Evaluating biogas in Norway - bioenergy and greenhouse gas reduction potentials

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Abstract: The aim of the study is to evaluate the potential of greenhouse gases, and production and substitution of fossil fuel from animal manure. This paper describes a model for the prediction of greenhouse gases (GHGs) and ammonia emissions, originated from animal husbandry, were presented. The input data in the model were primarily acquired from different Norwegian governmental institutions; however, some were unavailable. The remaining data were based on personal knowledge such as manure storage conditions (i.e., storage time on Norwegian farms, temperature ranges between storage periods, loading capacity of trucks for manure transport, etc.). The model included: methane emissions from animal facilities and waste storage units, ammonia emissions from storage units, nitrous oxide from stores, transportation of manure to collaborative biogas plants, and energy production and substituted energy when biogas production was selected. The model was then used to study the reduction in GHG emissions when anaerobic digestion was applied. All of the calculated gas emission values showed that methane was sensitive to temperature; however, only 4% of emissions were emitted from animal facilities due to minor amounts of manure. The contribution of stored manure in summer was approximately 62%, although some amounts were excluded because it was the grazing season. The estimates of GHG effects of anaerobic treatment was 45% lower than the governmental estimates. The contribution of ammonia emissions to GHG emissions is small due to low oxidation rates, but the reduction itself can lead to increase ammonia concentrations in manure and thereby reduce the need of artificial nitrogen input. Transportation represented a minor contribution to GHG outlets compared to the reduction potential when including the substitution effect of biogas as an energy carrier, even for the longest transportation distances modeled. The type of energy carrier biogas that would be substituted was the most important factor for the potential reduction in GHGs.

Keywords: biogas, bioenergy, greenhouse gas, renewable energy, model

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1 Introduction

One of the most substantial sources of organic materials comes from animal manure. When manure is untreated or poorly managed, it becomes a major source of methane and ammonia release (Nielsen et al., 2007). In addition, the observatory monitoring framework-indicator data sheet (UK, 2009) indicates that approximately two-thirds of nitrous oxide (N_2O) emissions are produced by agriculture. Soils contribute approximately 95% of the emissions, primarily as a result of fertilizer application and leaching. In addition, manure is not only a direct source of greenhouse gases (GHGs) but also a major source of indirect atmospheric N_2O associated with nitrogen (N) leaching and runoff from agricultural lands, and also produced from ammonia emissions due to oxidation, as mentioned by Lu et al. (2006).

The huge amount of waste produced in a concentrated area, in particular, requires urgent treatment and disposal solutions because ammonia and GHGs [methane (CH_4) and carbon dioxide (CO_2)] emitted from waste storage units may contribute to air pollution problems

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(Yetilmezsoy and Sakar, 2008). Thus, emissions of CH_4 and N_2O are regulated as part of the Kyoto Protocol under the United Nations Framework Convention on Climate Change (UNFCCC). The reduction target for the European Union (EU) in GHGs is 9% by 2008-2012 with reference to 1990, and the EU has proposed a further reduction target of 20% by 2020 (Sommer et al., 2009). To date, the largest GHG decrease occurred in industrial processes, followed by agriculture, waste and energy from 1990 to 2009 (UNFCCC, 2011). Agricultural emissions in 27 EU countries actually fell by 20% between 1990 and 2006 as a result of the significant decline in livestock numbers, more efficient application of fertilizers and improved manure management. This is well above the 11% average reduction in emissions in all EU sectors. Between 2008 and 2009, the impact of UNFCCC (2011) indicated that emissions from agricultural activities in these countries decreased by 1.8%. Similar results can be seen in the literature for Norway. In 2008, the agricultural sector was responsible for almost 9% of total Norwegian GHG emissions, which amounts to 4.8 million tons of CO_2-equivalent. The contribution of CH_4 was 44%, and N_2O (agricultural) was nearly 46%. The emissions from animals and manure management were 104 Gg for methane, with 85% from enteric fermentation and 15% from manure management (emissions from storage of manure) (LMD, 2009). From 1990-2011, GHG emissions were 5.8% higher in 2011 than in 1990 (SSB, 2011).

