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GREENHOUSE GAS EMISSIONS IN BEEF PRODUCTION

DECISION SUPPORT FOR CLIMATE CERTIFICATION

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1 INTRODUCTION

This report forms part of the project 'Climate Labelling of Food' initiated by KRAV and the IP Sigill quality system in 2007 with the aim of 'decreasing climate impact by creating a labelling system for food through which consumers can make conscious climate choices and businesses can increase their competitive power'. The project is being run by KRAV and the IP Sigill quality system in partnership with Milko, Lantmännen, LRF, Scan and Skånemejerier. The Swedish Board of Agriculture is also participating as an associate in the project (www.klimatmarkningen.se).

In spring 2009, the project commissioned the Swedish Institute for Food and Biotechnology AB (SIK) to draw up decision support for climate certification of beef, pork, chicken and eggs. This task was carried out by Ulf Sonesson, and the commissioning agents from the project were Anna Richert at Svenskt Sigill and Zahrah Ekmark at KRAV. In addition, Christel Cederberg, SIK, and Maria Berglund, Halland Rural Economy & Agricultural Society, were involved in producing this report.

Within the project, reports containing proposed criteria for fruit & vegetables, fish and shellfish, cereals and pulses, transport, animal feed and milk production have also been produced. A decision support report on packaging was completed in June 2009. A criteria report on lamb may be produced later in 2009.

The aim of the present report was to identify critical points in the life cycle of beef as regards the climate impact of this product. On the basis of this analysis, criteria for climate certification at product level are proposed. The starting point was mainly published Life Cycle Analyses (LCA) of the products, complemented with other relevant research and information.

Chapter 2 gives a detailed description of the climate impact of beef production, which provides the starting point for the remainder of the report. Chapter 3 deals with methane formation in ruminants, one of the most important factors in beef production, and identifies important aspects and measures. Chapter 4 deals with other methane emissions and emissions of nitrous oxide, Chapter 5 with energy consumption on the farm and Chapter 6 with animal feeding. Chapter 7 then presents proposed criteria.

2 CLIMATE IMPACT OF BEEF PRODUCTION – SUMMARY OF EXISTING KNOWLEDGE

2.1 BEEF PRODUCTION IN SWEDEN

The greatest proportion of beef production comprises 'by-products' from milk production, i.e. slaughtered dairy cows, bull calves for fattening and some heifer calves not required for recruitment and fattened for slaughter instead. In 2006, just over 466 000 head of beef cattle were slaughtered, of which approx. 315 000 were dairy breeds (see Table 1). Of the volume slaughtered in 2006 (137 000 tonnes of product including bone), just under 65% were by-products from milk production. As a result of increased yield per cow, fixed milk quotas and decreasing milk production in Sweden, the proportion of total beef production originating from dairy is decreasing as the number of dairy cows, and thus the number of calves from dairy cows, continually decreases.

Table 1. Number of animals slaughtered and age at slaughter, 2006

Animal category	**Age at slaughter, months**	**No. of animals slaughtered, 2006**
Calves (from dairy herds)	8.3	32 400
Bulls (from dairy herds), intensive	15	10 037
Bulls (from dairy herds), medium	19	65 243
Bulls (from dairy herds), extensive	21	25 094
Steers (from dairy herds)	26	50 100
Bulls, light beef breeds	17,5	26 143
Bulls, heavy beef breeds	16	54 382
Heifers, light beef breeds	24	9 910
Heifers, heavy beef breeds	22	22 057
Heifers, dairy herds	28	14 132
Cows of beef breeds, culled		36 453
Cows of dairy breeds, culled		120 147
Total beef animals slaughtered		***466 098***

There are no systematic studies or statistics providing data on the scope of different production systems for beef cattle, e.g. feed consumption, grazing, manure management system. With the help of advisors from Taurus Köttrådgivning AB (Taurus, 2009) and available statistics on slaughter, estimates have recently been produced for this (Cederberg et al., 2009a, see Appendix 1). In general, it can be said that suckler cows and all the heifers in beef production are reared and fed on a large proportion of grazing and forage and only small amounts of concentrate. In 2006, approx. 100 000 dairy breed bulls were slaughtered at an age of between 15-21 months depending on the intensity of fattening. These animals have no grazing and receive relatively large amounts of grain. Castrated bull calves from milk production are fattened as steers to a slaughter age of 26 months on average and this group consisted of approx. 44 000 animals in 2006. These animals have extensive grazing and this production system has come into being over the past 15 years, as there were very few steers in beef production around 1990. Beef breed bulls are reared on grazing with their mothers and after weaning in autumn they are fattened with different feeding intensities in houses to an average slaughter age of around 16-18 months. Certified organic slaughter comprised just over 12 300 animals (around 4% of slaughter) in 2006, but in practice many more beef animals are reared organically, with organic grassland and small amounts of concentrate. In 2006 a large proportion of suckler cows were included in the environmental compensation system for organic production but were not certified.

Around 130 000 tonnes of concentrate excluding cereals is used in beef production today. This is an increase compared with the figure in 1990 but on the other hand cereal use in beef production has decreased considerably since 1990 and has been replaced by more forage and grazing, one explanation for this being that more male animals are now reared as steers. A total of 250 000 tonnes of cereal are estimated to be used in beef production today, most of it directly on farms (~80%), i.e. not bought through the animal feed industry (Cederberg et al., 2009a).

2.2 LIFE CYCLE ASSESSMENT (LCA) OF BEEF

There are a number of scientific publications on the climate impact of beef, as well as a number of research reports that have not been externally reviewed but that can be considered to be of good scientific quality. Overall, there are large variations in the results from these studies. Some of this variation can be explained by choice of method, e.g. system boundaries (what is included) and how the environmental impact is allocated between products and by-products (for example milk/meat and rapeseed oil/rapeseed meal). However, there is also great variation depending on how the production is carried out. The range in emissions of greenhouse gases from specialist beef production is 22-40 kg CO_2-equivalents per kg meat. For beef produced from dairy herds (bull calves and cull animals) the figures are lower, in the range 14-19 kg CO_2-equiv/kg.

Table 2 summarises the results from the studies we found in the literature. We have also opted to show secondary energy consumption per kg meat. Secondary energy consumption refers to direct energy consumption, i.e. the amount of diesel, electricity and oil used on the farm, in contrast to primary energy consumption, which also includes the energy required for the production and transport of fuel and the amount of fuel needed to generate the electricity. **It must be pointed out that the studies presented here are not completely comparable.** A number of factors affect the results and these vary between studies. In several cases it was not possible to deduce how certain parameters had been dealt with. Aspects that differed included e.g. the functional unit selected, but wherever possible we have re-calculated this to ‘kg bone-free meat’, although uncertainties remain regarding e.g. killing-out percentage. Allocation between meat and other products such as hides and in certain cases milk differs between studies. In 2007 the weighting factors for methane and nitrous oxide were altered by the IPPC, with the factor for methane being raised from 21 to 25 and the factor for nitrous oxide being lowered from 310 to 298. For beef production, which is dominated by methane emissions, this means that older studies generally report lower values than more recent studies. Overall, it can be said that the aim of the presentation in Table 2 is to describe the main features and to a certain extent also the large variation between production systems.

