KLIMATMÄRKNING FÖR MAT.

REPORT 2009:3

GREENHOUSE GAS EMISSIONS IN MILK PRODUCTION

DECISION SUPPORT FOR CLIMATE CERTIFICATION

Written by Ulf Sonesson, Christel Cederberg and Maria Berglund
Translated by Mary McAfee

Contents

1 INTRODUCTION

Swedish Life Cycle Assessment (LCA) studies show that greenhouse gas emissions from the entire life cycle of milk production up to the farm gate correspond to 1 kg CO_2-equiv[1] per kg milk (Cederberg & Flysjö 2004; Cederberg et al., 2007). This includes emissions during production and end-use of all the input materials and from biological processes, apart from changes in the carbon stored in biomass and soil due to land use in feed production. A review of LCA studies from ten OECD countries shows that estimated emissions up to farm gate vary within the range 0.8-1.4 kg CO_2-equiv/kg milk, while a review of studies from six European countries shows emissions in the range 1-1.4 kg CO_2-equiv/kg milk (Sevenster & de Jong, 2008). In these studies there were minor differences between total greenhouse gas emissions per kg conventional and organic milk, but the relative proportions of the greenhouse gases differed somewhat. Organic milk production has higher methane emissions per kg milk due to the lower yield of the cows, but lower emissions of CO_2 and N_2O due to lower energy consumption and no use of mineral fertiliser.

Swedish milk production thus appears to lie within the lower end of the range as regards greenhouse gas emissions per kg milk. However any comparisons must be interpreted with caution, since methods and assumptions can differ somewhat between different studies, e.g. in terms of how system boundaries are set and how the by-product meat has been allocated. Emissions in transport and processing beyond the farm gate are estimated to increase emissions per kg milk by an additional 10-20% (Sevenster & Jong, 2008). The magnitude of these emissions depends on a number of factors, e.g. transport distance, energy consumption in creameries and degree of processing of the product.

This report deals with emissions in primary production, i.e. up to the farm gate. The largest contributor to greenhouse gas emissions from milk production is methane emissions resulting from feed metabolism by cows and recruitment heifers (40-45%). The next largest is feed production, which is estimated to represent 35-40% of total emissions and which is dealt with in a separate report. The remaining emissions come from manure, with methane production from slurry being the most important contributor, and direct energy consumption in milk production. Since the electricity used in Sweden comes from electricity generation processes with relatively low CO_2 emissions, electricity consumption in dairy houses is of little significance for total greenhouse gas emissions.

[1] 'Carbon dioxide equivalents' (CO_2-equiv) are used to allow comparisons of the greenhouse effect of different climate gases. In these LCA studies the conversion factors are based on former IPPC guidelines from 1996 (which are also used in the Kyoto protocol), i.e. 1 kg CH_4 = 21 kg CO_2-equiv and 1 kg N_2O = 310 kg CO_2-equiv . The most recent IPCC guidelines give the conversion factors 1 kg CH_4 = 25 kg CO_2-equiv and 1 kg N_2O = 298 kg CO_2-equiv (IPCC, 2007).

2 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 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. A dairy cow yielding 9 000 kg milk annually is estimated to produce around 120-130 kg methane per year.

2.1 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 SF_6[2]. 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. This method is being used in studies on dairy cows initiated in autumn 2008 at Kungsängen, SLU. 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 ruminants, 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 2.1 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

[2] Sulphur hexafluoride

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.

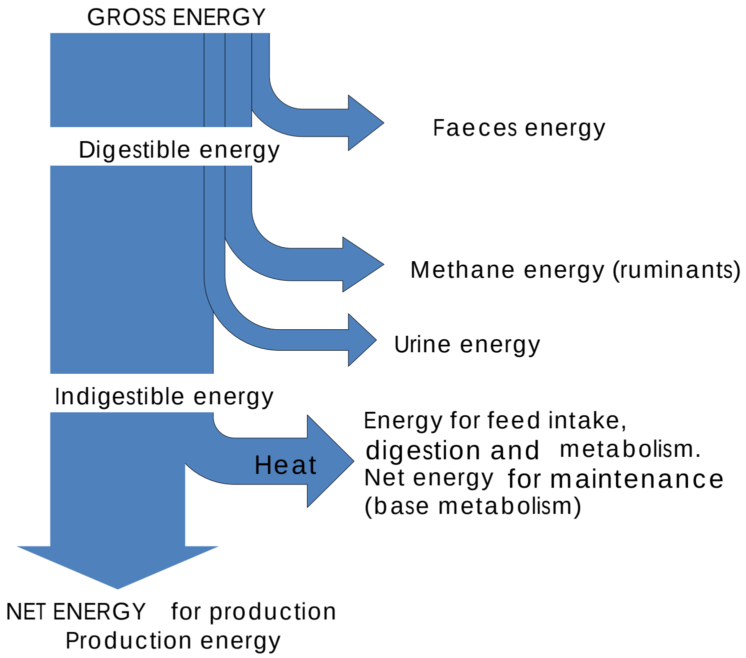

Figure 2.1. Various energy concepts used in evaluation of ruminant feed.

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 from dairy cows is 109 kg CH_4/animal and year at a yield of 6000 kg milk/yr. This yield level is far lower than the average for cows included in the Swedish dairy cow programme. More advanced mathematical models according to IPCC guidelines (Tier 2) include parameters such as live weight of the animal, milk production/day, the proportion of cows producing one calf per year and the digestibility of the feed. Feed digestibility is an important parameter in calculating the amount of energy available to the animal. The guidelines provide suggestions on digestibility coefficients for different categories of animal. The calculations in the IPCC guidelines (Tier 2) are based on net energy, which is currently a common measure in a number of countries. In Sweden we use the metabolisable energy concept at present, but the forthcoming feed evaluation system NORFOR uses net energy in calculations. The IPCC guidelines specify methane losses as a percentage of gross energy and therefore one has to calculate back to gross energy from the energy values that are available.

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. However, the results varied 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 grass, gives higher methane production than when the diet contains more digestible carbohydrates, for example by-products from the sugar industry.

An evaluation of various mathematical models commissioned by the Environmental Protection Agency proposes that Sweden use the Lindgren model in its reporting under the Climate Convention (Bertilsson, 2001). One of the reasons for this is that the Swedish feeding norms can be used to enter relevant data into the Lindgren model, since Sweden uses metabolisable energy, while it would be necessary to recalculate the energy content of the feed to net energy in order to use e.g. the models given in IPCC guidelines (Tier 2). Today equations according to the Lindgren model are used, together with Bertilsson's (2001) assumptions regarding digestibility, proportion of forage, etc., in the Environmental Protection Agency's reporting of Swedish greenhouse gases (Naturvårdsverket, 2007).

A German mathematical model by Kirchgessner et al. (1991) is often used in calculating methane emissions from dairy cows. This is based on cow weight and milk yields in trials on 67 milking cows.

Table 2.1 compares methane production from feed digestion by dairy cows calculated according to these different mathematical models. It can be seen that the emissions differ somewhat; calculations according to the Lindgren model indicate a lack of linear correlation between milk yield and methane emissions, whereas the IPCC model shows a clear linear relationship. Calculated emissions according to Kirchgessner et al. are somewhat lower than those in the other models. In LCA studies of a total of 46 dairy farms using input data from 2003 and 2006 (Cederberg & Flysjö 2004; Cederberg et al., 2007) the Kirchgessner et al. model was used, but upward adjustment was made for a certain degree of overfeeding, and thus the emissions factors in these studies are relatively similar to those used in the Environmental Protection Agency's climate reporting (i.e. Lindgren, 1980 updated by Bertilsson, 2001).

Table 2.1: Emissions factors for methane production by dairy cows (weight 600 kg) calculated using different mathematical models

Milk yield (kg ECM)	Methane production (kg CH_4/cow and year)			
	Lindgren[1]	IPCC Tier 2[2]	Kirchgessner[3]	Kirchgessner et al. used in LCA studies[4]
6 000	123	109	100	
9 000	135	138	114	125
10 000	136	148	118	130
11 000	137	158	123	135
12 000	136	167	127	

1) Calculations made according to Lindgren (1980); Bertilsson (2001). Overfeeding was assumed to be 10%.
2) Calculations based solely on IPCC guidelines, Tier 2 (IPCC, 2006)
3) Calculations according to Kirschgessner et al. (1991)
4) Calculations according to Kirschgessner et al. (1991) but adjusted upwards for overfeeding of 10%, these values used in LCA studies of milk production in Sweden (Cederberg & Flysjö, 2004; Cederberg et al., 2007).

When methane production is calculated according to the Lindgren model, there is only a marginal difference in methane emissions with a higher proportion of forage in the diet. If the proportion of forage in the diet increases from 50 to 70%, it is estimated that this only gives 1-2 kg CH_4 more per dairy cow and year. This is based on the forage having good quality, i.e. high digestibility.

As shown by the comparison in Table 2.1 differences exist between mathematical models, with in particular the high yield levels giving the IPCC guidelines considerably higher emissions. If these mathematical models are more accurate than the Swedish and Kirchgessner et al. models, this means that we have somewhat underestimated methane emissions from dairy cows in previous LCA studies and in the Environmental Protection Agency's climate reporting. This applies particularly at higher yield levels. The differences in methane emissions between different mathematical models shows the need for measurements in dairy cows with today's diets and yield levels. Such studies were started in autumn 2008 at Kungsängen, SLU.