Production of biogas through anaerobic digestion (AD) of manure is regarded as a viable method to reduce emissions from agricultural activities (Prapaspongsa et al., 2010; Banks et al., 2007; Clemens et al., 2006; Monteny et al., 2006; Sommer et al., 2004). Most Norwegian farms are comparatively small in size; however, there exists the potential to install cooperative plants in order to make biogas profitable for agricultural farmers. Thus, a significant challenge for farmers is how to efficiently transport manure from farms to a plant. Community manure handling systems (2006) reported that the use of a piping system to deliver manure to the facility would be more expensive than truck transportation. Although truck transportation is an economical means of transporting manure, it emits GHGs during transport. Both the distances between farms and the truck size are important factors for quantifying the emissions. Therefore, transport emissions should be evaluated along with economic considerations.

The aim of this research is to identify the main sources of GHG emissions during the management of manure in Norway and to quantify GHG reductions when choosing biogas treatment. Using government data (Statistic Norway, 2007), a novel modeling approach for the prediction of GHG emissions was developed. The objectives of this study are as follows:

(1) To present the model for calculating GHGs emissions, including CH_4 and N_2O, from manure storages at summer season and winter season.

(2) To examine the effect of establishing cooperative plants for GHG reductions.

(3) To explore the relationships between GHG emission reduction and its potential energy value.

Therefore, the model takes into consideration transportation from farms to plant, CH_4 emissions from stables (gathering) and stores, N_2O emissions from stores, including oxidizing of ammonia emissions and energy substitution. Lastly the model includes substitution of various energy carriers.

2 Definition of the model

In the present model, two of the greatest challenges associated with an estimate of emission reduction potential include building a prediction model for GHG emissions based on a country's condition and running it with proper data. The model comprises (GHG) emissions at summer season and winter season during manure management (except soil emissions and enteric fermentations), including indirect N_2O emissions and emissions during transportation of manure from farms to cooperative plants if the plants are established.

Although the model used in this paper is not a strict life cycle analysis (LCA) according to ISO 14040-44, it uses some elements from LCA models. Life cycle inventory (LCI) data of energy input was used, and the "avoiding burden" method (Finnveden, 1999), which is a type of energy carrier biogas substitute, was selected to evaluate different uses of biogas as an energy resource. The system boundaries were defined as the annual production of animal manure in Norway. Therefore, the functional unit is an annual manure production in Norway.

The import and flow of all products through the internal and external chains from farms to plants were modeled (Figure 1). Five sub-models constituted the model: (1) methane emissions from gutters (stables) and stores, (2) nitrous oxide from stores, (3) ammonia emissions from stables and storage, (4) transportation regarding both distance from farm to cooperative plant and truck size and (5) energy substitution.

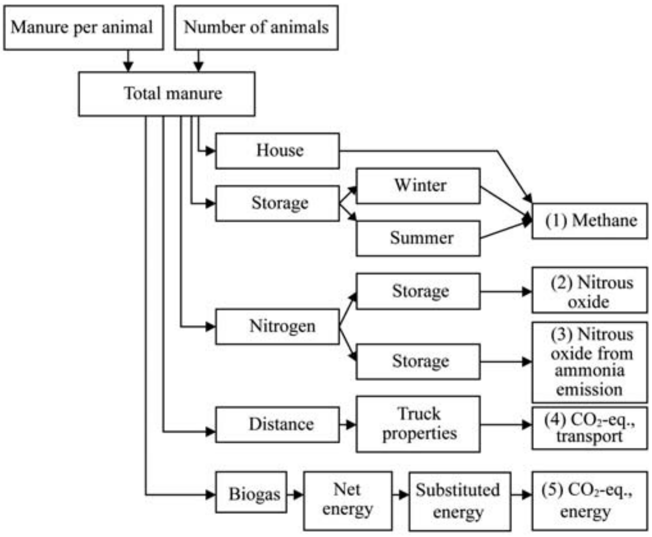

Figure 1 Structure of the model including the submodels

2.1 Methane emission

The aim of making a new model for methane emission was that we needed a model that could predict emission as a function of time. During agricultural activities, methane is emitted from gutters (stables) and stores (Sommer et al., 2004). The quantity depends on several factors such as the amount of manure, which is related to the species and numbers of animals, and the conditions of the manure collection process. It was reported that dairy cows' fertility was seasonally correlated (De Rensis and Scaramuzz, 2003). Because it has a positive correlation between an animal unit and a manure volume (Arthur and Baidoo, 2011), from an emission point of view, animal population and their corresponding manure production was evaluated during two different seasons: winter and summer. The winter manure storage period, which was used to collect half of the total amount of animal manure, was set to six months in the model. The summer storage period, which was used to collect the other half of total manure, was set to three months since the stores in this period are emptied twice (Figure 1). The gutters in Norway are normally emptied twice a day. GHG emission originating from stored manure displays variations due to the differing amounts of manure collected throughout the year.