Swedish beef production has been studied by Cederberg & Darelius (2000), who present results from a hypothetical organic steer fattening enterprise, i.e. there was no actual enterprise but the input data were taken from a description of production based on experiences from organic beef production. Cederberg & Nilsson (2004) presented results from ranch rearing in Skåne, while Anon. (2000) studied indoor fattening, which is the most common system in Sweden. LCA of beef production based completely on dairy herds have been presented by Cederberg & Darelius (2000) and Anon. (2000) and as mentioned, emissions of greenhouse gases for dairy-based beef are considerably lower than for specialist beef production. Finally, Cederberg et al. (2009a) carried out a so-called ‘top-down’ LCA study of all Swedish production of animal feed, divided into animal categories. From these data, it proved possible to quantify the climate impact of Swedish average beef, as a weighted mean value for Swedish beef production. In 2006, 64% of Swedish-produced beef had its origins in dairy herds (surplus calves fattened to slaughter and cull cows), while the remainder was produced in specialist beef units (suckler cows). However, the use of the results of that study is similar to that in other studies, it being possible to distinguish important areas of primary production that contribute most and also the types of gases emitted. The study has still not been published but will be in late 2009 and the values presented here are the final results. In the international literature, a few studies have been published. From Japan there is a study of very intensive indoor production using imported cereals and soyabean (Ogino et al., 2007). Beef production in Ireland has also been studied, as a study based on agricultural statistics (Casey & Holden 2006a), and as a study based on data collected from farms (Casey & Holden 2006b). The results of these did not differ greatly. A study from Canada presents results for all Canadian beef production for the years 1981 and 2001, and shows a decrease of approx. 35% between these years, from approx. 40 to 28 kg CO_2-equiv/kg meat (Verge et al., 2008). According to the authors, this decrease is due to an increase in intensity brought about by the majority of the animals being reared on cereals and soyabean in ‘feed lots’, i.e. grazing-based production has decreased and cereal-based increased. This may sound contradictory, but production in 1981 was inefficient, with a high calving age, few calves and low growth, which led to high greenhouse gas emissions per kg meat, particularly methane emissions, which are mainly due to length of life and are not solely a result of feed intake. Williams et al. (2006) included beef in a study of a range of agricultural products produced in the United Kingdom. That study was based on computer simulations and to a certain extent national statistics. A study of Brazilian beef production presented by Cederberg et al. (2009b) quantified the emissions of greenhouse gases for Brazilian average meat based on a combination of agricultural statistics and data from advisors and researchers in Brazil. The effects of deforestation are included in the report, but the data presented here exclude such deforestation effects.

To simplify matters somewhat, it can be said that greenhouse gas emissions from more extensive, grazing-based production systems are heavily dominated by methane emissions. For more intensive, cereal-based production systems, the climate impact is mainly caused by carbon dioxide and nitrous oxide. For both systems, however, methane is the single largest contributor. From a climate perspective, another general conclusion is that a good system must have good daily growth to decrease methane emissions per kg and that feed production must be climate-efficient.

Table 2. Emissions of greenhouse gases and use of secondary ('direct') energy from beef production. Compilation of published studies, data rounded up

Study	**CO_2-equiv./kg meat**				**MJ/kg meat**
	Total	**CH_4**	**N_2O**	**CO_2**	
Anon. (2000), 'milk-based'	14	6	5	3	39
Cederberg & Darelius (2000), 'milk-based'	17-19	9-10	5-6	3	44
Cederberg & Darelius (2000), 'suckler cows'	22	13	7	2	29
Cederberg & Nilsson (2004), (ranch system)	24	17	6	1	8
Cederberg et al. (2009a), 'Swedish average beef' [a]	28	17.5	7	3.5	
International studies					
Ogino et al. (2007), Japan	32	23	2	7	
Casey & Holden (2006a), Ireland	30				
Casey & Holden (2006b), Ireland	28-32				
Williams et al., (2006), 'average beef', UK	16				28
Williams et al., (2006), '100% suckler', UK	25				41
Verge et al., (2008) , Canada, average beef	30	15	11	4	
Cederberg et al. (2009b), Brazil, average beef	40	31	9	0	5

[a] 64% of beef originated from dairy herds (surplus calves and cull cows), the remainder from specialist beef production

Table 3 shows the emissions distributed over activities from some studies. In general, it can be seen that methane production by the animals dominates and whether feed production or manure management comes next depends on the production system.

Table 3. Proportion of greenhouse gas emissions from various activities

Study	Proportion of emissions (%)		
	Feed (growing, inputs)	**Animal rearing (methane from digestion)**	**Animal rearing (manure, energy)**
Cederberg et al. (2009a) (Sw. average beef)	22	54	24
Cederberg & Nilsson (2004) (ranch system)		70	
International studies			
Casey & Holden (2006b)	5-34	50-80	6-25
Williams et al. (2006) 'average British beef'	48	46	6
Cederberg et al. (2009b) (Brazilian average beef)	25	75	0

Beef is the most complex form of meat production and thus that for which it is most difficult to identify climate certification criteria. Some Swedish beef is produced with calves and cull animals from dairy herds, and the rest from specialist meat production with suckler cows. The climate impact of these two systems differs, with meat from specialist production having higher emissions since the mother animals only produce calves for fattening on to beef weight and not milk products.

The climate impact from beef cattle is caused to a relatively large degree by methane emissions from the digestive system of the animals. This can be controlled to some extent by changes in the diet, although knowledge in this area is limited. Having a higher proportion of concentrate in the diet decreases methane emissions per kg, due to a shorter rearing period (lower slaughter age) but also to differences in the metabolism of the animals. However, an increased proportion of concentrate decreases the positive effects of beef production, such as ley in the crop rotation increasing subsequent production in the system, carbon stocks in grassland (more on this below) and grazing animals improving the biological diversity of natural grasslands.

2.3 CARBON STOCKS IN SOIL

It has previously been 'well-known fact' that the carbon content in permanent grassland reaches an equilibrium. More recent research shows that this is probably not the case and that the carbon content in grassland can increase over a very long time. In a research project within the EU framework programme 'GreenGrass - Sources and Sinks of Greenhouse Gases from Managed European Grasslands and Mitigation Strategies' (Greengrass, 2009), measurements and analyses have been made of greenhouse gas flows from different types of grassland. The area is extremely complex and much remains to be done before detailed knowledge is available on how the flows can be optimised with the aid of mitigation strategies, but fundamental information has been produced. A summarising paper by Sousana et al. (2007) presents measurements from nine study sites covering grasslands of different ages. These studies reported an annual carbon sink of on average ~1000 kg C/ha and the study sites were spread throughout Europe, from north-west to south-east, covering varying climates and farming systems and the greenhouse gases nitrous oxide and methane. The results from that research project provide clear indications that extensive grasslands (but with good N-availability) have greater potential to store carbon than the intensive forage leys included in a crop rotation and therefore ploughed at regular intervals.

An additional argument for grass-based meat production from ruminants, with indirect links to the climate question, is that the animals can utilise resources that humans cannot eat to produce high value protein. Feed production with much grassland also has other positive environmental effects, e.g. a lower dependency on pesticides in feed production, decreased nitrogen leaching and increased biological diversity.

3 Methane formation in ruminants

Ruminants produce methane during digestion of feed in a natural and unavoidable process. The methane mainly leaves the animal with expired air, with only a small fraction (~2%) being formed in the large intestine. The ruminant stomach contains millions of microorganisms (bacteria, protozoa, fungi) that break down and render available feeds that monogastric animals have difficulty in utilising.

The feed mainly consists of carbohydrates, which constitute around 75% of the dry matter content in the diet. Most carbohydrates (e.g. starch) can be broken down with the help of enzymes, while the breakdown of cellulose requires the presence of microorganisms. The microorganisms break down the carbohydrates in the feed to volatile fatty acids, with acetic, propionic and butyric acids dominating. When acetic acid and butyric acid are formed there is an associated release of hydrogen ions, which are damaging to cattle. However, methane-producing bacteria metabolise these hydrogen ions into methane and water (Berglund et al., 2008).

The release of methane involves energy losses for the animal, with on average 6.5% of gross energy in the diet estimated to be lost as methane (IPCC, 2006). These losses can vary greatly, between 2-12%, but with the most extreme values having been reported in experiments.