2.2 WAYS TO DECREASE METHANE EMISSIONS

2.2.1 INCREASING MILK YIELD

A measure often discussed is to decrease methane emissions by aiming for high-yielding dairy cows. The idea here is that the base emissions of methane that every dairy cow produces through consumption of maintenance feed are distributed over more kg milk when the cow yields 10 000 kg milk/year compared with a cow yielding 8 000 kg milk/year. Emissions of methane per kg milk are thus lower from the high-yielding cow.

The EU EIPRO study investigated the products with the greatest significance for the environmental impact of consumption in the EU. Milk and beef were identified as products with a large environmental impact and therefore a major study of improvement measures was carried out for these products (Weidema et al., 2008). In this study an analysis was made of the effects of intensifying milk production in Europe. At present, there are 26 million dairy cows in EU-27, yield in Denmark and Sweden (high-yielding countries) is 8500 kg/cow and year and the average yield for all cows in the EU is 5900 kg milk/cow. If all cows yielded as much as Danish and Swedish cows, the number of cows in the EU could be reduced to 18 million and methane emissions from the dairy sector would decrease by 24%. However, this yield increase would have two important side-effects. First, more concentrate per kg milk would be needed to maintain the higher yield. Second, beef production (as a by-product) from the dairy sector would be lowered by an estimated 30% as the number of cows decreased due to increased yield per cow. These two effects would lead to increased emissions from feed production and increased emissions from the greater number of suckler cows required in agriculture to keep beef production intact (given constant beef consumption). The analysis also discussed the negative effects of higher yield on animal health and the risk of increased use of medication (e.g. more mastitis cases). The conclusion of this thorough analysis was that the negative effects of intensified milk production can generally be said to outweigh the positive effects. Weidema et al. (2008) claim that increased intensification of European milk production is not desirable from an environmental perspective.

In the LCA studies carried out using data from conventional and organic dairy farms in Western Sweden and Norrland (Cederberg & Flysjö, 2004; Cederberg et al., 2007), economic allocation was used to divide the environmental impact between milk and the by-product beef (surplus calves and beef from cull cows). The same allocation, which involved 90% of the environmental load being placed on milk and 10% on the by-products ‘surplus calves’ and ‘beef from cull cows’, was used for conventional and organic production. The organic dairy cows had a lower delivery of milk per cow (caused by lower gross yield and by raw milk from the cows being used to a greater extent in feeding calves on organic farms) but the milk price was higher, so the relative proportions of milk and beef were similar for the two production systems. This rather rigid method of dealing with the important by-product beef (based on the relationship milk price/beef price) gives methane emissions per kg milk that are higher for organic milk than for conventional. It can be concluded from this that the smaller amount of milk per cow in organic milk production is worse from a climate perspective.

However, if the two systems are analysed as in the study by Weidema et al. (2008), it emerges that the amount of by-product in the form of beef is lower in the more high-yielding conventional system. Conventional milk production therefore requires more beef production in a self-recruitment system with suckler cows in order to maintain a certain level of beef production for a given level of beef consumption. This is illustrated by the example in Table 2.2.

Table 2.2. By-products in the form of surplus calves and beef from cull cows in two production systems with different yield levels (in this case conventional and organic)

	Conventional	Organic	Comments
Delivered milk, kg/cow & yr	9000	7800	15% more in conventional
Cows/ton milk & yr	0.11	0.13	
Surplus calves to beef production, calves/ton milk*yr	0.069	0.084	1 calf/cow, 37% recruitment, 63% to beef production
Beef from cull cows, kg slaughter weight/ton milk*yr	11.8	13.9	37% cull cows/yr, 290 kg slaughter wt/cow

A conventional cow is estimated to deliver around 15% more milk per year than an organic cow, an assumption based on data collected on dairy farms in SW Sweden and Norrland (Cederberg & Flysjö, 2004; Cederberg et al., 2007). This means that 0.11 cows are needed per ton milk delivered to the creamery in conventional production and 0.13 cows in organic production. Assuming one living calf per cow and year and 37% recruitment in both systems, this means that 63% of the calves are so-called surplus calves that are available for beef production. Thanks to this calf production in the dairy sector, keeping a certain number of suckler cows that produce calves for beef production can be avoided (given that beef consumption remains constant). For conventional production 0.069 suckler cows/ton milk and year can be avoided and for organic 0.084 suckler cows/ton milk and year. In addition, there is the beef from cull cows. Assuming that 37% of dairy cows are culled annually, the same for both systems, and that slaughter weight is 290 kg/cow, this means that 11.8 kg slaughter weight and year (0.11*0.37*290=11.8) are produced per ton conventional milk and 13.9 kg slaughter weight and year (0.13*0.37*290 =13.9) per ton organic milk.

At present there is no systems analysis taking account of the entire milk-producing system in Sweden and investigating its interaction with beef production. The number of dairy cows has decreased by 30% in Sweden since 1990 but total production has remained unchanged thanks to increased yield per cow. At the same time, the number of suckler cows has increased sharply to compensate for the decrease in beef from the dairy herd. The total effect of this on climate impact has not been investigated. Continued intensification of milk yield per cow based on the argument that this decreases the climate impact is very doubtful, viewed in the light of the example above of conventional and organic milk production, where the production of more beef per ton milk in the organic system means that emissions from self-recruiting beef production are avoided, given a constant level of beef consumption. Analyses on improving European milk and beef production also show very clearly that increased intensification of European milk production is not desirable as long as beef consumption remains unchanged (Weidema et al., 2008).

No criteria are proposed here to increase yield per dairy cow with the aim of decreasing methane emissions per kg milk, since the net effect of this measure (as long as beef consumption does not decrease substantially) is small or perhaps even negative.

2.2.2 Healthy and fertile animals – animal welfare

Keeping dairy cows healthy and fertile so that they can produce milk for a long time and a calf every year is important for the overall efficiency of the dairy system. Sick dairy cows produce less than healthy cows and if medicine is needed, the milk may not be delivered to the creamery, i.e. there is a smaller amount of milk produced over which to divide greenhouse gas emissions. Having dairy cows that are easy to get in calf is very important for annual milk production, of course, but also for production of calves in the form of recruitment animals and surplus calves, the latter being important for national beef production. Some important indicators of healthy, ‘efficient’ animals are listed and discussed in Table 2.3.

Table 2.3. Indicators of efficient milk (and beef) production and animal welfare

Indicator	**Importance for climate-efficient milk production**
Percentage recruitment	According to the Swedish dairy cow monitoring programme, recruitment in Swedish milk production is currently between 36 and 38% and a large number of herds are in the range 35-45% (N-E. Larsson, pers. comm. 2008). This means that almost 40% of dairy cows are replaced by heifers (culled) ever year. It can be argued that a high turnover in dairy herds is not very significant from a climate perspective since a useful product (beef) is obtained from cull cows. However, dairy heifers probably require more resources than beef animals in the form of intensive feeding and probably less use of natural grazing, and thus have greater net emissions of greenhouse gases. At present there are on average 2.4 lactations per dairy cow, and if this lifetime production can be increased (i.e. percentage recruitment decreased), the emissions from rearing heifers (up to first calving) can be divided over more kg milk.
Mortality, cow	Not all cull cows arrive at the abattoir (and become a useful output product in the form of beef). Some die or are put down on the farm and become biological waste. Mortality in Holstein cows is just over 6% of the total number of cows and in SRB cows 4% (Lidfeldt, 2006). A high proportion of natural deaths/cows having to be put down is negative from an economic and an environmental perspective since no meat product is delivered from the dairy system and since costs (and emissions) are incurred in cadaver disposal.
Mortality, calf	The calves produced by the dairy herd are important since they have to replace culled dairy cows and are also an important ‘raw material’ in beef production. A healthy bull calf from a dairy enterprise is a significant resource since it avoids the need to keep a suckler cow for a year to produce a calf – which means a great saving in methane emissions in particular, but also in feed production viewed over the entire milk-beef system. High calf and young animal mortality in the dairy system is therefore negative from a climate perspective. Increased use of sex-separated sperm, so that calf production in the dairy herd can be planned according to the need for replacement heifers and bull calves for beef production, is an interesting option for more resource-efficient and climate-friendly milk and beef production in interaction.
Healthy animals – minimal medication	It is obviously important for the cows to be so healthy that they produce according to their capacity and that the use of medication can be minimised. Medication leads to quarantine periods for milk delivery and thus losses in production, i.e. not all the raw milk produced on the farm is delivered as a product to the creamery. In addition, studies show that sick animals contribute to greater feed consumption in a herd, as these cows have to eat more than healthy cows. The important key parameter of feed efficiency is thus affected in more than one way when animals are not healthy, particularly when extensive medication is required.

Svensk Mjölk is now developing an advisory system for animal welfare with the aim of using welfare indicators from the cow database to describe animal welfare on the individual farm and also to describe the importance of animal welfare for farm finances. Analyses from this project show that herds with good animal welfare have low mortality levels for calves, young animals and cows in combination with good fertility and generally also a low frequency of veterinary treatments. On the other hand, herds with mortality or poor fertility have a high risk of poorer animal welfare. The results indicate that by using a combination of in total ~10 key parameters from insemination records, animal health data and CDB, the animal welfare of a herd can be risk-classified with 90% certainty (Hallén Sandgren et al., 2008).

2.3 Suggested improvement measures

Our assessment is that the most important measure to decrease methane emissions from the overall milk production system, taking into account the interaction with beef production, is to increase efforts at farm level to decrease calf mortality (dairy cows, heifers and calves), improve fertility (no long calving intervals, lower calving age for heifers) and decrease the need for medication (healthy animals). Within the Svensk Mjölk project on animal welfare, an internet tool is now being developed that can be used directly out on dairy farms so that herds with poor values of important key indicators of animal health, such as high cow and calf mortality, can be alerted and advice provided. This system for animal welfare with follow-up advice if required is estimated to become operational in autumn 2009 and can therefore be used in a climate certification system for dairy farms from 2010.