Emissions from manure collection were not only dependent on storage time but also on storage temperature (Sommer et al., 2009; Massé et al., 2003) because temperature influences the metabolic activities of the microbial population (Metcalf & Eddy, 2003). Hence, the volume of produced methane shows variation. Norway is located in a cold climate zone. Research on CH_4 emissions in cold temperatures (Canada) showed that CH_4 fluxes were strongly related to manure temperature, with decreasing fluxes from July to April and higher fluxes in July when compared with November (Park et al., 2006). As observed previously, most Norwegian farms are comparatively small in size; for this reason, storage capacities of the farms are generally small. Because small storage capacity is affected by seasonal temperature changes, the corresponding GHG emissions display variations.

Taking into account the fact that not all the manure is collected during the summer months (100 d) for horses, cattle and goats, and nothing is collected from sheep, methane is emitted during the grazing period (at *c* in Figure 2) and after this period (at *a*, *d* and *f* in Figure 2). The gutters are normally emptied twice a day, and the storage is emptied twice a year (at *b* and *e* in Figure 2). However, when cooperative plants are used, the storage period (pre-storage of manure before it enters the biogas plant) is reduced to 30 d; otherwise, the storage period is zero as reported by Sommer et al. (2004). Therefore, there is no methane emission from the treated manure. Consequently, when building the methane emission portion of the model, the contribution of methane from storage is calculated to consider the amount of manure depending on both animal unit in two seasons and number of days in the collection period, tipping period of manure from the gutters, storage temperature and storage time of the manure in the storage tank. Equation (1) which was reported by Sommer et al. (2004) and modified by Chianese et al. (2009) is used for the calculation of methane emission:

$$E_{\mathrm{CH_4}}=\frac{24V_{S,d}b_1}{1000}\exp\left(\ln A-\frac{E}{RT}\right)+\frac{24V_{S,nd}b_2}{1000}\exp\left(\ln A-\frac{E}{RT}\right) \tag{1}$$

where, $E_{\mathrm{CH_4}}$ is the emission of methane from manure storage (kg CH_4 d^{-1}); $V_{S,d}$ and $V_{S,nd}$ are the degradable and non-degradable volatile solids (VS) in manure (g), respectively; b_1 and b_2 are rate correcting factors (dimensionless) as 1.0 and 0.01, respectively; A is the Arrhenius parameter; E is the apparent activation energy (J mol^{-1}); R is the gas constant (J K^{-1} mol^{-1}) and T is the temperature (K). From Sommer et al. (2004), the degradable VS entering the storage is calculated by Equation (2):

$$V_{S,d}= VS_{tot}\cdot\frac{B_0}{E_{\mathrm{CH_4},pot}} \tag{2}$$

where, VS_{tot} indicates total VS amount, which was set as 0.87 according to Chianese et al. (2009; and B_0, which is the maximum methane producing capacity (m^3 kg^{-1}VS), was set to 0.2 (Park et al., 2006; Sommer et al., 2004). $E_{\mathrm{CH_4},pot}$ is the potential CH_4 yield of manure (g kg^{-1} VS), which can be estimated using Bushwell's equation based on the average content of carbohydrates, fat and protein in manure. The Arrhenius parameter under Norwegian conditions was calculated from Equation (1) when E_{CH4} equals the calculation from SSB (2010). This method was chosen because Sommer et al. (2004) only gave figures for cattle and swine; however, in this study, calculations would be made for all animal types. Additionally, we wanted to normalize the figures similar to those from the IPCC (SSB, 2010).

