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Evaluering af mulige tiltag til reduktion af landbrugets metanemissioner

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Indhold

Forord

Som følge af Kyoto-protokollen fra 1997 og den efterfølgende byrdefordelingsaftale i EU fra 1998 har Danmark en forpligtelse til i perioden 2008-2012 at reducere den gennemsnitlige årlige udledning af drivhusgasser (CO_2, metan, lattergas samt visse industrigasser) med 21% i forhold til basisåret 1990. Det en del af målsætningen i Regeringens klimastrategi, at bidragene til den samlede danske reduktions-forpligtigelse af drivhusgasser fordeles på sektorerne på en afbalanceret måde. Inden for landbruget har især Vandmiljøplanerne bidraget til en betydelig reduktion af drivhusgasemissionerne. Der er imidlertid en række muligheder for yderligere at reducere emissionerne af drivhusgasser fra landbruget, og her har der hidtil kun været gennemført få tiltag men henblik på reduktion af metanemissioner fra landbruget. Disse emissioner stammer især fra fordøjelsesprocesser i husdyr (især kvæg, men også svin) og fra omsætning i gødningslagre. Disse forhold har været belyst i et udredningsprojekt i 2004 finansieret af Miljøstyrelsen.

I tillæg til dette har Danmarks Miljøundersøgelser foretaget en vurdering af effekter ved inddragelse af de emissionsbegrænsende tiltag i landbruget som forventes at kunne medtages i Kyoto-protokollens første forpligtigelsesperiode. Herunder er behovet for data og yderligere forskning vurderet.

Rapporten består af en samling selvstændige artikler på dansk og engelsk.

Arbejdet har været diskuteret i en arbejdsgruppe i forbindelse med evaluering af tiltag til reduktion af emissioner i de ikke-kvotebelagte sektorer. Gruppens medlemmer var Ulla Blatt Bendtsen, Lars Klem Nielsen, Camilla Damgaard & Trine Nielsen, Miljøstyrelsen, Lars Bach Jensen, Fødevareministeriet, Søren Tafdrup, Energistyrelsen, Peter Iversen og Kitt Bell Andersen, Skov og Naturstyrelsen, Jørgen E. Olesen, Danmarks JordbrugsForskning, Steen Gyldenkærne & Mette Hjorth Mikkelsen, Danmarks Miljøundersøgelser, Brian H. Jacobsen, Jens Abildtrup & Kurt Hjort-Gregersen, Fødevareøkonomisk Institut, og Lars Vesterdal, Skov og Landskab, KVL.

Sammenfatning og konklusioner

De hidtidige tiltag til reduktion af landbrugets emissioner af drivhusgasser har fokuseret på reduktion af emissionerne af lattergas (N_2O), primært som følge af Vandmiljøplanerne. Der er imidlertid en række muligheder for yderligere at reducere emissionerne af drivhusgasser fra landbruget, og her har der hidtil kun været gennemført få tiltag med henblik på reduktion af emissionerne af metan (CH_4) fra landbruget. Disse emissioner stammer især fra fordøjelsesprocesser i husdyr (især kvæg, men også svin) og fra omsætning i gødningslagre.

Effekter på den nationale emissionsopgørelse

Det vurderes, at ændret metodeopgørelse for metan fra fordøjelsesprocessen vil kunne bidrage til Danmarks reduktionsforpligtigelse med ca. 0,1 mio. tons CO_2-ækv.. For at opnå dette kræves en struktureret forskningsindsats som sandsynligvis vil kunne gennemføres inden udgangen af 2006, hvis den iværksættes nu.

Der er stor usikkerhed forbundet med metanemissionen fra lagret husdyrgødning. Det vurderes, at der ikke foreligger det fornødne datagrundlag til at ændre væsentligt i emissionsopgørelsen for metan fra lagring af husdyrgødning uden en betydelig forskningsindsats.

I de nuværende emissionsopgørelser for lattergas fra udbragt handels- og husdyrgødning er der hidtil anvendt den samme emissionsfaktor (1,25%). I litteraturen foreligger der efterhånden betydelig dokumentation for en differentieret emissionsfaktor, således at emissionerne fra husdyrgødning er større en fra handelsgødning. Emissionerne fra husdyrgødningen vil dog formentlig kunne reduceres ved at fjerne det let omsættelige stof i husdyrgødnignen. En dansk forskningsindsats på området er påtrængende, da danske jorder generelt er mere sandede end i vore nabolande.

Inddragelse af LULUCF i emissionsopgørelserne vurderes at kunne bidrage med en reduktion på 0,7 t CO_2-ækv frem til 2008-2012. For at kunne inddrage dette kræves en omfattende dokumentation af arealanvendelsen og ændringer heraf. Det er ikke muligt på nuværende tidspunkt at vurdere omkostningerne forbundet hermed. Herudover er det indenfor LULUCF-området ikke endelig afklaret, hvordan emission/binding fra mineraljorde skal vurderes.

Hvis der indføres nationale tiltag der reducerer CO_2-emissionen indenfor LULUCF-området, og som skal indgå i de nationale emissionsopgørelser, bør der snarest udarbejdes retningslinier herfor i samarbejde med øvrige relevante myndigheder, herunder etablering af rutiner og sagsgange, så sådanne projekter kan indgå i emissionsopgørelserne på en nem og hensigtsmæssig måde.

Metanemissioner fra malkekøer

Der er gennemført en modelbaseret analyse for at vurdere, om metanemissionerne fra malkekøer i Danmark er faldet i perioden 1991-2002. Køernes vinterfodring er i løbet af denne årrække ændret således, at foderniveauet er steget, foderets indhold af stivelse og fedt er steget, mens sukkerindholdet er faldet. En gennemgang af relevant litteratur har vist, at disse ændringer sandsynligvis har medført en lavere metanproduktion pr. kg fodertørstof og som pct. af foderets bruttoenergi.

Simuleringsmodellen Karoline blev anvendt til kvantitative forudsigelser af metanproduktionen hos malkekøer under varierende fodringsforhold med hensyn til foderniveau, kraftfoderandel i rationen, fordøjelighed af grovfoder, fedtindhold samt sukker- og stivelsesindhold i foderet. Resultaterne af disse simuleringer er i overensstemmelse med tilsvarende eksperimentelle data fra litteraturen, og det vurderes derfor, at Karoline er en pålidelig model til forudsigelse af metanproduktionen hos malkekøer.

Karoline blev endvidere anvendt sammen med tre andre modeller (regressionsligninger) til at beregne nedgangen i metanemissionen fra 1991 til 2002 på baggrund af de foderændringer, som har fundet sted i løbet af denne periode. Disse simuleringer viser, at det enteriske metantab (beregnet som pct. af bruttoenergi) fra malkekøer i Danmark er faldet med 5-6% fra 1991 til 2002.

Metan emissioner fra svineholdet

En gennemgang af de eksisterende danske data for metanemissioner viser, at pattegrisenes produktion af metan er ubetydelig, ca. 0,1% af bruttoenergien. Slagtesvin, der fodres med et lavt fiber indhold i foderet eller standard foderblandinger, har metanproduktion fra 0,2 til 0,5% af bruttoenergien. Fodres der med et højere fiberniveau, kan produktionen af metan afhængigt af fibertype udgøre op til 1% af bruttoenergien. Der ser ud til at være både en individuel og en racebetinget forskel på grises produktion af metan. Golde og drægtige søer fodret på vedligeholdelses-niveau har en metanproduktion fra 0,6 til 2,7% af bruttoenergien afhængigt både af foderniveau og fibertype. Metanproduktionen hos lakterende søer er målt til ca. 0,6% af bruttoenergien.

Der er kun medtaget typiske eksempler fra danske forsøg, hvor måling af metan er foretaget. Måling af metan har ikke været hovedformålet i nogen af forsøgene. Der er således ikke udført systematiske forsøg til belysning af variationen i metan produktionen eller udført forsøg til undersøgelse af muligheder for at reducere metan emissionen.

Metanoxidation i flydelag i gyllebeholdere

En fast overdækning synes at reducere metanemissionen fra gyllelagre. Sammenholdt med ny viden om metanoxidation i gyllelagres flydelag blev det vurderet, at et kontrolleret luftskifte over flydelaget muligvis kan reducere udledningen af metan til atmosfæren. Dette projekt beskriver konstruktion og afprøvning af en laboratorieskala forsøgsopstilling, som kan styre koncentrationen af metan eller ilt på grundlag af on-line målinger. Systemet består af to lager-beholdere (70 liter) med tætsluttende låg. Gasudtag før, i og efter hver beholder giver mulighed for at kvantificere udledningen fra lagret gylle med og uden et flydelag. Luftskiftet kontrolleres via PC af to peristaltiske pumper, og gassen pumpes frem til en bærbar gaschromatograf via en 6-ports ventil. Det nyskrevne software indlæser udvalgte data fra en GC-måling og beregner afvigelsen fra set-point samt den påkrævede nye pumperate for at korrigere til set-point i det efterfølgende tidsinterval. Pumperne er kalibreret individuelt. Systemets funktionalitet blev afprøvet med en kendt metanstandard, svarende til en konstant produktion, og med svinegylle. Det emissionsinterval, som pumperne kan kompensere for, op til ca. 30 g CH_4 m^{-2} d^{-1}, dækker de forventede emissionsrater fra lagret gylle.

Metanemissioner fra gødningshåndteringen

Der er på grundlag af den tilgængelige litteratur beskrevet modeller for metan- og lattergasemission fra lagre af gylle og fast staldgødning. Den tilgængelige litteratur er større for CH_4 end for N_2O, og den er også større for gylle end for fast gødning. Dette betyder, at det er svært at udlede emissionsmodeller for alle gasser, og at modellerne har varierende detaljeringsgrad, fordi der mangler information om indflydelse af visse faktorer på emissionerne.

I modellen for emissioner af metan fra gyllelagre indgår en betydelig usikkerhed omkring temperaturresponsen, der kvantificeres ved forskellige dannelsesenthalpier. Dette forårsager en usikkerhed på 15-90% i den årsgennemsnitlige CH_4 emissionen. Usikkerheden mht. mængden af gylle, som opbevares i forskellige måneder, fører til en usikkerhed på 10-30% i den årsgennemsnitlige CH_4 emission. Ved en temperaturstigning på 4°C, som er forudsagt for året 2100, vil den årsgennemsnitlige emission tiltage med maksimalt 35-220%. Ændring i opbevaringspraksis over perioden 1990-2003, som havde til formål at forbedre N-udnyttelsen af gylle, har resulteret i at den årsgennemsnitlige CH_4-emissionen pr. tons gylle er tiltaget med maksimalt 30-90% over denne periode. Det skyldes, at gyllen lagres over en længere tidsperiode.

Summary and conclusions

The measures for reducing greenhouse gas emissions from agriculture in Denmark have so far concentrated on reducing emissions of nitrous oxide, primarily as a consequence of the Aquatic Action Plans. There are, however, several options to further reduce agricultural greenhouse gas emissions, and so far only few measures have been implemented to reduce methane emissions from agriculture. These emissions primarily originate from enteric fermentation in animals (in particular cows, but also pigs) and from manure storages.

Effects in the national emissions inventory

It has been estimated that a change in inventory method for methane from enteric fermentation of dairy cows will contribute about 0.1 mill. ton CO_2-eq to the Danish national reduction commitment. Achieving this requires, however, a structured research effort, which could probably be completed by the end of 2006 if initiated now.

There is great uncertainty related to methane emissions from stored animal manure. It is estimated that the database required for changing the national emissions inventory for methane from manure storages will require a considerable research effort.

The current emissions inventory for nitrous oxide from field applied fertilisers and animal manure uses the same emission factor (1.25%). In the literature there is considerable support for using a differentiated emission factor, i.e. a higher value for manure N and a lower value for mineral N. The emissions from manure may possibly be reduced by removing the easily degradable organic matter in the manure. A specific Danish research in this area is recommended, because of the generally lighter soils in Denmark compared with other European regions.

The inclusion of LULUCF (Land Use Land Use Change and Forestry) in the emission inventory could contribute a reduction of 0.7 mill. ton CO_2-eq. by 2008-12 from the agricultural sector (excluding forestry). To include this amount in the emission inventory under the Kyoto-protocol will require a considerable effort to document land use and changes in land use. It is currently not possible to estimate the costs involved in this, nor has it been finally decided how carbon sequestration in mineral soils can be included in the emission inventory for the Kyoto Protocol.

If national CO_2 reducing projects within the LULUCF area is introduced, it will soon have to be decided how this is to be integrated in the national emissions inventory. It will require establishment of guidelines and routines, including collaboration with other authorities, in order for these projects to be included in an easy and flexible way.

Methane emissions from dairy cows

A model-based analysis has been conducted to assess the development in methane emissions from dairy cows during the period 1991 to 2002. The

winter-feeding of the cows has changed during this period so that the feeding level and the starch content has increased, whereas the sugar content has decreased. A review of relevant literature shows that these changes have probably led to a reduction in methane production per kg dry matter in feed and as percentage of the gross energy content of the feed.

The simulation model Karoline was used for quantitative prediction of the methane emissions from dairy cows under varying conditions with respect to level feed feeding, proportion of concentrates in the ration, digestibility of roughages as well as fat, sugar and starch content in the feed. The results of these simulations are in accordance with the corresponding experimental data from the literature, and Karoline is therefore considered a reliable model for predicting methane production by dairy cows.

The Karoline model was used in comparison with three other models (regression equations) to estimate the decrease in methane emissions from 1991 to 2002 based on the changes in winter-feeding practice that had taken place over this period. These simulations showed that the enteric methane emissions (as percent of gross energy intake) from dairy cows in Denmark was reduced by 5-6% from 1991 to 2002.

Methane emissions from pigs

A review of existing Danish data on methane emissions from pigs shows that the production of methane from piglets is insignificant, about 0.1% of gross energy intake. Slaughter pigs fed with a low-fibre diet or standard feed mixtures have methane emissions of 0.2 to 0.5% of gross energy intake. When feeding with a higher fibre content the production of methane may, depending on fibre type, increase to about 1% of the gross energy. There appears to be both individual and race-related differences in the methane production from pigs. Dry and pregnant sows fed at maintenance level have methane productions of 0.6 to 2.7% of gross energy depending on both feed level and fibre type. The methane production from lactating sows has been measured at about 0.6% of gross energy intake.

The review has only included typical examples from Danish experiments, where measurements of methane production have been included. Quantification of methane emissions was not a major objective in any of the experiments. There has thus not been conducted any systematic experiments to explore the variation in methane production or the possibilities to reduce the emissions.

Methane oxidation in surface crusts of slurry tanks

A fixed cover of slurry tanks appears to reduce methane emissions from slurry stores. In light of new knowledge on methane oxidation in the surface crust of slurry tanks it was hypothesized that control of the air exchange above the slurry surface crust may be able to reduce methane emissions to the atmosphere. Within this project a laboratory scale experimental facility was constructed, which controls the concentration of methane or oxygen on the basis of on-line gas analyses. The system consists of two storage containers (70 litres) with tightly sealed lids. Sampling of the venting air stream before, inside and after each container enables quantification of methane emissions from stored slurry with and without surface crusts. The air exchange is controlled via a PC by two peristaltic pumps. Air sub-samples for gas analysis are pumped to a portable gas chromatograph (GC) via a 6-port valve. The software written for this application analyses the GC output and calculates the deviation from a set-point, from which a modified pump-rate for the following time interval is calculated and communicated to the relevant pump. The pumps have been calibrated individually. The functionality of the system was tested with a known methane standard, corresponding to a constant production, and with pig slurry. The emission interval that the pumps can compensate is up to about 30 g CH_4 m^{-2} d^{-1}, which covers the range normally expected from stored slurry.

Methane emissions from manure handling

Models for methane and nitrous oxide emissions from stored slurry and solid manure have been described. The available literature is more extensive for CH_4 than for N_2O, and it is also more extensive for slurry than for solid manures. This means that for some greenhouse gas sources it is difficult to derive emission models, and that the models can not have the same level of detail, i.e. information is missing on the influence of some of the controlling factors.

The model for methane emissions from stored slurry includes a temperature response with a considerable uncertainty, as quantified by different enthalpies for methane formation. This gives an uncertainty of 15-90% in mean annual CH_4 emission. A temperature increase of 4°C as projected for 2100 will increase the annual emissions by 35-220%. The observed change in storage practice over the period 1990 to 2003 has increased the mean annual CH_4 emission by 30-90%, mostly due to changes in the amount of manure being stored.

1 Methane emissions from dairy cows

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1.1 Introduction

The feed composition affects methane production in the digestive tract of dairy cows as described by Weisbjerg et al. (2005). Here, the chemical composition of dairy cow rations in Denmark 1991-2002 is estimated from winter-feeding plans reported to The Danish Cattle Organization. According to these calculations, the composition of the feed for dairy cows has changed considerably during this period so that the dietary content of sugar has decreased (from 20.0 to 8.5% of feed dry matter (DM) and the starch content has increased (from 7.6 to 15.1% of DM). These changes are caused by an extensive replacement of fodder beets (about 70% sugar in DM) by maize silage (about 2% sugar and 30% starch in DM). A substitution of starch for sugar in the feed ration is expected to decrease the methane production in the rumen due to a changed fermentation pattern, which results in a higher propionate and a lower butyrate production (Møller, 1969; Sutton et al., 1993). Weisbjerg et al. (2005) used three different prediction equations to estimate the methane production based on the reported winter-feeding plans. Sugar and starch are explicit input parameters in only one of these equations (published by Hindrichsen et al., 2004), and results with this equation show that the methane production is reduced by 19% in the winter period (200 days) from 1991 to 2002. This corresponds to 10-11% lower methane emission on a yearly basis, but the calculations must be regarded with caution because of the assumptions that had to be made in order to apply the equation (Weisbjerg et al., 2005). Therefore, there is need for a further examination of whether it is probable that changes in feeding has substantially reduced the enteric emission of methane from dairy cows in Denmark during the period 1991 to 2002.