3.1 Measuring methane emissions

In the past, researchers have been interested in measuring methane production in ruminants since methane formation in the rumen involves energy losses for the animal. Methane production in individual animals has been measured in respiration chambers, head boxes and with ventilated hoods/face masks. The most modern measuring technique is a tracer technique using the gas sulphur hexafluoride, SF_6. A permeable tube containing a calibrated quantity of SF_6 is placed in the rumen, samples of expired air are taken at certain intervals and the CH_4/SF_6 ratio is calculated. Measurement of methane gas can also be carried out in full-scale houses, while there are in vitro methods with artificial rumens. Recently published empirical data from other countries (e.g. New Zealand, France, Brazil) are based on the tracer technique using SF_6 and it can be used for tied and loose-housed animals. This measurement technique is considered to give satisfactory results. Measurement of gases in animal houses requires a continuous measurement technique and very accurate calibration of instruments and gases.

At the present time, we have no actual Swedish empirical data on methane production in beef animals in meat production, so our input data are estimated using various mathematical models. All these models are based on determining or estimating the energy intake of the animal. When the different models are compared, it is important to know the energy concept referred to, since different concepts are used in different countries. Figure 1 illustrates the energy concepts used in evaluation of feed energy content. Gross energy is the value obtained when the feed is combusted and is rather similar for most feeds when calculated per kg dry matter. The International Panel on Climate Change (IPCC) guidelines for calculating methane emissions from ruminants are based on gross energy (see below). In Sweden, feed energy content is still evaluated in terms of digestible energy, while in neighbouring countries feed calculations are based on net energy.

In order to compare simulated values of methane emissions from different countries, it is important to have a standardised method for the calculation of e.g. feed energy content and to be able to derive every parameter. It can be difficult to derive the chemical composition of the feed and the underlying equations used to calculate methane production. The standard analyses of feed carried out today do not always cover the parameters required in the mathematical models. In addition, not all feed is analysed on a real farm and it is impossible to reliably determine what each animal actually consumes in total.

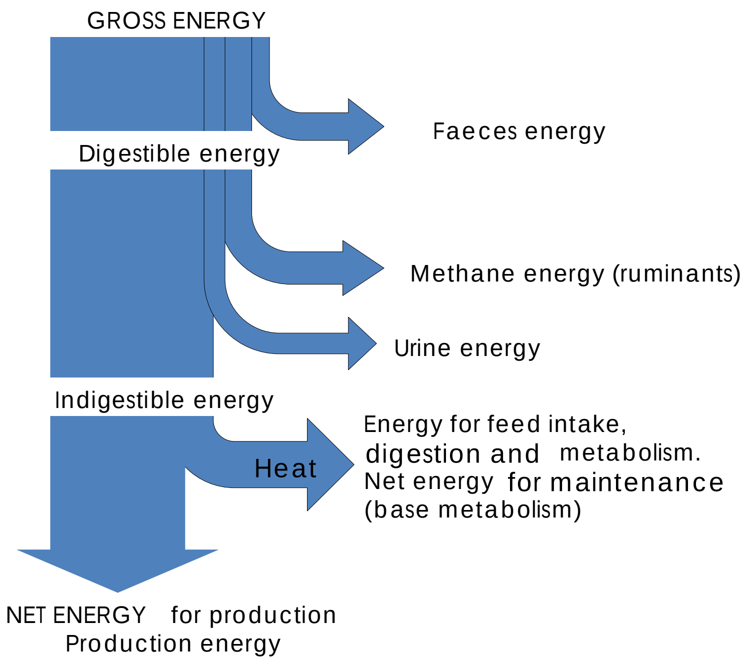

Figure 1. Various energy concepts used in evaluation of ruminant feed.

The IPCC guidelines include models for calculating methane emissions from digestion of feed by domestic animals (IPCC, 2006). These calculations are based on the energy requirement of the animals (given as gross energy) and the proportion of energy lost as methane. The energy requirement is calculated from the maintenance and production requirements. Factors affecting this include milk yield, work, animal growth and pregnancy. Account is also taken of the quality of the feed, with low quality giving low digestibility and thus higher methane emissions. In the simplest mathematical models, standard values (Tier 1) are allocated to different categories of animals and regions of the world. For western European conditions, the standard value for emissions for all cattle (except dairy cows) is 57 kg CH_4/animal and year. In Swedish reporting of greenhouse gases, the Environmental Protection Agency uses an emissions factor of 78 kg CH_4/animal and year for beef cows and 50 kg CH_4/animal and year for other beef animals. Berglund et al (2008) suggest reference values for evaluating methane emissions from meat animals of 72-82 kg CH_4/cow and year and 56-61 kg CH_4/bull and year, the variations being due to intensity, diet, etc.

The underlying data used for the Environmental Protection Agency's calculations of methane emissions from Swedish cattle are based on studies performed by Erik Lindgren at the end of the 1970s in which methane emissions from ruminants were calculated using literature data comprising 2500 individual determinations of methane losses. Mean methane losses amounted to 11% of digestible energy (see Figure 1) However, the results varied greatly and greatly and therefore this percentage figure is not recommended for use as a mean value for average methane losses from ruminants (Lindgren, 1980). According to the review carried out by Lindgren, methane production is mainly dependent on the amount of digestible carbohydrates supplied, but also the feeding level. Methane production, expressed as a percentage of feed intake, decreases when feed intake decreases and increases when feed intake increases. Carbohydrate digestibility also affects methane production. Lower digestibility of the carbohydrates, such as those in coarse forage, gives higher methane production than when the diet contains more digestible carbohydrates, for example by-products from the sugar industry.

3.2 WAYS TO DECREASE METHANE EMISSIONS FROM RUMINANT METABOLISM

3.2.1 FASTER GROWTH

Methane formation is a function of feed digestion in the rumen and the feed is used partly for growth and partly for maintenance. If growth is low, the majority of the feed is used for maintenance, while if growth is high the proportion used for growth increases. To summarise, this means that a high growth rate gives lower methane emissions per kg meat. High growth can be achieved in different ways, e.g. choice of breed, but the most important factor is the quality of the feed and, of course, the quantity. The feed must be palatable and have a high digestibility to allow high consumption and growth. However feed production causes emissions of greenhouse gases and these differ considerably between different feedstuffs – so consideration must also be given to feed production, i.e. the advantages of high growth can be 'eaten up' if it means that production of the feed caused high emissions. In addition, the feed must not compromise animal health as sick animals have poor growth. More on this below.

3.2.2 HEALTHY AND FERTILE ANIMALS – ANIMAL HEALTH

One factor in the total climate impact of specialist beef production is the number of calves a suckler cow has during her lifetime, since total emissions of greenhouse gases by a cow must be distributed over her calves and her slaughter weight. Having more calves per cow thus lowers the total emissions per kg meat for the entire system (suckler cow plus progeny). Lower calving age and production of a calf every year are important in achieving this, provided that animal health remains unimpaired, since otherwise the profits are soon eaten up.

The most important factor as regards animal health in beef production, however, is calf mortality. A high proportion of the bulls reared for meat production are bull calves from dairy farms (Table 1). Today it is becoming increasingly rare for those calves to be reared on the farms where they were born and instead they are sold on to farms specialising in beef production. When the calves from different herds are mixed in what are becoming increasingly large groups due to current farm rationalisation, the risks of parasites and diseases being spread are high and mortality can be up to 5% in the worst case scenario (M. Törnqvist, pers. comm. 2009). This can be counteracted by having between-farm agreements whereby calves are bought in from dairy farms through a planned contract and where the number of different farms from where calves are obtained is restricted. In order to receive government aid in the event of a salmonella outbreak in a beef herd, calves may only be bought from a maximum of five different herds. There is currently no organised system for between-farm agreements but this system is increasing at the expense of traditional calf trading since meat producers have seen clear benefits with it due to e.g. decreased disease pressure. The problem is perceived to be greatest for bull calves from dairy herds, which are reared in large herds, and less in production of dairy steers, since this takes place in smaller herds, is more extensive (longer rearing period) and involves outdoor grazing (M. Törnqvist, pers. comm. 2009). According to statistics from Taurus Beef Advisory AB, mortality in Swedish beef production with suckler cows was between 3.2 and 8.7% from birth to weaning (including stillborn calves) for the period 2002 to 2008 (Taurus, 2009).

