IMT-Rapport nr. 54/2013

Revision of the Norwegian model for estimating methane emission from manure management

John Morken, Shaza Ayoub, Zehra Sapci

Institutt for matematiske realfag og teknologi

3112
2013

Universitetet for miljø- og biovitenskap

ISSN 1503-9196

Universitetet for miljø og biovitenskap

Institutt matematiske realfag og teknologi

IMT-Rapport

Nr. 54/2013

Postadresse:	**Boks 5003,**	**1432 ÅS**
Besøksadr.:	**TF-kvartalet,**	**Drøbakvn. 31**
Telefon:	**Ekspedisjon:**	**64 96 54 00**
	Saksbehandler:	**64 96 54 59**
Telefaks:		**64 96 54 01**

DATO: **03.04. 2014**

Sammendrag (abstract): Det internasjonale klimapanelet (IPCC) har lagd modeller for beregning av metanutslipp fra gjødselhandtering. Modellene fra IPCC blir brukt til å beregne og rapportere utslippene årlig til United Nations Framework Convention on Climate Change. Målet med rapporten er å foreslå endringer av faktorer brukt i de norske beregningene. Dels er forslaget basert på egne målinger av potensielt utslipp, såkalt B_0-faktor (storfe, gris, hest), dels på litteraturvurderinger (resten av dyr). Metanproduksjon avhenger av gjødselproduksjonen fra dyrene, og vi forslår å basere disse beregningene på modeller utarbeidet av Institutt for Akvakultur og Husdyrfag (UMB). Utslippsmodellen inneholder en faktor (MCF) for hvor stor andel av potensiell produksjon som blir emittert som metan. Rapporten foreslår å bruke tall fra Sverige i stedet for «default»-verdiene fra IPCC. Dette vil bety rapporterte reduserte utslipp. Videre foreslår vi at man bruker statistikk som SSB har over husdyrgjødselsystemer (manure management) til å kvantifisere hvor stor andel av gjødsel fra respektive dyr blir lagret som bløtgjødsel og fastgjødsel, samt hvor stor andel av gjødsla som lagres.

Stikkord: Landbruk, husdyrgjødselhandtering, metanemisjon, beregning

Tilgjengelighet:

Åpen

Key words: Agricultural, manure management, methane emission, calculation

Oppdragsgiver: Statens Landbruksforvaltning og Miljødirektoratet

Rapport tittel: Revision of the Norwegian model for estimating methane emission from manure management

Rapport nr: 54 /2013

ISSN nr. 1503-9196

Oppdragsgivers referanse:

201116578 2/344

Forfatter: ***John Morken[1], Shaza Ayoub[1] og Zehra Sapci[1,2]***

[1] Norwegian University of Life Sciences, Dept. og Mathematical sciences and Technology
[2]Bitlis Eren University, Environmental Engineering Dept. Bitlis, Turkey

Godkjent av:

Antall sider: 10

Instituttleder: Cecilie Denby Rolstad (sign)

Revision of the Norwegian model for estimating methane emission from manure management

John Morken[1], Shaza Ayoub[1], Zehra Sapci[1,2]

December 10, 2014

[1]Norwegian University of Life Sciences, Dept. og Mathematical sciences and Technology

[2]Bitlis Eren University, Environmental Engineering Dept. Bitlis, Turkey

Abstract

The goal of this paper is to revise the factors used by Statistics Norway (SSB) to predict the methane emission from manure management under Norwegian conditions. The Tier 2 IPCC model for calculating methane emission from manure management includes evaluations of volatile solids produced per animal, biogas potential, factors related to the amount of the potential that will be utilized, and also the type of manure management. We have conducted research on biogas potentials for dairy cows, pig, and horses. The potential were estimated at 230 (average of 5 cows), 291, and 261 (ml/g VS) for dairy cows, pigs, and horses respectively. Based on available literature we suggest using 230 and 300 (ml/g VS) for dairy cows and pigs respectively. For horses we suggest that the default value of IPCC is used due to the limited number of studies supporting our findings. Estimation of volatile solids from estimations of the production of dry matter per animal are proposed. Utilization factors (so called MCF) were evaluated according to projects that were carried out in Sweden, and in this paper we propose factors for Norway based on these figures. These factors are also suggested by Statistics Sweden. The biggest difference is MCF factors for liquid manure (3.5% instead of 8% in earlier calculations). We also suggest that information on manure management systems should be used in the calculations, while the calculation method for volatile solids should be based on the estimation method of dry matter production per animal proposed by the Department of husbandry and aquaculture, Norwegian University of Life Sciences.