The purpose of the present analysis is to investigate this question partly by reviewing the literature and partly by using models to predict the methane production from dairy cows. The literature review is focused on experiments in which cows were fed different levels of sugar and starch and in which the methane production was measured or can be estimated from other parameters. However, reference is also given to studies that examine other aspects of nutritional and genetic changes that have taken place in Denmark during 1991-2002. The criterion for selection of models is that sugar and/or starch are included as independent variables.

1.2 Factors affecting the methane production in dairy cows

The change in the composition of the winter-feed during the last 10 years is characterized by decreased sugar content, increased starch content, a minor increase of the fat content and also an increased feeding level (Weisbjerg et al., 2005). At the same time, the breeding program for dairy herds has resulted in an increase in the genetic capacity for milk yield (Dansk Landbrugsrådgivning, 2004). The impact of these factors on the methane production is examined in the following by a survey of relevant published data.

1.2.1 Sugar and starch

The fermentation pattern in the rumen affects the extent of methane production. The formation of acetate (C_2) and butyrate (C_4) increases, while the formation of propionate (C_3) decreases the methane production (Hungate, 1966). The proportion of the ruminal concentrations of the individual short-chain fatty acids (SCFA) reflects to a large extent their relative rates of formation (Kristensen et al., 1996; Kristensen et al., 2003). Therefore, the conditions for methane formation in the rumen can be assessed from the concentrations of acetate, propionate and butyrate in the rumen fluid. An increased sugar content in the feed ration by use of fodder beets, molasses or sucrose increases the ruminal concentration of butyrate in dairy cows (Owen et al., 1967; Møller, 1969; Piatkowski et al., 1977; Piatkowski and Voigt, 1978; Krohn and Konggaard, 1987; Beever, 1993), in calves (Keusenhoff et al., 1988; Khalili and Huhtanen, 1991a) as well as in goats and sheep (Chamberlain et al., 1985). By contrast, Huhtanen (1988) found a lower butyrate concentration in the rumen of male calves by feeding beet pulp + molasses instead of barley. Feeds with high sugar content often decrease the acetate concentration (Møller, 1969; Piatkowski and Voigt, 1978; Chamberlain et al., 1985; Krohn and Konggaard, 1987; Keusenhoff et al., 1988; Khalili and Huhtanen, 1991a), have variable effects on the propionate concentration (Møller, 1969; Chamberlain et al., 1985; Huhtanen, 1988) and decrease the NH_4^+ concentration in the rumen (Møller et al., 1973; Chamberlain et al., 1985; Keusenhoff et al., 1988; Khalili and Huhtanen, 1991a). Apparently, the lower NH_4^+ concentration is related to a higher microbial protein synthesis in the rumen obtained with fodder beets (Huhtanen, 1988; Keusenhoff et al., 1988; Khalili and Huhtanen, 1991a). Microbial protein synthesis from NH_4^+ involves use of reduction equivalents (H^+ and e^-) and thereby a lower methane production (Demeyer and Van Nevel, 1975; Mills et al., 2001). However, feeding with sugar results in higher methane production than does starch feeding (Müller et al., 1994; Kirchgessner et al., 1994a; Torrent et al., c.f. Johnson and Johnson, 1995).

Normally, a high dietary starch content lowers acetate and increases propionate concentration in the rumen so that the ratio $(C_2+C_4)/C_3$ decreases (Owen et al., 1967; Sutton et al., 1988; Bergman, 1990; Beever, 1993; Sutton et al., 1993). Fermentation of starch yields less methane than fermentation of NDF (Moe and Tyrrell, 1979; Gordon et al., 1995b). However, Sutton et al. (1998) found the same methane production in dairy cows fed different proportions of grass silage and whole crop wheat silage.

Stoichiometric fermentation equations published by Baldwin et al. (1970), Murphy et al. (1982) and Bannink et al. (2000) show concordantly that fermentation of sugar results in higher production of butyrate and lower production of propionate than fermentation of starch. On this basis, replacement of sugar by starch in the feed ration is expected to decrease meth-ane production as actually shown by simulation with dynamic, mechanistic models (Mills et al., 2001; Kebreab et al., 2004) in which the fermentation equations of Bannink et al. (2000) were applied.

1.2.2 Fat

An increased dietary content of fat (especially unsaturated fat) reduces methane production (Holter and Young, 1992; Giger-Reverdin et al., 2003), but Johnson et al. (2002) found no consistent effect on the methane production in dairy cows by increasing the fat content (from 2.3 to 5.6% in DM) with supplements of whole cotton seeds and grinded rape seeds. Weisbjerg et al. (2005) have reported the major reasons for the reduction of methane formation by dietary fat:

- Unsaturated, long-chain fatty acids increase propionate formation, inhibit fermentation of cell wall carbohydrates and inhibit activity of methanogenic bacteria in the rumen
- Fatty acids reduce the number of protozoa, which produce high proportions of butyrate
- Reduction equivalents are used in hydrogenation of unsaturated fatty acids in the rumen
- Fatty acids are not fermented in significant amounts and therefore do not contribute to formation of methane.

1.2.3 Feeding level

An increased feeding level apparently changes the fermentation pattern in the rumen of dairy cows so that the ratio $(C_2+C_4)/C_3$ decreases (Sutton et al., 1988). Furthermore, high feeding levels increase the ruminal passage rate of microbial matter and undigested material leading to lower digestibility of organic matter (OM) in the rumen (Gabel et al., 2003). Both the changed fermentation and the increased passage rate contribute to a reduced formation of methane per kg DM when the feeding level is increased (Schiemann et al., 1970; Schiemann et al., 1971; Gordon et al., 1995b; Cammell et al., 2000; Yan et al., 2000; Giger-Reverdin et al., 2003). This effect of feeding level is also demonstrated by use of a mathematical simulation model (Mills et al., 2001).

1.2.4 Genetic potential

Possible influences of the genetic capacity for milk yield on the fermentation pattern and in turn on the methane production in dairy cows have not been examined to any large extent. Two studies have shown no difference in the methane energy loss (as percentage of gross energy (GE)) in cows with different breeding indexes for milk yield (Grainger et al., 1985; Gordon et al., 1995a). On the other hand, Ferris et al. (1999) found a lower methane production (6.3% of GE) in cows with a high than in cows with a medium breeding index (7.0% of GE), but this difference in methane loss may be explained fully or partly by a little higher feed intake of the high potential cows.

1.2.5 Conclusions from the literature survey

Replacement of sugar by starch in feed rations for dairy cows can be expected to cause a decreased ratio $(C_2+C_4)/C_3$ in the rumen and in turn a lower methane production. Increased dietary fat content and the feeding level reduce the production of methane per kg DM. The genetic capacity for milk yield in cows has no consistent effect on the methane formation.

1.3 Simulation of methane production

1.3.1 Effects of stage of lactation, feeding level and feed composition

The simulation model Karoline, which is a dynamic, mechanistic whole animal model of lactating cows, has been used previously by Weisbjerg et al. (2005) to predict the methane production from different feed rations. In all cases, the model simulated higher values of methane production than two selected empirical regression equations (IPCC, 1997; Kirchgessner et al., 1994b). The model has been adjusted since then and is at present in the process of being published (Danfær et al., 2005). The methane production in Karoline is calculated on the basis of stoichiometric fermentation equations for individual nutrients that are fermented in the rumen and the hindgut. The predicted methane formation is corrected for the use of reduction equivalents for microbial cell synthesis, synthesis of microbial fatty acids and hydrogenation of unsaturated dietary fatty acids. The latest version of Karoline (MixKarO, October 2004) has been changed further from the published version (MixKarH) as described below:

- Increased use of reduction equivalents for microbial syntheses and hydrogenation of unsaturated fatty acids
- Changes in the stoichiometric fermentation equations for starch and sugar (lower acetate and higher propionate and butyrate formation from starch; lower propionate and higher butyrate formation from sugar).

In the following, some simulation results obtained with Karoline (version MixKarO) are presented. The purpose is to evaluate the model's ability to give realistic predictions of the methane production in dairy cows depending on stage of lactation, feeding level and feed composition.

Table 1.1 shows input parameters for the simulations: cow weight, stage of lactation, feeding level and composition of the feed ration. The basal ration is composed (on DM basis) of 37.5% barley, 10.0% rape seed cakes, 2.5% soybean meal and 50.0% clover grass silage. The cow weight is 600 kg and the stage of lactation is 18 weeks after calving except for simulations 4 and 5. Simulations 1-3 are with the basal ration at different feeding levels (15, 20 and 25 kg DM/d, respectively), simulations 4 and 5 are with the basal ration (20 kg DM/d) and different stages of lactation (4 and 32 weeks after calving, respectively), simulations 6 and 7 are with low and high proportion of concentrates in the ration, simulations 8 and 9 are with grass silage of low and high digestibility, simulations 10 and 11 are with low and high dietary fat content, simulation 12 is with high dietary sugar content and simulation 13 is with high dietary starch content. All rations are balanced with respect to protein level (AAT and PBV) as well as physical structure (fill) according to Danish feeding standards (Strudsholm et al., 1999).

Results from the 13 simulations are collected in Table 1.2. The first three simulations show that the methane production per kg DM or as per cent of GE decreases with increasing feed intake, which is in agreement with experimental data as quoted above. Simulations 4 and 5 show that stage of lactation has no effect on the total methane formation, but the production per kg milk or as a percentage of net energy (NE) increases during lactation because of the decreasing milk yield. Studies of Cammell et al. (2000) and Sutter and Beever (2000) showed no consistent effect of lactation stage on the methane production. Cammell et al. (2000) recorded an increasing methane loss as percentage of digestible energy (DE) from week 6 to week 24 after calving, but this can be explained fully or partly by a concurrently decreasing feed intake. A high proportion of concentrates in the ration reduces the methane production per kg DM and as a percentage of GE (shown in simulations 6 and 7). This is confirmed by experimental results (Holter and Young, 1992; Ferris et al., 1999; Hindrichsen et al., 2004) and by other model simulations (Mills et al., 2001). The methane loss (g per kg DM or per cent of GE) is expected to increase with increasing digestibility of the fibre fraction (Holter and Young, 1992). Simulations 8 and 9 demonstrate this even though the feed intake is higher for the silage with high digestibility. The lowest methane production (15.9 g/kg DM) is obtained with a high dietary fat content (simulation 11) in agreement with data from the literature (Holter and Young, 1992; Giger-Reverdin et al., 2003). The last two simulations show that replacement of fodder beets + clover grass silage by barley + maize silage decreases the methane production both in absolute amount and per kg DM as also found by Müller et al. (1994) and Kirchgessner et al. (1994a).

It is concluded in the light of these 13 simulations that the model Karoline gives realistic predictions of the methane production in dairy cows at different feeding levels and with different feed compositions.

Table 1.1. Description of feed input for simulations with Karoline

Simulation no.	1	2	3	4	5	6	7	8	9	10	11	12	13
Cow weight, kg	600	600	600	600	600	600	600	600	600	600	600	600	600
Week of lactation	18	18	18	4	32	18	18	18	18	18	18	18	18
Feedstuff:	Dry matter (kg/d)												
Barley	5.62	7.50	9.37	7.50	7.50	2.55	9.45	5.73	7.50	6.25	4.75	4.00	6.00
Rape seed cake	1.50	2.00	2.50	2.00	2.00	0.85	3.15	2.34	2.25			3.50	3.00
Soybean meal	0.38	0.50	0.63	0.50	0.50	0.85	1.31	0.43	0.25	2.25	2.89	0.50	1.00
Vegetable fat											0.86		
Beet pulp							1.84			1.50	1.50	0.45	
Fodder beets												5.50	
Clover grass silage	7.50	10.00	12.50	10.00	10.00	12.75	1.58			3.50	3.50	5.00	2.60
Grass silage, early									10.00				
Grass silage, late								8.50					
Whole crop barley silage										6.25	6.25		
Maize silage													6.00
Grass hay							2.10						0.90
Wheat straw							1.57			0.25	0.25	1.05	0.50
Total, kg DM[1]/d	15.00	20.00	25.00	20.00	20.00	17.00	21.00	17.00	20.00	20.00	20.00	20.00	20.00
Total, FU$_C$[2]/d	14.78	19.71	24.63	19.71	19.71	15.44	21.19	15.30	20.37	19.59	21.24	19.75	19.76

[1] Dry matter, [2] Feed units (cattle)

Simulation 1: Basal ration, low feeding level
Simulation 2: Basal ration, medium feeding level
Simulation 3: Basal ration, high feeding level
Simulation 4: Basal ration, early lactation (4 weeks post partum)
Simulation 5: Basal ration, late lactation (32 weeks post partum)
Simulation 6: Low proportion of concentrates
Simulation 7: High proportion of concentrates
Simulation 8: Low digestibility of silage
Simulation 9: High digestibility of silage
Simulation 10: Low fat content
Simulation 11: High fat content
Simulation 12: High sugar content
Simulation 13: High starch content

Table 1.2. Simulation results with Karoline.

Simulation no.	1	2	3	4	5	6	7	8	9	10	11	12	13
Cow weight, kg	600	600	600	600	600	600	600	600	600	600	600	600	600
Week of lactation	18	18	18	4	32	18	18	18	18	18	18	18	18
FU_C/d	14.8	19.7	24.6	19.7	19.7	15.4	21.2	15.3	20.4	19.6	21.2	19.8	19.8
ECM[1], kg/d	24.8	31.7	37.0	38.2	29.0	25.8	33.4	25.1	31.7	30.3	32.6	30.6	31.5
							Methane production:						
g/d	317	387	450	387	387	375	373	299	380	392	319	392	356
g/kg DM	21.1	19.4	18.0	19.4	19.4	22.1	17.7	17.6	19.0	19.6	15.9	19.6	17.8
g/kg milk	12.9	12.1	11.7	10.3	13.9	15.2	10.3	11.2	11.6	11.8	9.2	12.5	10.6
mol/mol C fermented	0.059	0.056	0.054	0.056	0.056	0.066	0.052	0.056	0.056	0.058	0.048	0.058	0.053
MJ/MJ GE[2]	0.065	0.060	0.056	0.060	0.060	0.070	0.054	0.054	0.059	0.061	0.048	0.061	0.054
MJ/MJ DE[3]	0.086	0.080	0.076	0.080	0.080	0.094	0.073	0.078	0.079	0.084	0.065	0.083	0.075
MJ/MJ NE[4]	0.153	0.151	0.153	0.152	0.155	0.178	0.139	0.145	0.148	0.162	0.118	0.159	0.140

[1] Energy corrected milk, [2] Gross energy, [3] Digestible energy, [4] Net energy

Simulation 1: Basal ration, low feeding level
Simulation 2: Basal ration, medium feeding level
Simulation 3: Basal ration, high feeding level
Simulation 4: Basal ration, early lactation (4 weeks post partum)
Simulation 5: Basal ration, late lactation (32 weeks post partum)
Simulation 6: Low proportion of concentrates
Simulation 7: High proportion of concentrates
Simulation 8: Low digestibility of silage
Simulation 9: High digestibility of silage
Simulation 10: Low fat content
Simulation 11: High fat content
Simulation 12: High sugar content
Simulation 13: High starch content

1.4 Changes from 1991 to 2002

In order to examine whether the methane production from dairy cows in Denmark has been reduced from 1991 to 2002, the estimated average combination of feedstuffs in the winter-feed for dairy cows in 1991 and 2002 is shown in Table 1.3. These estimations are based on information from the Danish Cattle Organization on the nutrient composition of the winter-feed for dairy cows during this period (see Weisbjerg et al., 2005) and show that the ration content of fodder beets + beet pulp is reduced by 3.70 kg DM, while maize silage is increased by 4.24 kg DM per cow daily. These changes result in a decrease of the sugar content of the ration from 198 to 84 g/kg DM and an increase of the starch content from 74 to 152 g/kg DM as shown in Table 1.4. The dietary nutrient composition calculated from Table 1.3 can be compared with the corresponding figures reported by the Danish Cattle Organization for 1991 and 2002, respectively.

The information in Tables 1.3 and 1.4 is the basis of calculations of the methane production in dairy cows during the winter periods 1991/92 and 2002/03 by means of four different models. The models 1-3 are empirical regression equations, and model 4 is the simulation model Karoline (version MixKarO). The regression equations are defined as follows:

Model 1 (Kirchgessner et al., 1994a):
Y (g CH_4/d) = 172 + 9,1 * sugar (kg/d) + 92,5 * digestible crude fibre (kg/d)

Model 2 (Johnson and Ward, 1996):
Y (Mcal CH_4/d) = 0,54 + 0,39 * digestible sugar (kg/d) + 0,08 * digestible starch (kg/d) + 0,68 * digestible cell wall carbohydrates (kg/d)

Model 3 (Hindrichsen et al., 2004):
Y (g CH_4/d) = 91 + 50 * digestible cellulose (kg/d) + 40 * digestible hemicellulose (kg/d) + 24 * starch (kg/d) + 67 * sugar (kg/d).