The Swedish Animal Health Service have a division (Beef Animal Health) that monitors the production and health of beef herds and provides advice on how animal health in the herd can be improved.

3.2.3 Choice of feed and feeding level

As mentioned above, methane formation diminishes if feed with a higher digestibility is used. Recent results from trials at Kungsängen Research Farm, SLU, measuring methane emissions from dairy cows on different diets showed that provided high quality (high digestibility) forage was used, there were very small differences in emissions per dairy cow for two different diets consisting of 50% or 70% forage (Danielsson, 2009). An increase in the proportion of concentrate brings other undesirable environmental effects from a climate perspective (higher emissions of CO_2 and N_2O) and also greater use of pesticides, lower biological diversity and probably also eutrophication. A good grass sward generates lower greenhouse gas emissions per MJ digestible energy harvested compared with cereals, approx. 30 g CO_2-equiv/MJ digestible energy for silage and 35-40 for cereals (recalculated from Flysjö et al., 2008 and the standard energy content of the feed). A characteristic of high quality forage is that it has a high digestibility and this is very important to consider when composing the overall diet. Other aspects include the potential for improvement in choice of feed as summarised in section 6, ‘Feeding’.

3.2.4 Suggested improvement measures

Our conclusion is that the most important measure to decrease methane emissions from the overall beef production system, including the interaction with milk production, is to increase efforts at farm level to improve animal health, in particular to decrease calf mortality, improve fertility (avoid long calving intervals) and decrease the need for medication (healthy animals). Animal health should also be monitored by an advisory system so that measures can be taken in herds where mortality is high. The need for such an advisory system exists primarily in large herds. In small herds the infection pressure is lower, as it is on dairy farms where the bull calves are kept on for fattening to slaughter (not exposed to new infections).

4 Ways to decrease emissions of nitrous oxide and methane (other than from animal metabolism)

There are many ways to decrease greenhouse gas emissions from manure management. A fundamental requirement is to manage the nitrogen, which involves measures to decrease nitrogen losses and overfeeding of protein. It also involves decreasing losses of methane and reactive nitrogen compounds, e.g. through appropriate technical design and the collection of greenhouse gases.

4.1 Improving nitrogen use efficiency

Optimising protein feeding means that the nitrogen content in the manure can be decreased. It also means that the risk of nitrous oxide and ammonia emissions can decrease. In addition, cultivation of protein feedstuffs produces relatively high greenhouse gas emissions (Flysjö et al., 2008) and decreasing overfeeding of protein thus provides dual benefits.

By adding acid to slurry and thereby lowering the pH, ammonia losses can be decreased considerably, but the risk of nitrogen leaching increases slightly (Weidema et al., 2008). At lower pH values the equilibrium between ammonium and ammonia (the form that can be lost as a gas) is displaced so that the proportion of ammonium nitrogen increases. However, the net effect on greenhouse gas emissions is influenced by the way in which the effect of the nitrogen saved in the manure is evaluated and the amount of mineral fertiliser assumed to be replaced by the acid-treated manure. At low pH, however, a larger proportion of the nitrogen is lost as nitrous oxide through both nitrification and denitrification, and the direct nitrous oxide emissions from the stored manure are therefore higher (Sommer et al., 2001; IPCC, 2006). Research on acid treatment of cattle slurry has shown that methane emissions from the stored manure are greatly decreased (Faculty of Agricultural Sciences, 2008). The methane-producing microorganisms are sensitive to pH and their activity declines sharply at low pH values.

Within beef production, deep litter is being used to an increasing extent and from an environmental and resource perspective this is an unsuitable manure system. Losses of ammonia in the house and from stored manure are considerably higher than for slurry. Ammonia losses mean indirect emissions of nitrous oxide and also that the nitrogen in the manure is lost to the atmosphere instead of benefiting crops through manuring. For conventional producers this means using more supplementary mineral fertiliser (which involves production emissions), while for organic producers it means lower yields or having to purchase organic fertilisers (which leads to higher greenhouse gas emissions per kg manured crop) since nitrogen is often a limiting nutrient in organic production. When deep litter manure is stored (in the house and in a storage bay), in some cases emissions of both methane and nitrous oxide occur, since there are aerobic and anaerobic zones in the material.

Ammonia emissions vary greatly and depend on water content, pH, type of bedding, air exchange around the stored material, temperature and composition of the manure, so it is difficult to specify exact figures on ammonia emissions. In the Swedish Board of Agriculture's computer programme STANK in MIND (Jordbruksverket, undated), the following factors are used for deep litter systems: Losses in the house are 20%, while 30% of the nitrogen that ends up in storage is lost. Trials carried out by the Swedish Institute of Agricultural and Environmental Engineering (JTI) (Rogstrand et al., 2005) evaluated different ways to decrease ammonia losses from solid manure (not deep litter manure). Covering the material with a suspended rubber cover (as a simple roof) and incorporation of peat proved to be the most efficient methods, with a 28% reduction compared with normal storage in an open clamp. These measures would probably also decrease ammonia losses from deep litter, but this has not been investigated. The use of peat is debatable, since some consider it to be a fossil resource. Use of a covering can be an interesting alternative, however.

Solid manure systems have the same weaknesses as deep litter, although to a smaller extent, but ammonia emissions and nitrogen losses can be high. The emissions factor for ammonia used in STANK in MIND (Jordbruksverket, undated) is 4% in the house, while 20% of that which ends up in storage is lost as ammonia. According to measurements carried out on real farms, total nitrogen losses during the storage season amounted to between 16 and 18% of total nitrogen (Rogstrand et al., 2005). According to the same source, nitrogen losses decreased if there was efficient urine separation.

4.2 Decreasing direct emissions of greenhouse gases from stored manure

Methane and to some extent nitrous oxide are formed during storage of slurry, since the stored slurry itself is virtually anoxic. A project at JTI has examined methane and nitrous oxide formation in cattle slurry (Rodhe et al., 2008). The project included both experimental manure stores and actual stores with different coverings (no cover, floating straw crust and plastic sheet). The results showed that emissions of methane were considerably lower than those reported in the literature, a finding attributed to low temperatures and shorter storage duration. Nitrous oxide emissions were generally low, apart from in some cases where a floating straw crust was used. From the results summarised in Table 4, it is obvious that the floating straw crust did not reduce methane emissions as efficiently as the plastic sheet.

Table 4. Methane emissions from stored cattle manure with different coverings (Rodhe et al., 2008)

	kg CH_4 / kg VS	Kg CH_4 / cow&yr
Without cover	6.4	12.4
Floating straw crust	5.9	11.4
Plastic sheet	4.3	8.3

4.3 Biogas production from manure

Cattle manure, particularly slurry, can be a good substrate in biogas production. Cattle slurry gives a slightly lower biogas yield than e.g. pig slurry, since much of the readily degradable organic material has already been broken down in the rumen. Slurry is considered to be more suitable for biogas production than deep litter manure. Today, most biogas plants are based on fermentation in a liquid process and slurry works well in such a process. Such plants can find it difficult to handle deep litter manure in practice, since it needs to be broken down before being placed in the biodigestion chamber if disruptions to production are to be avoided. Deep litter manure also contains a lot of straw, which is relatively difficult to break down in the biodigestion process, while the composting that occurs in deep litter consumes some of the readily degradable organic material that would otherwise go to producing biogas. However, deep litter can be suitable for dry biodigestion, but there is a lack of experience of this process in Sweden.