Sammendrag

Det internasjonale klimapanelet (IPCC) har lagd modeller for beregning av metanutslipp fra gjødselhandtering. Modellene fra IPCC blir brukt til å beregne og rapportere utslippene årlig til United Nations Framework Convention on Climate Change. Målet med rapporten er å foreslå endringer av faktorer brukt i de norske beregningene. Dels er forslaget basert på egne målinger av potensielt utslipp, såkalt MCF-faktor (storfe, gris, hest), dels på litteraturvurderinger (resten av dyr). Potensielt utslipp ble beregnet til 230 (gjennomsnitt av 5 kyr), 291 for grisegjødsel og 261 (ml/g VS) for hestegjødsel. sammen med vurdering av tilgjegelig litteratur foreslår vi 230 og 300 (ml/g VS) henholdvis for kugjødsel og grisegjødsel. Metanproduksjon avhenger av gjødselproduksjonen fra dyrene, og man forslår å basere dette på modeller fra Institutt for Akvakultur og Husdyrfag (UMB). Utslippetsmodellen inneholder en faktor for hvor stor andel av potensiell produksjon som blir metanutslipp. Rapporten foreslår å bruke tall fra Sverige i stedet for «default»-verdiene fra IPCC. Den største forskjellen er MCF for bløtgjødsel (3,5 % i stedet for 8 % i tidligere beregninger). Dette vil bety reduserte utslipp. Videre foreslå vi at man bruker statistikk som SSB har over husdyrgjødselsystemer (manure management).

Keywords: Methane, IPCC model, biogas potential

Contents

1 Introduction **2**

2 IPCC Tier 2 model and SSB model **2**

3 B_0 experiment **3**
- 3.1 Methane Production potential (B_o) of dairy cattle, pigs and horses . . . 3
  - 3.1.1 Introduction . . . 3
  - 3.1.2 Material and methods . . . 4
  - 3.1.3 Results and discussion . . . 4

4 Recommendations **5**
- 4.1 B_o . . . 5
- 4.2 VS . . . 6
- 4.3 MCF . . . 6
- 4.4 MS . . . 7

5 Conclusion **7**

6 Acknowledgment **8**

1 Introduction

Methane emission from manure management systems has to be reported to the United Nations Framework Convention on Climate Change (UNFCCC), one of the methods outlined in the intergovernmental Panel on Climate Change (IPCC)[1]. Norway has used these calculations according to the IPCC, but has used national parameters[2]. These parameters are weakly documented, and in some cases differ from the default values proposed in the document of IPCC[3].

The goal of this paper is to revise Norwegian parameters used in the IPCC model, and to suggest new values for these parameters. The suggestions will either be based on experimental investigation, or information available in the literature.

2 IPCC Tier 2 model and SSB model

Since 1997 the Intergovernmental Panel on Climate Change (IPCC) has described models for calculating methane emission from manure management. These models have been revised twice in 2000 and 2006 [1]. In addition, they propose three different ways of calculating emissions. Tier 1 is the simplest model where only number of each animal type and emission per animal (for the actual temperature zone for the country) is multiplied. The calculations can be done without any knowledge on farm types. The more advanced model is Tier 2, which is used in most developed countries. If a country has more specific data on the emission they can use Tier 3, which is a country specific model.

This paper will discuss Tier 2 since this model is the model used in the Nordic countries, at least for the dominant animal types. From 1997 the Tier 2 model was expressed in the document “Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories” . In Tier 2 the emission is a multiplication of various parameters per animal type. The emission from each animal type is then summed up.

The IPCC Tier 2 model which will be used is:

$$EF_{(T)} = \left(VS_{(T)} \cdot 365\right) \cdot \left[B_{o(T)} \cdot 0.67 \cdot {}_{S,k}\sum \frac{MCF_{S,k}}{100} \cdot MS_{(T,S,k)}\right] \tag{1}$$

Where,

$EF_{(T)}$ = annual methane emission factor for livestock category T, kg CH_4animal^{-1}yr^{-1}
$VS_{(T)}$= Volatile solid excretion per day on a dry-matter weight basis (kg-dm/day)
$B_{o(T)}$ = Maximum methane producing capacity for manure produced by an animal within defined population i, m^3 CH_4/kg VS
$MCF_{S,k}$ = Methane conversion factors for each manure management system S by climate region k
$MS_{(T,S,k)}$ = Fraction of animal species/category T's manure handled using manure system S in climate region k.