3 Manure management

This chapter deals with the emissions of methane and nitrous oxide that arise from manure management from the time the manure leaves the animal until it is spread in the field. Compared with pig production, greenhouse gas emissions from cattle manure make up a smaller proportion of total emissions. This is due e.g. to the methane from ruminant digestion having a much greater impact and to methane production from cattle manure being relatively low.

Methane is formed when microorganisms break down organic material under anaerobic conditions. Within the manure handling system, most of the methane production takes place from the stored manure. In e.g. the IPCC guidelines, only methane production from manure storage is included (IPCC, 2006). When the manure is managed in the form of slurry, most of the decomposition takes place in an anaerobic environment, and methane production can be considerable. A floating crust, which is often present on cattle manure, causes some of the methane to be broken down (oxidised) when the gas passes through the crust since it contains both anaerobic and well-aerated zones. The total methane emissions are therefore lower if the slurry has a floating crust than if there is no crust. According to the IPCC guidelines, a floating crust is estimated to reduce methane production in a slurry tank by approx. 40% (IPCC, 2006). For manure stored in solid form or spread on grazing, oxygen availability is higher and methane production is therefore lower. If oxygen availability is low in solid manure storage (e.g. low DM content and thus potentially poorer structure and air permeability), methane production can be higher. Methane production from deep litter can be of the same order of magnitude as that from slurry, with emissions affected by storage time (IPCC, 2006).

The amount of methane formed is also affected by temperature, storage duration and the composition of the manure. At low temperatures, microbial activity declines and thus methane production also declines. Cattle manure generally produces less methane per kg VS (Volatile Solids, i.e. organic material) than pig manure since the feed has already been broken down by microorganisms in the rumen and the fraction of readily degradable organic material is lower in cattle than pig manure. On a dairy farm, most of the methane production comes from ruminant digestion, while manure management is the largest source of methane in pig production.

Nitrous oxide can be formed directly via nitrification and denitrification of the nitrogen present in the manure and indirectly via losses of reactive nitrogen (ammonia, nitrogen oxides), which are converted to nitrous oxide in other parts of the ecosystem. Just like emissions from soil (see section on feed), direct nitrous oxide emissions are dependent on nitrogen availability, water content and temperature, as well as carbon content, storage time and how the manure is managed. In order for nitrous oxide to be formed in the manure, ammonia must first be oxidised to nitrate (nitrification), which demands the presence of oxygen. Denitrification, i.e. when nitrate and nitrite are converted to nitrogen gas and nitrous oxide, only occurs in anaerobic conditions. The proportion of nitrous oxide increases at lower pH, high nitrate content and lower availability of moisture (IPCC, 2006). In an environment where there are alternating anaerobic and aerobic zones, both nitrification and denitrification can occur, which promotes nitrous oxide emissions. Such environments arise in e.g. a floating crust and in solid manure. Overall, this means that nitrous oxide emissions are estimated to be higher from solid manure and slurry with a floating crust than slurry without a crust, which is the reverse of the situation with methane emissions from solid manure and slurry systems. In the case of deep litter, nitrous oxide emissions are thought to be considerable, possibly due to nitrous oxide production being stimulated by trampling and mixing of manure and bedding material (IPCC, 2006)

When it comes to indirect nitrous oxide emissions, there are a number of factors affecting ammonia losses in house, store and field. Ammonia losses are generally greater in storage than in the house. In order to decrease ammonia losses, it is important to reduce air exchange over the surface of the manure, e.g. through covering it or reducing the contact area with the air. Ammonia emissions are also lower at low temperature and low pH. At lower pH values the equilibrium between ammonium and ammonia is displaced so that the proportion of ammonium nitrogen increases. The carbon/nitrogen ratio affects ammonia emissions, since the microorganisms can bind more nitrogen in organic compounds if they have good access to (relatively easily degradable) carbon. The effect of bedding on ammonia emissions in animal houses depends on e.g. the amount of bedding and its absorbency. Peat, which has good absorbency, can also decrease ammonia losses since it lowers the pH value. Ammonia losses in the house are reported in the literature to between ~5-20% of the nitrogen content of the manure, with deep litter generally giving higher losses and houses with tied cows giving lower losses (small manure surface exposed to the air). Storage losses are reported to be lowest for slurry (a few %), higher for solid manure (~20%) and highest for deep litter manure and urine (30-40%), but a number of factors such as covering, temperature and air exchange affect these losses. Losses from spreading vary greatly, with rapid incorporation into the soil and spreading in the growing crop being two ways to minimise losses (Greppa Näringen, 2008).

In field trials measuring methane, nitrous oxide and ammonia emissions from spreading slurry using various spraying equipment, it was found that methane losses over a longer period were negligible or even negative, which means that the soil acts as a sink for the methane. Nitrous oxide emissions were significantly higher from plots where the manure was tilled in instead of being strip-sprayed (Rodhe & Pell, 2005).

3.1 CALCULATING METHANE EMISSIONS AND NITROUS OXIDE EMISSIONS

A common way of calculating the methane and nitrous oxide emissions from stored manure is to follow the IPCC guidelines (IPCC, 2006). In these (according to Tier 2), ***methane***

emissions from storage are calculated on the basis of the organic matter content of the manure, maximum methane production potential (B_o, see Table 3.1) and a methane conversion factor (MCF) stating the fraction of this potential achieved (see

Table 3.2). The values in the table correspond to the values in the IPCC guidelines that we consider to be relevant for Swedish milk production. Note however that the methane conversion factor (MCF) is temperature-dependent and that the values in Table 3.2 apply at mean temperatures up to 10°C, which is the lowest temperature range in the guidelines. The mean temperature in stored manure in Sweden can be lower, which affects methane production.

For slurry (with floating crust from dairy cows, the estimated methane production from the stored manure is 0.24*0.1 = 0.024 m^3 methane per kg organic material. If farmyard manure contains 7% DM and VS comprise 87% of DM, methane production in storage would be 0.024*0.07*0.87*1000=1.5 m^3 methane per m^3 slurry or **1.0 kg methane per m^3 slurry** (1 m^3 CH_4 = 0.67 kg CH_4) or **25 kg CO_2-equiv per m^3 slurry**.

Table 3.1. Maximum methane production potential, B_o, for manure from different types of animals (IPCC, 2006)

Type of animal	B_o (m^3 CH_4/kg VS) [a]
Dairy cows	0.24
Other cattle	0.18

[a] Standard values for Western Europe. VS = Volatile solids, d v s organic material

Table 3.2. Methane conversion factor, MCF, for different manure storage methods at mean temperature ≤10 °C (IPCC, 2006)[a]

Storage method	MCF (% of B_o)	Comment
Grazing, feedlot	1	Manure left lying undisturbed on the ground
Solid manure	2	
Slurry, without floating cover	17	
Slurry, with floating cover	10	A floating cover can reduce emissions by approx. 40%
Deep litter	3	Refers to storage periods of less than 1 month
Deep litter	17	Refers to storage periods of less than 1 month

[a] MCF is given as a percentage of methane production potential B_o (see Table 3.1).

According to IPCC guidelines (Tier 2), ***direct nitrous oxide emissions*** are based on the total nitrogen in the manure, with no account taken of ammonia losses in house and storage, and an emissions factor (see Table 3.3) giving the proportion of the nitrogen lost as nitrous oxide. This emissions factor can vary between different types of manure and management systems.

For a nitrogen content in cattle slurry of 4 kg N-tot/m^3 (excluding ammonia losses in house and storage), the direct nitrous oxide emissions from stored slurry with a floating crust would be 4*0.005 = 0.02 kg N_2O-N/m^3 manure. This is equivalent to **0.031 kg N_2O/m^3 manure** (1 kg N_2O-N = 1.57 kg N_2O) or **9 kg CO_2-equiv/m^3 manure**.

Table 3.3. Emissions factor for direct nitrous oxide emissions, EF_3, from manure stored in different types of system (IPCC, 2006)

Storage method	EF_3 (kg N_2O-N/kg N released)	Comment
Solid manure	0.005	>20% DM
Slurry, without floating crust	0	Emissions assumed to be negligible due to lack of oxidised forms of nitrogen and non-existent nitrification and denitrification
Slurry, with floating crust	0.005	
Deep litter, without mixing	0.01	
Deep litter, with mixing	0.07	
Poultry manure	0.001	

According to IPCC guidelines, ***indirect nitrous oxide emissions*** are calculated from total nitrogen losses and an emissions factor giving the proportion of the nitrogen lost that is converted to nitrous oxide. For ammonia, this emissions factor is given as 1%. If combined ammonia losses in house, storage and spreading are 30% of total nitrogen, the indirect nitrous oxide emissions as a result of these ammonia emissions in the example above would be 4*0.3*0.01 = 0.012 kg N_2O-N/m^3 manure. That is equivalent to **0.019 kg N_2O/m^3 manure** (1 kg N_2O-N = 1.57 kg N_2O) or **5.6 kg CO_2-equiv/m^3 manure.**

Total estimated greenhouse gas emissions from the system with slurry and a floating crust would be 40 kg CO_2-equiv per cubic metre. Without the floating crust estimated methane emissions would be higher (see Table 3.2), while direct nitrous oxide emissions would be lower. In order to assess the total effects on greenhouse gas emissions, account must also be taken of indirect nitrous oxide emissions and how the nitrogen in the manure is utilised. If the manure is stored uncovered and ammonia losses therefore increase, it is estimated that indirect nitrous oxide emissions from conversion of ammonia in other parts of the ecosystem would also increase. Ammonia losses also mean that a smaller amount of nitrogen remains for plant production. If this is compensated for through increased use of mineral fertiliser nitrogen there would be higher greenhouse gas emissions, partly because there would be more nitrogen circulating in the system as a whole and partly because more mineral fertiliser nitrogen would have to be produced, and such production is associated with high greenhouse gas emissions. A system with solid manure is estimated to give lower methane losses, provided that it is stored with good access to oxygen. However, the risk of ammonia losses is greater, especially from urine if the tank is not covered, which risks leading to higher indirect nitrous oxide emissions and poor nitrogen use efficiency, to be compensated for with more mineral fertiliser. Storage of solid manure gives direct nitrous oxide emissions.

