion of cattle and sheep wastes. Agricultural Wastes 3. 65-73.

Johnson, D.E., Hill, T. M., Ward, G. M., Johnson, M. E., Branine, B. R., Carmean, B. R., Lodman, D. W. 1993. Principle factors varying methane emissions from ruminants and other animals. In M. A. K. Khalil. Atmosperic methane: Sources, sinks and role in Global change. NATO ADI series, 113. Springer-Verlag, Berlin, Germany.

Johnson, K. A. & Johnson, D.A. 1995. Methane emissions from cattle. Journal of Animal Science 73. 2483-2492.

Johnson, D. E., Ward, G. M. 1996. Estimates of animal methane emissions. Environmental Monitoring and Assessment 42. 133-141.

Jordbruksverket. 2008a. Husdjur i juni 2008. Statistik, Statistiska Centralbyrån.

Jordbruksverket. 2008b. Jordbruksstatistisk årsbok 2008.

Jordbruksverket. 2008c. Minska jordbrukets klimatpåverkan! Del 1: Introduktion och några åtgärder/styrmedel. Rapport 2008:11.

Judd, M. J., Kellier, F. M., Ulyatt, M. J., Lassey, K. R., Tate, K. R., Shelton, D., Harvey, M. J., Walker, C. F. 1999. Net methane losses from grazing sheep. Global Change Biology 5. 647-657.

Kelliher, F.M., Dymond, J.R., Arnold, G.C., Clark, H., Rys, G. 2007. Estimating the uncertainity of methane emissions from New Zealand´s ruminant animals. Agricultural and Forest Meteorology 143. 146-150.

Kelly, N. C., Thomas, P.C. 1978. The nutritive value of silages: Energy metabolism in sheep receiving diets of grass silage or grass silage and barley. Britsh Journal of Nutrition 40. 205-219.

Kirkpatrick, D. E., Steen, R. W. J. 1999. The effect on method of conservation of grass and supplementation on energy and nitrogen utilization by lambs. Journal of Agricultural Science 133. 409-417.

Kirkpatrick, D. E., Steen, R. W. J., Unsworth, E. F. 1997. The effect of differing forage:concentrate ratio and restricting feed intake on the energy and nitrogen utilization by beef cattle. Livestock Production Science 51. 151-164.

Knight, T. W., Molano, G., Clark, H., Cavanagh, A. 2008. Methane emissions from weaned lambs measured at 13, 17, 25 and 35 weeks of age compared with mature ewes consuming a fresh forage diet. Australian Journal of Experimental Agriculture 48. 240-243

Lassey, K., Ulyatt, M. J., Martin, R. J., Walker, C. F., Shelton, I. D. 1997. Methane emissions measured directly from grazing livestock in New Zealand. Atmospheric environment 31. 2905-2914.

Leng, R.A. 1982. Dynamics of Protozoa in the rumen of sheep. British Journal of Nutrition 48. 399-415.

Leuning, R., Baker, S.K., Jamie, I. M., Hsu, C. H., Klein, L., Denmead, O. T., Griffith, D. W. T. 1999. Methane emission from free-ranging sheep: a comparison of two measurement methods. Atmospheric Environment 33. 1357-1365.

Lindgren, E. 1980. Estimation of energy losses in methane and urine by ruminants. A review. Report 47, Department of Animal Nutrition, Swedish University of Agricultural Sciences.

Lockyer, D. R. 1997. Methane emissions from grazing sheep and calves. Agriculture, Ecosystems and Environment 66. 11-18.

Lockyer, D. R., Champion, R. A. 2001. Methane production by sheep in relation to temporal changes in grazing behaviour. Agriculture, Ecosystems and Environment 86. 237-246.

Lockyer, D. R., Jarvis, S. C. 1995. The measurement of methane losses from grazing animals. Environmental Pollution 90. 383-390.

Loyon, L., Guiziou, F., Saint Cast, P. 2008. Impact of manure management of different livestock on gaseous emissions:laboratory study. Australian Journal of Experimental Agriculture 48. 128-131.

LRF. 2008. Den svenska maten och klimatet.

Machmüller, A., Clark, H. 2006. First results of a meta-analysis of the methane emission data of New Zealand ruminants. International Congress Series 1293. 54-57.