For describing the temperature dependence of the methane emission rate, temperature variability was included in the Arrhenius equation as in the study of Mangio et al. (2002). According to Sommer et al. (2004), the Arrhenius constant can be determined by solute Equation (1) when the emission is equalized to the emission provided by the IPCC Tier 2 model (Hoem, 2006). The assumption of the emission factor (MCF-factor) of methane from the storage of biogas treated manure is similar to the factor that IPCC suggested (0.01). The sum of emissions from the facility, winter storage and summer storage equals the result of Equation (1), which was then used for determining the Arrhenius parameter. A corrected emission was then calculated from the sum of emissions from the facility, winter storage, and summer storage multiplied by $\frac{y-g}{y}$, where y represents half of the year (182.5 d) and g represents the grazing period (100 d) for animals that are grazing during the summer period.

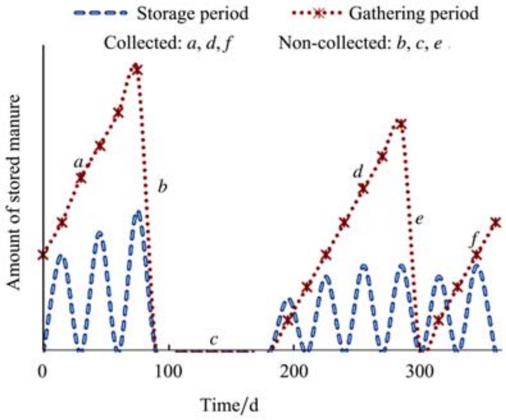

Figure 2 Principle of modelling the amount of stored manure

It is believed that selecting the appropriate parameters for this model is extremely important for getting sound forecasting results. Although the main data for the prediction model from agricultural activities are taken from the literature, particularly public research reports or personal communication from farmers, some data require assumptions for running the model since the value of using parameters in the model shows differences depending on the region and time period. One of the assumptions in the model was made for methane emission values for treated manure. The amount depends on several factors such as temperature, rate of degradation, coverage of storage tanks, etc. In this study, we assumed that the storage tanks have coverage and are used as gas storage; thus, there would be no methane emissions from the treated manure. After personal communication with Norwegian farmers and considering the study of Mathot et al. (2012), the second assumption in the model concerned temperature ranges within the storage and in the gutters. Temperature of the stored manure was assumed to be 15℃ and 20℃ for winter and summer, respectively, and likewise, it was assumed to be 25℃ for manure in gutters.

2.2 Nitrous oxide emission

Nitrous oxide can be emitted from stored manure and fields (IPCC, 1997a, b). Nitrous oxide has a global warming potential of 298 CO_2-equivalents (Sintori et al., 2010; Cherubini et al., 2009; Forster et al., 2007). Thus, emissions from manure management systems were evaluated in the present model (Figure 1). Values for these emissions were taken from Statistics Norway (Hoem, 2006), which used Equation (3) in accordance with the IPCC Tier 2 method (IPCC, 1997a, b):

$$E = \Sigma_s \{[\Sigma_i (N_i Nex_i MS_{i,s})] EF_s\} \qquad (3)$$

where, E is the emissions of N_2O-N per year (kg); N is the population of animals; Nex is the annual average N excretion per year(kg N·); MS is the fraction of total excretion per species for each management system; EF is the N_2O emission factor; s is the manure management system and i is the species. The emission factors used in this study are given in Table 1.

Table 1 Nitrous oxide emission factors

Livestock types	*EF*
Swine	0.01
Hen	0.02
Broiler	0.02
Mink	0.02
Fox	0.02
Horses	0.01
Dairy cattle	0.01
Non-dairy cattle	0.01
Sheep, Goats	0.01

The IPCC model calculates the N_2O emission to be proportional to the nitrogen produced per year due to anoxic conditions in the top layer when manure is exposed to air. Park et al. (2006) investigated the GHG emissions from stored liquid swine manure in a cold climate. The result suggested that N_2O emissions from non-aerated liquid swine manure storage could be ignored in GHG inventories (Park et al., 2006). This could be explained by a negligible top layer. Thus, we assumed that the biogas treated manure also had no top layer and, therefore, had zero emissions. If manure is used in cooperative biogas plants, it is assumed that the manure is stored one month before collection and transport to the plant. As a result, the emission will originate from pre-storage of manure before it is transported to the biogas plant, as shown in Equation (4):

$$E = \Sigma_s\{[\Sigma_i (N_i Nex_i MS_{i,s})] EF_s\}p/12 \qquad (4)$$

where, p is the storing period. According to IPCC (2000), there is no difference in the emission factors for the application of untreated and treated slurry.