It is considered more relevant to biodigest cattle manure in central biogas plants than in individual farm-scale biogas plants, since biogas production has major economies of scale and it can be difficult to finds outlets for all the gas at farm level. Beef enterprises mainly use electricity and diesel, and have no great need for heating. The farm-scale biogas plants that are being built today are mainly intended for heat or combined heat and power production. If manure production is 0.7 ton DM per animal and year (if all manure ends up in the house) and biogas yield is 175 m^3 methane per ton DM, this would give 1.2 MWh biogas per year (Berglund & Börjesson, 2003; Jordbruksverket, undated). If the gas were to be used for combined heat and power production with an energy conversion efficiency of 30% and a heat conversion efficiency of 50% (with half the heat used internally to heat the biogas plant), this would give just under 400 kWh of electricity and 300 kWh of heat per animal and year.

Without an outlet for the excess heat, it would be very difficult to balance the budget for farm-scale biogas production.

4.4 SUGGESTED IMPROVEMENT MEASURES

Measures that can decrease emissions of nitrous oxide and methane, in addition to those reported in Chapter 3, are:

- Efficient covering of stored slurry, for example using plastic sheeting. A floating straw crust is inadequate.
- Avoid deep litter manure
- If deep litter or solid manure are stored, this must be under a roof or equivalent (suspended rubber sheet).
- In solid manure systems it is important to separate out urine efficiently.
- Avoid overfeeding with protein
- Use slurry for biogas production

5 ENERGY CONSUMPTION

Energy consumption represents a relatively small proportion of the total greenhouse gas emissions from agriculture. Based on statistics on energy consumption in the agricultural sector and standard values for the climate impact of different energy carriers, these emissions are estimated to be just over 1 million tonnes of CO_2 equivalents per year (SCB, 2008; Berglund et al., 2009). This can be compared with estimated methane and nitrous oxide emissions from the Swedish agricultural sector of 8.8 million ton CO_2-equiv per year (Naturvårdsverket, 2009). This does not include emissions from the production of input materials such as mineral fertiliser and imported feedstuffs or the effects of changes in carbon stocks in the soil.

Total energy consumption in agriculture calculated for the year 2007 amounted to 3.1 TWh for heating, lighting, etc. (excluding residences and greenhouses) and 2.9 TWh in the form of fuel for vehicles (SCB, 2008, see Table 5). Energy consumption varies from year to year due to e.g. variations in the weather (which affects e.g. the oil required for drying) and structural changes.

Table 5. Energy consumption in Swedish agriculture, 2007 (SCB, 2008)

Energy category	Volume of energy consumed	Calorific value	Energy consumption (TWh)
Heating, lighting, etc.			
Oil	$5.6*10^4$ m^3	9.95-10.58 MWh/m^3	0.57
Wood	$4.8*10^5$ m^3	1.24 MWh/m^3	0.59
Straw	$6.1*10^4$ ton	4.1 MWh/m^3	0.25
Chippings, bark, sawdust	$2.8*10^5$ m^3	0.75 MWh/m^3	0.21
Other biofuels (grain, pellets, etc.)	n.a.	n.a.	0.11
Paraffin, etc.	n.a.	n.a.	0.010
Electricity			1.4

Total			***3.1***
Use in vehicles			
Diesel	$2.8*10^5$ m^3	9.8 MWh/m^3	2.7
Petrol	$1.3*10^4$ m^3	8.7 MWh/m^3	0.11
RME[1] + ethanol (E85)	n.a.	n.a.	0.04
Total			***2.9***

[1]*RME = rape methyl ester*

Although energy consumption represents a small part of the climate impact of agriculture, the climate question is strongly linked to energy consumption in a wider societal perspective. Measures aimed at improving energy efficiency or decreasing greenhouse gas emissions from energy consumption are therefore important in all sectors, including agriculture, in order to decrease the total climate impact of society and the dependency on fossil energy.

This chapter discusses the energy consumption that occurs on the farm and how the efficiency of this can be improved, i.e. by decreasing overall consumption and the proportion of fossil energy, but does not always calculate how greenhouse gas emissions are affected by these changes. The reason for this is that greenhouse gas emissions vary widely between different energy sources and thus the effects of changes in energy consumption are strongly affected by the type of energy assumed to be affected by the change. In terms of the entire life cycle of electricity, wind, hydro and nuclear electricity only produce a few grams of CO_2-equiv per kWh electricity, while greenhouse gas emissions from fossil fuel-based electricity are around a hundred times higher. The effects of increased efficiency in electricity or of new electricity production is thus very strongly affected by the assumptions made about the origins of the electricity. This reasoning also applies to the effects of producing biofuel on the farm, since the biofuel can replace fossil fuel or other renewable fuels. In order to assess and optimise the effects of increasing energy efficiency or energy production, there is also a need for a wider societal perspective where account is taken of how the changes affect the entire energy system and where e.g. the biofuel produced can be used to best advantage.

This chapter deals with the direct energy consumption that takes place on the farm, e.g. in the form of diesel for tractors, but not the indirect energy consumption that can be associated with the production of mineral fertilisers, purchased feeds and other external inputs. However, it is important to note that the same units (e.g. MJ) are used for different energy sources and energy carriers, but despite this they are not directly additive and comparable. One MJ of biofuel cannot be used for the same purposes and does not give the same benefits as 1 MJ of diesel or 1 MJ of electricity. The biofuel can admittedly be used e.g. to produce electricity, but conversion losses mean that more than 1 MJ of biofuel is needed to produce 1 MJ of electricity. One way to compare different types of energy is therefore to convert them to primary energy, which involves specifying the amounts of natural resources used in production of raw materials, production, distribution, etc. One MJ of electricity produced in a natural gas power station with a conversion efficiency of 50% would thus be equivalent to approx. 2.2 MJ of primary energy in the form of natural gas (incl. harvesting of the natural gas and distribution losses in the electricity grid). However, like other energy carriers and energy sources, electricity can be produced in many different ways with differing conversion losses and therefore different conversion factors. The primary energy concept can also be difficult to assimilate intuitively. Therefore where possible, energy consumption is divided into electricity, diesel, biofuel, etc. here in order to make reporting as transparent as possible.

5.1 ENERGY CONSUMPTION IN BEEF ENTERPRISES

5.1.1 WITHIN-FARM CONSUMPTION OF ENERGY

There have been few reviews of energy consumption in beef production. The rearing system, and thus also the energy requirement, can vary widely between farms. Energy consumption and the relative proportions of electricity and diesel used for tractors and front loaders is determined by the system used for manure management, feeding, ventilation, etc. Feeding and manure removal with a loader or tractor give rise to high diesel consumption. One explanation is that the efficiency is considerably worse in a diesel engine than in an electric engine. It is estimated that approx. 25% of the energy supplied as diesel ends up as axle power from a tractor, while the efficiency of an electric motor is around 80-90%. The electricity requirement for ventilation is of course strongly affected by whether mechanical or natural ventilation is used.

The data available on energy consumption in beef production vary greatly. The Swedish Rural Economy and Agricultural Society calculations are based on e.g. electricity consumption of 175 kWh per animal place and year for beef bulls and approx. 300 kWh per animal place and year for bullocks and steers (Hushållningssällskapet, 2008). In an LCA of beef from conventional young bulls, electricity consumption was estimated to be around 280 kWh per bull produced, and diesel consumption for extraction and feeding of silage to be 3.4 litres of diesel per bull produced (Cederberg & Darelius, 2000). The bulls were reared on slats. That LCA also included an organic suckler herd with a long grazing season and very simple houses with deep litter. Electricity consumption in the latter system was estimated to be 37 kWh per slaughter animal, while diesel consumption for feeding, bringing in straw and bringing out the deep litter was estimated to be 44 litres per beef animal during its entire lifetime. In an energy study by LRF Konsult involving two farms with suckler cows, energy consumption per slaughter animal was estimated to be 220 kWh electricity and 300 kWh diesel in a modern unventilated outhouse and 260 kWh electricity and 880 kWh diesel in an old house (Neuman, 2009).