Margan, D. E., Faichney, G. J., Graham, McC., Donnelly, J. B. 1982. Digestion of a ground and pelleted diet in the stomach and intestines of young sheep from two breeds. Australian Journal of Agricultural Research 33. 617-627.

Massé, D. I., Masse, L., Claveau, S, Benchaar, C., Thomas, O. 2008. Methane emissions from manure storages. American Society of Agricultural and Biological Engineers 51. 1775-1781.

McDonald, P., Edward, R. A., Greenhalgh, J. F. D., Morgan, C. A. (2002). Animal nutrition. 6. ed. Essex: Pearson Prentice Hall.

McGinn, S. M., Beauchemin, K. A., Iwaasa, A. D., McAllister, T. A. 2006. Assessment of the sulfur hexafluoride (SF_6) Tracer Technique for measuring enteric methane emissions from cattle. Journal of Environmental Quality 35. 1686-1691.

Meiner, M., SLU, JTI. Personal message, 2009-03-01.

Miljömål, 2009- 04. Updated 2009-04-01. www.miljomal.se

Mirzaei- Aghsaghali, A., Maheri-Sis, N., Mirza-Aghazadeh, A., Ebrahimnezhad, Y., Dastouri, M. R., Golshani, A. A. 2008. Estimation of methane production in sheep using nutrient composition of the diet. Journal of Animal and Veterinary Advances 7. 765-770.

Molano, G., Clark, H. 2008. The effect of level of intake and forage quality on methane production by sheep. Australian Journal of Experimental Agriculture 48. 219-222.

Moss, A. R., Givens, D. I. 2002. The effect of supplementing grass silage with soya bean meal on digestibility, in sacco degradability, rumen fermentation and methane production in sheep. Animal Feed Science and Technology 97. 127- 143.

Murray, P. J., Gill, E., Baldson, S. L., Jarvis, S. C. 2001. A comparison of methane emissions from sheep grazing pastures with differing management intensities. Nutrient Cycling in Agroecosystems 60. 93-97.

Murray, P. J., Moss, A., Lockyer, D. R., Jarvis, S. C. 1999. A comparison of systems for measuring methane emissions from sheep. Journal of Agricultural Science 133. 439-444.

National Research Council (2007). *Nutrient requirements of small ruminants.* 6. ed. Washington D. C. : The National Academies Press

Naturvårdsverket, 2002. Utveckling av metodik för att kvantifiera jordbrukets utsläpp av växthusgaser. Dnr: 108-356-01 Md, Swedish Environmental Protection Agency, Stockholm.

New Zealand greenhouse gas inventory 1990-2005. 2007. Ministry of the Environment. Reference ME811.

Nicholson J. W. G., Sutton, J.D. 1969. The effect of diet composition and level of feeding on digestion in the stomach and intestines of sheep. British Journal of Nutrition 23. 585-601.

Oh, J. H., Hume, I. D., Torell, D. T. 1972. Development of microbial activity in the alimentary tract of lambs. Journal of Animal Science 35. 450-459.

Pelchen, A., Peters, K. J. 1998. Methane emissions from sheep. Small Ruminant Research 27. 137-150.

Pinares-Patiño, C. S., Ulyatt, M. J., Lassey, K. R., Barry, T. N., Holmes, C. W. 2003a. Rumen function and digestion parameters associated with differences between sheep in methane emissions when fed chaffed lucerne hay. Journal of Agricultural Science 140. 205-214.

Pinares-Patiño, C. S., Ulyatt, M. J., Lassey, K. R., Barry, T. N., Holmes, C. W. 2003b. Persistence of differences between sheep in methane emission under generous grazing conditions. Journal of Agricultural Science 140. 227-233.

Pinares-Patiño, C. S., Holmes, C. W., Lassey, K. R., Ulyatt, M. J. 2008. Measurement of methane emission from sheep by the sulphur hexafluoride tracer technique and by the calorimetric chamber: failure and success. Animal 2. 141-148.

Penning, P. D., Rook, A. J., Orr, R. J. 1991. Patterns of ingestive behaviour of sheep continuously stocked on monocultures of ryegrass or white clover. Applied Animal Behaviour Science 31. 237-250.