Table 1.3. Estimated composition of the winter-feed for dairy cows in 1991 and 2002.

	Winter 1991	Winter 2002
Feedstuff:	Dry matter (kg/d)	
Barley	1.91	2.53
Rape seed cake	2.73	3.17
Soy bean meal	0.82	0.58
Beet pulp	2.73	1.95
Fodder beets	4.09	1.17
Clover grass silage	4.55	5.85
Maize silage	-	4.24
Grass hay	0.91	-
Wheat straw	0.46	-
Total, kg DM/d	18.20	19.49
Total, FU_C/d	17.9	19.1

Table 1.4. Chemical composition (g/kg DM) of the winter-feed for dairy cows in 1991 and 2002.

	Winter 1991		Winter 2002	
Chemical fraction:	1)	2)	1)	2)
Crude protein	166	166	168	167
Crude fat	42	43	48	48
Sugar	198	200	84	85
Starch	74	76	152	151
Cell wall carbohydrates	447	426	480	467
Crude fibre	162	156	175	171
NFE	556	546	542	533
Dig. cell wall carbohydrates	324		341	
Dig. crude fibre	110		117	

1) Calculated from the feed composition in Table 3, the Danish feedstuff table (Møller et al., 2000) and digestibilities of crude fibre (Andersen and Just, 1983)
2) Calculated by Weisbjerg et al. (2005) based on reports from The Danish Cattle Organization.

The independent variables can be derived from Table 1.4. Digestible sugar is calculated as sugar * 0.98, digestible starch as starch * 0.92, and digestible cellulose and hemicellulose are calculated as digestible cell wall carbohydrates times 0.2 and 0.3, respectively, as assumed by Weisbjerg et al. (2005). Inputs to the Karoline model are the feed rations given in Table 1.3, a cow weight of 600 kg and a lactation stage of 18 weeks after calving.

Results from the four models are shown in Table 1.5. The daily methane production per cow decreases from 1991 to 2002 with model 2-4, but not with model 1, whereas all four models show a decreasing methane production per kg DM and as a percentage of GE. The predicted decline in methane energy (as percentage of GE) varies from 6.0 to 22.1%, lowest with model 1 and highest with model 3. Models 2 and 4 show that the methane production (per cent of GE) in the winter feeding period is decreased by approximately 10% from 1991 to 2002.

Table 1.5. Predicted methane production in dairy cows, winter periods 1991 and 2002.

Year	1991				2002			
DM intake, kg per cow daily	18.20				19.49			
Model	1	2	3	4	1	2	3	4
(A) Methane, g per cow daily	389	454	494	387	398	445	418	377
(B) Methane, g per kg DM	21.4	25.0	27.1	21.3	20.4	22.8	21.5	19.3
(C) Methane energy, % of GE	6.7	7.9	8.6	6.7	6.3	7.1	6.7	6.0
Decrease in (C) 1991-2002, %					6.0	10.1	22.1	10.4

Model 1: Kirchgessner et al. (1994a), Model 2: Johnson and Ward (1996), Model 3: Hindrichsen et al. (2004), Model 4: Karoline, version MixKarO (2004).

1.5 Discussion and conclusion

The choice of models for calculation of methane production in dairy cows was based on whether dietary sugar and/or dietary starch were independent variables, but also on whether the models were available for use. There are other mechanistic simulation models than Karoline that are able to predict methane production in dairy cows (Mills et al., 2001; Kebreab et al., 2004), but these models were not immediately available.

Out of the four models used here, Karoline is the only one, which takes into account all the nutritional factors that have changed from 1991 to 2002: feeding level as well as dietary contents of sugar, starch and fat. Furthermore, it is concluded from the literature review and the simulation results in Table 1.2 that Karoline can give realistic predictions of various nutritional effects on the methane production in dairy cows. Model 1 (Kirchgessner et al., 1994a) contains sugar, but not starch as an independent variable, and the basis for model 3 (Hindrichsen et al., 2004) is feed rations that are very different from those normally used for dairy cows in Denmark. Moreover, the assumptions used in the calculation of digestible cellulose and hemicellulose are problematic as pointed out by Weisbjerg et al. (2005). The mean result from the four models is a 12% decline from 1991 to 2002 in the methane production (expressed as per cent of GE), which is close to the simulation result obtained with Karoline (Table 1.5).

In conclusion, the enteric methane loss (per cent of GE) from dairy cows in the winter feeding period in Denmark is likely to have decreased by approximately 10% from 1991 to 2002. This is equivalent to a 5-6% decrease on a yearly basis if a winter feeding period of 200 days is assumed.

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2 Methane emissions from pig production

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2.1 Introduction

Increased demand of high energy cereals for direct human use and increased availability of fibre rich ingredients from, for instance, the feed milling or starch extraction/fermentation industries have promoted an increased utilisation of fibre rich by-products in the pig feeds. The direct use of forage is also increasing. Other benefits, such as increased wellbeing of animals, improvement of the gut transit or reduction of stomach ulcers also favour an increased utilisation of fibre rich ingredients in pig feeds. An increased dietary fibre level in the diet is on the other hand associated with a reduced available energy content, so if the diet is not combined with high energy ingredients such as animal fat or vegetable oil, the amount of feed required per produced animal unit will increase.

The fermentation of carbohydrates in the pigs' digestive system specially the lower gut results predominantly in short chain fatty acids as acetic, propionic and butyric acid, gasses as carbon dioxide (CO_2), hydrogen (H_2) and methane (CH_4), urea and heat. It should also be noted that, during the fermentation process, an important bacterial mass is produced. The short chain fatty acids can be utilised in the pigs' metabolism and can contribute with a significant part of its maintenance. From an energy point of view, only CH_4 and H_2 are important as they represent a loss of energy. However, information on gas production by pigs is rather limited. From an environmental point of view CH_4 is especially interesting as it contributes to global warming. The CH_4 productions by pigs vary with their age or live weight and the type of diet they receive. Here the type and amount of dietary fibre is most important. In the present report some examples from experiment with pigs measuring methane production will be discussed. All experiments were carried out in the respiration chambers at Research Centre Foulum.

2.2 Data material

The respiration chambers were established at Foulum in 1990 and several experiments have been carried out on growing/finishing pigs from 30 – 120 kg live weight. Other experiments on sows in different stages as dry, pregnant and lactating including their piglets. To measure emissions from the piglets alone, experiments have been carried out with artificial sows.

The respiration chambers consist of climatic controlled airtight rooms, where the animals' energy metabolism can be measured. The measured parameters are heat production and the animals' consumption of oxygen and production of carbon dioxide, methane and hydrogen. The chambers work from the so called indirect principle, where the atmospheric air is ventilated through the cambers and the amount of air is measured together with the concentration of oxygen, carbon dioxide and methane in both ingoing and outgoing air (Jørgensen, 2001; Jørgensen et al., 1996). When the consumed amount of oxygen and produced amount of carbon dioxide and methane is known the heat production can be calculated (Christensen and Thorbek, 1987).

2.3 Results and discussion

In general the gastrointestinal tract of pigs develops with age towards increased capacity and ability to ferment the dietary fibre fraction of the diet. This is illustrated for growing pigs in Table 2.1. The results show an increase in methane production from 3.4 to 5.6 litres CH_4 per day. However, expressed relative to either digested energy or gross energy there is only a slight increase.

Table 2.1. Methane production by growing pigs.

Live weight, kg	Dietary fibre, %	DM intake, kg/day	Ferm. fibre, g/kg DM	***CH_4*, l/day**	CH_4 % DE	DC energy, %	CH_4 % GE
46	21.3	1.47	132	3.4	0.6	84	0.47
58	24.1	1.68	159	2.5	0.4	85	0.31
64	23.8	1.75	153	4.3	0.7	83	0.51
72	23.8	1.84	150	4.9	0.7	83	0.55
82	25.0	1.92	170	5.6	0.8	84	0.61

DE, digested energy; DC, digestibility coefficient; GE, gross energy.

Sows are normally feed restricted in the dry and following pregnancy period (approximately 2 Feed Units (FUp) per day) in order not to gain excessive weight and following health problems around farrowing and lactation. The last 3-4 weeks during pregnancy, the feeding level is in general increased to 3 FUp per day. Table 2.2 shows results from an experiment with pregnant sows fed a standard diet or one of two fibre rich diets supplemented with either wheat bran or sugar beet pulp. Fibre from wheat bran is more resistant to fermentation than fibre from sugar beet pulp and as expected the amount of fibre fermented and the production of CH_4 is higher when sows are fed sugar beet pulp. A higher feeding level increases the methane production but relative to either digested energy or gross energy the production is lower.

Table 2.2. Pregnant sows feed on 2 feeding levels.

Diet - Feeding level	Dietary fibre, %	LW, kg	DM intake, kg/day	Ferm. fibre, g/kg DM	***CH_4*, l/day**	CH_4 % DE	DC energy %	CH_4% GE
Control - Normal	17.5	225	1.63	120	5.4	0.9	86	0.70
Control – High	17.5	239	2.69	137	7.0	0.7	84	0.55
Wheat bran - Normal	24.3	226	2.42	181	6.9	1.1	79	0.79
Wheat bran – High	24.3	219	3.79	185	6.3	0.6	77	0.47
Sugar beet pulp - Normal	21.1	223	1.65	210	9.0	1.5	85	1.16
Sugar beet pulp - High	21.1	248	2.73	231	10.6	1.1	82	0.83

LW, live weight; DE, digested energy; DC, digestibility coefficient; GE, gross energy.

A comparison of the ability of growing pigs and sows to digested and utilise various fibre rich feedstuffs are shown in Table 2.3. The sows' production of methane is as expected higher than for the growing pig even with equal inclusion level of fibre rich feedstuffs. The reason is the sows relatively greater capacity for fermentation and also that the sows are fed on a relatively lower level relative to body size. However, in the actual experiment for the most voluminous fibre feedstuffs neither the sows nor the growing pigs were able to consume more. The experiment also shows great variation in the fermentability of the different fibres. Fibre in seed residue is an example of fibres resistant to fermentation. Furthermore, there was variation among animals, some animals had low methane production independent of amount and fibre source. Fibre easily fermented are pea hulls, sugar beet pulp and potato pulp and in the experiment with sows the methane production can be as high as 2.7% of the gross energy. When comparing different fibre rich feedstuffs contributing to CH_4 emission it must be considered that the lower energy digestibility will imply that the pigs must consume a larger quantity to obtain the same production.

Table 2.3. Methane production by dry sows and growing pigs feed different fibre-rich by products.

Animals Diet	Dietary fibre, %	LW, kg	DM intake, kg/day	Ferm. fibre, g/kg DM	***CH_4*, l/day**	CH_4 % DE	DC energy %	CH_4 % GE
Growing pigs								
Control diet	17.7	60	1.77	92	2.3	0.4	81	0.28
+ Seed residue	34.6	69	2.05	84	1.2	0.2	60	0.12
+ Brewers' grain	32.4	61	1.73	126	0.8	0.2	67	0.11
+ Potato pulp	29.6	67	1.72	220	5.8	0.9	81	0.70
+ Pea hulls	33.8	56	1.77	203	6.8	1.1	74	0.79
+ Pectin residue	32.3	53	1.42	185	1.4	0.3	73	0.19
+ Sugar beet pulp	33.2	63	1.61	257	7.7	1.3	77	0.98
Dry sows								
Control diet	19.8	220	1.71	132	6.4	1.0	85	0.81
+ Seed residue	46.0	218	2.12	87	7.6	1.7	46	0.77
+ Brewers' grain	42.1	216	1.97	178	9.0	1.4	64	0.90
+ Potato pulp	40.4	200	1.60	339	15.1	2.5	83	2.09
+ Pea hulls	45.4	238	2.32	394	28.7	3.2	84	2.69
+ Pectin residue	49.4	203	1.57	310	4.1	0.8	67	0.56
+ Sugar beet pulp	46.2	207	1.64	422	14.4	2.3	82	1.90

LW, live weight; DE, digested energy; DC, digestibility coefficient; GE, gross energy.

Feeding of lactating sows require diet with a higher energy density, which means a diet with low fibre content, and in order to obtain higher energy density addition of fat is a normal practice. Table 2.4 shows lactating sows fed with low and high dietary fat. The total daily amount of produced methane is

12 – 17 litre/day. However, because of relative low fibre content and high feed intake methane energy expressed relative to gross energy is measured to 0.5 – 0.7%. Increased amount of fat in a diet for ruminants is expected to decrease CH_4 production in the rumen. Pigs as non-ruminants have their main fermentation in the hindgut after digestion and absorption of the fatty acids. Most fat sources have a relative high digestibility (90%) (Jørgensen and Fernández, 2000) and consequently only limited amount of the fatty acids reach the hindgut. The present experiment used addition of animal fat with a high digestibility and there was not any effect on CH_4 production (Jørgensen et al., 1996). However, in other experiments with growing pigs fed with either rapeseed oil or fish oil, which have mostly long chain fatty acids, marginal reductions in the methane production have been found. The slightly higher methane production of the high fat diet shown in Table 2.4 could partly be explained by a higher content of soybean meal to supply equal amount of protein per net energy unit (Theil et al., 2004). Soybean meal is known to have an easily fermented fibre (Jørgensen, 1997). It remains to be tested if fat sources with medium chain fatty acids, i.e. coco-nut oil and palm oil which is known to depress methane production in ruminants (Machmüller et al., 2003), would have a beneficial effect in reducing methane production in pigs as well. In the experiment with the lactating sows the measurement was done on both sow and piglets. In an other experiment where the piglets were fed with a artificial mother the piglets had a methane production of approximately on 0.1% on the gross energy.

Table 2.4. Methane production by lactating sows feed low and high dietary fat (Theil et al. 2004).

Diet - Dietary fat	Dietary fibre, %	LW, kg	DM intake, kg/day	Ferm. fibre, g/kg DM	***CH_4, l/day***	CH_4 % DE	DC energy %	CH_4% GE
Low fat – 3.0 %	17.3	219	4.87	109	12.1	0.6	85	0.53
High fat – 11.3 %	15.1	192	4.76	98	16.9	0.9	82	0.71

LW, live weight; DE, digested energy; DC, digestibility coefficient; GE, gross energy.

Diets for growing pigs have changed over time. In order to reduce N-pollution to the environment, diets have been formulated more close to the pigs' requirement with regard to amino acid composition. This trend in diet composition is illustrated in Table 2.5 with diet no 5 and 6 (Sørensen and Fernández, 2003), where diet no 6 is supplemented with free amino acids. Both diets give the same growth potential, but diet no 6 has a reduced dietary protein content and because of a reduced content of especially soybean meal less fibre is fermented. A slightly lower production of methane can be expected. Based on the data shown there was a satisfactory correlation between the amount of fibre fermented and the CH_4 production both on growing pigs and sows. In both cases the methane production is below 0.6 % of gross energy as given in the report on emission from the Danish agriculture (Mikkelsen et al., 2004).

In the dry and pregnancy period up to a few weeks before farrowing sows are feed restricted in order to avoid problem with overeating. Therefore it is of interest to feed high fibre diets. Table 2.5 shows two typical diets, no 11 with relative low dietary fibre content and the other no 12 with high fibre content. The diets were chosen as representative for sow diets with low (normal) dietary fibre content and high dietary fibre content. The fibre from sugar beet pulp is easily fermented and is also known to have positive effect on the sows' behaviour. The production of methane of both diets is above the value of 0.6 % as indicated for sows by Mikkelsen et al. (2004).

Table 2.5. Examples on trend in diets for growing pigs and dry sows (Data from Sørensen & Fernandez, 2003).

Animal	Growing pigs		Dry sows	
Diet	5	6	11	12
Composition of diet				
Wheat	33.3	40.1	-	40.7
Barley	25.1	33.9	81.2	4.6
Soybean meal	15.4	10.0	3.7	-
Peas	11.6	4.3	-	-
Sweet lupine	10.0	6.6	0.5	10.1
Sugar beet pulp	2.0	2.0	12.5	42.8
DL-Methionine 40	0.14	0.20	0.05	0.13
L-Threonine 50	-	0.30	0.05	0.19
L-Lysine 50	-	0.70	-	-
Mineral + Vitamins	2.46	1.90	2.00	1.48
Chemical composition				
Dietary protein, % in DM	23.3	20.0	13.0	15.1
Dietary fibre, % in DM	22.5	21.0	27.9	41.5
DM-intake, kg/day	1.53	1.55	1.83	1.77
DC energy	83	82	83	84
Fermented fibre, g/kg DM	139	123	180	335
Expected[1] CH_4, l/day	2.4	1.8	7.6	13.1
CH_4-energy % GE	0.33	0.25	0.90	1.61

[1] Calculated from amount of fermented fibre (equations based on data in Table 1, 2, 3 and 4 for growing pigs and sows, respectively).
DC, digestibility coefficient; GE, gross energy.