It is difficult to identify individual measures to increase energy use efficiency in beef production due to the huge differences between rearing systems and thus the huge differences in conditions and requirements between farms. To keep energy consumption down, it is important to plan for rational and energy-efficient operations in new builds or renovations. If possible, it is good from a greenhouse gas perspective to choose electric-powered equipment instead of diesel-powered as the efficiency is much higher in an electric engine than in a combustion engine. In addition, greenhouse gas emissions per kWh electricity are considerably lower (applies e.g. to the hydro and nuclear power that dominates Swedish electricity production) than per kWh diesel. It is also important to avoid running equipment monitoring or maintenance systems unnecessarily, e.g. the electricity supply to heat water bowls or other equipment to prevent water from freezing should only be in operation during the cold period.

5.1.2 ENERGY CONSUMPTION IN FIELD WORK

The energy requirement during **harvest** and **storage** of forage is affected by the choice of management system (see Table 6). Different storage techniques have somewhat different energy consumption, but attention should also be given to the design of the feeding system. In a Life Cycle Analysis of feed, the total energy consumption from harvest to feeding trough was estimated to be somewhat lower for hay and silage from a tower silo than for systems with round bales or a bunker silo (Flysjö et al., 2008). However this study included the petroleum products used in manufacture of the plastic. It should also be borne in mind that electricity, mainly for fans, comprises around three-quarters of the energy consumption in harvesting and storage of artificially dried hay, while electricity consumption is considerably lower for other options. Identification of the most energy-efficient option is affected by how the analyst chooses to evaluate electricity in relation to diesel. Maintenance is an important measure in keeping diesel consumption down during forage harvesting. In a silage harvester, a large proportion of the energy (~1/3) is used for chopping and blade sharpness is therefore important in decreasing consumption (Fogelberg et al., 2007).

In managing and spreading **manure**, transport between store and field comprises a relatively large proportion of diesel consumption, and the transport distance is therefore highly significant. Pumping slurry instead of transporting it by tractor to the field can reduce energy consumption considerably, especially if an electric pump is used. If manure has to be transported to satellite wells in the field or to another farm, transport by lorry is more energy-efficient than transport by tractor. Another way to improve the efficiency of manure management is to reduce the volume, e.g. by putting a roof over the manure store and thus decreasing the entry of rain water. Rain water falling on a slurry tank can comprise 15-20% of the volume of the slurry, based on annual rainfall of 500-800 mm and a tank depth of 3-4 m. Covering the stored manure also decreases ammonia emissions, which is positive from a climate perspective since it leads to lower indirect nitrous oxide emissions and allows for greater use efficiency of the manure nitrogen.

Road transport by tractor is a more energy-demanding option than transport by lorry. Diesel consumption in transport by tractor lies within the range 0.035-0.08 litres per ton*km (load weight ~8-20 ton). The corresponding figures for lorries are 0.03-0.04 l/ton*km for a medium-weight lorry (load capacity approx. 15 ton) and 0.012-0.02 l/ton*km for a heavy lorry with trailer (load capacity 40 ton). With hay and straw, for example, load size can be limited by volume instead of weight, and diesel consumption per ton*km is then higher (Fogelberg et al., 2007).

Table 6. Key data on diesel consumption in field work (Lindgren et al., 2002; Edström et al., 2005; Baky & Olsson, 2008)

Operation	Diesel consumption (l/ha)
Ploughing	15-30
Stubble cultivation	10-17
Drilling + rolling	5-10
Spreading mineral fertiliser	1-5
Spreading slurry	6-13
Spreading farmyard manure	5-8
Spraying	1-5
Harvesting, wheat/barley	20-25
Mowing conditioning, per cut	5-8
Precision chopping, per cut	Approx.14
Bringing in hay (trailer) + transport (around 1 km), per cut	5 + 5
Transport of silage (around 1 km), per cut	3
Round baling + wrapping, per cut	Approx.10+10
Packing in bunker silo, per cut	Approx. 5

General measures to decrease diesel consumption in tractor work include regular machine maintenance, avoiding engine idling or excessive wheel slip (10-20% wheel slip gives the best efficiency) and driving at the right rev count and with a high power output. Correct setting of tyre pressure decreases diesel consumption slightly. A somewhat lower tyre pressure in field work gives better grip and less wheel slip, while a higher pressure decreases surface resistance in road transport.

Ecodriving decreases energy consumption, greenhouse gas emissions and diesel costs and thus provides a direct financial benefit for the farmer. Ecodriving involves e.g. choosing the best gear and engine load for the task in hand, minimising idling and avoiding unnecessary work. Incorporation of ecodriving into tractor work has been shown to give fuel savings of around 20% (Fogelberg et al., 2007). In occasional demonstration events considerably greater savings have been recorded, while the time requirement is also decreased when driving is more carefully planned.

There are cases where tractors can be fuelled fully or partly with biofuels such as FAME (fatty acid methyl esters), including e.g. rape methyl ester (RME), biogas or ethanol. The most realistic alternative today is considered to be a low inclusion of biofuel, e.g. RME, in the diesel. This measure gives only a small decrease in greenhouse gas emissions from individual vehicles, but since it does not require any major alterations to the vehicle fleet and can be implemented on a very large scale, it is a simple way to increase the proportion of biofuel. Nearly all the FAME usage in the transport sector currently consists of low inclusion in diesel, and in 2007 two-thirds of the diesel used contained 2-5% FAME (Energimyndigheten, 2008). Total greenhouse gas emissions from a tractor are estimated to be 3.25 kg CO_2-equivalents per litre of diesel (without inclusion of biofuel, but including emissions from production, distribution and end-use). With low inclusion of 5% RME, emissions would be 3.20 kg CO_2-equivalents per litre of fuel (including emissions from growing the rape, production, distribution and end-use). More refined biofuel alternatives may require greater adaptations and adjustments, e.g. addition of an ignition improver so that ethanol can be used in diesel engines or fitting of pressurised tanks for biogas. The use of biogas as a vehicle fuel is also regulated by far-reaching legislation, and current legislation on approval of tractor types only covers liquid fuels. Those wishing to use farm-produced biogas as a tractor fuel also need to consider that biogas production is relatively constant during the year, whereas the fuel requirement of tractors follows the crop growing season and thus varies greatly. Long-term storage of biogas is not an option due to the high costs, so other solutions are needed to find an outlet for the gas. There is a need for deeper systems analyses in order to assess how and where biofuels can best be used in society and this may be in other contexts rather than as a fuel for agricultural machinery.

5.1.3 SUGGESTED IMPROVEMENT MEASURES

It is difficult to identify specific measures on energy consumption that should be included as a criterion in climate certification of beef. The situation and requirements differ between farms and thus also the scope for, and effects of, different measures. Energy consumption also has a relatively small influence on the total climate impact of beef production.

We suggest two overarching measures (*Improvements at investment* and *Energy mapping*, see below) to be adapted to the situation on the farm. These measures are relevant regardless of farm enterprise and should therefore be coordinated with the general regulations for climate certification and applied to all types of farms in a climate certification system. The aim of these measures is to improve the efficiency of farm energy consumption, partly through decreasing total energy consumption, and partly through increasing the proportion of renewable energy. This can also cover utilising resources on the farm for energy generation, e.g. from manure.