Poe, S. E., Ely, D. G., Mitchell, G. E., Deweese, W. P., Glimp, H. A. 1971. Rumen development in lambs: 1. Microbial digestion of starch and cellulose. Journal of Animal Science 32. 740-743.

Russell, J. B. 1998. The importance of pH in the regulation
of ruminal acetate to propionate ratio and methane production in vitro. Journal of Dairy Science 81. 3222–3230.

Sjödin, E., Eggertsen, J., Hammarberg, K., Danell, Ö., Näsholm. A., Barck, S., Green, D., Waller, A., Hansson, I., Persson, I., Kumm, K. 2007. Får 7. ed. Stockholm: Natur och Kultur.

Soveri, T., Nieminen, M. 2007. Papillar morphology of the rumen of forest reindeer (Rangifer tarandus fennicus) and Semidomesticated Reindeer (R. t. tarandus) Anatomia, Histologia, Embryologia 36. 366–370.

Spörndly, R. 2003. Fodertabeller för idisslare 2003. Rapport 257, Sveriges lantbruksuniversitet.

Stobo, I. J. F., Roy, J. H. B., Gaston, H. J. 1966. 1. The effect of diets containing different proportions of concentrates to hay on rumen development. British Journal of Nutrition 20. 171- 188.

Stobo, I. J. F., Roy, J. H. B., Gaston, H. J. 1966. 2. The effect of diets containing different of concentrates to hay on digestive effiency. British Journal of Nutrition 20. 189- 215.

Swainson, N. M., Hoskin, S. O., Clark, H., Villalobos, L. 2008. Effect of age on methane emissions of red deer stags from weaning until one year of age grazing perennial ryegrass-based pasture. Australian Journal of Experimental Agriculture 48. 126- 127.

Swedish Meats. 2009-02. Updated 2009-02-24 www.swedishmeats.se

Svensson, E. Swdish Meats. Personal message, 2009-03-03.

Tamate, H., McGilliard, A. D., Jacobson, N. L., Getty, R. 1962. Effect of various dietaries on the anatomical development of the stomach in the calf. Journal of Dairy Science 45. 408- 420.

Trei, J. E., Scott, G. C., Parish, R. C. 1972, Influence of Methane Inhibition on Energetic Efficiency of Lambs. Journal of Animal Science 34. 510-515.

Ulyatt, M. J., Lassey, K. R., Shelton, I. D., Walker, C. F. 2005. Methane emission from sheep grazing four pastures in late summer in New Zealand. New Zealand Journal of Agricultural Research 48. 385-390.

Ulyatt, M. J., Lassey, K. R., Shelton, I. D., Walker, C. F. 2002a. Methane emission from dairy cows and wether sheep fed subtropical grass-dominant pastures in midsummer in New Zealand. New Zealand Journal of Agricultural Research 45. 227-234.

Ulyatt, M. J., Lassey, K. R., Shelton, I. D., Walker, C. F. 2002b. Seasonal variation in methane emission from dairy cows and breeding ewes grazing ryegrass/white clover pasture in New Zealand. New Zealand Journal of Agricultural Research 45. 217-226.

Van der Meer, H., G. 2008. Optimising manure management for GHG outcomes. Australian Journal of Experimental Agriculture 48. 38-45.

Váradyová, Z., Zelenák, I., Siroka, P. 2000. In vitro study of the rumen and hindgut fermentation of fibrous materials (meadow hay, beech sawdust, wheat straw) in sheep. Animal Feed Science and Technology 83. 127-138.

Warner, R. G., Flatt, W. P., Loosli, J. K. 1956. Dietary factors influencing the development of the ruminant stomach. Ournal of Agriculture and Food chemistry 4. 788-792.

Viklund, E. 2009. Lammens energibehov- förslag till normer. Nytt från Institutionen för norrländsk jordbruksvetenskap- Husdjur 1. Sveriges lantbruksuniversitet.

Warner, R. G., Flatt, W. P., Loosli, J. K. 1956. Dietary factors influencing the development of the ruminant stomach. Agricultural Food Chemistry 4. 788- 792.