2.4 Conclusions

Production of methane by piglets is low and is measured to be around 0.1% of the gross energy. Growing pigs' fed with low fibre content in the diet or a standard diet have a methane production from 0.2 to 0.5% of the gross energy. When feeding higher dietary fibre content the methane production can depending on fibre type and content contribute up to 1% of the gross energy. The trend in diet for growing pigs seems over the years to be a reduced protein content and thereby a slight reduction in fermentable fibre and CH_4. Dry and pregnant sows fed on maintenance have a methane production from 0.6 to 2.7 % of the gross energy depending on feeding level and fibre type. The methane production by lactating sows was measured to approximately to 0.6 % of the gross energy. In all the experiments the methane production by sows have been found to exceed 0.6 %.

This report only shows some examples of the Danish experiments, where measurements of methane have been included. In none of the experiments measurement of methane the main objective. Thus there have not been carried out systematic experiments to look at variation in methane production or using various fat sources or other means to possibly reduce methane emission from pigs. A more comprehensive review of all the available data and possible relation from chemical analysis or in vitro analysis to the measured in vivo measurements is warranted.

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3 Metanoxidation i flydelag

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3.1 Indledning

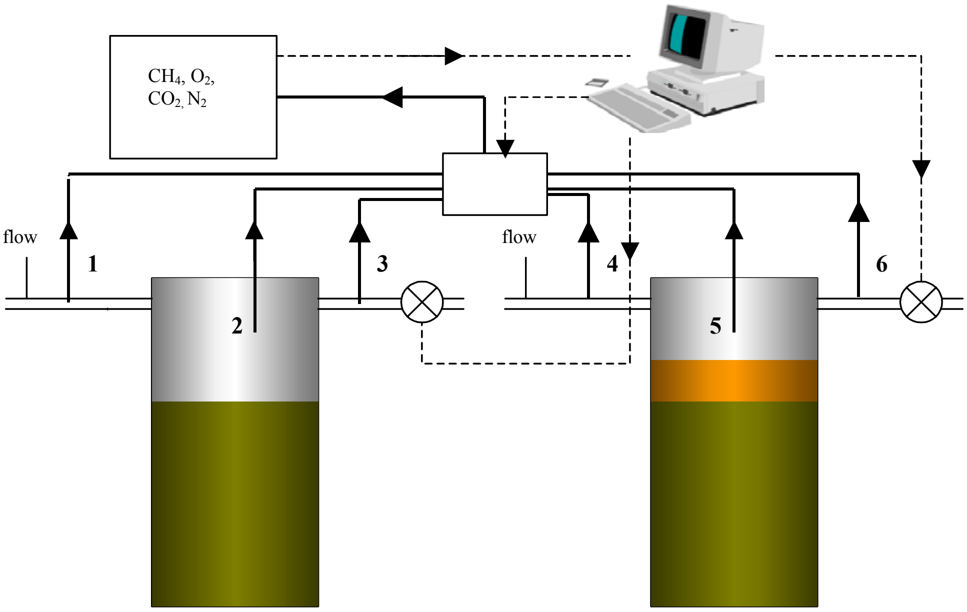
Landbrugets udledning af drivhusgasser til atmosfæren udgør ca. 18% af de samlede antropogene udledninger i Danmark (Olesen et al., 2005). Metan repræsenterer godt en trediedel af disse udledninger, som primært stammer fra husdyrs fordøjelse og fra husdyrgødning. Hovedparten af husdyrgødningen i Danmark håndteres som gylle, en flydende blanding af fæces og urin, eventuelt iblandet strøelse. I dette stærkt anaerobe miljø er der et betydeligt potentiale for metandannelse, og gyllelagre er derfor en væsentlig kilde til metan, hvis drivhuseffekt er 21 gange større end effekten af CO_2.

Målinger under praktiske og forsøgsmæssige lagringsforhold har tidligere indikeret, at et flydelag kan reducere udledningen af metan til atmosfæren (Husted, 1994; Sommer et al., 2000). Forekomst af metanoxiderende bakterier i flydelaget har været foreslået (Sommer et al., 2000; Miner et al, 2003), men ikke dokumenteret. Nye undersøgelser har nu vist, at metanoxidation finder sted i dette miljø, og at aktiviteten er på niveau med hvad man har målt i fx rismarker og sumpområder (Petersen et al., 2005; Petersen & Ambus, 2005; Ambus og Petersen, 2005). Petersen et al. (2005) fandt metanoxidation i såvel et naturligt flydelag på lagret kvæggylle som i et lag halm, der fungerede som kunstigt flydelag i et lager med biogasbehandlet kvæggylle. I en efterfølgende screening af intakte flydelag fra lagre med kvæg- og svinegylle var der et potentiale for metanoxidation i alle lagre; dog viste prøver udtaget fra et lag Leca-sten ingen målbar aktivitet (Petersen & Ambus, 2005). Inkubation med ^{13}C-mærket metan viste desuden omdannelse af metan til CO_2 i alle materialer undtagen prøverne med Leca-sten (Ambus & Petersen, 2005).

En fast overdækning kan tilsyneladende reducere udledningen af metan (Clemens et al., 2005). Årsagen kan være, at et låg stabiliserer fugtighed og temperatur i flydelaget og dermed giver bedre vilkår for opformering af metanoxiderende bakterier. Overdækningens tæthed kan variere, og det vil påvirke luftskiftet over den lagrede gylle. Williams & Nigro (1997) varierede luftskiftet over gylle mellem 0,5 og 0,0025 m pr. sekund i et laboratorieforsøg og fandt, at emissionen af metan ved det laveste flow var 90% lavere end ved det højeste flow, der skulle svare til en udækket beholder. Forfatterne vurderede, at metan blev tilbageholdt i bobler under flydelaget, og at reduktionen derfor ikke nødvendigvis var udtryk for metanfjernelse. Imidlertid har nye forsøg vist, at metanoxidationen øges med stigende metankoncentration i luften over flydelaget (Petersen & Ambus, 2005). En alternativ forklaring på den reducerede emission af metan er derfor, at metanoxidationen stimuleres som følge af den højere steady state-koncentration i luften over gyllen. Denne forklaring støttes af, at halvmætningskonstanten for metanoxidation i de fleste naturlige miljøer svarer til 1500-7000 ppm CH_4, dvs. langt over det atmosfæriske niveau på 1,8 ppm (King, 1992).

På baggrund af de observationer og resultater, som er beskrevet ovenfor, var udgangshypotesen for dette udviklingsprojekt, at styring af luftskiftet over gyllelagre med flydelag kan reducere udledningen af metan til atmosfæren.

Målsætningen for denne indledende fase var at udvikle et styringsværktøj, som kan regulere luftskiftet over lagret gylle på grundlag af gasanalyser før, i og efter lukkede beholdere med lagret gylle. Konkret var det målet at designe, konstruere og teste et system, der kan løse denne opgave.



Figur 3.1. En principskitse af forsøgsopstilling til styring af luftskifte på grundlag af gasanalyser. Gasudtag er markeret med numrene 1-6, og gasledninger er vist med fuldt optrukne streger. Elektriske signaler til gasrelæ og de to pumper er markeret med stiplede streger. Gaschromatografen analyserer gassen for metan, ilt, CO_2 og N_2, men til styringen anvendes kun informationer om ilt og metan.

3.2 Forsøgsopstilling

Forsøgsopstillingen er skitseret i figur 3.1. Gasudtag før, i og efter hver af to 70-liters beholdere af polyethylen (Bonar Plastics, Smørum) samles i en seksportsventil (Cheminert, Valco Instr., Schenkon, Schweiz) via 1/16” PTFE-slanger. Gassen analyseres ved hjælp af en Model 3000 Micro GC (Agilent, Nærum) med to separate analyseenheder, begge med TCD detektor, og gaskoncentrationsdata lagres i en .csv-fil. Et program skrevet i Visual Basic sørger for, at ventilen skifter mellem de seks kanaler. Hvis der er tale om gasprøver fra et af lagrenes headspace (position 2 eller 5), beregnes desuden ny pumpehastighed på grundlag af forskellen mellem ilt- eller metankoncentration og det valgte set-point. Udledningen af metan kan beregnes på grundlag af metankoncentrationen i udgangsluften og den tilhørende pumpehastighed.

Denne første version af programmet sigter mod at styre luftskiftet til en forvalgt værdi for enten ilt eller metan. Hensigten er at bruge forsøgsopstillingen til en systematisk undersøgelse af sammenhængen mellem substrattilgængelighed og metanoxidation. En analyse-sekvens er skitseret i tabel 3.1.

Tabel 3.1 Analysesekvens for program til styring af luftskifte i måleopstillingen.

1. Udgangssituation	Startværdier for pumpehastighed samt set-points for ilt og/eller metan (de to primære substrater for metanoxidation) defineres i en .ini-fil. Via software til styring af GC startes en sekvens, som automatisk gennemfører en måling med 3 min tidsinterval, svarende til en 15-min cyklus. Udtagningsstedet, kanal ***n***, defineres af et separat program via en post run-kommando, som styrer gasrelæet med de 6 indgående linier.
2. Måling	GC'en tager gasprøve ind og analyserer - signalet opsamles i database.
3. Post-run	Via post run-programmet hentes og gemmes udvalgte parametre i .csv-fil, hvorefter styreprogrammet kaldes og gør følgende: a. læser csv-filen; b. evaluerer afvigelse fra set point. Hvis gasrelæet er i position 2 eller 5, dvs. der måles på lagrenes headspace, genberegnes pumpehastigheden, og der sendes besked til den relevante pumpe; c. gemmer informationer om gaskoncentrationer og pumpehastighed i output-fil (.csv-format); d. skifter gasrelæ til kanal ***n - 1***.
4. Afslutning	Målesekvensen afsluttes manuelt i Cerity

Der er fastsat en max-værdi på 20 vol% for metan af hensyn til eksplosionsfaren; overskrides denne tærskel, ændres pumpehastigheden til højeste værdi.

Ilt forbruges i mange mikrobielle processer udover metanoxidation, og den kombination af ilt og metan i lagrenes headspace, som er optimal med hensyn til at minimere metanudledningen, kan ikke nødvendigvis opnås blot ved at justere luftskiftet med atmosfærisk luft. Derfor er systemet forberedt til indblæsning af ren ilt via ekstra ventiler.

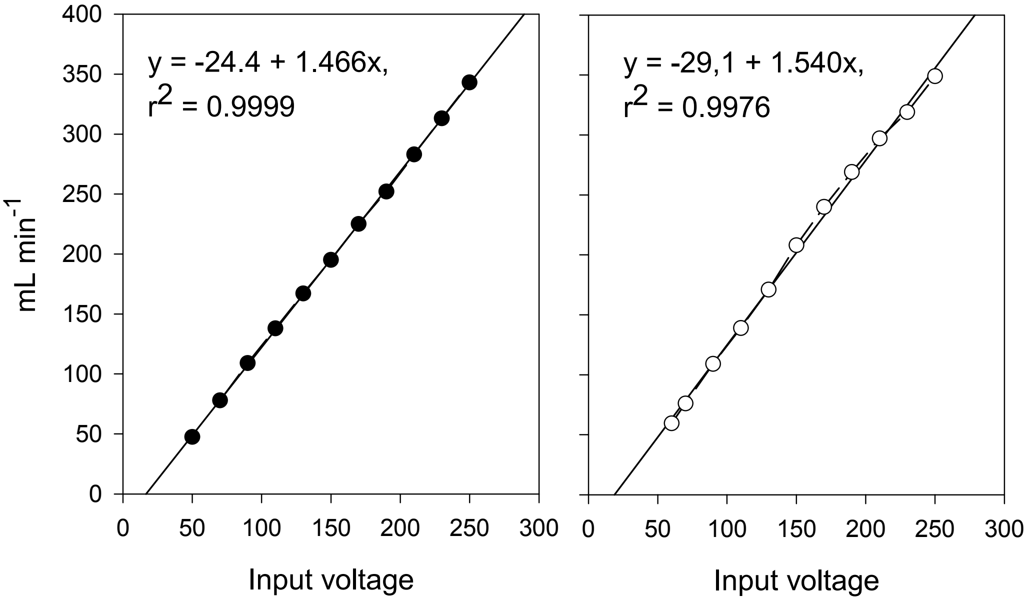
3.3 Afprøvning

I løbet af december 2004 blev systemet samlet og software-kommunikation etableret. Herefter blev følgende aktiviteter gennemført:

3.3.1 Kalibrering af de peristaltiske pumper

Luftflowet afhænger af slangediameter og pumpens specifikke ydelse som funktion af input-spænding. De to pumper blev kalibreret individuelt ved hjælp af en elektronisk flowmåler (se figur 3.2). Responsen var tilnærmelsesvis lineær, men forskellig for de to pumper. Derfor blev der lagt en separat omregning fra luftflow (som beregnes efter hver måling) til spænding ind i pumpestyringsprogrammet.

Det var ikke muligt at aktivere pumperne ved en spænding på under ca. 50 V, og derfor stoppes pumperne helt, hvis det beregnede pumpeflow svarer til en spænding <60 V. I praksis betyder det, at gasfasekoncentrationen vil fluktuere omkring den fastsatte værdi.



Figur 3.2. Kalibreringskurver for de to pumper til styring af luftflow i beholdere med lagret gylle.

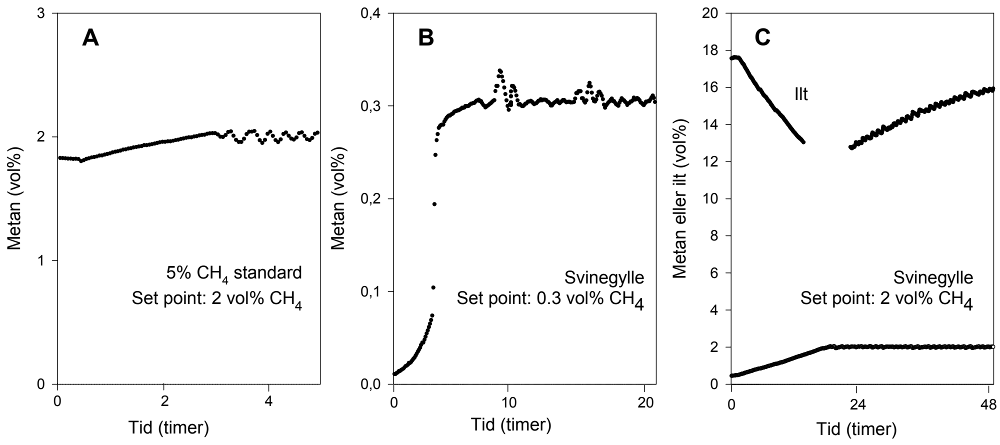
3.3.2 Kontrol af pumpestyring, metanstandard

Et kontrolforsøg blev gennemført, hvor gas med et kendt indhold af metan (5 vol%) blev pumpet ind i en 70-liters beholder med varierende hastighed. Der blev benyttet et fortryk på 10 psi, mens det aktuelle flow blev reguleret via et kugle-flowmeter.

Der blev eksperimenteret med forskellige koncentrationer og tilførselsrater for at belyse, hvilken metan-emissionsrate der kan kompenseres for med den aktuelle opsætning. Et konkret eksempel er vist i figur 3.3A.

Kompensationsgrænsen blev estimeret til ca. 30 g CH_4 m^{-2} d^{-1}. Til sammenligning målte Clemens et al. (2004) i et netop afsluttet EU projekt emissioner fra forsøgslagre med kvæggylle på 0,2-10 g CH_4 m^{-2} d^{-1}, mens Sommer et al. (2000) målte maksimale emissioner på 18 g CH_4 m^{-2} d^{-1}. Det indikerer, at forsøgsopstillingen vil være i stand til at styre gasfasekoncentrationen af metan til et ønsket niveau.

Eksempler på inkubation af frisk svinegylle er vist i figur 3.3B og 3.3C. Som det fremgår af figur 3.3B, så steg metanudviklingen i starten eksponentielt, men blev fastholdt ved det valgte set-point på 0,3 vol%. I figur 3.3C vises resultater, hvor metankoncentrationen fik lov at stige fra 0,3 vol% op til 2 vol%. I stigningsperioden faldt iltkoncentrationen, fordi pumperne stod stille indtil det nye set-point var nået. Systemet er som tidligere nævnt udstyret med ventiler, som gør det muligt at kompensere for dramatiske fald i iltkoncentrationen, men disse er ikke taget i brug endnu.



Figur 3.3. Udvalgte resultater med pumpestyring på baggrund af metankoncentrationen i den lukkede beholder. A. En kendt standard (5 vol% CH_4) blev pumpet ind i beholderen med kendt hastighed. B. Inkubation af svinegylle (set-point 0,3 vol% CH_4). C. Koncentrationer af ilt og metan under og efter overgang til et nyt set-point på 2 vol% CH_4.

3.4 Konklusion

Der er udviklet et system til styring af metan- og/eller iltkoncentrationen i en lukket beholder, hvis funktionalitet er blevet valideret. Det er muligt at fastholde en ønsket koncentration indenfor et emissionsinterval, som er realistisk i forhold til forventede emissioner under praktiske lagringsforhold. Målsætningen for denne første etape af udviklingsprojektet er dermed opfyldt.