The IPCC Tier 2 also suggests a method to calculate VS as a function of energy intake of the animal. If country specific data of VS is available it could be used. Otherwise there are two other options. One is to use default values given from IPCC or to calculate VS according based on the feed intake:

$$VS = GE(\frac{1}{18.45}) \cdot (1 - \frac{DE}{100}) \cdot (1 - \frac{ASH}{100}) \tag{2}$$

Where,
GE = Gross energy intake (MJ/animal/day)
DE = Digestible energy (%) (see methane emissions from enteric fermentation)
ASH = Ash content of manure (%) (IPCC default values used)

The methodology for emission calculations in Norway is given in [2]. The model is based on IPCC model from 1997:

$$E_i = \frac{N_i \cdot M_i \cdot VS_i \cdot B_{oi} \cdot MCF_i}{1000} \cdot \rho_{CH4} \tag{3}$$

Where,
E_i: Emissions of methane
N_i: Population of animals
M_i: Production of manure (kg/animal/year) (sum of faeces and urine)
VS_i: Volatile solids (per cent)
B_{oi} : Maximum methane producing capacity for manure produced by an animal within defined population i, m^3CH_4/kg VS
MCF_i: Methane conversion factor
$_i$: Species
ρ_{CH4}: Density methane (0.662 kg/m^3)

Hence, the Norwegian model is in a way similar to the IPCC model, but there are differences also:

- VS (kg/day) are specifically given for the different types of animals. VS differ from the default values of IPCC.
- B_{oi} differ from the default values that have been suggested by IPCC.
- MCF_i, in many cases the values are lower, but the model does not include the MS, and therefore one has to assume that the MCF_i also comprises of both methane conversion factor and the management system factor for the various animal types.

3 B_0 experiment

3.1 Methane Production potential (B_o) of dairy cattle, pigs and horses

3.1.1 Introduction

Anaerobic digestion is a natural process in which the micro-organisms consume organic matter under an oxygen-free environment. It results in the production of microbial biomass and greenhouse gases (CO_2 and CH_4). In order to assess the contribution of manure waste to the greenhouse effect, the factor B_o or the ultimate methane yield has been formulated to define production potential of biological methane [3, 4].

Ultimate methane yield (B_o) is defined as the maximum quantity of methane which can be produced by 1 kg of volatile solids present in a manure treatment system under optimal conditions. Being the maximum potential value, (B_o) is not influenced by the digestion temperature[3]. On other hand as stated by Hashimoto 1981 ration, species, breed and growth stage of animals, amount and type of bedding material, manure age, degradation process during pre-storage [5] and climatic conditions can influence the value of B_o. The VS composition in manure is crucial for the generation of CH_4 [6, 7]. Manure VS is mainly composed of fatty acids, protein and carbohydrates of which fatty acids, protein and a portion of the carbohydrates are easily biodegradable. However, a substantial fraction of the carbohydrates withstand the degradation and are slowly or partially consumed.

The goal of this study was to determine the values of B_o for pigs, dairy cattle and horses in a typical Norwegian perspective. This will be vital in the development of the inventory of greenhouse gases by the Norwegian agriculture sector and thus to reduce the uncertainty related to the Norwegian, as well as global estimate of greenhouse gases.