Wester, T. J., Britton, R. A., Klopfenstein, T. J., Ham, G. A., Hickok, D. T., Krehbiel, C. R. 1995. Differential effects of plane of protein or energy nutrition on visceral organs and hormones in lambs. Journal of Animal Science 73. 1674-1688.

Weston, R. H., Margan, D. E. 1979. Herbage digestion in the stomach and intestines of weaner lambs at different stages of their maturity. Australian Journal of Agricultural Research 30. 543-549.

Widheden, A., Strömberg, K., och Andersson, K., Ahlmén, K. 2001. LCA Kyckling. CIT Ekologik, Miljöledarna Ciconia. Svensk Fågel.

Wright, A. D. G., Kennedy, P., O'Neill, C. J., Toovey-ej säkert att den är med.

Yáñez-Ruiz, D. R., Hart, K. J., Martin-Garcia, A. I., Ramos, S., Newbold, C. J. 2008. Diet composition at weaning affects the rumen microbial population and methane emissions by lambs. Australian Journal of Experimental Agriculture 48. 186-188.

APPENDIX 1 Frågeformulär

Gård, brukare *farmer*:

Adress *address*:

Telefon *phone number*:

Antal installade tackor 2008 *Number of ewes 2008*

Antal baggar vid installningen av tackor *Number of rams*

Ras på får och baggar *Breeds*

När på året föds respektive slaktas de flesta av lammen? *When are the lambs born and slaughtered?*

Mängd förbrukat proteinfoder och spannmål och under hur lång tid denna mängd förbrukats. Används något av fodermedlen enbart till någon speciell djurkategori får detta gärna skrivas under Kommentar. *Amounts of feedstuffs used.*

Fodermedel (produktnamn, innehåll eller spannmålsslag)	Mängd, kg	Kommentar

Vilken typ av ensilage används? Om blandvall används, nämn gärna ungefärlig procent baljväxter i vallen. *What kind of silage is used at the farm? If it contains legumes, mention the percentage included.*

Hur mycket ensilage går åt per tacka? Här räcker det att ange hektarskörd vall per år och antal hektar som används till odling av grovfoder **eller** hur länge en ensilagebal räcker, ungefär hur mycket de väger och ungefärlig ts-halt (om enbart några av dessa värden är kända, nämn isåfall gärna dessa). *How much silage is used per ewe and year?*

Ungefär hur lång tid per år är fåren på bete?Dieten ska då bestå till största delen av just bete och inte tillskottsutfodring. Är det naturbetesmark eller annat bete? *When are the sheep on pasture?*

Hur lagras gödseln? Är eventuella flyt och/eller urinbehållare täckta? *How is the manure stored?*

Tar ni själva vara på skinnet eller tar slakteriet hand om det? *Do you use the skin yourself or is it sold to the slaughterhouse?*

Om eventuella foderanalyser finns får dessa mer än gärna bifogas! *If you have any feed analyses, please send them.*

Tack så mycket för hjälpen!

Farm Extensive

Antal installade tackor 2008 *Number of ewes 2008* **:** 150

Antal baggar vid installningen av tackor *Number of rams***:** 4

Ras på får och baggar *Breeds***:** 130 st Gotlandsfår och 20 st ”Sveafår”

När på året föds respektive slaktas de flesta av lammen? *When are the lambs born and slaughtered?*

Lammen föds i mars/april och slaktas från september till December

Born in march/ April and slaughtered from September to December

Mängd förbrukat proteinfoder och spannmål och under hur lång tid denna mängd förbrukats. Används något av fodermedlen enbart till någon speciell djurkategori får detta gärna skrivas under Kommentar. *Amounts of feedstuffs used.*

Fodermedel (produktnamn, innehåll eller	Mängd,	Kommentar

spannmålsslag)	kg	
Sund Ängsull Lantmännen	8000	

Vilken typ av ensilage används? Om blandvall används, nämn gärna ungefärlig procent baljväxter i vallen. *What kind of silage is used at the farm? If it contains legumes, mention the percentage included.*

Hösilage med en blandning av vitklöver (20%)- timotej- eng. rajgräs-en del örter såsom svartkämpe och cikoria.

Timothy, perennial ryegrass, herbs and white clover (20 %).