Næste skridt vil være at gennemføre lagringsforsøg med og uden flydelag på gyllen for at bestemme potentialet for metanoxidation i flydelaget, og forsøg med flydelag, men med eller uden ilt. Endvidere bør det undersøges, om metankoncentrationen i headspace vekselvirker med metanoxidationen, dvs. om det er muligt at mindske emissionen fra lageret ved at fastholde en forhøjet koncentration af metan i lagerets headspace.

3.5 Referencer

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4 Modelling greenhouse gas emissions from manure handling

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4.1 Introduction

Emissions of the greenhouse gases methane (CH_4) and nitrous oxide (N_2O) from agriculture is closely coupled to the turnover of carbon (C) and nitrogen (N), which also are closely coupled and where other emissions also are involved (e.g. CO_2, N_2, NO, NH_3, NO_3^-). It is therefore important to describe the emission of these greenhouse gases as a part of the C and N cycle, so that the consequences of emission reduction measures for one gas can be evaluated also on other environmental emissions.

Berntsen et al. (2003) developed a process oriented whole-farm model of the C and N flows and related emissions. However, the existing version of FASSET does not include all greenhouse gas emissions, only emissions of N_2O from the fields and CH_4 emissions from enteric fermentation in cattle are included. However, a less detailed model of greenhouse gas emissions from cattle farms (FarmGHG) has been developed by Olesen et al. (2005). The work presented here uses existing knowledge to develop models for FASSET for the emissions of CH_4 and N_2O from slurry and solid manure.

The emissions of CH_4 and N_2O from manure storages are the result of physiochemical and microbiological processes and are influenced by agricultural practice, such as manure handling system, housing design, cleaning habits etc. Physicochemical processes can be described relatively easily, whereas microbiological processes are much more complicated. The complexity of such processes makes it more difficult to generalize experimental results, e.g. different emissions can be observed at apparently the same conditions. In that case factors that are important for the process have apparently been overlooked.

The best way to model the emissions is to include all the processes and the interaction between the emission processes for all gases (including CO_2 and N_2) and to include all compounds, so that a mass balance approach can be followed. This is the approach that as far as possible is used here.

4.2 Emission models

4.2.1 Methane emissions from slurry

Based on studies of Sommer et al. (2004) and Olesen et al. (2005) the following descriptive model for methane emissions from slurry based systems is proposed:

$$F(t) = factorNH_3 * factoramount * \left(VS_d b_1 + VS_{nd} b_2\right) \exp\left(\ln(A) + \left(\Delta E / RT\right)\right)$$

where ***factor*** $\boldsymbol{NH_3}$ is factor by which the CH_4 emission rate is reduced due to the concentration of high free NH_3 molecules. This factor will be a function of the free NH_3 concentration, but the precise description of this function cannot yet be given. It cannot be excluded that this factor is different for pig and cattle slurry. ***factoramount*** is a factor by which the CH_4 emission rate is increased due to the fact that it increases with the amount present in the tank. The precise description of this function cannot yet be given. It is likely that it will be different for pig and cattle slurry. $\boldsymbol{VS_d}$ is the concentration of easily degradable volatile solids (kg kg^{-1}). $\boldsymbol{VS_{nd}}$ is the concentration of slowly degradable volatile solids (kg kg^{-1}). $\boldsymbol{b_1}$ is a rate correction factor for VS_d (can be different for pig and cattle slurry). $\boldsymbol{b_2}$ is a rate correction factor for VS_{nd} (can be different for pig and cattle slurry). $\boldsymbol{A}$ is an Arrhenius parameter (can be different for storage in-house and storage outside) (g CH_4 kg^{-1} VS h^{-1}). ΔE is the heat of formation (J mol^{-1}) (can be different for pig and cattle slurry). $\boldsymbol{R}$ is the gas constant (8.314 J K^{-1} mol^{-1}). $\boldsymbol{T}$ is the temperature (K).

Different authors give different values for the heat of formation ΔE, depending on the type of slurry (cattle or pig), season or presence of crusts (Table 4.1). The emissions in all experiments increase with temperature, but to different extents. There are a few possible explanations for the differences in temperature responses. It could partly result from the fact that there are different CH_4 forming bacteria that have their own temperature optimum. Another explanation is that ebullition of CH_4 may have occurred in summertime, which reduces the transport time through the crust, where CH_4 oxidation takes place. According to De Mol and Hilhorst (2003) there is no CH_4 emission below 4°C. Amon et al. (2003) found that during the summer measurements the accumulated CH_4 emission reaches a plateau, whereas this is not observed during the winter measurements. A possible reason for this could be that there is not enough VS_d left at the end of the summer experiments.

Table 4.1. Heat of formation for CH_4 emission used by different authors.

Reference	ΔE (J mol^{-1})	Comments
Husted (1994)	-85×10^3 (4-18°C)	Cattle slurry, uncertainty of same order as ΔE. Storage is outside. Not clear if data are for slurry with or without a crust
Husted (1994)	-140×10^3 (4-18°C)	Pig slurry, uncertainty of same order as ΔE. Storage is outside. Not clear if data are for slurry with or without a crust
Sommer et al. (2000)	-230×10^3 (summer) -80×10^3 (winter)	Cattle slurry with crust or other cover. Storage outside
Amon et al. (2003)	-122×10^3 (summer + winter) –53 to –85 (winter) – 135 to –245 (summer)	Cattle slurry (with crust or cover), storage outside
Béline (2003)	-44×10^3 (8-18°C) -38×10^3 (8-18°C)	Cattle slurry, Farm1, storage outside Cattle slurry, Farm2, storage outside, crust
Hüther (1999)	-91×10^3 (10-25°C) -432×10^3 (5-10°C)	Pig slurry, storage in the laboratory, no crust Pig slurry, outdoor conditions, no crust

The CH_4 emission rate is a function of the pH. At pH 7 the emission shows is maximum and at a pH of 6.5 or 8.3 it is about half this value (De Mol and Hilhorst, 2004). It should be noted that changes in TAN (total ammoniacal nitrogen = $NH_3 + NH_4^+$) in general also will affect the pH, i.e. the TAN concentration and the pH are not independent variables.

Hüther (1999) investigated the influence of the NH_3/NH_4^+ concentration on methane and nitrous oxide emissions. Investigations with just one microorganism species have shown that the undissociated forms NH_3 and HNO_2 are much more inhibiting than the ionic forms. NH_3 in high concentrations slows down the activity of methane bacteria and both nitrosomonas and nitrobacter that are involved in the nitrification. The NH_4-N concentrations in cattle and pig slurry depend on age, water content, animal species and feeding and lies between 1.5 and 5.5 g kg^{-1}. As the NH_3 concentration in aqueous solution is highly dependent on the pH, it could in principle occur that the NH_3 concentration becomes so high that CH_4 and N_2O emissions are influenced. The experiments have also shown that NH_4^+ concentrations that occur in practise can slow down the activity of methane bacteria. So higher NH_4^+ concentrations will lead to lower CH_4 emission during normal storage periods of 3-6 months.

NH_4-N concentrations in pig and cattle slurry in Denmark vary between 3 and 4 g kg^{-1} (Poulsen et al., 2001), i.e. in the range where an effect on the CH_4 emission can be expected, but it will also depend on the pH. There is only limited data available on slurry pH that have been made simultaneously with the NH_4-N concentration measurements in Denmark. However, the observed ranges indicate that the CH_4 emission in Denmark can be reduced by NH_3.

Angelidaki and Ahring (1993a) investigated the effect of inhibition of CH_4 emission by anaerobic digestion of livestock waste by ammonia. They state also that free NH_3 (i.e. not in the form of NH_4^+) inhibits the CH_4 emission, but that a the inoculum can adapt to higher NH_3 concentrations if the concentration is raised gradually. Angelidaki et al. (1993b) made a mathematical model for anaerobic digestion of manure. Their equations show that the formation of VFA (volatile fatty acids) is not influenced by free NH_3, only the last step: formation of CH_4 from acetic acid seems to be influenced by the free NH_3 concentration. Inhibition by free NH_3 leads to higher VFA concentrations.

CH_4 emission of slurry covered by a natural crust is usually lower than the emission without a crust (e.g. Husted, 1994). The reason for this could be oxidation of CH_4 in the crust. Amon et al. (2003) found that the emission of cattle slurry with a cover was about 5% less than the emission without a cover (but with a crust). Hüther (1999) found that there was not much difference between CH_4 emission from untreated cattle slurry with and without a Leca cover.

Hüther (1999) mentions that the CH_4 emission per tonne slurry decreases if the ratio surface to volume becomes larger.

4.2.2 Methane emissions from solid manure

Solid manure is essentially slurry to which straw is added. Degradation of straw can also lead to CH_4 emission. Farmyard manure has a varying straw content. Information from Germany shows that the dry matter content of farmyard manure varies from 12 to 30% with an average of 22% (Hüther, 1999). The dry matter content of deep litter is larger than 22%. The difference between farmyard manure and composting farmyard manure is that a farmyard manure heap is anaerobic, while the composting farmyard manure is aerobic because it is turned regularly. Due to processes in the manure or composting manure, heat is generated. During composting higher temperatures are reached than without composting. The temperature of the heap does, however, also depend on the outdoor temperature. This means that the temperature is higher during in the summer than in the winter. The temperature is not constant, but varies with time, which means that the influence of the ambient temperature on the processes also will vary with time.

Solid manure with a low straw content is wet and is not porous. Farmyard manure with a high straw content is humid or dry and is very porous. In the manure and in its aggregates oxygen gradients will exist that are a function of position and time. Aerobic processes occur at the surface, whereas anaerobic processes occur deeper in the manure and in its aggregates. For these reasons it can be expected that the CH_4 emission from farmyard manure is a function of the straw content. For composting manure the CH_4 emission decreases with the dry matter content (Hüther, 1999). Heaps with manure are usually stored outside the farm building. As a result they are also exposed to rain and snow, which may reduce oxygen penetration into the heap.

There is only a set of two experiments with cattle farmyard manure of which data can be used for a parameterization (Amon, 1998; Amon et al., 2001). The dry matter content of this farmyard manure was 20-21%.

One experiment was conducted in summertime during about 80 days (average ambient temperature 15.4 °C). It takes a few days before the emission rate is at a higher level. This is apparently due to the fact that the microbial activity needs some time to start. A statistical analysis shows that the CH_4 emission rate was more related to the temperature in the heap than to the time after the start of the experiment. After the initial maximum in the emission that is reached after a few days the CH_4 emission rate decreases about exponentially with time. At 80 days the emission rate is still about 15% of the maximum emission rate. This means that the duration of the experiment was too short to measure the maximum accumulated emission over time.

One experiment was conducted in wintertime during about 80 days (average ambient temperature 7.7 °C). This experiment was apparently influenced by water originating from melting snow. The shape of the emission rate as a function of time looks similar to the shape for the summertime experiment. In this case it took a longer time to reach the maximum emission rate. At the end of the experiment the ambient temperature increased and as a consequence the emission rate increased too. The duration of this experiment was apparently also too short to measure the maximum accumulated emission over time.

The function for the CH_4 emission rate was derived from the experiments performed by Amon (1998). Due to the fact that the winter experiment is influenced by precipitation it is more difficult to reach a conclusion.

The CH_4 emission rate as a function of time is somewhat arbitrarily given by:

$$E = E_0 * \exp(-a*d) \text{ (g } CH_4/(t.d))$$

where E_0= facttemp*E_{ref} with E_{ref} = 13 g CH_4/(t.d) (where t = tonne manure, d = day); a= 0.03466 d^{-1}.

The temperature factor facttemp was estimated from the Arrhenius equation:

$$\mathrm{facttemp} = \frac{E}{E_{ref}} = \exp\left(\frac{\Delta E}{R}\left[\frac{1}{T} - \frac{1}{T_{ref}}\right]\right)$$

where E is the actual emission rate (g CH_4 /(t.d)), E_{ref} is the emission rate at reference temperature (same units as E), ΔE is the enthalpy of formation (J mol^{-1}); in this case -9.0×10^4 J mol^{-1} is taken, and R is the gas constant 8.314 J mol^{-1} K^{-1}, T is the actual temperature (K), and T_{ref} is the reference temperature (K, 5°C = 278.15 °K).

It should be noted here that the above function is just a function that approximately fits the few measurements of Amon (1998), but that its use in fact is limited to those measurements as some of the following conditions will be different in the Danish situation:

- Dry matter content/content of easily degradable VS.
- Temperature.
- Air flow (influences the transport of oxygen into the manure).

4.2.3 Nitrous oxide emissions from slurry tanks

N_2O can be formed as a by-product during the nitrification (from NH_3 to NO_3^-) if not enough oxygen is present. N_2O can also be formed as a step in the denitrification (from NO_3^- to N_2). N_2O is generated at the boundaries between aerobic and anaerobic environments and is a result of a competition between various processes. This makes it much more difficult to model N_2O emission than CH_4 emission.

Sommer et al. (2000) measured the emission of CH_4 and N_2O (August-October 1996; June-September 1997) of stored cattle slurry and fermented slurry in buried containers outside. The experiments lasted between 9 and 12 weeks. The cattle slurry was between 2 and 4 months old. The fermented slurry contained 2-4 weeks old slurry from dairy farms and 20% organic waste, mainly from food processing industries. The experiment included different covers (the containers were open to rainfall):

- Uncovered (no crust developed on the fermented slurry; the crust on the cattle slurry was removed)
- Surface crust (crust from another cattle slurry store was added to the fermented slurry; 7-10 cm crust on cattle slurry developed naturally)
- Leca pebbles (10 cm thick)
- Straw (15 cm thick chopped wheat straw)

Sommer et al. (2000) found that no N_2O was emitted from any treatment (fermented or normal cattle slurry; covers) during the fall experiments of 1996. The covers visually appeared saturated with water during this period, which was characterized by a positive water balance.

Sommer et al. (2000) found that in the summer experiments significant N_2O emissions of up to 25 mg N m^{-2} h^{-1} were encountered, but only in slurry stores with surface covers. This suggests that N_2O production took place at the interface between the anaerobic slurry and the air-filled surface covers. N_2O emission from cattle slurry was highest when covered by a natural crust and appeared earlier than with covers of Leca or straw. The high emission rate is associated with the drying out of the surface layers in periods with more evaporation of water than precipitation. Drying will create oxic zones in the surface cover and will enhance convection of liquid upward through the cover, where dissolved NH_4^+ can be oxidized by nitrifying bacteria in the oxic zones, while in anoxic zones the products of nitrification can be denitrified. As the N_2O is formed in the surface crust, it is likely to be function of the surface area, rather than the volume (emission m^{-2} crust).

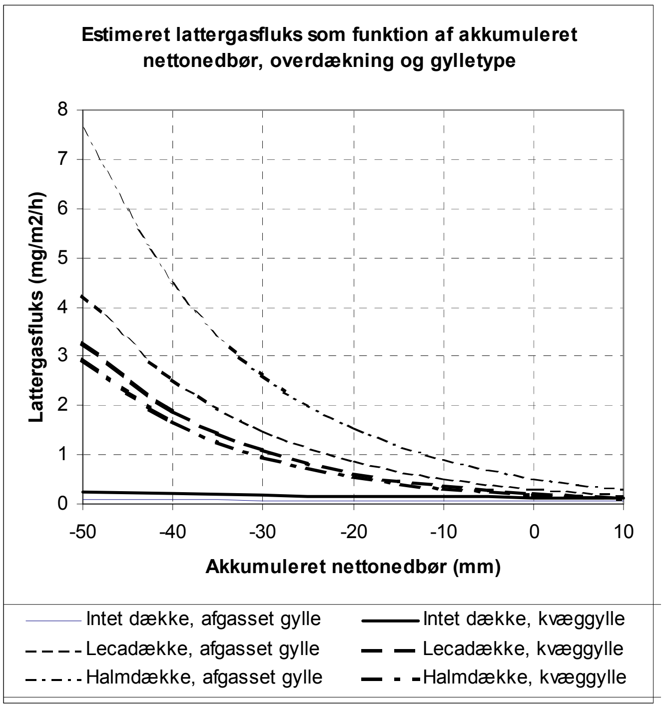

Figure 4.1. Modelled N_2O flux as a function of the net precipitation amount and the type of cover as derived by Sommer et al. (2000) from their measurements.

Sommer et al. (2000) performed a statistical analysis and derived average N_2O fluxes from their measurements (Figure 4.1). The emissions show variations in time. Almost no emission occurred for the situation without a crust. For the situation with a surface crust the emission rate was also often almost zero, but a maximum up to 22 mg N m^{-2} h^{-1} was observed.

The following equation describes the statistical relation:

$$\ln\left(E_{i,j}\right) = \mu + C_i + S_j + kw + CS_{i,j} + c_i w + s_j w + \varepsilon_{i,j,k}$$

where $\boldsymbol{E}$ is the emission rate, $\boldsymbol{i}$ is an index for cover: 1 = no cover, 2 = floating Leca pebbles, 3 = straw, $\boldsymbol{j}$ is an index for manure type: 1 = fermented slurry, 2 = cattle slurry, μ is mean ln (natural logarithm) emission, $\boldsymbol{C_i}$ is additional ln emission due to cover, $\boldsymbol{S_j}$ is additional ln emission due to slurry type, $\boldsymbol{CS_{i,j}}$ is additional ln emission due to the interaction between cover i and slurry type $\boldsymbol{j}$, $\boldsymbol{k}$ is mean slope of the linear relationship between the ln emission and the water balance, w is water balance (precipitation – evaporation), $\boldsymbol{c_i}$ is additional contribution to the slope of the linear relationship between the ln emission and the water balance for cover $\boldsymbol{i}$, $\boldsymbol{s_j}$ is additional contribution to the slope of the linear relationship between the ln emission and the water balance for slurry type $\boldsymbol{j}$, $\varepsilon_{i,j,h}$ is the residual for cover $\boldsymbol{i}$, slurry type $\boldsymbol{j}$ and time of measurement $\boldsymbol{h}$. The residual is here set to 0.