3.1.2 Material and methods

The ultimate methane yield (B_o) was determined in a batch experiment. The experiments were performed in 1000-ml infusion bottles. The bottles were closed with butyl rubber stoppers, sealed with aluminum crimps and incubated at 37ºC. The method used is described in the international standard ISO 11734 (ISO 11734). The test medium was faeces taken directly after excretion from pigs, horses and dairy cattle of different physiological conditions and under different feeding regimes. The faeces was collected in 4 liter plastic containers from animals at the Animal Science Department farm at UMB,and subsequently transported to the lab at UMB where it was kept at 4ºC and used with in 24 hours. Inoculum from a farm–scale biogas plant at the Tomb agricultural college in SE Norway, running under mesophilic conditions and using cow manure and food waste as a co-substrate, with volatile solid (VS) content of 80% (w/w), was used. The inoculum had been at 37ºC for two weeks before the test to remove most of the remaining methane production in the inoculum. The ratio between inoculum and substrate was 3:2 based on volatile solids. The tests were carried out in triplicate. Three replicates with only water and inoculum were inoculated as controls to measure the methane production originating from the inoculum. In addition, three replicates where cellulose were used was included to test the quality of the inoculum. The gas produced by controls was subtracted from the actual gas produced through digestion of the medium. The volume of the gas produced was calculated by daily measurement of pressure in the head space (ISO 11734). The gas was analyzed for CO_2 and CH_4 regularly throughout the incubation period by gas chromatography. During the first week, daily measurement was necessary later it was sufficient to measure once a week. Manure from three different cows on pasture (numbers in the brackets shows identification of the cow), and additionally manure from cows fed with two types of concentrates; barley and oat based was used in the tests. Manure was collected and mixed from two cows of each concentrate type.

3.1.3 Results and discussion

Table 1 shows some of the characteristics of the manure and the inoculum used. Since the manure contained only faeces without urine for cow manure, the dry matter content was relatively high. The exclusion of urine could be accepted since degradation of urine only results in ammonia and carbon dioxide [10].

Table 2 indicates that the inoculum was suitable for the experiment because of the yield from cellulose, which was used as a reference. The results show that there was some variation between cow manure from the various cows, with an average of 230 ml/g VS. The specific methane yield is equivalent to B_o. Methane yield from pig manure gave a considerable lower result than the default value recommended by the IPCC (450 ml/g VS). The explanation is probably both a result of bedding material of saw dust (which could not be avoid), and grain based feed instead of corn-based feed [10]. Saw dust has a high volatile solids content, but is very hard to degrade due to the high lignin content. Compared to the default value of the IPCC for horse manure our result was 13 % lower.

Table 1: The characteristics (moisture -, volatile solids -, ash content, and pH) of the various manure types used.

Substrate	Moisture content	dry matter, %	Volatile solids, % of dry matter	Ash, % of dry matter	pH
Cow manure (cow no 5344)	87	13	87	13	7.3
Cow manure (cow no 5454)	88	12	80	20	7.5
Cow manure (cow no 5532)	90	10	82	8	7.3
Cow manure (barley concentrate)	89	11	86	14	7.3
Cow manure (oat concentrate)	87	13	88	12	7.3
Pig manure	76	24	89	11	7.4
Horse manure	80	20	92	8	7.7
Inoculum	93	7	80	20	7.9

Table 2: Accumulated biogas production, specific methane yield, and methane percentage for the various substrates used.

Substrate	Accumulated biogas production, ml	Specific methane yield, ml/g *VS*	Methane %
Cow manure (cow no 5344)	401	226	56.4
Cow manure (cow no 5454)	364	206	56.6
Cow manure (cow no 5532)	425	244	57.7
Cow manure (barley concentrate)	378	221	58.6
Cow manure (oat concentrate)	425	251	59.0
Pig manure	397	293	60.3
Horse manure	494	261	52.9
Inoculum	160	105	53.3
Cellulose	740	394	65.7

4 Recommendations

4.1 B_o

The results of the B_o experiment for dairy cows gave a lower value than the default value of the IPCC, while the variation between samples was high, the potential was 0.23 m^3 CH_4/kg *VS*. This value has also been suggested to be used in Germany [10]. Therefore, we recommend use of 0.23 m^3CH_4/kg *VS* instead of the currently used value of 0.18 m^3CH_4/kg *VS*.

The very low B_o values (as compared with the default values of IPCC) obtained from the pig manure were assumed to be as a result of the saw dust bedding. However, it should also be considered that the original IPCC default values (0.45 m^3CH_4/kg *VS)* originated from the USA where feed composition consists of more maize than the European feed composition. KTBL in Germany suggest the use of 0.27, but Dämmgen *et al.* [10] suggest 0.30, which is more similar to our results. Therefore, we suggest the use of 0.30 for Norway.

For horse manure more experiments are needed, since no paper has been found to support our results. Until further experimental evaluation of this value is possible, we recommend the use of the default value of B_o.