Criteria at investment

In order to decrease energy consumption by farm businesses, it is important that the right choices are made when investments are being planned, e.g. new builds, renovations or replacement of old equipment. Energy-efficient equipment and system solutions should be prioritised to lower energy consumption and costs. One way to identify good solutions is to calculate and compare the Life Cycle Costs of different options. When LCC are calculated, account is taken of the investment costs and the operating costs (including energy costs and maintenance) during a certain number of years (e.g. the predicted lifetime of the product). Operating costs and energy consumption often represent a considerable proportion of the total life cycle costs for energy-demanding equipment. It is also important to design installations according to the actual requirements.

The following are some examples of energy-demanding processes for which the life cycle costs should be considered at investment, with possible options to be weighed up:

- Feeding: Is it possible to have a high proportion of electric-powered equipment for feeding and filling tower silos? System solutions for short and efficient transport between feed store and animal house.
- Manure removal: Is it possible to have an electric-powered manure moving system or can slurry flow to the tank?
- Lighting: Plan for good use of natural light and control of lighting.
- Ventilation: Natural ventilation, rev count limiters in mechanical ventilation.

Energy mapping

Energy mapping on the farm provides information about where the energy is actually used and the potential for improvement that exists. In general, farms keep a good check on the cost of total consumption of electricity, diesel, etc., but are less aware of the proportion of that electricity and diesel that goes to different processes. Analysis and documentation is necessary to give a good understanding of the situation on the farm and to establish a good foundation for monitoring farm energy consumption. Energy mapping should include a review of current energy consumption on the farm, subdivided into different types of energy and how total energy consumption is distributed between sub-processes, and the calculation of key data (e.g. kWh electricity per animal place and year or litres of diesel per hectare). The mapping should also include suggestions for efficiency improving measures that substantially affect energy consumption on the farm and that are practically and financially feasible to introduce. It is important for the mapping and introduction of measures to be monitored regularly. The key data can be used for comparisons in subsequent monitoring and updating of the energy mapping. At present, there are few general key data that can be used to determine the status of the farm in comparison with other businesses. However, work is being done in various projects and by farming and advisory organisations to produce such key data.

Energy mapping can be carried out either by an energy advisor or by the farmer himself. The advantage of employing a specialist energy advisor is that they have good knowledge of possible solutions and the options available on the market. Energy is used in many different areas and in different ways on the farm, and there are a number of possible technical and system solutions. It can therefore be difficult for the individual farmer to keep abreast of all that is happening within the area of energy area of relevance for farm operations. It can also be good to have a fresh external eye that can uncover areas of potential improvement and systematically analyse energy consumption on the farm. A number of advisory organisations offer various types of energy advisory services at present, including the Rural Economy & Agricultural Societies and LRF Konsult. There are also courses available in ecodriving at e.g. the local authorities. In addition, at the beginning of June 2009, the government tasked the Swedish Roads Administration, the Swedish Board of Agriculture and the Swedish Forest Agency with drawing up an action plan for promoting ecodriving of large diesel-powered machinery within e.g. road work and forestry (Regeringen, 2009). However, if a requirement is set that energy mapping must be carried out with an energy advisor before entry into climate certification, there is a risk of lack of capacity since there are relatively few agricultural energy advisors. The alternative, where the farmer carries out the energy mapping, demands the availability of a full range of good data. Today there are e.g. simple and general formulae that can be used to estimate how electricity consumption is divided between different processes on the farm (Hadders, undated), but as far as we are aware there are no complete or enterprise-specific data that are intended for use directly by farmers. However, work is underway to develop various tools, e.g. at Odling i Balans, the Rural Economy & Agricultural Societies and LRF Konsult.

Measures to be identified in energy mapping can include:

- ***Greater radical changes***, e.g. in the form of investment in more energy-efficient technology or conversion to reduced tillage where that is considered a possible solution.
- ***Training*** in e.g. ecodriving, reduced tillage or precision cropping.
- ***Procedures at the point of purchase,*** e.g. how life cycle costs should be taken into account on purchase of energy-demanding equipment, or the demands that should be set when signing energy contracts or purchasing fuel and oil (e.g. low inclusion of RME in diesel).

- ***Maintenance procedures***. The energy requirement can be decreased through good maintenance. This includes keeping e.g. fittings, ventilation channels, etc. free from dust and dirt and drawing up a schedule for regular checks of equipment.

6 FEEDING

Emissions from the growing and production of different types of feedstuffs and suggested criteria for climate certification of feed are presented in a separate report. Other measures within feeding that affect the total emissions from beef production include increasing efficiency (decreasing feed waste and overfeeding), changing the diet so that it includes a greater proportion of forage with low greenhouse gas emissions in its production chain and growing a large proportion of the feed close to the animals.

6.1 IMPROVING EFFICIENCY

Losses occur during storage and conservation of forage and these are mainly determined by the water content of the forage at entry and the conservation system used (see Table 7). As can be seen in Table 7, when the losses in storage and conservation are compared for the different systems, the lowest cumulative dry matter losses occur at the DM contents currently recommended for silage harvest. Note that for hay the greatest losses occur in the field (repeated turning) while losses during storage and conservation are relatively small. Making silage from very wet forage causes relatively high losses and also requires more energy since more water is transported with the forage.

Table 7. Losses (%) during storage and conservation of forage

% DM in forage at entry	Steel tower	Bunker	Big bales (plastic wrap)	Clamp	Hay
>15		25-35		30-35	
15-20		16-22		20-30	
20-25	10-15	14-18		18-25	
25-30	9-11	15-20	10-16	20-27	
30-40	8-9	17-22	8-12		
40-50	10-16		5-10		
50-60			8-12		7-12
60-70					4-7
70-80					3-4

Source: Svensk Mjölk, www.svenskmjolk.se

Feed waste, where conserved feed is not used in production but discarded, e.g. due to poor hygiene quality, causes unnecessary emissions of greenhouse gases. Practical experience shows that this is more common for forage than for grain and other concentrates. The silage-making process can fail, resulting in misfermentation, the plastic on round silage bales can be pierced by birds or voles or hay can become dusty during storage.

A common experience in advisory work is that there can be a great difference between the amount of forage the farmer estimates is harvested in the field and the amount of forage that eventually ends up in the feeding trough. It is difficult a devise a few simple criteria leading to direct measures that decrease feed waste, since the quantities of waste are not quantified and we do not know the current situation. First, official statistics on yields of forage are inadequate and many farmers do not weigh their forage, so we have a poor picture of normal grassland yields (production). Second, there are very few farmers who systematically weigh the amounts of forage consumed in beef production, i.e. we have unreliable data on actual consumption.

Since forage comprises the majority of cow and heifer feed intake during the housed period, (see Cederberg et al. 2009a, Appendix 1) and is also very important in the diet of bulls, our assessment is that high efficiency in production and consumption of forage, defined as low losses and low waste, is an important measure for decreasing greenhouse gas emissions in beef production. It is also very important for the forage to have good quality – particularly high digestibility – in order to minimise methane emissions from digestion and to allow a relatively high rate of growth.

Overfeeding, i.e. supplying more feed than the estimated requirements of the animals, is mainly believed to occur with forage in beef production, particularly with cows and heifers. Many farms do not use any feeding advisory services at all and do not carry out any analyses of forage, which means that it is very difficult to calculate the optimal diet. As discussed previously, overfeeding of protein increases the nitrogen content of the manure and thus also increases the risk of ammonia and nitrous oxide losses.

We consider analysis of forage and reviewing the diet with the aid of a feed advisor to be an important measure in decreasing overfeeding and in monitoring potential feed waste. For example, the advisory modules in Greppa Näringen covering diet appraisal have been shown to give good results.

6.2 Using feeds with lower emissions

In comparison with milk production, relatively little protein concentrate is used for beef herds. The diet is dominated by forage supplemented with different proportions of grain depending on the production system. Grazing often comprises a large proportion of the diet in certain systems, particularly organic production and for all cows and heifers.