Hur mycket ensilage går åt per tacka? Här räcker det att ange hektarskörd vall per år och antal hektar som används till odling av grovfoder eller hur länge en ensilagebal räcker, ungefär hur mycket de väger och ungefärlig ts-halt (om enbart några av dessa värden är kända, nämn isåfall gärna dessa). *How much silage is used per ewe and year?*

Det har gått åt 157 balar och vi siktar på 55-60% i Ts-halt i fodret.

Totalt ca. 47-48 ton Ts = 365 Ts/tacka

365 tonnes dry matter per ewe

Ungefär hur lång tid per år är fåren på bete?Dieten ska då bestå till största delen av just bete och inte tillskottsutfodring. Är det naturbetesmark eller annat bete? *When are the sheep on pasture?*

Betessläpp ca. 5 maj och installning ca 15 december, tillskottsutfodrar från och med 1 november på bete. *Out on pasture the 5th of May and in from pasture the 15th of December.*

Hur lagras gödseln? Är eventuella flyt och/eller urinbehållare täckta? *How is the manure stored?*

Djupströbädden i stallet körs ut i juni-juli månad och lagras i stuka tills vi plöjer ner den på hösten vid vallbrott. *The deep litter bedding is emptied in June/ July and spread on the field in autumn.*

Tar ni själva vara på skinnet eller tar slakteriet hand om det? *Do you use the skin yourself or is it sold to the slaughterhouse?*

Alla skinn tas tillvara och bereds på Tranås skinnberedning. Därefter säljer vi de hemma från gården. *All the skins are prepared at Tranås Skinnberedning and are sold at the farm.*

Om eventuella foderanalyser finns får dessa mer än gärna bifogas! *If you have any feed analyses, please send them.*

2008 togs inga foderanalyser pga. att vi fick så dålig skörd pga. torkan. Vi hade så många små bitar och olika kvalitet på fodret så det kändes inte rättvisande. Det finns ju ingen möjlighet att ta analys på varenda liten bit man skördar på. *No feed analyses attached.*

Vi har analyser från 2007 om du är intresserad av de.

Tack så mycket för hjälpen!

Farm Intensive

Antal installade tackor 2008 *Numer of ewes 2008***:** 132

Antal baggar vid installningen av tackor *Number of rams***:** 5

Ras på får och baggar: 2 texelbaggar, 2 finullsbaggar, 1 mjölkfårsbagge. Halva besättningen rena finullstackor, halva besättningen korsningstackor med främst mjölkfår och finull, även en del texelinblandning förekommer

När på året föds respektive slaktas de flesta av lammen? *When are the lambs born and slaughtered?*

Lamningen sker i huvudsak under 6 veckor med start vid julen-07, då föddes ca 250 lamm Några eftersläntare ca 30 lamm föddes under en andra omgång från ca 20/2 till 31/3. Lammen slaktades med start den 27/3 till 26/6. Fyra lamm slaktades 23/7. 9 ”skräplamm” slaktades feb-09. *250 lambs born during 6 weeks with start Christmas -07. About 30 lambs were born from 20/2 to 31/3. Slaughtered from 27/3 to 26/6.*

Mängd förbrukat proteinfoder och spannmål och under hur lång tid denna mängd förbrukats. Används något av fodermedlen enbart till någon speciell djurkategori får detta gärna skrivas under Kommentar. *Amounts of feedstuffs used.*

Fodermedel (produktnamn, innehåll eller spannmålsslag)	Mängd, kg	Kommentar
Foderkorn, egen odling *Barley*	Ca 10-12 ton	Till tackor inför lamning och under digivning *Ewes*
Unik 52	6000 kg	Till tackor inför lamning och under digivning *Ewes*
Lammfor 300	17460	Till Lammen *Lambs*

Vilken typ av ensilage används? Om blandvall används, nämn gärna ungefärlig procent baljväxter i vallen. *What kind of silage is used at the farm? If it contains legumes, mention the percentage included.*

Rundbalsensilage, 100% gräs, 2:a och 3:dje skörd (första skörden säljs som hästfoder). *100 % grass.*