In spite of the recommendations from the IPCC [1] of the contribution from urine to *VS*, Dämmgen *et al.*[10] argue that urine does not contribute to methane production nor to ash content, and therefore it should be excluded from the calculations. The results presented in Table 1 indicates that the dry matter content of cow manure was between 10 and 13% as a result of not collecting urine. There were some variations in volatile solids of various manures, but these did not follow variations of dry matter content.

As a result of mixture of bedding and faeces from pigs, the dry matter content of this animal type was high, even higher than it was from the horse. Manure from pigs were collected in the pen (10 pigs), and manure from the horse was collected directly from one animal.

4.2 VS

According to the IPCC [1] the *VS* should be calculated from energy content in the feed intake, but as discussed by Dämmgen *et al* [11] there are some problems with using energy content for calculations. These problems are:

- *VS* excreted with urine is not effective as a source of methane, and should not be included.
- Feed intake should be calculated using a national procedure, and not using default values of *GE*. National inventories of feed intake would also provide energy concentrations of the feed used.

Therefore Dämmgen *et al.*[11] recommended the use of feed digestibility for organic matter rather than using energy to calculate *VS* excretion rates. We suggest that instead of using the figures of *VS* (kg/head and day) that are used until now, that *VS* (kg/head and day) should be based on the *TS* production per head, which has been calculated from IHA [12]. Then we need estimations of *VS* as percentage of *TS*.

4.3 MCF

So far a MCF of 8 % has been used for liquid manure [2], but one has to consider also that the Norwegian model does not include a factor for manure management (MS), so one could say that MCF also includes MS. According to IPCC the MCF should be 0.10 for cold climate [1]. Very few experiments so far have been carried out internationally. It has not been possible for us to carry out our own research and therefore we have based our recommendations on the literature. Experiments from countries with cold climates, such as Sweden and Canada, indicate that the MCF of 0.10 is too high ([13, 15, 2]).

Dämmgen *et al.* [10] evaluated many studies reporting MCF. There are many factors that contribute to MCF; temperature, manure type dry matter content, formation of natural crust, covering, and maximum methane potential. The report of Rodhe *et al.* [13] argues that manure temperature is more relevant than the air temperature, which is recommended for use by the IPCC [1]. In this report, MCF of 3 was calculated. In another paper ([15]) pig manure (liquid) in Sweden was calculated as having MCF factor from 1.4% (plastic film cover) to 2.8% (straw crust) as an annual average. Highest factors calculated was from summer without coverage (4.0%). The results of [13, 15] are the basis for the reduced values that Sweden has decided to use. Formation of natural crust and covering of the storages could also lead to low MCF. For cattle manure this is probably valid, but may pig manure does not typically for a crust and it has a higher methane potential (B_o) [10]. Therefore it is suggested distinguishing between cattle and pig, with a difference is 150 % (for pig manure without crust). Therefore making the possibility for underestimation. The Swedish Environmental Protection Agency has now reconsidered the MCF factors, and uses background data presented in [13]. The factors are given in table 3 (after National Inventory Report Sweden [15]). The methane emission from storages is very depended on temperature, and one can assume that Norwegian temperatures are similar to Swedish temperatures. Therefore we suggest that we use the Swedish factors for cattle manure (table 3). These figures are the same for cattle manure and pig manure. If we use the same increase as Dämmgen *et al. [10]* suggest for Germany, the MCF for pig manure will be 5.3 %. A more recent study support the factors Sweden use [15]. [11] suggests a MCF for deep litter (Austrian solution) of 0.17 instead of the default value of 0.39 [1].

Table 3: Emission factor for manure management (after [15])

Manure management	Emission factor (MCF) for CH_4	Reference
Solid manure (all animal)	1% of B_o	[1]
Liquid manure (all animal)	3.5 % of B_o	[13]
Deep litter	39 % of B_o	[1]

4.4 MS

The model used by SSB[2] does not include the MS (Management system) factor. The MS-factor distinguishes between stored manure, and manure that is deposited on pasture. Also dry matter content is included in the management system, so it does not distinguish between solid manure, liquid manure and deep litter systems. Since SSB already has the necessary information, it is recommended to use these data.