A system with deep litter manure seems to give high methane and nitrous oxide emissions (see Table 3.3) and is therefore less suitable from a climate perspective. However, this manure management system is seldom used in milk production, with the exception of young animal rearing.

The discussion above is based on IPCC model calculations, which are adapted for international conditions. The Swedish Institute of Agricultural and Environmental Engineering (JTI) is currently carrying out measurements of greenhouse gas emissions from manure management under Swedish conditions (JTI, 2008). The results of these trials will lead to better knowledge of greenhouse gas emissions from manure systems in Sweden under the conditions prevailing in the country.

3.2 Ways to decrease greenhouse gas emissions

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

3.2.1 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. Previous studies show that by altering the diet of Swedish dairy cows it would be possible to decrease the nitrogen content of manure by 10% without any negative effects on yield or animal health (Greppa Näringen, 2008). This can be done by decreasing the crude protein content of the feed and by differentiating the feed throughout the lactation. 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.

Covering stored manure affects greenhouse gas emissions. Cattle slurry generally forms a good floating crust, which can reduce methane emissions but increase nitrous oxide emissions. Biodigested manure forms a poorer crust than non-biodigested. Adding straw to biodigested manure in an attempt to provide better cover increases the risk of greenhouse gas emissions, since it creates a layer with both anaerobic and aerobic zones that can stimulate nitrous oxide formation, while supplying a relatively easily degradable carbon source can stimulate methane production. An airtight roof or cover over the post-digestion chamber and collection of the gas decreases emissions from the stored material. In practice, however, it can be difficult to achieve a fully airtight system.

Adding **acid** to slurry and thereby lowering the pH can decrease ammonia losses considerably, but the risk of nitrogen leaching can increase 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, 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 beef 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.

3.2.2 BIOGAS PRODUCTION FROM MANURE

Biogas production[3] from manure has a number of potential advantages from a climate perspective:

- Biodigestion of manure can substantially **reduce methane emissions** from stored manure since the biogas from the digestion chamber is collected and since there is little easily degradable organic material remaining in the biodigested manure that can be converted to methane during subsequent storage. Trials in Denmark have shown that methane losses from manure management can be halved when the manure is biodigested instead of being stored in conventional ways (Sommer et al., 2001). However, the effects on methane emissions vary greatly depending on the design and losses in the system, see discussion below.

- Biodigested manure is potentially a **better fertiliser** than non-biodigested. The proportion of directly plant-available nitrogen increases when manure is biodigested since the organic material is broken down and organically-bound nitrogen is thereby released. If this nitrogen it utilised efficiently it can decrease the need for mineral fertiliser. However the risks of nitrogen losses from storage are greater for biodigested manure than non-biodigested, since pH values are higher, the amount of ammonium nitrogen is higher and the biodigested manure does not form a floating crust as readily (see section above on covering). The biodigested manure is more free-flowing and thus penetrates into the soil on spraying, but ammonia losses are also affected by spraying technique and weather conditions. Research indicates that nitrous oxide emissions from the soil are lower from biodigested manure, which can be explained by it containing less readily available carbon to be used by nitrous oxide producing microorganisms (Sommer et al., 2001).

- Biogas is a **renewable energy source** and can replace fossil fuel. Biodigestion is often the only possibility of producing energy from manure. The average amount of manure produced by a cow of 2 ton DM per year could provide around 3.6 MWh biogas per year. If account is taken of the energy required to produce the gas, the net gas yield is estimated to be just over 2 MWh per cow and year (refers to production in a central biogas plant, including transport, heat and electricity required for the biogas) (Berglund & Börjesson, 2003).

[3] Biogas production, or biodigestion, involves microorganisms breaking down organic material, e.g. manure, in an anaerobic environment. The biogas mainly consists of methane, which is an energy-rich gas, and carbon dioxide. The gas is collected and used for energy purposes. The digested product is sometimes called biodigestate. This chapter only discusses biogas production from farm-based biogas plants and co-digestion facilities (also known as central biogas plants). Biogas production from sewage sludge is not included.

Previous systems analyses of biogas production have shown that manure can be the best substrate from a greenhouse gas perspective, and can even give 'negative' emissions if the biogas replaces fossil fuel and account is taken of the decreased methane losses from the stored manure (Börjesson & Berglund, 2007). However this assumes that losses of biogas and reactive nitrogen are small and that the gas actually replaces fossil fuel! The amount of methane produced per cubic metre manure is considerably greater for biodigestion than for conventional storage of manure, and thus even small percentage losses can be highly significant. If the biogas yield from cattle manure is approx. 210 litres methane per kg VS, that would be equivalent to ~8.5 kg methane per cubic metre cattle slurry (same conditions as in the example in section 3.1), which can be compared with approx. 1 kg methane from conventional storage. If more than 12% of the biogas were to leak out from the biogas system, the methane losses in this sample calculation would be lower from the conventional manure management system than from the biogas system. Note that this takes no account of the benefit of the biogas replacing fossil fuel. In a previous systems analysis of biogas, it was found that methane losses in biogas production from pig manure could amount to up to 30% of the biogas produced before a fossil fuel-based energy system would give lower greenhouse gas emissions (Börjesson & Berglund, 2007). However there is a lack of good information on the magnitude of leakages in biogas production, especially in farm-scale plants. Older estimates from central biogas plants indicate that methane emissions from stored biodigestion residues can represent ~10% of total biogas production in the plant (ibid.), and it is therefore important to collect this methane. If there is no outlet for all the gas produced it is important that it is combusted (flared) before being released to the atmosphere, since methane is a very potent greenhouse gas.

In Sweden, there are around 15 central biogas plants in which animal manure often comprises a large percentage by volume of the substrate. Manure is a good substrate since it contributes to process stability, but the biogas yield per unit volume is low. For animal producers who supply manure to a central biogas plant and take back the residues, it can be an advantage if manure from different animal species is mixed in the biogas plant, since this alters the plant nutrient composition of the residues. Pig and poultry producers export phosphorus (and possibly nitrogen) from the farm and import potassium, while milk producers export potassium and import phosphorus. However, co-digestion plants involve expensive transport and carry a potential risk of spreading diseases between farms. A large proportion of the biogas from these plants is upgraded to vehicle gas quality, i.e. carbon dioxide and other undesirable gases are removed and the gas is pressurised.

At present there are relatively few farm-based biogas plants and the plants that have been built often have special circumstances, e.g. farming colleges, very large herd size or a need to handle waste from a farm abattoir or to supply plant nutrients for organic crop production. Some of the reasons for the low rate of building for farm-scale biogas production to date are the low profitability and the limited outlets for the biogas. Biogas production has large economies of scale and therefore many animals are often needed to bring production costs down to a reasonable level. In terms of outlets for the gas, the need for heating, which is the simplest and cheapest way to use the biogas, is often considerably lower on the farm than the rate of biogas production. In the past, payment for electricity production has been low in Sweden, but with increasing electricity prices and the availability of electricity certificates, the profitability of combined heat and power has improved. To date, there is no commercial solution for production of vehicle gas at farm level, but a number of projects are currently working to develop such technology.

There is now increasing interest in farm-based biogas production due e.g. to proposed subsidies for investment and increasing energy prices. An important motive for the subsidies is that biogas production from manure gives major climate benefits. Over the past few years, there have been a number of projects throughout Sweden to build more farm-scale biogas plants that are linked up to a joint gas network, providing an outlet for the gas and allowing it to be upgraded and used as vehicle fuel. Such solutions are most realistic where there are a number of large farms interested in biogas within a limited area.

Comparing biogas production in conjunction with pig or milk production, the benefits appear greater for a pig farm. Pig manure gives more biogas per kg VS than cattle manure since in the latter much of the readily degradable material has already been broken down in the rumen. Today combined power and heat production is often the most interesting option for farm-based biogas production. A combined heat and power plant generally generates more heat than is required to heat the biogas plant, and there is more probability of pig producers, especially those rearing piglets, needing the excess heat. Manure management represents a greater proportion of the total climate impact in pig production than in milk production (see e.g. Berglund et al., 2008), and collection of greenhouse gases from stored manure via biogas production thus gives a greater percentage reduction on pig farms.

Biogas production has the potential to be an efficient means of emphatically decreasing greenhouse gas emissions in a number of areas of the animal production life cycle, but there is also a risk of greenhouse gas emissions increasing if there are high losses of methane or nitrogen. We have poor knowledge of greenhouse gases emissions from farm-based biogas production. Careful covering of biodigestion residues (preferably with a tarpaulin or roof so that the gases can be collected) and collection of all biogas, by flaring if all else fails, are two important ways to minimise losses.