Hur mycket ensilage går åt per tacka? Här räcker det att ange hektarskörd vall per år och antal hektar som används till odling av grovfoder eller hur länge en ensilagebal räcker, ungefär hur mycket de väger och ungefärlig ts-halt (om enbart några av dessa värden är kända, nämn isåfall gärna dessa). *How much silage is used per ewe and year?*

Totalt har 60900 kg ts ensilage förbrukats under stallperioden vilket blir 234 kg ts per tacka (då ingår även lammens konsumtion av ensilage). *234 kg dry matter per ewe and year.*

Ungefär hur lång tid per år är fåren på bete? Dieten ska då bestå till största delen av just bete och inte tillskottsutfodring. Är det naturbetesmark eller annat bete? *When are the sheep on pasture?*

Tackorna släpptes på bete sista veckan i april -08 och stallades in 30/11.

Betessläpp sker på naturbeten där de går hela för- och högsommaren.

Inför betäckning i augusti går de på vallåterväxt för att sedan återvända till naturbeten under senare delen av september. Stödutfodring börjar i regel vid halva oktober.

The ewes were let out on pasture the last week of April and were brought inside the 30th of November.

Hur lagras gödseln? Är eventuella flyt och/eller urinbehållare täckta? *How is the manure stored?*

Djupströbädden gödslades ut under sommaren och lagrades i stuka ute på åkern för att sedan plöjas ner under hösten inför sådden av höstraps (sept-09).

Andra år har gödseln lagrats på gödselplattan fram till kommande vår. Regnvatten på gödselplattan pumpas till urinbrunn med svämtäcke. Urinmängd ca 100 kbm/år beroende på nederbörd.

The deep litter bedding was emptied during summer and thereafter stored in the field and spread in the autumn.

Tar ni själva vara på skinnet eller tar slakteriet hand om det? *Do you use the skin yourself or is it sold to the slaughterhouse?*

Slakteriet. *Slaughter house.*

Om eventuella foderanalyser finns får dessa mer än gärna bifogas! *If you have any feed analyses, please send them.*

Hittar enbart notering om ett av ensilagepartierna som använts under stallsäsongen

10,9 Mj per kg ts *Silage10.9 MJ and 136 g crude protein/ kg dry matter*

136 gr råprot per kg ts

Detta parti räckte ca 2/3 av stallperioden. *This silage was used 2/3 of the time in the barn.*

Gödselanalys taget genom att borra ett tvärsnitt i gödselhögen ca 1 månad efter utgödsling

TS 31,5%

Tot kväve 8,7 kg/ton

Org kväve 6,54 kg/ton

Ammoniumkväve 2,18 kg/ton

Tot fosfor 0,79 kg/ton

Tot kalium 5,69 kg/ton

Tot kol 140,6 kg/ton

C/N-kvot 21,5

pH 8,4 (verkar högt, beror troligen på att gödselhögen kalkats för att bekämpa flugor)

Tack så mycket för hjälpen!

APPENDIX 2 Karma Agro KB data

Produktionsinriktning			
1	Livtackor totalt		146
Livdjursförsäljning	Livtackor lammande		132
Inköpta vinterlamm st		0	
Ras		x	
Slaktdata	Totalt		Per lamm
Slaktvikt kg/lamm			19,4
Köttklass			8,8
Fettklass			6,6
Uppfödningstid dagar/lamm			110
Födda lamm totalt			285
Födda lamm/tacka			2,16
Slaktade lamm	201		71%
Sålda livlamm	43		15%

Antal lamm till egen rekrytering	16		6%
Sålda lamm + egen rek. Totalt	260		91%
Sålda lamm/tacka	1,97		
Förlorade lamm	25		9%
Rekryterings %	15%		
Foder & Strömedel			
Grovfoder kg ts tackor	60900		234
Grovfoder kg ts lamm	0		
Grovfoder kg ts utslaget totalt	60900		234
Grovfoderkostnad kr/kg ts		1,3	
Grovfoder MJ/kg ts		10,9	
Grovfoder gr. Råprot./kg ts		136	
Kraftfoder kg tackor	19000		73
Kraftfoder kg lamm	17460		67
Kraftfoder kg totalt	36460		140
Kraftfoder kr/kg (genomsnitt)		2,30	
Kraftfoder kr	83858		323
Övrigt foder kr	8200		32