2.3 Ammonia emission

Agriculture is the largest contributor of ammonia (NH_3) to the environment in Norway (96% of the emissions) (Morken, 2003a). More detailed descriptions of the agricultural ammonia emission model were provided in a previous study (Linjordet et al., 2005; Morken, 2003b). The NH_3 data were taken from Statistics Norway (SSB) (Hoem, 2006) and used to set the prediction model. Because emissions of NH_3 from manure depend on several factors such as animal type, nitrogen content in fodder, manure management, storage periods, facility types, storage types, and climate (Aasestad, 2008; Morken, 2004), emission factors for each county were calculated separately (one by one) (Morken, 2003c) and then aggregated for the entire country.

Most Norwegian farms store their manure in the basement of the animal facilities, and sufficient information regarding the ratio of NH_3 volatilization from this storage and the animal facilities was not provided. Therefore, for the model, 2/3 of the NH_3 emissions were determined to originate from storage areas and the other amount (1/3) from housing (Figure 1) (Morken et al., 1999).

AD of organic matters leads to increased NH_3 content. It is normal for 50% to 60% of VS to degrade, which theoretically corresponds to 50% to 60% mineralization of organic nitrogen. This results in an increase of 25% in NH_3 content according to the study of Rodhe et al. (2006). Table 2 gives an overview of the calculation of the increase in mineralized nitrogen in manure. Documentation of farm-scale mesophilic AD plants (not published) indicates that only 40 % of VS is degraded.

Therefore, we assumed that degradation is only 40%.

Table 2 The content of total nitrogen and ammonia in cattle and pig slurry, untreated and treated

Manure type	Total nitrogen content /kg mg^{-1}		Ammonia content /kg mg^{-1}		Increase in ammonia content /%
	Untreated	Treated	Untreated	Treated	
Cattle	4.0	4.0	2.0	2.8	20
Pig	5.0	5.0	3.5	4.1	20

2.4 Transport

Most Norwegian farms are comparatively small in size – the average area is 20.2 hm^{-2}, and average cow farm hold 23 cows (Statistics Norway, 2011). Therefore, to make biogas profitable for agricultural farmers, installing cooperative plants may be favorable. However, transportation will emit GHGs if fossil fuels are used for transportation. Nevertheless, the transport distances from the farm to a plant should be economically situated depending on its energy requirement, such that the higher the energy requirement, the further the material can be transported. In the literature, the following were used for the transportation of manure to energy facilities: high dry matter feedstock (~70%) may be transported from within a 40 km radius of the site, low dry matter feedstock (<10%), and typical slurries are transported from within a 10 km radius of the site (Dagnall et al., 2000). In fact, we discovered that transport distances between various types of farms and a biogas plant ranged from 10 km to 50 km in the literature (Pertl et al., 2010; Singh et al., 2010; Wiens et al., 2008; Ghafoori et al., 2007). In the present study, distances of 10 km, 20 km and 30 km were hypothesized due to the requirements in Norway. Moreover, return transport was calculated on the basis of the following assumptions; the loading capacity of trucks was calculated as 50%, but when we assumed that the loading capacity was 100%, the returning transport was included. Therefore, transport emissions were calculated from (a) the amount of manure which must be transported, (b) the size of a vehicle, (c) the GHG emissions from an actual vehicle, and (d) the average distance between farms and a plant. This is calculated as a life cycle inventory (LCI) (emission from crude oil extraction, transport, refinery plant, and fuel consumption) (Rydh et al., 2002). The equation (5) gives emission from the transport:

$$E_{transport}=TDc\times 10^{-6} \quad (5)$$

where, T is the amount of slurry which must be transported (Mg); D is the average distance between farms and plant (10, 20 and 30 km) and c is the greenhouse emissions which is given as 176, 136 and 52 g (Mg km)$^{-1}$ CO_2-eq, for the truck types light truck (3.5-14 t), medium size truck (14-24 t), and semi-trailer truck (40 t) respectively, (Rydh et al., 2002).