3.3 Suggested improvement measures and criteria

A basic requirement for achieving low greenhouse gas emissions from manure management is to manage the nitrogen, by utilising the nitrogen contained in the manure and by decreasing the nitrogen content of animal faeces and urine. High nitrogen losses give rise to greenhouse gas emissions in several areas of the life cycle. The nitrogen can be lost directly as nitrous oxide. When the nitrogen is lost in reactive form, e.g. as ammonia or nitrogen oxides, this leads to indirect nitrous oxide emissions when the nitrogen is converted to nitrous oxide in other parts of the ecosystem. If the nitrogen in manure is not well utilised and has to be complemented with a large proportion of mineral fertiliser nitrogen, this gives rise to higher direct nitrous oxide emissions since there is more nitrogen circulating in the system and higher greenhouse gas emissions from production of the mineral fertiliser. An important measure to decrease the nitrogen content in the faeces and urine leaving the animal is to avoid overfeeding of protein. This decreases the nitrogen content of the manure and thus also the risk of nitrogen losses. Work to improve nitrogen management is completely in line with environmental protection work in animal husbandry.

Biogas production from manure can be one way to decrease greenhouse gas emissions in several parts of the animal production life cycle. Biogas production has the advantages of providing renewable fuel, allowing more efficient use of the nitrogen in manure and potentially decreasing greenhouse gas emissions from manure management. However, our assessment is that it is too early for criteria on biogas production on individual dairy farms. There are ten or so farm-based biogas plants in Sweden today, which can placed in relation to approx. 7 000 milk producers. The majority of these lack the conditions for profitable biogas production due to small farm size in this context and a lack of potential outlets for the gas. In addition, the effect on total greenhouse gas emissions of the farm business is greater on a pig farm than on a dairy farm, since manure management is more significant for total emissions on the pig farm and pig manure gives more biogas. Progress is continuing and conditions may improve in the future.

As regards different types of manure management system, deep litter appears to give relatively high nitrous oxide and methane emissions. In addition, this system carries a risk of high ammonia losses in house, storage and spreading. However, deep litter is uncommon in milk production (where it is mainly used in rearing young animals) and is more relevant for other types of animals and forms of production. At present, we therefore consider that is not relevant to have restrictions on deep litter manure in milk production.

4 ENERGY CONSUMPTION

Energy consumption represents a relatively small proportion of the total climate impact of agriculture, with the majority of greenhouse gas emissions arising in various biological processes instead. Based on statistics on energy consumption in the agricultural sector (see Table 4.1) and standard values for greenhouse gas emissions for fossil fuel (0.26-0.29 kg CO2-equiv/kWh) and electricity (55 g CO2-equiv/kWh), energy consumption in agriculture would contribute just over 1 million tonnes of CO_2 equivalents per year. 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.

Based on the results of a questionnaire sent out to farm businesses, the total energy consumption by Swedish agriculture in 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 (see Table 4.1). 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 4.1. 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*

In a life cycle analysis of milk production in south-west Sweden, total energy consumption[4] up to the point of the milk leaving the farm was estimated to be approx. 2 MJ fossil energy and 0.6 MJ electricity per kg ECM in conventional production. The corresponding figures for organic production were approx. 1.4 MJ fossil energy and 0.7 MJ electricity per kg ECM. This would be the equivalent of around 0.18 kg CO_2-equiv per kg ECM[5] in conventional production and 0.13 kg CO_2-equiv per kg ECM in organic, which can be compared with total estimated greenhouse gas emissions of around 1.0-1.1 CO_2-equiv per kg ECM[6] for conventional and 1.0 kg CO_2-equiv per kg ECM for organic (Cederberg & Flysjö, 2004). A similar analysis of conventional and organic milk production in Norrland showed similar total greenhouse gas emissions, but energy consumption per kg ECM was somewhat higher and thus constituted a higher proportion of total greenhouse gas emissions (Cederberg et al., 2007).

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

4.1 Evaluating energy

Greenhouse gas emissions from energy consumption vary between different energy sources and forms of production (see e.g. Table 1.1 in our report on emissions of greenhouse gases in feed production), and therefore it can be difficult to unequivocally evaluate the climate impact of energy consumption. This is particularly the case for the climate impact of electricity production. Production of electricity in e.g. wind, hydro and nuclear power plants only produces a few grams of CO_2-equiv per kWh electricity. However, electricity production based on fossil fuels such as coal, oil and natural gas gives approx. 150-300 g CO_2-equiv per MJ electricity, with the actual level of emissions being determined by the fuel used and the conversion efficiency of the power plant (Berglund et al., 2008). The climate impact of electricity consumption on the farm is thus strongly influenced by the assumptions made on the origins of the electricity. At present it is possible to enter electricity contracts that consider the origins of the energy. The idea is that this system will stimulate electricity production with a low negative environmental impact. However, buying only e.g. renewable electricity does not automatically mean that electricity production will move in the right direction, since the outcome may be that electricity customers who have not actively chosen this option receive an electricity mix with a lower proportion of renewable electricity.

A common argument for the production of biofuel, e.g. from energy crops or harvest trash, is that they can be used to replace fossil fuels and thus contribute to decreasing greenhouse gas emissions. However it can be difficult to assess how total greenhouse gas emissions are affected by such a measure. If the biofuel is used as a biopropellant, e.g. in the form of RME or ethanol, it is highly likely to replace fossil fuel, e.g. via low inclusion in diesel or petrol, and the effects are easy to evaluate. However, if the biofuel is used for heat and possibly

---

[4] Energy consumption is given as *secondary energy*, i.e. the form in which the energy is used in the processes. Includes the energy used on the farm for production of input materials.

[5] Based on the assumption that energy consumption gives rise to ~85 g CO2-equiv/MJ fossil fuel (corresponds to the emissions from a diesel lorry, includes emissions from production and end-use of the fuel) and ~15 g CO2-equiv/MJ electricity (corresponds to the average electricity mix used in Sweden, account taken of emissions from production and distribution losses).

[6] Here the calculations have been updated with conversion factors for methane and nitrous oxide according to IPCC (2007), i.e. 25 kg CO_2-equiv/kg CH_4 and 298 CO_2-equiv/kg N_2O.

electricity production the picture is more complex, and a number of factors need to be taken into account in order to evaluate e.g. how the fuel mix in the heating system is affected and the consequences of this. At present, wood fuel, waste and other biofuels make up two-thirds of the energy supply in Swedish district heating plants, but in the beginning of the 1980s most district heating was produced using oil (Energimyndigheten, 2007). This major change can be attributed to cost changes, the effects of control tools and the flexibility of district heating plants to use different fuels. If biofuel is produced and used on-farm, account must be taken of the type of fuel replaced, the need for boiler replacement (affects efficiency and thus fuel requirement) and whether the heat is used for new purposes (e.g. to heat previously unheated areas).

When discussing the environmental impact of energy consumption and the effects of changing fuel or producing renewable energy, it is not enough to simply consider the individual farm or the agricultural sector, since this creates a great risk of suboptimisation or missing considerable effects in the rest of society. For example, if the farmer starts to harvest straw for energy purposes this can admittedly lower greenhouse gas emissions on the farm if the straw replaces e.g. oil for heating on the farm. This can be a good measure, but the overall reduction in emissions could perhaps have been even greater if the straw had been co-combusted in a coal-fired power station and thus used to decrease coal. More in-depth systems analyses are needed in order to evaluate the total effects of various measures and identify the most efficient alternatives.

Although the same units (e.g. MJ) are used for different energy sources and energy carriers, they are not directly 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 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 method used to compare different types of energy is to convert them to primary energy. This involves considering the indirect energy inputs used in production of raw materials, production, distribution, etc. If the electricity is produced in e.g. a natural gas-fired power station with a conversion efficiency of 50%, 1 MJ electricity would be equivalent to approx. 2.2 MJ of primary energy in the form of natural gas, including 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 the amount of primary energy varies depending on the method of production. This report does not use the primary energy concept or similar methods to recalculate energy sources and energy carriers to comparable units. This means that our compilation of total energy consumption may be flawed, but such recalculations are strongly influenced by the assumptions made and such units can be difficult to assimilate intuitively. Instead, energy consumption is reported separately, where possible, as MJ electricity, diesel, biofuel, etc. in order to make reporting as transparent as possible.

In this chapter the focus is placed on direct energy consumption on the farm and how this can be decreased, e.g. by decreasing total consumption and the proportion of fossil energy. Such measures can decrease greenhouse gas emissions, but in view of the methodological issues discussed above, the effects of these measures have not been quantified in terms of decreased greenhouse gas emissions. 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. In this report, energy production is included only in those cases where it has a direct link to milk production, e.g. as regards biogas and heat recovery from the milk tank, while the production of bioenergy, energy crops, wind power, etc. falls outside the boundaries of this study.

4.2 Energy consumption in dairy enterprises

There are relatively few studies on total energy consumption in Swedish dairy enterprises. In a study of energy consumption in the agricultural sector, it was estimated that Swedish dairy enterprises overall used 0.44 TWh electricity and 0.15 TWh diesel within the farm, i.e. exclusively work in the field (see Figure 4.1), which shows energy consumption as kWh per cow place and year) (Edström et al., 2005). Energy consumption for feed production was estimated e.g. for all ley crops in Sweden to be 0.41 TWh diesel and 0.09 TWh electricity (including growing, harvest, transport and storage). There is a lack of data on the proportions of different crops going to milk production. The calculations presented by Edström et al. (2005) are based on key parameters that do not fully take into account how the energy requirement is affected by local conditions, choice of machinery, etc. and in certain cases the key parameters are based on old measurements from the 1980s. Despite the uncertainties created by these factors, the electricity consumption calculated using key parameters agrees relatively well with available statistics, although the deviations are greater as regards diesel and fuel for heating.