5 Conclusion

Instead of using the default values of *VS*, the *VS* should be calculated from *TS* production of the various animal types. Karlengen et al. [12] estimated *TS* production from cattle, pigs, and hens. Estimations of *VS* (as precentage of *TS*) were partly based on general anaerob digestion research, and partly on values reported in the literature. For the animal types where estimates of *TS* production were not included in Karlengen et al. [12], we suggest to estimate these factors on the basis of Morken & Hoem [3] and Karlengen et al.[12]. We suggest that a *VS*- percentage of 0.90 should be used. National figures of *VS* % per animal for the manure production (kg/day) per animal is used in IPCC Tier 2. The formula can be used to calculate Manure *TS*:

$$M_{TS} = \frac{M_{kg} \bullet VS_d}{VS_{\%}} \tag{4}$$

Where M_{TS} is Manure *TS* production (kg dry matter per day), M_{kg} is the total manure production per day (kg/day) given by [2], VS_d is VS as percentage of M_{kg}, also given by [2], and $VS_{\%}$ is assessed VS i percentage of M_{TS} .

We also suggest that B_o factor should be changed, but there should be a combination between default values of IPCC [1]and [15] reported European figures [10, 11]. Some of these figures were also supported by own measurements. Recent investigations of MCF-factors under Swedish climate conditions conclude that the default factors that IPCC suggest for liquid manure are too high. Since Norway is situated on the same latitudes as Sweden, we recommend that these factors should be used. Values from solid manure and deep litter systems will not be changed from the default values of IPCC, since we don't have experimentally validated values. Management system factors (MS) should be incorporated into the calculations in Norway since SSB has available data.

Table 4: New factors for manure production (kg ts/day), volatile solids (% of produced ts per day), methane potential (B_o), and emission factors (MCF) for the animal categories in Norway.

	Manure TS (kg ts/day)	VS (per cent of ts)	B_o (m3/kgVS)	MCF (per cent)
Dairy cattle				
Liquid	5.70 [12]	88[1]	0.23[1]	3.5[15]
Solid waste	5.70 [12]	88 [1]	0.23[1]	1 [2]
Deep litter	5.70 [12]	88[1]	0.23[1]	39 [2]
Grazing	5.70 [12]	88[1]	0.23[1]	1 [2]
Bulls > 1 year	2.01 [12]	88[1]	0.17 [1]	3.5 [15]
Heifers > 1 year	1.91 [12]	88[1]	0.17 [1]	3.5 [15]
Non-dairy cattle < 1 year	1.53[2]	88[1]	0.17 [1]	3.5 [15]
Horses	4.65[2]	90 [3]	0.27[1]	1 [2]
Sheep > 1 year	0.43[2]	90[3]	0.19 [1]	1 [2]
Sheep < 1 year	0.22[2]	90[3]	0.19 [1]	1 [2]
Dairy goats	0.46[2]	90[3]	0.19 [1]	1 [2]
Other goats	0.26[2]	90[3]	0.19 [1]	1 [2]
Pigs for breeding	1.21 [12]	88 [17]	0.30[10]	3.5 [15]
Pigs for slaughter	0.53 [12]	88 [17]	0.30 [10]	3.5 [15]
Hens	0.029 [12]	90[3]	0.32 [10]	1.5 [2]
Chicks bred for laying hens	0.021 [12]	90[3]	0.32 [10]	1.5 [2]
Chicks for slaughter	0.021 [12]	90[3]	0.32 [10]	1.5 [2]
Ducks for breeding	0.17[2]	90[3]	0.32 [10]	1.5 [2]
Ducks for slaughter	0.057[2]	90[3]	0.32 [10]	1.5 [2]
Turkey and goose for breeding	0.12[2]	90[3]	0.32 [10]	1.5 [2]
Turkey and goose for slaughter	0.052[2]	90[3]	0.32 [10]	1.5 [2]
Mink, males	0.062[2]	90[3]	0.25 [2]	1 [2]
Mink, females	0.124[2]	90[3]	0.25 [2]	1 [2]
Fox, males	0.100[2]	90[3]	0.25 [2]	1 [2]
Fox, females	0.20[2]	90[3]	0.25 [2]	1 [2]
Reindeer	0.43[2]	90[3]	0.25 [2]	1 [2]
Deer	2.42[2]	90[3]	0.25 [2]	1 [2]
Ostrich	1.28[2]	90[3]	0.25 [2]	1 [2]

[1]Own research
[2]Calculated from formula (4)
[3]Assessment

6 Acknowledgment

The paper is result of a project financed by Agricultural Authority, Norway, and the Norwegian Environment Agency. We would also like to thank Mary Anderson-Glenna for her help with the report.