In addition, the tank on the truck with slurry was filled up with energy, and the tank was emptied at the biogas plant. Virtually the same amount of energy (E_p) was used for loading and unloading, and therefore, the equation is multiplied by 2:

$$Ep= 2TF_c E_d U\times 10^{-6} \quad (6)$$

where, T is the amount of manure which will be pumped (t); F_c is the fuel consumption of pumping (L t^{-1}); E_d is the energy content of diesel (MJ L^{-1}) and U is the CO_2-equivalents per MJ diesel (Mg CO_2-eq·MJ^{-1}). It was applied to fuel consumption (F_c) of 0.1 L mm^{-3} (Dalgaard et al., 2001), and then the energy content (E_d) was used in diesel of 35.9 MJ·L^{-1} (Kelm et al., 2004). This represents the heat value of diesel, but there remains a need for the energy used in distribution and extraction to be added. Kelm et al. (2004) suggested that this contributes to 3.8 MJ L^{-1}. The emission of GHGs is equal to 89.9 g CO_2-equivalents per MJ (Nielsen et al., 2003). Finally, the total GHG emission (E_{tot}) was calculated as follows:

$$E_{tot}= E_{transport}+ E_p \quad (7)$$

Transport distances from farms to cooperative biogas plant were calculated and evaluated in Briseid et al. (2010). According to this paper, average transport distances of 10, 20 and 30 km were chosen.

2.5 Energy substitution

A life cycle inventory (LCI) of energy input was used, and the method of "avoiding burden", which is a type of energy carrier biogas substitute (Finnveden, 1999), was used to evaluate different uses of biogas as an energy resource. The energy content of biogas varied according to the content of methane, though the energy content of methane in this study was 9.98 kW h·m^{-3}. The total energy was calculated theoretically (Deublein and

Steinhauser, 2008; Burton et al., 2003). However, detailed calculations can be found in Raadal et al. (2008).

The present model was analyzed to provide information that contributes to a better understanding of the net GHG emissions generated by different energy resources in the life cycle of agricultural activities as other substitute energy sources such as natural gas and petroleum are investigated.

In the model, part of the energy in biogas is used internally for heating. The data from Deublein and Steinhauser (2008) was used (13% of the produced energy). Additionally, the biogas plants use electricity for pumps and mixers. Electricity generation in Norway is hydroelectric, which is regarded as renewable, and without GHG emission. Therefore, in the present model, electric power consumption of biogas plants will not contribute to GHG emissions. Data for GHG outlets from the energy substituted from natural gas and petroleum is found in Global Emission Model for Integrated Systems (GEMIS, 2007), and the substitution effects used were 260.26 and 328.99 g CO_2-eq·kWh from natural gas and petroleum, respectively. Electricity from hydropower plants is deemed to be renewable with no GHG emission (GEMIS, 2007). Net energy produced by biogas (total-energy for heating, energy for pumps, and eventually upgrading) was multiplied by the emissions from the fossil fuel alternatives to find the combined effect. It was assumed that biogas can substitute for both petroleum and diesel as fuel for cars. When upgrading to substitute petroleum, 2% of the energy in biogas is used for the upgrading process.

Global warming potential per functional unit is characterized in gCO_2-equivalents (CO_2-eq) on a 100 year time scale using factors recommended by IPCC, as similarly reported by Pertl et al. (2010), Lechón et al. (2009) and Meisterling et al. (2009) (Table 3).

Table 3 Global warming potentials for selected greenhouse gases

Substance/kg	Global warming potential	Sources
CO_2	1.00	Brentrup et al. (2004)
CH_4	21.00	Brentrup et al. (2004)
N_2O	310.00	Brentrup et al. (2004)
NH_3 *	3.1	IPCC (1997b)

Note: *Conversion factor from NH_3 to N_2O.

2.6 Statistical analysis

Model output values are generally related to input data. The validation procedures require that we have statistical estimates of output. In the present model, two of the greatest challenges associated with an estimate of emission reduction potential include building a prediction model for GHG emissions based on a country's condition and running it with proper data. The model prediction data were compared with data from the IPCC model.

A two-sample t-test were also performed to evaluate the relationship between methane emission from summer seasons and methane emission from winter seasons using Minitab® 16.1.1 statistical software package. An alpha (α) level of 0.05 was used to determine the statistical significance in the analyses.