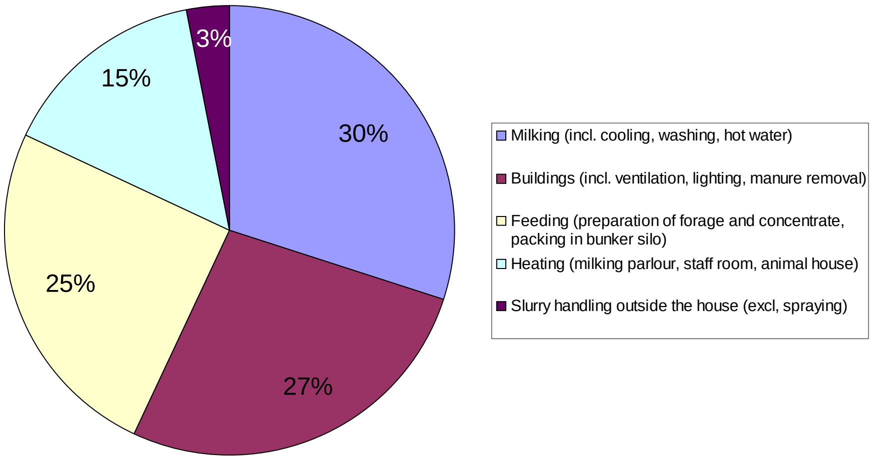

Figure 4.1. Within-farm distribution of energy consumption in milk production. Refers to direct consumption of electricity and diesel (Edström et al., 2005).

4.2.1 Within the farm

In a study of energy consumption in farm buildings, measurements were made on four dairy farms (see Figure 4.2). There were large differences between the farms in terms of feed handling, ventilation, housing for young animals and dry cows and milking system, and these differences were reflected in energy consumption (Hörndahl, 2007). Most energy consumption was in the form of electricity, with a total of between ~900-1100 kWh per cow place and year. Previous LCA studies showed higher electricity consumption. Electricity consumption on dairy farms in northern Sweden was on average ~2 200 kWh per year and cow+recruitment, and on dairy farms in south-west Sweden ~1 200 (conventional production) or 1 600 (organic production) kWh per year and cow+recruitment (Cederberg & Flysjö, 2004; Cederberg et al., 2007). The differences were explained by e.g. different degrees of mechanisation in the houses and feeding methods, with a number of the northern farms using electricity-demanding tower silos and robots.

In the measurements presented in Figure 4.2 a large proportion of the energy was generally used for feeding, but the variation was very large. The lowest energy consumption for feeding was recorded on farms that only used electricity for this process, while feeding was carried out to varying degrees with a tractor on other farms. One of the main explanations for this difference is that the efficiency is much higher in an electric motor than in a diesel engine. Milking is another energy-demanding process, particularly for powering vacuum pumps and cooling the milk (applies both to milking parlour and robot milking). Mechanical ventilation (present on farms B and D in Figure 4.2) obviously demands considerably more electricity than natural ventilation but overall, ventilation represented a very small fraction of total energy consumption on the dairy farms studied. The 'Other' category included e.g. electronic equipment, heating of staff rooms, etc.

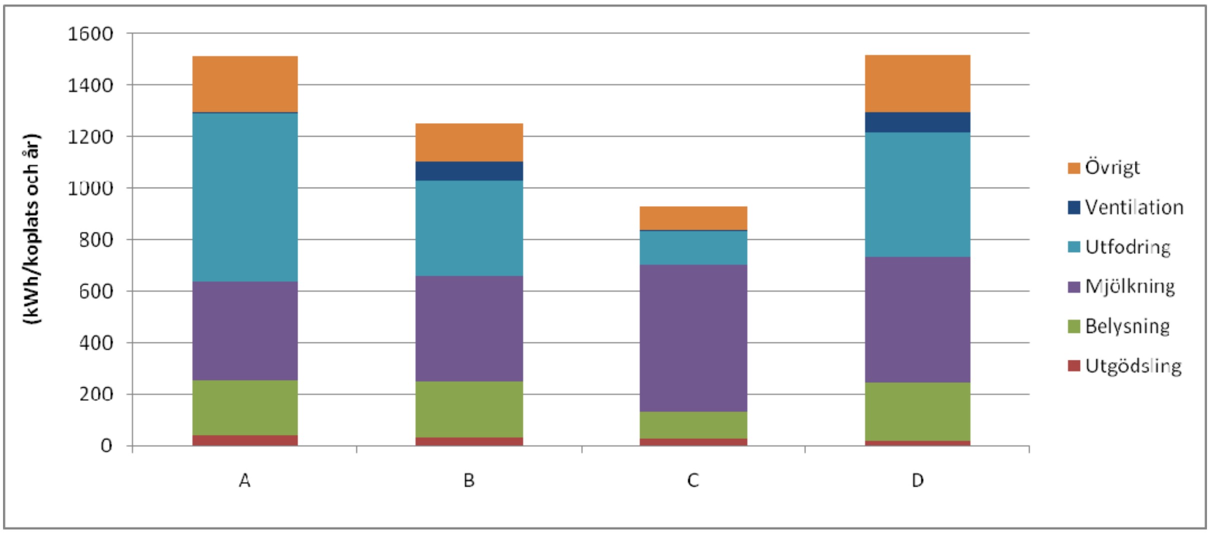

Figure 4.2. Results from measurements of energy consumption in four dairy houses (A–D), given as kWh electricity and diesel per cow place and year (Hörndahl, 2007). The parameters include Other/Ventilation/Feeding/Milking/ Lighting/ Manure removal.

The energy requirement for **milking** (e.g. vacuum pumping, cooling milk and heating water for washing) can vary between different houses. A previous review of the literature showed that the total energy requirement for milking varied between ~300 and 600 kWh per cow place and year (including systems with robots, tied cows and milking parlours). The variation was less when energy consumption was expressed per ton milk (~40-55 kWh/ton milk). The relative proportions of the energy used for milking, hot water and cooling milk varied greatly (Hörndahl, 2007). A market review of milking robots from 2006 showed that the manufacturers stated an electricity requirement for milking and washing of around 15 and 25 kWh per ton milk, respectively, and a water requirement of 200-400 litres per ton milk (Petersson, 2006). Measurements in Denmark show large variations in electricity consumption (20-60 kWh/ton milk, in some cases up to 80 kWh) and water consumption (200-600 l/ton milk, in one case up to 900 l) for robot milking (Brøgger Rasmussen & Pedersen, 2004). It was estimated that through monitoring and better tuning, consumption could be decreased in a number of cases. The electricity requirement in the milking parlours studied lay within the same range, while water consumption was somewhat lower.

There are several measures to improve the efficiency of energy consumption in **milking**. Correct design (e.g. appropriate size and temperature of water heater) and maintenance (e.g. to repair leaks in the vacuum system) are important in utilising equipment efficiently. Another measure is heat recovery from the milk tank for hot water production. Heat recovery is mainly used for pre-heating the water and a rule of thumb is that cooling 1 litre milk gives 1 litre of warm water with a temperature of around 50°C (if the water is heated from around 25°C). The temperature is then increased further in an electric water heater. Heat recovery would thus give approx. 30 kWh warm water (50°C) per ton milk. Heat recovery from the milk tank often generates considerably more warm water than is used in the house. In some cases it can be practicable and economically beneficial to use the tank heat for heating e.g. dwelling houses. The best conditions for such a solution are if there already is a water-borne heat distribution system in the dwelling (preferably underfloor heating since heat recovery gives low temperature water), good space for accumulator tanks (accumulator volume should be about the same as milk tank volume), a short distance between the buildings to keep down the cost of pipelaying and sufficiently high heat production from the milk tank so that a large proportion of the household heat requirements can be met.

Energy consumption for **feeding** is largely governed by the degree to which electric engines (e.g. for rail-based feed carts) and diesel engines (tractors) are used and by the design of the feeding system. On the four farms in Figure 4.2, energy consumption for feeding is lowest for the farm where all equipment is powered by electricity. An important explanation for the differences in total energy consumption is that the efficiency is much lower in a diesel engine than in an electric motor. 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%. When e.g. a complete ration is used, the energy requirement for feed mixing is affected by the amount of feed in the mixer (more feed give a higher energy requirement) and the dry matter content of the feed (dryer feed gives a higher energy requirement) (Hörndahl, 2007).

Compared with e.g. pig and poultry production, **lighting** represents a relatively large proportion of energy consumption on a dairy farm since the cows need light to produce high milk yields. An important measure to get good light returns is to keep fittings and reflectors clean. Energy consumption can be decreased by controlling the lighting with timers or dimmer switches. In new builds and renovations, plans should aim for good use of natural light and energy-efficient lighting. There are several alternatives to the conventional fluorescent tube (T8) that are more energy-efficient and have a longer life. By choosing fluorescent tube light fittings with a high frequency (HF) ballast and suitable for so-called T5 tubes, electricity consumption compared with a fitting designed for T8 tubes can be reduced by around 40% for the same light returns. The HF ballast gives flicker-free light and can prolong the life of the tube by 25-50%, but it must be installed correctly. In new animal houses it has become increasingly common to install pressurised sodium light fittings, which use half as much electricity as fluorescent tube fittings for the same light returns. They have a long life and few fittings are needed since the light output is high, but they require a high installation height and give a yellow light that can be perceived as unpleasant.