Emissions of greenhouse gases can be decreased by altering the composition of the diet, i.e. by formulating diets with a lower global warming potential (GWP) value per kg feed. For this to be possible, information must be available on the climate impact of different feedstuffs and feed raw materials. The company Lantmännen has recently announced that it is to climate-declare its range of concentrate feeds. This declaration system will be based primarily on the SIK feed database (Flysjö et al., 2008). This move by Lantmännen to supply concentrates with lower greenhouse gas emissions compared with its current range is very interesting. Concentrate use in beef production is currently based on either complete feed, where the farmer buys a concentrate product containing both grain and protein, or a protein concentrate, where the farmer has grain on the farm and buys a concentrate consisting of different protein raw materials, currently mainly rapeseed meal and soyabean. If a climate certification system places demands on how forage and grain are grown on actual dairy farms (see our report on animal feed production) and then opts for concentrate products that have verified low GWP values, this can drive a change towards feed production for the beef industry that decreases total greenhouse gas emissions relatively significantly.

Soyabean meal is a protein concentrate with relatively high emissions and when the effects of deforestation from expanding soyabean cultivation in South America are included this protein feed has an even higher carbon footprint. To date, emissions from deforestation have not been included in the GWP value of feeds, since the methodology is insufficiently developed in terms of how emissions should be allocated to different products from the deforested area (e.g. lumber, grazing, soya, maize), how the time factor should be accounted for and how to deal with the indirect effects of changes in land use. According to the FAO report ‘Livestock´s Long Shadow’, an estimated 6% of global greenhouse gas emissions are caused by deforestation carried out in South America to provide more land for grazing and feed production. We consider that there are complete alternatives to soyabean meal in beef rearing (peas, field beans, rapeseed meal) and therefore it is reasonable to completely exclude this protein feed in a climate certification system for beef. The same applies for palm kernel expeller, which is a concentrate raw material of little significance but with a relatively high GWP value due to long transport distances from south-east Asia.

For organic concentrate raw materials there is no database with GWP values per kg feed, as discussed in our report on feed. In the past, a small proportion of conventionally produced concentrate was permitted. Today, however, there are demands for 100% organic feed and in order to achieve low to acceptable emissions per kg feed, it is important that yields are maintained at a reasonable level and that excessive nitrogen is not supplied via green manure crops (see our report on animal feed production).

6.3 Increasing the proportion of locally grown feed

If a large proportion of the feed is grown near to the animals, transport of feed decreases. Here the concept ‘near’ refers to forage growing on animal farms or feed growing in partnership with neighbouring arable farms producing e.g. grain and legumes for direct delivery to the beef producer and taking back the manure. Since a very large proportion of the feed in beef production is forage and grain grown on-farm, plus a small fraction of grain coming via the feed industry (Cederberg et al., 2009a), a large proportion of the feed is already being ‘locally produced’. For very specialised beef herds with large amounts of manure and a limited area for spreading this, it is desirable to have some form of between-farm contract.

6.4 Grazing

As mentioned previously in section 2.2 ‘Carbon stocks in the soil’, grazing provides the opportunity to utilise permanent grasslands and leys on arable land. Despite the limited availability of data and the need for extensive research before quantified data on the actual effects of greenhouse gas flows can be generated, our level of knowledge is sufficient to support the claim that grazing is highly likely to lead to net storage of carbon in the soil under Swedish conditions.

6.5 Suggested improvement measures

Good use efficiency of feed is important for greenhouse gas emissions from beef production. The efficiency can be increased by decreasing overfeeding and feed waste. Feedstuffs with high greenhouse gas emissions should be phased out. Forage grown with little or no addition of mineral fertiliser and that is harvested with good quality and high digestibility has good potential to give high growth in production, while also lowering the greenhouse gas emissions from production and giving other positive environmental effects. It is desirable for an increasing proportion of the feed to be grown on beef farms or in partnership with neighbouring arable farm/s, in order to decrease feed transport and provide better opportunities for the manure to be used as a plant nutrient resource in feed growing. Soyabean meal and palm kernel expeller should be completely avoided due to high emissions in production, transport and negative effects on land use due to the expansion of cropping in rainforest areas.

Grazing of well-managed and productive grasslands is highly likely to be positive for carbon stocks, although there may be exceptions. However, more information is needed in order to quantify the climate effects under Swedish conditions.

7 Proposed criteria for beef production

The criteria we have identified are presented below. These are based on the suggested improvements described earlier in this report. The difference is that the criteria must be appraisable and must provide unequivocal improvements. This means that certain suggested improvements at the present time cannot form the basis for criteria, but this may change as more knowledge of production systems is generated.

These proposals apply for both conventional and organic beef production.

An important line of demarcation for the beef sector is that production based on calves from dairy herds and cull cows generates considerably lower emissions of greenhouse gases than specialist production (suckler cow-based). The logical conclusion is thus that only 'dairy herd-based' production can be climate-certified. However, we consider that complete exclusion of specialist production from a climate certification system cannot be justified, as a large proportion of beef production in Sweden (and an even higher proportion internationally) consists of specialist production, and excluding this would mean providing no incentive for improvements in this form of production.

7.1.1 Feeding

Proposed criteria:

- Forage must be analysed.
- Feeding must be reviewed annually together with a feed advisor, e.g. through the Greppa Näringen module for feed monitoring.
- At least 70% of the diet during the housed period must consist of good quality forage.
- Feed produced on-farm must be climate-certified.
- Purchased feed must be climate-declared.
- Soyabean meal and palm kernel expeller are not permitted.
- Animals must be kept on productive grazing (not feedlots) during the grazing season.

Consequence analysis:

Well-managed grassland has positive effects for the carbon balance in the soil and gives a forage with a relatively low GWP value. In addition, grass leys and permanent grassland provide other positive environmental effects, e.g. increasing biological diversity and decreased use of chemical pesticides. New research shows that provided that the forage has high digestibility, methane emissions from ruminant metabolism do not appear to increase with forage intake. There are now protein feedstuffs that provide a complete alternative to soyabean and palm kernel expeller and therefore we consider it to be relatively problem-free to completely avoid these feedstuffs in beef production.

7.1.2 Manure management

Proposed criteria:

- Manure must not be applied to autumn cereals.

- Manure must be analysed in terms of nitrogen content.

7.1.3 Energy on the farm

Proposed criteria:

- Energy mapping must be carried out on entry into climate certification. This mapping must include a review of energy consumption on the farm, the calculation of key data and creation of an action plan. The action plan must be monitored and the mapping revised every 5 years.
- In conjunction with new investment or re-investment, new builds or renovations, the energy efficiency of energy-demanding processes, e.g. ventilation, feeding, lighting, must be taken into account and consideration given to the energy-related life cycle costs of different options.
- Low inclusion of RME in the diesel used on the farm.

Consequence analysis:

The criteria for energy consumption have a limited impact on actual greenhouse gas emissions from beef production, where energy consumption is less important than for other animal products since total emissions from beef are higher so the relative contribution from energy consumption is lower.

7.1.4 Production efficiency

Proposed criteria:

- The highest permissible slaughter age for bulls is 18 months.
- The high permissible slaughter age for steers and heifers is 24 months.
- For specialist beef production, the highest permissible calving age for heifers is 26 months as a herd average.

Consequence analysis:

The single greatest item in the emissions budget is methane from ruminant metabolism. Through having efficient production, i.e. a high growth rate and many living calves per suckler cow, reductions in greenhouse gas emissions are possible. The above criteria presume that growth rate does not decline, a parameter for which high quality forage is very important.

7.1.5 Animal health

Proposed criteria:

- For specialist beef production, mortality between birth and weaning must be lower than 5% (including stillborn calves).
- The production enterprise must be a member of the Swedish Animal Health Service's beef animal health programme

Consequence analysis :

Decreasing mortality is a relatively effective and unequivocal way to decrease emissions of greenhouse gases.

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