It should be noted that due to an error, the term $\boldsymbol{s_j w}$ in this equation was left out in the article (Henning T. Søgaard, personal communication). The values of the parameters are also not published in the paper, but were also obtained from Henning T. Søgaard: μ = -8.6071286, C_1= -0.8225919, C_2 = 0.31584853, C_3 = 0.50674336, S_1 = 0.1140391, S_2 = -0.1140391, k = -0.0404785, $CS_{1,1}$ = -0.54147, $CS_{1,2}$ = 0.54147, $CS_{2,1}$ = 0.0971813, $CS_{2,2}$ = -0.0971813, $CS_{3,1}$= 0.4442888, $CS_{3,2}$ = -0.4442888, c_1 = 0.02803831, c_2 = -0.0135708, c_3 = -0.0144675, s_1 = 0.00170533, s_2 = -0.00170533.

It was not possible to find information on measured N_2O emissions from slurry, where all factors that potentially could influence the emission were investigated, but the approach of Sommer et al. (2000) could be used as a start. It should be noted, however, that this parameterization is presumably rather specific for this experiment.

4.2.4 Nitrous oxide emissions from solid manure

The following parameterisation of the emission rate E was found for solid manure stored in a heap outside (Amon, 1998):

$$E = 1.97*\exp(-0.3466e-1*(day-8)) \quad (g\ N_2O/(t.d)$$

The emission before day 8 has in this way be set to 0.

The parameterisations of the results of Amon (1998) are too specific for that particular situation and cannot be used in general. Information is also lacking on important factors that influence the emission rate.

4.3 Scenario analyses

The CH_4 emission depends on the amount of slurry stored and is also a function of the temperature. To get an impression how the CH_4 emission changes with agricultural practise two simple scenarios were adopted, where e.g. no slurry was applied in the summer.

- Scenario “May 1” it is adopted that there is no slurry in the tank on May 1 and all the slurry present on April 1 is applied in April (Table 4.2).
- Scenario “April 1” it is adopted that there is no slurry in the tank on April 1 and all the slurry present on March 1 is applied in March (Table 4.2).

In both cases it is assumed that the amount produced in September and October is applied in those months. These scenarios are about in agreement with the results of an inquiry that addresses the amount of slurry applied in different seasons (Dansk Landbrug, 2004).

Table 4.2. Average amount of slurry stored for each month for different scenarios, expressed in the amount produced in one month.

Month	Amount stored Scenario May 1	Amount stored Scenario April 1	Amount stored Scenario 1990	Amount stored Scenario 2003
January	6.50	7.50	3.00	6.60
February	7.50	8.50	4.20	7.68
March	8.50	4.50	4.08	7.68
April	4.50	0.50	1.44	4.56
May	0.50	1.50	0.84	0.96
June	1.50	2.50	1.44	1.68
July	2.50	3.50	1.92	2.16

August	3.50	4.50	2.16	2.52
September	4.00	5.00	1.44	2.52
October	4.00	5.00	0.60	3.36
November	4.50	5.50	0.72	4.44
December	5.50	5.50	1.92	5.52

From Sommer et al. (2004) it can be seen that almost only the easily degradable VS content plays a role in the emission of CH_4. To simplify the calculations in this sensitivity study it was therefore assumed that the increase and decrease of the CH_4 emission rate as a function of the temperature can be described by only the taking the emission from the easily degradable VS into account. Average monthly temperatures for Foulum were used in the calculations. It was implicitly assumed that fraction of VS_d that was converted to CH_4 was the same at the same time of the year for different values for the heat of formation. The effect of this is discussed wherever it is relevant.

To simplify the calculations further the ratio emission rate at the actual temperature/emission rate at the annually averaged temperature at Foulum (***facttemp***) was calculated for each month. The (relative) emission rate as compared to the annually averaged temperature at Foulum was described by:

$$\mathrm{facttemp} = \frac{E}{E_{ref}} = \exp\left(\frac{\Delta E}{R}\left[\frac{1}{T} - \frac{1}{T_{ref}}\right]\right)$$

where E is actual emission rate at temperature T (g CH_4-C g^{-1} VS d^{-1}), E_{ref} is the emission rate at reference temperature (same units as E), ΔE is the enthalpy of formation (J mol^{-1}), R is the gas constant 8.314 J mol^{-1} K^{-1}, T is the actual temperature (K), and T_{ref} is the annually averaged temperature at Foulum (7.3°C = 280.4 K).

The relative emission was multiplied by the amount of slurry stored for each month. At last these results were summed up. In that way a relative annual emission was obtained for one scenario that can be compared with the relative annual emission of another scenario.

As there is uncertainty on the enthalpy of formation, the calculations were made with the value that Sommer et al. (2004) took (-1.127×10^5 J mol^{-1}) to obtain the same result as the IPCC methodology for the present storage practise. The calculations were also made with values that represent more extreme cases found in the literature: -0.5×10^5 J mol^{-1} and 2×10^5 J mol^{-1}.

Table 4.3 illustrates that the uncertainty in the CH_4 emission from slurry due to only the uncertainty in the amount stored will be of the order of 10-30%. The emission in the “April 1” scenario is larger than that of the “May 1” scenario because in general more slurry is stored.

Table 4.3. Ratio annual emission of scenario “April 1”/annual emission of scenario “May 1” for different enthalpies of formation for CH_4.

Enthaply of formation (J mol^{-1})	Emission ratio “April 1”/”May 1”
-1.127×10^5	1.23
-0.5×10^5	1.11
-2.0×10^5	1.32

Notes: The same enthalpy is taken in both scenario’s.

Table 4.4 illustrates that the uncertainty in the enthalpy of formation for CH_4 can lead to uncertainties in the annual CH_4 emission of 15-90%. It should be noted, however, that in these calculations it is not taken into account that the amount of easily degradable VS remaining varies with the enthalpy of formation of CH_4. This effect would lead to smaller changes in emission than calculated here.

Table 4.4. Ratio annual emission calculated with different enthalpies/ratio emission for an enthalpy of -1.127×10^5 J mol^{-1}.

Enthaply of formation (J mol^{-1})	Ratio emission/emission for $\Delta E = -1.127\times10^5$ J mol^{-1}
-1.127×10^5	1.00
-0.5×10^5	0.85
-2.0×10^5	1.89

A policy to reduce NH_3 emissions was adopted in the nineties, where the period during which slurry was applied was reduced and the capacity to store slurry was increased. Steen Gyldenkærne (National Environmental Research Institute, Roskilde, Denmark) has performed a recalculation on the amounts stored for each month for the situation in 1990 when no measures were taken and for 2003 when the policy was established (Table 4.2) based on data obtained from the Danish Agricultural Advisory Centre.

The results of the calculations for those scenario's are presented in Table 4.5. The CH_4 emission increased by 30-90% during this period, which is mainly due to the increased amount of slurry stored.

Table 4.5. Ratio emission 2003/emission 1990 for the same amount of slurry produced.

Enthaply of formation (J mol^{-1})	Ratio emission 2003/emission 1990
-1.127×10^5	1.58
-0.5×10^5	1.88
-2.0×10^5	1.33

The results of climate models for Denmark indicate that the average annual temperature in 2100 could be 3-5 °C higher than in 1990 (Olesen et al., 2004). The warming is largest during the night and there is only small difference between the rise in temperature during summer and winter. To get an impression of the possible effect of the rise in temperature on the emission of CH_4 from storage an increase in temperature of 4°C was assumed for every month. For the "May 1" scenario (see previous section) this leads to an increase in the CH_4 emission of about 90% (for an enthalpy formation of -1.127×10^5 J mol^{-1}), 35% (for an enthalpy formation of -0.5×10^5 J mol^{-1}) or 220% (for an enthalpy formation of 2.0×10^5 J mol^{-1}). It should be noted, however, that these calculations do not taken into account that the amount of easily degradable VS is partly consumed and that a reduced amount of easily degradable VS will lead to reduced emissions and a larger amount of easily degradable VS would lead to larger emissions. If this effect would be taken into account this would lead to smaller changes in emission than calculated here.

4.4 Conclusions

There is in general knowledge on which factors potentially influence the emission of CH_4, N_2O and NH_3 from manure storages. However, there is almost no experimental investigation where factors that influence the emission of greenhouse gases as a function of time have been investigated systematically. For that reason there is not yet possible to describe the emission of CH_4 and N_2O in a satisfactory way with the FASSET model, although a preliminary approach is proposed for the emission of CH_4 and N_2O from slurry.

The emissions of CH_4, N_2O and NH_3 are not independent, e.g. high concentrations of NH_3 in the slurry may lead to smaller emissions of CH_4 and N_2O. Having a crust on slurry may reduce the emission of CH_4 and NH_3, but could potentially lead to an increase in the N_2O emission. Any research of the possibilities to reduce the emission of one agricultural gas, should also include the effects on the emissions of the other agricultural gases. Other factors should also been taken into account, such as animal welfare, CO_2 emissions (to make it possible to make a complete C balance in a model) and N_2 emissions (to make it possible to make a complete N balance in a model), emission of odour and energy consumption. If such and integrated approach is not done, there is a considerable risk that a political focus on one of these problems will lead to and increase of the other problems.

A model like FASSET that is based on C and N balances and should be able to predict emissions of CH_4, N_2O and NH_3 can only be based on the results of experiments where factors that influence the emission are varied systematically. However, attempts at such experiments have almost never been done, and there is thus a need for a comprehensive research in this area where experiments are linked to a mechanistic modelling of the processes.

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5 Inddragelse af landbrugstiltag i den nationale emissionsopgørelse

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5.1 Indledning

Jordbruget omfatter ca. 13% af den samlede danske drivhusgasudledning i 2003. Dette notat er en uddybning af muligheder og konsekvenser for implementering af nogle af de foreslåede tiltag i indeværende rapport samt andre væsentlige drivhusgaskilder. De foreliggende forslag dækker dels over hvordan drivhusgasemissionen kan nedbringes og dels metodebeskrivelser til en mere akkurat opgørelse, men primært har forslagene en reduktionseffekt på længere sigt. Endvidere vurderes muligheden for at forbedre emissionsopgørelsen fra landbruget på udvalgte områder. Der er primært fokuseret på muligheden for ændringer som vil kunne påvirke emissionen indenfor første forpligtigelsesperiode (2008-2012), mens der ikke er taget stilling til mulige forbedringer på længere sigt. Den nuværende emissionsopgørelse er på de fleste områder baseret på nationale aktivitetsdata (antal dyr, kvælstofomsætning, antal hektar, osv.). De nationale aktivitetsdata kendetegnes generelt af en lav usikkerhed. En forbedret emissionsopgørelse på baggrund af forbedrede aktivitetsdata vil derfor ofte ikke være mulig, med undtagelse af opgørelserne af arealanvendelse. Der fokuseres derfor her primært på de anvendte emissionsfaktorer, hvor der i øjeblikket ofte anvendes standardfaktorer fra IPCC. Ændringer i emissionsfaktorerne fra IPCC standard til nationale faktorer kræver omfattende dokumentation.

Der er her udvalgt nogle hovedområder, hvor en indsats vil kunne forbedre emissionsopgørelsen væsentlig, velvidende at der er andre områder hvor usikkerheden er betydeligt større, men hvor en forbedring ikke vil have stor indflydelse på den samlede danske emission.

Intergovernmental Panel on Climate Change (IPCC) udarbejder på baggrund af FNs klimapanel (UNFCCC) kravene til de nationale emissionsopgørelser. IPCC har udarbejdet guidelines for hvordan opgørelserne kan foretages. De fem vigtigste hovedkrav benævnes ofte som TACCC (Transparent, Accurate, Comparable, Complete og Consistent). De enkelte lande kan vælge at udarbejde emissions-opgørelserne efter guidelines men også anvende nationale metodikker, såfremt disse anses for at være mere nøjagtige i relation til landets specifikke landbrugsforhold. Beregningsmetoden for emissionsopgørelser-ne inddeles generelt på tre niveauer, Tier 1-3, hvor Tier 3-metoden betegner det mest detaljerede niveau. Tier 1-metoden er standard og kan udarbejdes for alle lande uden egne data. I Tier 2 anvendes nationale tal på baggrund af standardemissionsfaktorer og på Tier 3 niveau anvendes nationale metoder, hvor landet selv udarbejder metode og den nødvendige dokumentation for metoden. En væsentlig betingelse for at kunne anvende et højere Tier-niveau er at usikkerheden på emissionsopgørelsen er mindre end foregående Tier niveau. Er dette ikke tilfældet ***skal*** et lavere Tier niveau anvendes. For at kunne inddrage nationale metoder er det derfor et ufravigeligt krav at metoden er sikker og grundigt dokumenteret. Den nuværende opgørelse er primært baseret på Tier 2-metoder, hvor der anvendes standard emissionsfaktorer.

5.2 Metan fra fordøjelsesprocessen

I 2003 er metan fra husdyrenes fordøjelse opgjort til 2,73 mio. t CO_2-ækv./år Dette er et fald fra 1990 på 0,43 mio. t CO_2-ækv/år. Emissionen stammer især fra drøvtyggere. I den nuværende opgørelsesmetode anvendes Tier 2. Emissionen beregnes ud fra energien i foderet. Opgørelsen er baseret på foderforbruget i de danske normtal og er derfor beregnet ud fra de aktuelle års foderforbrug (Poulsen et al., 2001) ganget med en emissionsfaktor, der er individuel for den enkelte dyreart. I perioden 1990 til 2003 er der for metandannelseskapaciteten anvendt standardemissionsfaktorer fra IPCC Good Practice Guidance (IPCC, 1996). Reduktionen i den hidtidige opgørelse skyldes derfor udelukkende, at antallet af kvæg reduceret. Den enteriske metandannelse fra enmavede dyr (svin) er forholdsvis lav, hvorfor stigningen i den danske svineproduktion kun har en begrænset indflydelse her. Stigningen i svineproduktionen har dog også en effekt på emissionen fra husdyrgødning.

Metandannelsen i vommen hos drøvtyggere er afhængig af fodersammensætningen (Weisbjerg et al., 2005). I 1990 bestod kvægets vinterfodring af store mængder roer (højt sukkerindhold), medens den i dag primært udgøres af stivelsesholdige produkter (majs og græs). Dette er dokumenteret i et stort antal vinterfoderplaner fra Landscentret (kapitel 1) og kan ligeledes verificeres med at sukkerroe arealet til foder er reduceret fra 102.000 ha i 1990 til 8.000 ha i 2003 (Danmarks Statistik 2005) og at majsarealet til opfodring er forøget fra 19.000 ha til 118.000 ha. Danmarks JordbrugsForskning har udviklet en ”modelko” (Karoline-modellen) (kapitel 1) som på baggrund af fodersammensætningen hos malkekøer kan beregne metanemissionen. På baggrund af modelberegninger vurderes det i kapitel 1, at metanemissionen fra malkekøer på baggrund af foderændringen er reduceret med ca. 9,4% fra 1991 til 2002, hvis malkekøerne blev foderet året rundt med vinterfoder. Korrigeret for en aktuel vinterfoderperiode er det vurderet at emissionen er reduceret med 5-6% (kapitel 1).

En sammenligning mellem Karolinemodellen og den nuværende anvendte Tier 2 metode er vist i tabel 5.1. I kapitel 1 er den modelberegnede emission i 2002 opgjort til 377 g CH_4 per dag ved et foderforbrug på 19,49 FE_K per dag svarende til 7111 FE_K per år . I følge normtallene var det gennemsnitlige foderforbrug 6100 FE_K . I nedenstående tabel er der følgelig korrigeret.

Modelskifte fra den nuværende Tier 2 til Tier 3 vil øge basisemissionen i 1990, mens den i 2003 vil være på det samme niveau som med den nuværende Tier 2 model. Som følge af en øget mælkeproduktion per ko og dermed et øget foderforbrug vil emissionen per ko dog stige svagt fremover.

Tabel 5.1 Estimerede ændringer i enterisk CH_4-emission, mellem Karolinemodellen og den nuværende anvendte Tier 2-metode i 1991 og 2002, kg CH_4 per malkeko per år.

	1991	2003
Karoline-modellen[1]	123,2 (87,2% af foderplan)	120,4 (87,5% af foderplan)
Nuværende Tier 2 (stor race)	112,5	120,4
Forskel 1991-2002	+ 10,7	+ 0

[1] Foderforbruget i de anvendte vinterfoderplaner er højere end normtallene, hvorfor disse er korrigeret til normtalsniveau. Der er korrigeret i forhold til stor race.