4.2.2 In the field

Diesel consumption in field work varies greatly between different activities (see Table 4.1) and is affected by the equipment used and conditions in the field such as soil texture, soil structure and water content. In general **soil tillage**, in particular ploughing, is the most diesel-demanding operation. The diesel requirement is generally higher for ploughing on clay soil than on light soil, and is also higher for wet conditions and greater working depth. Reduced tillage, which can involve shallow or no ploughing, can be an effective alternative to decrease diesel consumption and tillage costs, while also improving the soil structure and maintaining the organic matter content. Some soils and crops are better suited to reduced tillage, well-structured clays and winter wheat being good examples, while other systems are not at all suitable. Measurements in the field show that diesel consumption for tillage can be decreased by between 15 and 60% depending on tillage system (Ericsson, 2004; Olesen et al., 2005). Changes in tillage method can also affect nitrous oxide emissions and soil carbon stocks, since tillage stimulates microbial activity in the soil (and thus turnover of organic material). Reduced tillage can also decrease oxygen availability in the soil, which could enhance nitrous oxide formation. However, the few studies that exist reveal no unequivocal or significant differences between different tillage systems (ibid).

The energy requirement during **harvest** and **storage** of forage is affected by the choice of management system (see Table 4.1). Different storage techniques have somewhat different energy consumption, but attention should also be paid to the design of the feeding system. In a Life Cycle Assessment 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 electricity is evaluated 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).

Diesel consumption in **grain harvesting** is affected by factors such as yield level. For combine harvesting, consumption is roughly 5 l per hectare plus 2 l per ton grain harvested (Edström et al., 2005). The oil requirement for drying grain is estimated to be around 0.15 l per kg water removed, but the requirement is affected by the efficiency of the drier. Through heat recovery, this value can be reduced by an estimated 10% (ibid). The energy requirement per ton grain varies between years depending on the starting water content of the grain and the air humidity. Preservation methods other than hot air drying or complementary use of biofuel can reduce oil consumption. The high power requirement for drying and the high investment costs per kW for solid fuel boilers can give very high costs if drying is based completely on biofuel, especially if the boiler is only used for drying during a short period in autumn. Dairy enterprises seldom have any great power requirement for heat production, the exception being heating of large buildings and dwelling houses, which could justify investment in a large solid fuel boiler.

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.

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 4.1. ***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. It is also important to match the implement to the tractor. Measurements of diesel consumption in a tractor ploughing with a three-, four- or five-furrow plough showed that ploughing with the four-furrow plough gave the highest consumption per hour, but that this option was the most fuel-efficient when the consumption was expressed per hectare (24 l/ha, compared with 28-30 l/ha for the other options). In this example the five-furrow plough was too large for the tractor and wheel slip was high (30%) (Lindgren et al., 2002).

Training and implementation of ecodriving, which includes elements such as those described above, has been shown to give fuel savings of around 20% (Fogelberg et al., 2007). In occasional demonstration events considerably greater savings have been recorded. Ecodriving not only reduces energy consumption and greenhouse gas emissions but also diesel costs, and thus gives a direct financial gain to the farmer.

There are cases where tractors can be fuelled fully or partly with biofuels such as RME, biogas or ethanol. The most realistic alternative today is considered to be a low inclusion of biofuel, e.g. RME, in the diesel. Such diesel is already sold and used on a wide scale at present. 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. 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. 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.

4.3 Suggested improvement measures

It is difficult to identify specific measures on dairy farms that should be included as a criterion in climate certification of milk. The situation and requirements differ between farms and thus also the scope for, and effects of, different measures. Therefore two overarching measures are suggested (*Improvements at investment* and *Energy mapping*, see below) that can 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 overall 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 includes utilising resources on the farm for energy generation, e.g. from manure or through heat recovery. However, more knowledge and systems analyses that include all of society will be needed in order to assess how the renewable energy produced can best be used from a societal perspective. For example, how should straw harvested for energy purposes be used – on the farm for heat production in the business, selling heat to other properties (e.g. residences) or selling the straw to a power or district heating plant. However, carrying out such analyses is beyond the scope of the climate certification project.

4.3.1 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 the life cycle costs 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 and have control and regulation devices (e.g. rev count on fans). For example, an unnecessarily large compressor will be largely underused and will use electricity without producing any benefit. If a smaller compressor is chosen instead, it will work to its capacity for a longer period, but total electricity consumption will be lower since idling losses will be greatly decreased.

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.
- Milking: Is heat recovery from the milk tank possible?
- Lighting: Plan for good use of natural light and control of lighting.
- Ventilation: Natural ventilation, rev count limiters in mechanical ventilation.

4.3.2 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) and suggestions for important and realistic measures. 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 (e.g. through its Energikollen). There are also courses available in ecodriving at e.g. the local authorities. 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 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, LRF and LRF Konsult will issue a handbook (Energy Saving Catalogue) in 2009.

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 cooling equipment or looking for and repairing leaks in the vacuum system.

5 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.

5.1 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 5.1). As can be seen in Table 5.1, 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 5.1 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 advisory website

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 often represents 50% of total feed intake by cows (calculated on a dry matter basis), 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 milk production.

Overfeeding, i.e. supplying more feed than the estimated requirements of the animals, is believed to occur to a higher degree with concentrate than with forage. Overfeeding with concentrate is probably more common in conventional than organic production, since concentrate is more expensive in relative terms in organic production. On farms participating in the advisory programme IndividRam, overfeeding is estimated to be around 10%. 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 concentrate ration in relation to milk yield. 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. IndividRam is the most widely used advisory programme, but the advisory modules in Greppa Näringen covering diet appraisal have also been shown to give good results in terms of monitoring feed consumption relative to milk yield on the individual farm.

5.2 CHANGING TO FEEDS WITH LOWER EMISSIONS

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. Svensk Mjölk calculated different diets using the new feeding programme NORFOR, based on a diet for dairy cows (yield approx. 10 000 kg ECM) that consisted of pure grass silage, grain and a complete protein concentrate (in which the most important raw materials were rapeseed meal, soyabean meal and beet pulp). An alternative diet (for the same milk yield) was also calculated, consisting of clover/grass silage (mixed ley with lower N fertiliser), grain and raw materials in the form of peas, rapeseed meal (ExPro) and beet pulp (Betfor). This alternative decreased emissions in feed production by around 25% (Cederberg, 2008).

The company Lantmännen has recently announced that it is to climate-declare its range of concentrate feeds. This accounting system will be based primarily on the SIK feed database. A protein feed ('Unik Nära') that has lower greenhouse gas emissions per kg than ordinary protein concentrate has been developed. This protein feed only contains European raw materials (no soyabean or palm kernel expeller) apart from a small amount of vegetable oils. Lantmännen considers the raw materials base for this protein feed product to now be relatively good thanks to the increased RME production in Europe, which is generating additional rapeseed meal as a by-product (M. Murphy, pers. comm. 2008).

This move by Lantmännen to supply concentrates with lower greenhouse gas emissions compared with its current range is very interesting. Concentrate use in milk 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 declaration system places demands on how forage and grain are grown on actual dairy farms (see separate 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.

Svensk Mjölk has investigated the possibility of using more locally produced concentrate in milk production and this work has provided good basic data on current use of different feed raw materials. In 2004, an average of around 330 kg soyabean and 125 kg palm kernel expeller was used per dairy cow, based on the entire cow population of 403 700 cows (Emanuelson et al., 2006). Soyabean meal and palm kernel expeller are among the raw materials with the highest emissions per kg and are used in large amounts, so it is desirable to decrease the use of these and replace them with a diet with foodstuffs with lower GWP emissions. In addition, these feedstuffs are associated with deforestation (direct or indirect), which has huge environmental consequences.

The Svensk Mjölk investigations have shown that completely excluding (banning) raw materials (in particular soyabean) from other continents can be expensive, particularly if raw material availability in Europe is poor, e.g. through poor harvests). Allowing entry to a certain amount of soyabean is an insurance to prevent compromising milk yields, particularly in the case of high-yielding herds. One requirement as regards the composition of the diet can be to decrease the use of soyabean to 100 kg per dairy cow and year within three years and then carry out an assessment of how this has affected milk yield and health status. In the longer term it is desirable to completely phase out soyabean and palm kernel expeller. The feed industry can then adapt its concentrate products so that dairy farms participating in a climate certification system can obtain products with a lower proportion of soyabean and palm kernel expeller (or none at all).

For organic concentrate raw materials there is no database with GWP values per kg feed, as discussed in our separate report on animal feed. In the past, a small proportion of conventionally produced concentrate was permitted and this often comprised conventional maize gluten meal and vegetable oils in organic concentrate mixes. 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 separate report on animal feed production). Organic lucerne meal is often present in concentrate mixes as a protein raw material. Here, drying can give rise to rather high energy consumption and from a climate perspective care should be taken about the energy source used, with renewable energy naturally being given priority.

5.3 Increasing the proportion of locally grown feed

If a large proportion of the feed is grown near to dairy cows, transport of feed decreases. Here the concept 'near' refers to forage growing on dairy farms or feed growing in partnership with neighbouring arable farms producing e.g. grain and legumes for direct delivery to the dairy farm and taking back the manure. The greatest environmental impact with such a feed growing arrangement is probably not decreased transport but the manure being applied on a larger area and to more different crops, which should provide the conditions for better nitrogen use efficiency. According to SCB investigations of fertilisation systems and fertiliser products, around half of the ley area receives manure annually and at certain times manure spreading on grassland is associated with high losses of ammonia. There are advantages with applying the manure from dairy farms to a number of different feed crops and not using it to such an extent for grassland as is the case today.

5.4 Suggested improvement measures

Good use efficiency of feed is important for greenhouse gas emissions from production. The efficiency can be increased by decreasing overfeeding and feed waste. Feedstuffs with high greenhouse gas emissions should be phased out over the long term, with particular attention being paid to feed raw materials obtained from regions where deforestation takes place to increase the arable acreage. It is desirable for an increasing proportion of the feed to be grown on dairy 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.