References

[1] Intergovernmental Panel of Climate Change (IPCC) ,2011. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 10: Emissions from Livestock and Manure Management http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

[2] Sandmo, T. 2011. The Norwegian Emission Inventory 2011 - Documentation of methodologies for estimating emissions of greenhouse gases and long-range trans boundary air pollutants. SSB Documents 21/2011. Statistics Norway, Oslo/Kongsvinger Norway

[3] Morken, J. & Hoem, B. 2011. Models for calculating methane emission from manure management in Norway. IMT Report 43/2011, Aas, Norway

[4] L.M Safley jr. and P.W. Westerman, psychrophilic anaerobic digestion of animal manure: proposed design methodology, Biological Wastes 34 (1990), pp.133-148.

[5] A.G.Hashimoto, V.H. Varel, and Y.R. Chen, Ultimate methane yield from beef cattle manure: Effect of temperature ration constituents, antibiotics and manure age, Agricultural Wastes 3 (1981), pp.241-256.

[6] E. Gonzales-Avalos and L.G. Ruiz-Suarez, Methane conversion factors from cattle manure in Mexico, Atmosfera 20, pp83-92 (2007).

[7] A. Dustan, Review of methane and nitrous oxide emission factors for manure management in cold climate, jti-rapport Lantbruk &Industri 299, Stockholm, Sweden, 2002.

[8] S.G. Sommer, S.O. Petersen, and H.B. Møller, Algorithms for calculating methane and nitrous oxide emissions from manure management, Nutrient Cycling in Agroecosystems 69 (2004).

[9] LMD, 2009. Klimautfordringene – Landbruket En Del Av Løsningen. Ministry Of Agriculture and Food. Oslo. Norway. 2009; 39: 174.

[10] Dämmgen, U., Amon, B., Hutchings, J.N., Haenel, H.-D. and Rösemann, C. 2012. Data sets to assess methane emissions from untreated cattle and pig slurry and solid manure storage systems in the German and Austrian emission inventories. Agriculture and Forestry Research 1/2 2012 (62) 1-20

[11] Dämmgen, U., Amon, B., Gyldenkærne, S., Hutchings, J.N., Klausing, H.K., Haenel, H.-D. and Rösemann, C. 2011. Reassessment of the calculation procedure for the volatile solids excretion rates of cattle and pigs in the Austrian, Danish and German agricultural emission inventories. Agriculture and Forestry Research 2 2011 (61) 155-126.

[12] Karlengen, I.J., Svihus, B., Kjos, N.P. and Harstad, O.M. 2012. Husdyrgjødsel; oppdatering av mengder gjødsel og utskillelse av nitrogen, fosfor og kalium. Sluttrapport. Institutt for husdyr- og akvakulturvitenskap, Universitetet for miljø- og biovitenskap (in press)

[13] Rodhe L., Ascue, J., Tersmeden M., Ringmar A., Nordberg Å. 2008. Växthusgasemissioner från lager med nötflytgödsel. R 370 JTI Sweden. English summary can be found at: L Rodhe et al 2009. Emissions of green-house gases (methane and nitrous oxide) from cattle slurry storage in Northern Europe. IOP Conf. Ser.: Earth Environ. Sci. 8(1) doi:10.1088/1755-1315/8/1/012019

[14] VanderZaag, A.C., et al., Effects of winter storage conditions and subsequent agitation on gaseous emissions from liquid dairy manure. Canadian Journal of Soil Science, 2010. 90(1): p. 229-239.

[15] Naturvårdverket, 2012. National Inventory Report Sweden 2012. Swedish environmental protection agency, pp 412.

[16] Rodhe, L.K.K., Abubaker, J., Ascue, J., Pell, M., Nordberg, Å. 2012. Greenhouse gas emissions from pig slurry during storage and after field application in northern European conditions. Biosystems Engineering 113: 379-394.

[17] Intergovernmental Panel of Climate Change (IPCC), 2001. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Chapter 4, Agriculture. http://www.ipcc-nggip.iges.or.jp/public/gp/english/index.html

[18] Kjos, N., P. 2012. Personal communication.