Der findes vinterfoderplaner tilbage til 1990, hvorfor de grundlæggende forudsætninger for ændring fra Tier 2 til Tier 3 er tilstede. Det er derfor muligt at forbedre emissionsopgørelsen. I den følgende beregning er der ikke taget kontakt til Landscentret for at vurdere vinterfoderperiodens længde, men kun foretaget en vurdering ved 6 mdr. vinterfoder eller en reduktion i emissionsfaktoren på 5% for malkekvæg samt opdræt (ej tyrekalve). En reduktion på 5% vil reducere den nationale emission fra 1990 til 2003 med ca. 5 Gg CH_4 svarende til 0,1 mio. tons CO_2-ækv/år. Et yderligere fald i de kommende år vil ikke kunne forventes ved at øge stivelsesindhold i foderet, da sukkerholdige fodermidler næsten er udfaset (på nær roepiller). Yderligere fald per dyr i den enteriske metandannelse skal derfor ske ved andre fodertiltag. Fremover vil den samlede enteriske metandannelse fra kvæg dog fortsat falde som følge af et forventet færre antal malkekøer.

I kapitel 1 er Karoline-modellen sammenholdt med andre metanmodeller. Der er angivet mange litteraturkilder der sandsynliggør sammenhængen mellem stivelse og sukker og metanemissionen. Der foreligger kun en simpel validering af Karoline-modellen mod et foderforsøg med 18 køer, hvor der er målt metan (Allan Danfær, personlig meddelelse). På trods af store variationer er der en god sammenhæng mellem model og forsøg. Der kunne dog ønskes en bedre validering af modellen mod flere forsøg, ligesom der skal angives estimater for usikkerheden. Det anses derfor vanskeligt på baggrund af kapitel 1 at ændre den nuværende opgørelsesmetode uden yderligere dokumentation, hvor en egentlig validering samt usikkerhedsberegninger er foretaget. Karoline-modellen er udviklet til foderoptimering hos malkekøer. DJF har endvidere udviklet modellen ”GYSSE” til foderoptimering hos slagtesvin.

Et modelskifte fra den nuværende Tier 2 til Tier 3 kun bør kun ske, hvis der udarbejdes validerede modeller med angivelse af usikkerheder for alle væsentlige drøvtyggere, herunder opdræt, tyrekalve og ammekvæg samt for svin. Modellerne skal kunne opfylde de af IPCC opstillede kriterier for validitet. Her gælder bl.a. at usikkerheden i metanemissionen skal estimeres til <8%.

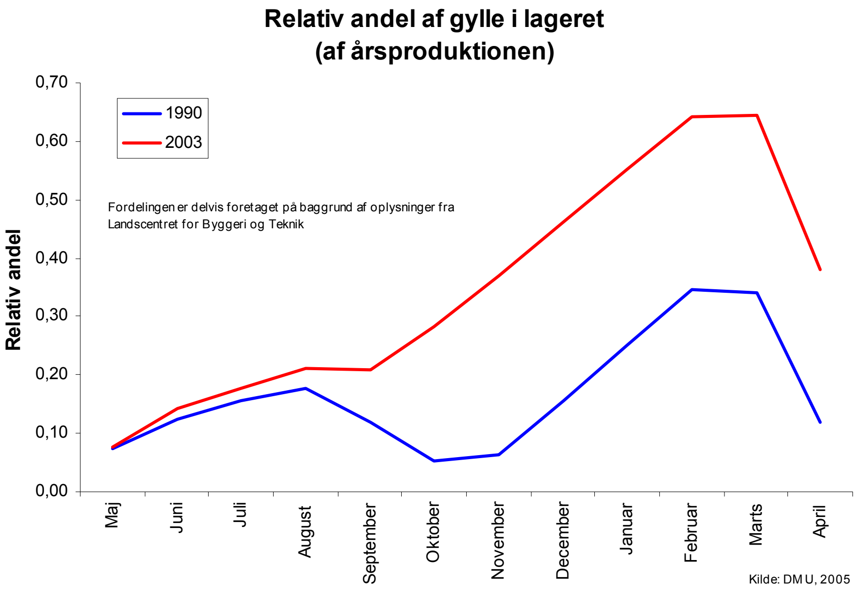
5.3 Metan fra husdyrgødning

Metandannelse i husdyrgødningslagrene er med den nuværende Tier 2-metode i 1990 opgjort til 35,9 Gg CH_4 (0,76 mio. t CO_2-ækv/år). Denne er frem til 2003 steget med 12,4 Gg CH_4 til 48,3 Gg CH_4 (1,01 mio. t CO_2-ækv/år), primært som følge af en stigende svineproduktion og at en større andel af husdyrgødningen håndteres som gylle.
Metanemissionen er med den nuværende IPCC-metode beregnet ud fra

$$\text{kg } CH_4 = VS * B_0 * 0{,}67 * MCF$$

hvor VS er mængden af omsættelig organisk stof i gødningen, B_0 angiver hvor stor en mængde der reelt kan dannes uanset ydre forhold indenfor en given tidsperiode (ISO-standard, ISO 11734) og MCF (Metan Conversion Factor) omregner til den aktuelt dannede mængde. Vha. MCF tages der hensyn til de aktuelle klimatiske forhold.

Da MCF i princippet er integralet over den lagrede mængde multipliceret med en metandannelsefaktor *f*(M,T), bør MCF varieres over tid hvis der sker ændringer i f.eks. den lagrede mængde husdyrgødning eller i ændringer i metanoxidationen i flydelaget som følge af ændrede overdækningsforhold. Siden 1990 er der sket ændringer både i hvor mange gyllebeholdere der var dækket af flydelag og i lagringstiden. I 1990 er det vurderet at 40% af gyllebeholdere med svinegødning ikke var dækket med flydelag og 20% for beholdere med kvæggylle (Mikkelsen et al., 2005). I 2003 er disse tal ændret til hhv. 5% for svinegylle og 2% for kvæggylle. Figur 5.1 viser den relative andel af årsproduktionen af gylle som befinder sig i lageret, både indendørs i stalde og udendørs i gyllebeholdere.
Figuren er baseret på oplysninger fra Landscentret omkring udbringning af husdyrgødning og data som indgår i ammoniakemissionsopgørelserne. Det skal dog bemærkes at lagerforøgelsen primært sker om vinteren med relativt lave temperaturer.



Figur 5.1. Den relative andel af årsproduktionen af gylle som er lagret i enten gyllekanaler eller gylletanke. Den blå linier afspejler forholdene i 1990 og den røde forholdene i 2003.

Mængden af VS i husdyrgødningen er i emissionsopgørelsen beregnet antallet af husdyr multipliceret med mængden af gødning i de respektive dyregrupper som indgår i opgørelsen (Mikkelsen et al. 2005). Mængden af gødning er baseret på de danske fodernormer (Poulsen et al., 2001). B_0 afhænger af foderet og kan variere betydeligt. Generelt gælder at finmalet foder med høj fordøjelighed såsom svinefoder har en høj B_0, mens grovfoder (kvægfoder) har en lav værdi (Tabel 5.2). For MFC gælder ligeledes at den er usikkert bestemt. MCF for gylle under danske forhold var i Guidelines fra 1996 (IPCC, 1996) opgjort til 10%. I den reviderede guideline (IPCC, 2000) er denne opgjort til 39%, eller en firdobling. Danmark har fastholdt anvendelsen af de 10% i de nuværende emissionsopgørelser, hvilket også er bemærket i den internationale reviewproces som Danmark netop har være igennem. DMU's argumenter er begrundet i at de 10% i Guidelines fra 1996, stammer fra danske undersøgelser (Husted, 1994) samt at canadiske målinger under lignende klimatiske forhold som danske (Massé et al., 2002) har fundet tilsvarende værdier. Endvidere har et litteraturstudie i Sverige (Dustan, 2002) anbefalet at der i de svenske opgørelser anvendes en MCF på 10% (på baggrund de danske undersøgelser af Husted (1994)). Dette fastholdes også i Finland (P. Pärelä, personlig meddelelse). På baggrund af de ændrede lagringsforhold og stigende gennemsnitstemperaturer er det relevant at se nærmere på hvorvidt den anvendte metode afspejler den reelle dannede metanmængde.

Møller et al. (2004) (Danmarks JordbrugsForskning) har estimeret B_0 for forskellige gødningstyper for kvæg og svin. Konklusionen fra undersøgelsen er at IPCCs B_0-værdier er ”i den høje ende” (Henrik Møller, personlig meddelelse). I tabel 5.2 er vist værdier fra IPCC og Møller et al. (2004) samt forudsætninger for efterfølgende beregninger.

Tabel 5.2. B_0-værdier for hhv. kvæg og svin

Dyreart	Gødningstype	IPCC	Møller et al. (2004)	Anvendt værdi i beregninger
Kvæg	Malkekøer, fæces	0,24	0,10-0,12	0,19
	Malkekøer, gylle	0,24	0,15-0,21	0,19
Svin	Søer, fæces	0,45	0,25-0,32	0,27
	Søer, gylle	0,45	NE	0,27
	Smågrise, gylle	0,45	NE	0,35
	Slagtesvin, gylle	0,45	NE	0,35
	Slagtesvin, fæces	0,45	0,33-0,40	0,35

NE = not estimated

Tabel 5.2 viser tydeligt at de anvendte B_0-værdier fra IPCC angiveligt er overestimerede for danske forhold. En ændring i emissionsopgørelsen af B_0 til de i tabel 5.2 angivne værdier, med samme MCF faktor vil reducere det samlede niveau i emissionen med 0,15 mio. t CO_2-ækv/år i 1990 stigende til 0,2 mio. t CO_2-ækv/år i 2003, svarende til reduktion i perioden på ca. 0,04-0,05 mio. t CO_2-ækv/år i forhold til den nuværende opgørelse (tabel 5.3). Ændringer i B_0 medfører således kun små ændringer i det absolutte niveau og meget små ændringer i udviklingstrenden. Det formodes ikke at være større ændringer frem til perioden 2008-2012.

Tabel 5.3. Ændringer i metanemissionen fra husdyrgødning som følge af ændringer i B_0.

	1990 Gg CH_4	2003 Gg CH_4	Ændring	Ændring i mio. t CO_2-ækv.
Nuværende opgørelse	33,9	44,8	+10,0	0,21
Ændret B_0 (tabel 5.2)	26,7	34,9	+8,2	0,17

I Kapitel 3 samt Sommer et al. (2000) er vist at kombinationen af flydelag og overdækning kan reducere metanemissionen væsentlig. I den nuværende emissionsopgørelse er der anvendt den samme MCF-værdi, på 10% i alle år på trods af de ændrede overdæknings- og lagringsforudsætninger. Det skyldes primært usikkerheden omkring MCF-værdien. Sommer et al. (2000) har vurderet at metanemissionen fra gyllebeholdere er ca. 40% lavere med flydelag end uden. På grund af den generelle usikkerhed omkring MCF-værdien er det ikke muligt at foretage et skøn over hvilken effekt den ændrede overdækning har på emissionen.

I kapitel 4 er det på baggrund af DMUs oplysninger omkring ændrede lagringsforhold beregnet, at ændringen i lagringstiden medfører en stigning i metanemissionen på 33-88%, med en sandsynlig værdi på 58% (afhængig af aktiveringsenergien). Det medfører at hvis en MCF på 10% i 1990 var korrekt, bør den i 2003 ændres til 15,8%.

I tabel 5.4 er angivet den sandsynlige stigning i metanemission på grund af ændret lagring ved hhv. MCF på 10%, 20% og 39%, hvor middelværdien er angivet for en aktiveringsenergi på $–1,27x10^5$ $Jmol^{-1}$ og minimum og maximum er angivet for aktiveringsenergier på $–2,0x10^5$ $Jmol^{-1}$og $–0,5x10^5$ $Jmol^{-1}$.

Tabel 5.4. Forventede ændringer i CH_4-emissionen som følge af ændrede MCF-faktorer med uændret B_0, mio. tons CO_2-ækv per år.

	1990		2003		Ændring 90-03
	MCF	mio. t CO_2-ækv.	MCF	mio. t CO_2-ækv.	mio. t CO_2-ækv.
Uden korrektion for lagringstid	10%	0,75	10%	0,97	0,21
	20%	1,43	20%	1,95	0,52
	39%	2,73	39%	3,74	1,01
Med korrektion for lagringstid	10%	0,75	16%	1,55 (1,31-1,84)	0,80
	20%	1,43	32%	3,04 (2,57-3,61)	1,62
	39%	2,73	62%	5,88 (4,96-6,98)	3,15

Som det fremgår af tabel 5.4 er der i de nuværende opgørelse sket en stigning fra 1990 til 2003 på 0,21 mio. tons CO_2-ækv/år. Hvis Danmark skulle følge guidelines ville stigningen have været 1,01 mio. tons CO_2-ækv/år uden korrektion for lager. Hvis der korrigeres for lagringstid vil stigningen være på 0,8 mio. tons CO_2-ækv/år med en MCF på 10%. Hvis den skulle beregnes ud fra guidelines ville stigningen være 3,15 mio. tons CO_2-ækv/år. Hertil skal lægges usikkerheden på bestemmelsen af aktiveringsenergien.

Sommer et al. (2004) har udviklet en model til beregning af den årlige metanemission for typiske svin og kvæggødninger i Danmark. Modellen inkluderer en balanceret VS (Volatile Solids) sammensætning i gyllelageret og tager hensyn til at gyllen delvis opbevares i gyllekanalen og delvis i gylletanke. Artiklen viser en enkelt beregning af metanemission fra gylle hos malkekvæg under forudsætning af at al gylle køres ud i april. Dette svarer til den nuværende 2003 situation. Beregningen angiver en emission på 9,9 kg CH_4 under forudsætning af at der hver dag tilføres lageret et kg VS. I den nationale opgørelse med en MCF på 10% giver samme metode en værdi på 9,3 kg CH_4 fra malkekvægsgylle, eller et tilsvarende tal. Det skyldes blandt andet at modellen (Sommer et al., 2004) er parameteriseret mod data fra Husted (1994), som er de grundlæggende forudsætninger for valget af MCF-faktor på 10% i IPCC guidelines fra 1996. Modellen kan derfor ikke anvendes til at beregne de absolutte CH_4 emissioner, men forklare sammenhænge i ændrede lagringsbetingelser.

Da det samtidig er den samme aktiveringsenergi som indgår i beregningerne af MCF faktoren i kapitel 4 og modellen fra Sommer et al. (2004), dels at det er usikkert bestemt og at det stammer fra samme grunddatasæt vurderes det, at der ikke foreligger et tilstrækkeligt valideret grundlag for at ændre MCF faktoren på trods af den eksisterende viden omkring ændrede lagringsforhold. En justering af B_0 i emissionsopgørelser vil kunne ske uden yderligere dokumentation udover Møller et al. (2004). En justering af MCF faktoren vil kræve betydelig ekstra dokumentation.

Da metanemissionen fra husdyrgødning beregnes ud fra to korrelerede variabler, B_0 og MCF bør der ikke foretages ændringer i B_0 uden at MCF-værdierne undersøges nærmere. Et modelskifte fra Tier 2 til Tier 3 til en dynamisk modeltype (Sommer et al., 2004) vurderes ikke at være muligt på det nuværende vidensgrundlag.

Metan fra husdyrgødningslagre, er med de ovennævnte meget store usikkerheder, opgjort til ca. 10% af landbrugets samlede udledning af drivhusgasser. Det er ikke muligt at vurdere effekten af fast overdækning på metanemissionen ud fra de foreliggende oplysninger. Der syntes dog store muligheder for, at metanemissionen fra gødningslagre kan reduceres væsentligt. Det kræver at husdyrgødningen hurtigst muligt efter udskillelse føres ud af stalden og bringes under kontrollerede forhold, hvor tætsluttende beholdere og lave temperaturer er væsentlige parametre. Udarbejdelse af byggeblade som indeholder anvisninger på hvordan drivhusgasemissionen reduceres mest effektivt fra husdyrgødningen (f.eks. supplering af BAT-byggeblade, www.lr.dk/bygningerogmaskiner/ informationsserier/ batbyggeblade/bat_oversigt_bb_bat.htm) må anses for at være et betydningsfuldt bidrag.

Hvis der skaffes det fornødne grundlag for en ændringer af B_0 og MCF vil det samtidig medføre ændrede økonomiske forudsætninger for beregning af effekten af evt. klimagastiltag vedrørende håndtering af husdyrgødning og biogasanlæg.

5.4 Lattergas fra udbragt handels- og husdyrgødning

Lattergasemissionen fra alle kvælstofkilder beregnes i guidelines som en procentandel af den samlede kvælstofmængde (N). For de fleste kvælstofkilder er der hidtil anvendt en faktor på 1,25%. Der er efterhånden ved at være omfattende dokumentation for at en mere nuanceret emissionsfaktor bør anvendes, hvor især den hidtidige emissionsfaktor for lattergas fra udbragt handels- og husdyrgødning på 1,25% bør reduceres for handelsgødning og fordobles for husdyrgødning (Klemedtsson and Klemedtsson 2002, Lægreid og Aastveit, 2002). I emissionsopgørelserne er der siden 1990 opgjort et fald i emissionen fra udbragt handels- og husdyrgødning fra 3,5 mio. tons CO_2-ækv/år til 2,3 mio. tons CO_2-ækv/år i 2003. Faldet på 1,2 mio. tons CO_2-ækv/år skyldes primært at mængden af udbragt N i handelsgødning er reduceret som følge af Vandmiljøplanerne. En ændring af emissionsfaktorerne til hhv. 0,75% og 2,5% vil medføre en svag stigning i basisåret på 0,1 mio. tons CO_2-ækv/år. Endvidere vil den i øjeblikket indregnede reduktion på 1,2 mio. tons CO_2-ækv/år ændres og således kun udgøre 0,7 mio. tons CO_2-ækv/år. Samlet vil en ændring af metoden medføre en stigning i Danmarks reduktionsforpligtigelser i forhold til de nuværende beregninger på 0,5 mio. tons CO_2-ækv/år.