3 Results

Results obtained from the sub-models of CH_4 emissions, N_2O emissions, NH_3 emissions, and the resultant GHG emissions from transportation due to the usage of fossil fuels are given. The results of energy substitution are summarized at the end.

3.1 Methane emission

Table 4 shows the results of the methane model. The Arrhenius number varied between the animal species because of the differences in emissions per animal provided in the IPCC model. It was calculated that in total, 4% of the emission arises from animal facilities, 34.5% from the winter storage period, and 61.5% from the summer storage period. Some animal species graze in pastures, and therefore, were not subjects for manure storage; as such, the methane model gave 34% less emission than the SSB model. When manure was used in biogas plants, the storage period, depending on the study's literature (Zhu et al., 2000) and the common application in Norway (personal communication with public farmers), was chosen as 30 d. This reduced the emission by 31% on a yearly average.

Table 4 shows that methane emissions from both gutters and storage changes, depending on the animal species and the housing period. Additionally, methane emissions, especially from animal manure storage, are different ($p < 0.05$) between summer and winter seasons.

Table 4 Calculated Arrhenius parameter and emissions divided into emission from house, and storage in summer and winter, and also comparison of methane emissions from the new model and the IPCC model for Norway

Animal type	Arrhenius	CH_4 Emission /t			Total emission		Differences of both emission model /%**
		House	Storage*		new modell*	IPCC	
			Winter	Summer			
Horses	47.0	20.9	179.5	260.1	460.41	775.5	40.6
Bulls (< 1 year old)	47.0	25.5	220.7	319.8	566.0	953.6	40.7
Heifers(< 1 year old)	47.0	22.7	196.0	284.0	502. 7	846.9	40.7
Bulls(> 1 year old)	47.0	36.0	310.2	449.5	795.8	1340.6	40.6
Heifers(> 1 year old)	47.0	50.6	436.7	632.7	1120.1	1886.8	40.6
Dairy cattle	46. 9	123.3	1060.8	1537.0	2721.1	4520.3	39.8
Sheep(< 1 year old)	46.5	0	0	151.0	151.0	198.1	23.8
Sheep(> 1 year old)	46.5	23.9	207.5	0	231.4	896.4	74.2
Goats	46.5	1.4	11.8	17.1	30.3	51.1	40.6
Swine	47.0	35.9	310.7	995.7	1342.3	1342.3	0
Poultry	47.2	40.9	354.7	1136.93	1532.52	1532.52	0
Other animals	47.2	76.01	57.2	183.2	242. 1	242.1	0
Total		382.7	3345.7	5967.2	9695.6	14586.2	33.5

Note: *without treatment; ** differences of both emission model is calculated as (IPCC emission value-new model emission)*100 /IPCC emission value.

3.2 Nitrous oxide

According to the IPCC, biogas treatment of slurry led to a 90% reduction of emission. The emission is, therefore, calculated to reduce from 19.2 to 1.69 Mg per year for the total herd in Norway.

3.3 Ammonia emission

Table 5 shows the result of the NH_3 sub model. When treatment in common plants was chosen, the reduction was almost 60%. One must be aware of the increased ammonia content, both from treatment and coverage of the storage tanks. However, if injection is not chosen, then anaerobic treatment can lead to increased emissions.

Table 5 Ammonia emissions from house and storage, untreated and treated manure, and change in Norway

Emission source	Untreated/t	Treated/t	Change/t
House	2012	2012	0
Storage	4024	335*	3698
Sum	6036	2347	3698

Note: *Emission value if the pre-storage periods are applied.

3.4 Transport

Table 6 shows the results of GHG emissions in the model associated with both the amount of slurry and the distance from the farm to the plant. Table 6 indicates that there is a positive correlation between transportation capacity, which changes according to truck size and average distance.