6 Proposed criteria for milk production

These proposals apply for both conventional and organic milk production.

Methane formation in ruminants

Our assessment is that the most important measure to decrease methane emissions from the total milk production system, taking into account the interaction with beef production, is to increase efforts at farm level to decrease calf mortality (dairy cows, heifers and calves), improve fertility (no long calving intervals, lower calving age for heifers) and decrease the need for medication (healthy animals). Within the Svensk Mjölk project on animal welfare, an internet tool is now being developed that can be used directly on dairy farms so that herds with poor values of important key indicators of animal health, such as high cow and calf mortality, can be alerted and advice provided.

Proposed criteria:

- Dairy farms in a climate certification system must use the Svensk Mjölk advisory system for animal welfare (under development, planned start autumn 2009) and the reasons for any deviations from the animal welfare indicators must be analysed together with an animal advisor and improvement measures introduced.

FEEDING

Efficient use of feed is important for greenhouse gas emissions from production. The efficiency can be increased by decreasing overfeeding and feed waste. Feedstuffs with high greenhouse gas emissions should be phased out over the long term, with particular attention being paid to feed raw materials obtained from regions where deforestation takes place to increase the arable acreage. It is desirable for an increasing proportion of the feed to be grown on dairy 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.

Proposed criteria:

- Analyses of the nutrient content of forage must be carried out. On dairy farms, an annual appraisal of feeding must be carried out together with a feed advisor, e.g. using the Greppa Näringen module for feed monitoring or IndividRam. Any feed waste or overfeeding must be eliminated.

- Concentrates with declared low GWP values must be used. Within three years, a maximum of 100 kg soyabean and 50 kg palm kernel expeller per cow should be allowed. The soyabean/palm kernel expeller used must be sustainability-certified (hexane-extracted soyabean meal and palm kernel expeller are not appropriate for organic production).

- At least 70% of the feed (for dairy cows and recruitment heifers in total) must be grown on the dairy farm or in partnership with a neighbouring arable farm.

MANURE MANAGEMENT

A fundamental requirement in decreasing greenhouse gas emissions from manure management is to manage the nitrogen, which involves measures to decrease nitrogen losses and overfeeding of protein. By using the manure for biogas production, the greenhouse gas emissions can be decreased in several areas of the life cycle, but it is too early at present to set criteria as regards biogas production for the individual farmer. Deep litter manure appears to be the least appropriate option from a greenhouse gas perspective but is seldom used within milk production, and we therefore consider that it is not relevant to have a criterion regarding this manure system.

Proposed criteria:

- Monitoring of feeding to avoid overfeeding, see under ‘Feeding’.

- Analysis of nitrogen flows on the entire farm, e.g. a plant nutrient budget according to Greppa Näringen, to be set up and monitored annually.

ENERGY ON THE DAIRY FARM

It is difficult to identify any specific measure on dairy farms that should be included as a criterion in climate certification of milk. Criteria for energy consumption should therefore be included in the general farm regulations. The situation and requirements differ between farms and therefore so do the conditions for, and effects of, different measures. We therefore propose two overarching measures to be adapted to the situation on farms.

Proposed criteria:

- In conjunction with new investment or re-investment, new builds or renovations, the energy efficiency of energy-demanding processes, e.g. milking, feeding, lighting, must be taken into account and consideration given to the life cycle costs of different options.

- 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.

7 REFERENCES

Berglund M & Börjesson P. 2003. Energianalys av biogassystem. Rapport 44, Miljö- och energisystem, Lunds tekniska högskola.

Berglund M, Cederberg C, Clason C, Henriksson M, Törner L. 2008. Jordbrukets klimatpåverkan - underlag för att beräkna växthusgasutsläpp och nulägesanalyser av exempelgårdar. Delrapport 1 i Jokerprojektet, Hushållningssällskapet Halland. *Manuskript*

Bertilsson J. 2001. Utvärdering av beräkningsmetodik för metanavgång från nötkreatur. Internt dokument, Naturvårdsverket. Sverige

Brøgger Rasmussen J & Pedersen J. 2004. Electricity and water consumption at milking. FarmTest – Cattle nr 17. Danish Agricultural Advisory Service. Århus

Börjesson P & Berglund M. 2007. Environmental systems analysis of biogas systems - Part II: The environmental impact of replacing various reference systems. Biomass and Bioenergy 31: 326-344.

Cederberg C & Flysjö A. 2004. Life cycle inventory of 23 dairy farms in South-Western Sweden. Rapport 728, SIK Institutet för livsmedel och bioteknik.

Cederberg C. 2008. Olika sätt att minska växthusgaserna i foderproduktionen. In: Proceedings från Svensk Mjölks Djurhälso- och utfodringskonferens, Norrköping, 27-28 aug 2008. Svensk Mjölk, Stockholm.

Cederberg C, Flysjö A, Ericson L. 2007. Livscykelanalys (LCA) av norrländsk mjölkproduktion. Rapport 761, SIK Institutet för livsmedel och bioteknik.

Edström M, Pettersson O, Nilsson L, Hörndahl T. 2005. Jordbrukssektorns energianvändning. JTI-rapport Lantbruk & Industri 342, JTI Institutet för jordbruks- och miljöteknik.

Emanuelson M, Cederberg C, Bertilsson J, Rietz H. 2006. Närodlat foder till mjölkkor – en kunskapsuppdatering. Rapport nr 7059-P. Svensk Mjölk , Stockholm.

Energimyndigheten. 2007. Energiläget 2007. Rapport ET 2007:49, Energimyndigheten

Ericsson K. 2004. Miljöeffekter av reducerad jordbearbetning – i jämförelse med traditionell plöjning. N kunskapssammanställning av HIR Malmöhus.

Faculty of Agricultural Sciences. 2008. Acidic slurry more climate-friendly. http://www.agrsci.org/ny_navigation/nyheder/nyheder/acidic_slurry_more_climate_friendly 2008-10-23

Flysjö A, Cederberg C, Strid I. 2008. LCA-databas för konventionella fodermedel – miljöpåverkan i samband med produktion: Version 1. SIK-rapport 772. Institutet för livsmedel och bioteknik. Göteborg.

Fogelberg F, Baky A, Salomon E, Westlin H. 2007. Energibesparing i lantbruket år 2020 - Ett projekt utfört på uppdrag av Statens naturvårdsverk. JTI Uppdragsrapport.

Greppa Näringen. 2008. Uppslagsboken. www.greppa.nu

Hadders G. odat. Minska elanvändningen! SLA, Skogs- och lantarbetsgivareförbundet.

Hallén Sandgren, C m fl. 2008. Slutrapport SLF-projekt Välfärdsindikatorer - System för Djurvälfärd för användning i mjölkproduktionen - Dnr 310/04, Projnr: 0430036

Hörndahl T. 2007. Energiförbrukning i jordbrukets driftsbyggnader – en kartläggning av 16 gårdar med olika driftsinriktning. JBT Rapport 145, Inst. för jordbrukets biosystem och teknologi, Sveriges Lantbruksuniversitet. Alnarp.

IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan

IPCC. 2007. Climate Change 2007 – The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

JTI. 2008. Forskningsområden – Gödselhantering och växthusgaser. http://www.jti.se/index.php?page=Husdjur-och-stallgodsel 2008-03-07

Kirchgessner M, Windish W, Müller H, Kreuzer M. 1991. Release of methane and of carbon dioxide by dairy cattle. Agribiological research 44 (2-3): 91-102.

Lidfeldt M. 2006. Lönsamhetsjämförelse mellan SRB och SLB. Projektarbete SRB-föreningen. www.srb.se

Lindgren E. 1980. Skattning av energiförluster i metan och urin hos idisslare. En litteraturstudie. Rapport 47. Avd för Husdjurens Näringsfysiologi, Sveriges Lantbruksuniversitet.

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

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

Olesen J E, Hansen E M, Elsgaard L. 2005. Udledning af drivhusgasser ved pløjefri dyrkningssystemer. I: Olesen, J.E. 2005.Drivhusgasser fra jordbruget – reduktionsmuligheder. DJF rapport Markbrug nr 113. Danmarks JordbrugsForskning. Tjele.

Petersson J. 2006. Stort utbud för mjölkning i robot. Husdjur 10 (2006): 13-15

Rodhe L & Pell M. 2005. Täckt ytmyllning av flytgödsel i vall – teknikutveckling, ammoniakavgång, växthusgaser och avkastning. JTI-rapport Lantbruk & Industri 337, Institutet för jordbruks- och miljöteknik. Uppsala

SCB. 2008. Energianvändningen inom jordbruket 2007. Statistiska centralbyrån.

Sevenster M & de Jong F. 2008. A sustainable dairy sector. Global, regional and life cycle factors and figures on greenhouse-gas emission. CE Delft. www.ce.nl

Sommer S G, Møller H B & Petersen, S O. 2001. Reduktion af drivhusgasemission fra gylle og organisk affald ved biogasbehandling. DJF rapport nr 31 Husdyrbrug. Danmarks JordbrugsForskning, Tjele.

Weidema B, Wesnæs, M, Hermansen, J, Kristensen, T, Halberg, N, Eder, P (ed), & Delgado, L. (ed). 2008. Environmental Improvement Potentials of Meat and Dairy Products. EU Commission, Joint Research Team and Institute for Prospective Technological Studies. ISBN 978-92-79-09716-4

7.1 PERSONAL COMMUNICATIONS

Larsson, Nils-Erik, Svensk Mjölk, Stockholm

Murphy, Michael, Lantmännen, Stockholm.