Den større lattergasemission fra udbragt husdyrgødning end fra handelsgødning skyldes at der dannes iltfrie forhold i klumper af husdyrgødningen med stort indhold af letomsætteligt kulstof (Petersen, 2004). Afgasning af gylle medfører dels en reduceret ammoniakfordampning og en højere udnyttelsesprocent af kvælstof i gyllen, ligesom gyllen ændrer karakter og bliver tyndere og trænger hurtigere ned i jorden. Herudover er der målt en lavere lattergasemission, som sandsynligvis skal tillægges, at der ikke længere er lettilgængeligt kulstof tilstede (S.O. Petersen, personlig medd.). Den sidste formodning skyldes at en tilsvarende reduktion ikke ses for separeret gylle hvor lettilgængeligt C følger med over i den tynde fraktion. Syrebehandling af gylle reducerer også ammoniakemissionen og øger kvælstofudnyttelsen i gyllen. Her er det dog uklart om det også reducerer lattergasemissionen, men på baggrund af den højere udnyttelse af N mindskes behovet for anden kvælstoftilførsel, hvorfor den samlede lattergasemission reduceres.

Der er en tendens til at lattergasemissionen fra udbragt gødning er lavere på sandjorde end på lerjorde. Da en stor andel af den danske husdyrbestand findes på de lettere jorde og de svenske undersøgelser primært er foretaget på lerjorde vil de svenske erfaringer ikke umiddelbart kunne overføres til danske forhold. En nærmere analyse af N_2O-emissionen fra danske jorde bør derfor foretages inden skifte af emissionsparametrene.

Som under CH_4-emission fra husdyrgødning vil ændringen i emissionsfaktorerne ændre forudsætningerne for beregning af reduktionseffekten for biogasbehandling af husdyrgødning.

5.5 Arealanvendelse (LULUCF)

Inddragelse af Land Use, Land Use Change and Forestry (LULUC(F)) i de fleste lande er af nyere dato (undtagen for forestry (skov)), da guidelines herfor først var færdigudarbejdet i 2004. For Danmarks vedkommende er implementering af LULUC(F) sket i 2005 (heri indgår estimater fra 1990 og frem) (Gyldenkærne et al. 2005). Da arealanvendelse varierer meget fra land til land og der er store forskelle i hvilke grunddata de enkelte lande har til rådighed vil der være store forskelle mellem lande i hvordan LULUC(F) implementeres. De danske opgørelsesmetode for landbrugssektoren under LULUC(F) omfatter både Tier 2 og Tier 3 metoder. Da metoderne er meget nye har de ikke været igennem en international review proces, hvorfor det ikke vides hvordan metodikkerne vil blive vurderet internationalt.

Den samlede nationale emissionsopgørelsen er opdelt i seks sektorer, hvoraf Agriculture (landbrug) udgør én sektor (metan og lattergas) og "LULUCF" (Land Use, Land Use Change and Forestry) udgør en anden sektor (kuldioxid). En reduktion i drivhusgasemissionen i alle sektorer undtagen LULUCF kan direkte indregnes i Danmarks reduktionsforpligtigelse. Reduktioner som skal indgå i Kyoto-forpligtigelsen, foretaget i LULUCF-sektoren, kan kun indregnes under helt givne forhold, hvor man til- og fravælger undersektorer. Undersektorerne udgøres af: Forestry, Cropland Management (CM), Grassland Management (GM), Wetlands, Settlements og Other (klipper, is etc.). Hvis Danmark tilvælger en undersektor for at inddrage denne i Koyto-forpligtigelsen, skal alle relevante CO_2-kilder indenfor undersektoren indgå i opgørelsen. Dette kræver en fuldstændig redegørelse for hele arealet indenfor undersektoren fra 1990 og fremover, samt i kommende forpligtigelsesperioder, ligesom alle ændringer i C-balancen som sker inden for undersektoren, skal kunne dokumenteres samt opgivelse af hvornår disse ændringer har fundet sted. Hvis Danmark f.eks. vælger at inddrage Cropland Management (CM) i Kyoto-opgørelsen, skal man derfor gøre rede for alle ændringer i C-balancen indenfor det opgivne areal. Det areal som man ønsker at inddrage kan ikke ændres, hvorfor hvis Danmark tilvælger CM for hele landbrugsarealet vil man skulle gøre rede for samtlige 2,8 mio. ha som er udgangspunktet i 1990 og de ændringer som er sket i arealanvendelsen siden da. Det betyder at man skal redegøre for hvilke arealer som f.eks. er overgået til bebyggelse. Da der skal redegøres for hele C-balancen, medfører det endvidere at forbruget af jordbrugskalk, hegnsrejsning på landbrugsjord og andre væsentlige arealrelaterede ændringer i perioden skal registreres. Selvom anvendelse af jordbrugskalk ikke er arealrelateret, har man fra IPCC's side valgt at indføre kalkning under LULUCF i stedet for under sektoren Agriculture.

Tabel 5.5. Foreløbig skøn i reduktionseffekten for forskellige undersektorer.

	Undersektor	Forventet effekt i 2008-2012 i forhold til 1990 (mio. tons CO_2-ækv.)	Kommentar
Mineral jorde	CM	0 (-2,6)	Den mest sandsynlige effekt af ændringer i mineraljordenes indhold af C, og som kan indgå i Kyoto-regnskabet, er ud fra en faglig betragtning 0 mio. tons CO_2. Beregnet på grundlag af IPCCs Tier 2, med en 20-årig gennemsnitsperiode, er der beregnet en netto emission i 1990 på 1,6 mio. tons CO_2, mens et skøn for 2008-2012 er en binding på 1,2 mio. tons CO_2 (Ændring i alt –2,6 mio. tons CO_2).
Organiske jorde	CM	-0,20	I denne effekt indgår etablering af planlagte vådområder på organiske jorde. En bedre kortlægning af mineraljordene kan medføre at tallet reduceres til ca. -0,10 fordi der er anvendt en liniær metode til beregning af arealet af organiske jorde. Det må formodes at det reducerede landbrugsareal især er forekommet på mineraljorde til bebyggelse, hvorfor arealet med organiske jorde som er udgået er mindre.
Kalkning	CM	- 0,30	Der vil sandsynligvis ikke forekomme yderligere reduktioner end den der allerede er sket i perioden fra 1990 og frem til 2001, da det vurderes at kalkforbruget ikke kan nedsættes yderligere.
Hegnsrejsning	CM	-0,20	Det forudsættes at der fremover hvert år vil blive rejst 8-900 km 6-rækket hegn, svarende til det nuværende niveau. Dette niveau kan kun fastholdes hvis der også fremover afsættes midler til hegnsrejsning via finansloven.
Tørvegravning	Wetland	-0,003	Nedbrydning af organisk stof i overfladen kan inddrages, men ikke den mængde tørv som bliver afgravet. Det medfører at den reduktion på ca. 0,05 mio. tons CO_2-ækv. som vil ske ved Lille Vildmoses overgang til Nationalpark og dermed stop for tørveudvinding ikke vil kunne indregnes. Der indgår opbygning af nyt organisk materiale i de åbne områder.
Total		-0,7 (-3,3)	

Forbruget af jordbrugskalk ($CaCO_3$) er reduceret med 60% fra 1990 til 2003 svarende til en reduktion i den danske drivhusgasemission på 0,3 mio. tons CO_2. For at kunne inddrage denne reduktion i Kyoto-forpligtigelsen ***skal*** Danmark derfor vælge CM og hvad deraf følger omkring registrering af arealer og deres C-balance indenfor det område. Det tolkes af DMU som om, at der skal opbygges et C-balancesystem som år for år viser alle arealers C-status indenfor den valgte undersektor. Dette inkluderer også arealer der er taget ud af drift, herunder overgang til bymæssig bebyggelse eller anden anvendelse. Denne opgave kan vise sig at være omfangsrig .

En endelig tolkning af reglerne for inddragelse af landbrugsjorde i Kyoto-opgørelsen samt metoden for opgørelse af emissionen fra mineraljorde i landbruget, som udgør en væsentlig post, er endnu ikke endelig afklaret. I tabel 5.5 er der angivet nogle foreløbige skøn for hvor store mængder CO_2 der kan indgå i Kyoto-regnskabet i 2008-2012 i forhold til 1990.

I tabel 5.5 er det skønnet at der muligvis kan inddrages 0,7 mio. tons CO_2-ækv/år i Danmarks Kyoto forpligtigelse ved inddragelse af undersektorerne i LULUCF (eksl. skov). Dette kan kun realiseres, hvis der foreligger den fornødne dokumentation af arealændringerne samt at der opbygges et system der fremover kan dokumenter ændringerne. Dette vil være en omfattende opgave som udover store startomkostninger også vil krævende løbende udgifter. Der er ikke foretaget en vurdering af hvor stor denne opgave er. Det vil meget afhænge af hvilke oplysninger der på nuværende tidspunkt er tilgængelige i eksisterende registre samt hvordan amtslige grunddata vil være tilgængelige efter gennemførelsen af kommunalreformen.

5.6 Vådområder og ændret afvanding af landbrugsarealer

Etablering af vådområder og ændret afvanding sker typisk på organiske jorde. Hvis etableringen sker på landbrugsjord er den største effekt, at nedbrydningen af organisk stof standser samt at der sker en opbygning af nyt organisk stof. En kortlægning af de hidtidige udpegninger af vådområder har vist at 69% af landbrugsarealet udpeget til vådområder er organiske jorde (Gyldenkærne et al., 2005). Den tilsvarende andel for 20-årig ændret afvanding er 81%. I alt planlægges udlagt 8-9000 ha vådområder i løbet af de kommende år. Hvis arealerne følger mønstret for de hidtidige udpegninger vil det medføre at 3-4000 ha landbrugsjord i omdrift overgår til vådområder. Det er estimeret at 1 ha vådområde, under de hidtidige udpegninger i gennemsnit reducerer emissionen med 8,5 tons CO_2 per ha udpeget og at 20-årige MVJ-ordninger reducerer emissionen med ca. 5,6 tons CO_2 per ha (Gyldenkærne et al., 2005). Forskellen skyldes at MVJ-jordene ofte i forvejen ikke indgår i rotationen men er henlagt som vedvarende græs. Udpegning af yderligere 8-9000 ha vådområder vil således medføre en reduktion der kan indregnes i reduktionsforpligtigelsen med 0,068-0,076 mio. tons CO_2/år. Disse indgår i effektvurderingen under de organiske jorde i tabel 5.5. Da der er stor usikkerhed omkring fremtidige MVJ-ordninger og at de primært vil blive allokeret til habitatområder er der ikke foretaget noget skøn på dette område. I alt vil vådområder og MVJ-ordninger være medvirkende til en reduktion af emissionen med ca. 0,1 mio. tons CO_2/år i 2008-2012.

5.7 Usikkerheder omkring opgørelsen af LULUCF

De største usikkerheder knyttet til arealanvendelse og hvor der bør foretages bedre dokumentation for emissionsberegningerne gælder alle de i tabel 5.5 nævnte områder.

Til estimering af mineraljordenes C-indhold er der anvendt IPCCs Tier 2 metode, idet det er skønnet at der ikke findes tilstrækkeligt datagrundlag for at anvende Tier 3. I Gyldenkærne et al. (2005) er det imidlertid vist at metoden med overvejende sandsynlighed ikke er retvisende. Der er således behov for en bedre bestemmelse af ændringer i mineraljordenes C-indhold.

For de organiske jorde er der stor usikkerhed omkring jordbundskarteringen. Opgørelsen er foretaget på baggrund af Den danske Jordklassificering (DJF) som blev udarbejdet i 1970'erne. Især bør der fokuseres på arealstørrelsen, idet det kan vise sig at mange områder ikke længere kan klassificeres som organiske jorde, fordi det organiske stof er afbrændt. En reduktion af arealet med organiske jorde vil reducere det absolutte emissionsniveau, men ikke påvirke trenden mellem 1990 og 2008-2012. Halvdelen af de danske organiske jorde har et indhold på 10-20% organisk stof. I litteraturen er der ikke fundet målinger af CO_2-emissionen fra denne kategori (Gyldenkærne et al., 2005), hvorfor anvendelse af emissionsestimater for jorde med >20% organisk stof er anvendt. Nye emissionsdata bør derfor fremskaffes for disse jorde. En ændring i emissionsfaktoren for disse arealer vil medføre en ændring i det absolutte niveau men ikke påvirke trenden.

Der er stor usikkerhed omkring opbygningen af organisk stof i vådområder som tages ud af drift. Det nuværende estimat i emissionsopgørelsen er bedste skøn. Der bør derfor foretages målinger af opbygningen af organisk stof i flere vådområder og Lille Vildmose. Dette kan foretages vha. højdemålinger over flere år kombineret med samtidige målinger der beskriver vandindholdet af hensyn til kvælninger eller måling af tilvækst og mineraliseringer. Da ændringerne er små i forhold til den samlede mængde skal målingerne foretages over en årrække (Carl Chr. Hoffmann, DMU, personlig meddelelse)

Den nuværende opgørelsesmetode for jordbrugskalk antager at al tilført karbonat omdannes til CO_2. I forbindelse med målinger i vandløb og indre farvande kan det imidlertid konstateres at der sker en kalkaflejring (Stiig Markager, DMU, personlig meddelelse). Disse stammer sandsynligvis fra udvasket karbonat, men er ikke nærmere undersøgt. Det må derfor formodes at den anvendte emissionsfaktor på 100% er overestimeret. Der er et stort behov for at få nærmere undersøgt hvor meget CO_2 der reelt dannes ved anvendelse af jordbrugskalk. I øjeblikket foreligger der ikke noget grundlag for at ændre emissionsfaktoren.

Samlet set er der meget store usikkerheder omkring landbrugsjordenes samlede kulstofkredsløb, hvorfor en struktureret og målrettet indsats på området er ønskeligt.

5.8 Konklusion

I forbindelse med Danmarks ratificering af Klimakonventionen samt Kyotoaftalen har Danmarks Miljøundersøgelser ansvaret for udarbejdelse af emissionsopgørelserne. Indenfor landbrugssektoren "Agriculture" vil der vha. af en begrænset forskningsindsats være muligt at forbedre emissionsopgørelsen for enterisk metandannelse og udarbejde en mere præcis opgørelse som vil give en yderligere reduktion i den nuværende opgørelse på 0,1 mio. tons CO_2-ækv per år.

For lagret husdyrgødning er der store usikkerhed forbundet med opgørelsesmetoden. Usikkerheden vil ikke kunne reduceres uden en betydelig forskningsindsats.

N_2O emissionen fra udbragt handels- og husdyrgødning er meget usikkert bestemt. Der findes ikke danske tal som bidrager til forbedring af emissionsfaktorerne.

I forbindelse med inddragelse af LULUCF i Kyoto-opgørelsen er der behov for dokumentation af ændringer i arealanvendelse for at disse kan inddrages i opgørelsen. De arealer som inddrages i emissionsopgørelsen skal ikke bare kunne følges i de næstfølgende år, men også i de kommende forpligtigelsesperioder. Der forestår derfor et omfattende arbejde med monitering og registrering af data som bør koordineres med andre tiltag omkring datahåndtering i relation til den kommende kommunalreform. Det er dog stadig for tidligt at vurdere det tidsmæssige omfang af denne opgave.

I øjeblikket findes der ikke tilskudsordninger for nationale tiltag der kan reducere drivhusgasemissionen. Det bør overvejes om, hvordan og på hvilke områder evt. tilskudsordninger kan implementeres. I denne sammenhæng er det endvidere vigtigt at forholde sig til at hvordan sådanne tiltag kan indgå i de nationale opgørelser på en let og hensigtsmæssig måde uden alt for mange administrative byrder.

Gyldenkærne et al. (2005) har opstillet en model for indregning af etableringen af vådområder i emissionsopgørelsen. Effekten af disse vurderes på baggrund af arealudpegninger som fås fra amterne koblet med oplysninger om jordbundstype og arealanvendelse i det Generelle Landbrugsregister (GLR). I gennemsnit har de hidtidige udpegninger medført en reduceret emission på 20-30 tons CO_2 ha^{-1} $år^{-1}$. Disse arealer er forholdsvis små. Hvis f.eks. sådanne ordninger skal kunne indgå i emissionsopgørelserne bør der udarbejdes retningslinier til de administrative myndigheder om, hvordan en sådan opgørelse udarbejdes og hvordan data skal indsamles. Dette bør foretages centralt og videregives til DMU i forbindelse med beregning af de nationale emissionsopgørelser. Det er derfor nødvendigt at få udarbejdet instruktionsmateriale for de foreliggende områder. For vådområders vedkommende kunne dette kunne evt. indgå i det materiale som foreligger til beregning af den kvælstoffjernende effekt af vådområder.

5.9 Referencer

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