Table 6 Transportation's GHG emissions for various transportation distances

T /km	D /mg	$E_{\text{Transport}}$ /mg	E_p /mg	E_{tot} /mg
10	20	15184	7970	23155
20	20	30369	7970	38339
30	20	45553	7970	53524
10	30	4147	7970	12117
20	30	8294	7970	16264
30	30	12441	7970	20411

3.5 Energy substitution

Table 7 shows the main result of modeling CH_4 emissions from manure management. CH_4 emissions from animal facilities were not reduced when the biogas alternative was chosen. This represents 4% of the total emissions. Because of the reduction in storage time, and because of the reduction of these emissions (CH_4 and N_2O) for the biogas alternative, the reduction was calculated as 66%. Indirectly, N_2O emissions from ammonia were reduced to 39%. This could be explained by the reduced ammonia emissions from storage (slurry was stored in closed tanks after it was treated in a biogas reactor), and the reduced emission attributed to the injection technique.

Energy from anaerobic fermentation of manure was evaluated to be GHG neutral. Therefore, when it substitutes fossil energy, it reduces the net outlet of CO_2.

This is clearly shown in Figure 3 as the alternative energy from biogas is used to substitute hydroelectricity is 0. Although the average distance between the farms and the plant is tripled, the transportation outlet was still relatively small.

When energy from biogas substitutes fossil fuels, there was more than a 50% reduction in potential CO_2-equivalents. The reduction was somewhat higher when petroleum was substituted. When this contribution was included in total emissions from the agricultural sector, the reduction ranged from 19% to 23% if all agricultural waste is treated.

Table 7 Emission of greenhouse gasses from handling of manure from untreated and treated manure

Emission area	Emission	
	No treatment/mg	Treated by anaerobic digestion/mg
House	8037	8037
Storage	201527	63624
Indirect (from ammonia emission)	18713	11436
Total	228277	83097

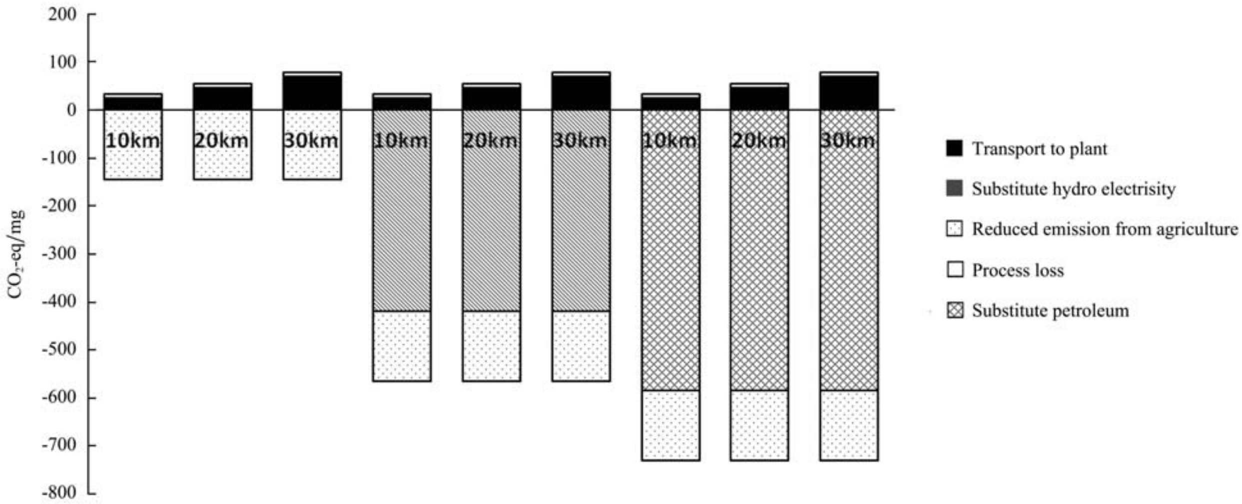

Figure 3 Greenhouse gas reductions (Mg CO_2-eq.) for cooperative plants with various transportation distances and various energy carriers

4 Discussion

4.1 General discussion of the model

Reduction of GHG emissions has become an issue of growing importance due to climate change; as such, manure management could contribute to the reduction. The study was carried out to help us quantify the reduction potential. Based on modeling studies (Xie et al., 2006; Wu and Chau, 2006; Zhao et al., 2006), it is imperative to select a good model and select appropriate input parameters. It is also important that the computer model is carefully managed. Model output values are generally related to input data. In the present model, two of the greatest challenges associated with an estimate of emission reduction potential include building a prediction model for GHG emissions based on a country's condition and running it with proper data. National and international reports did not include GHG emission values for gutters and stores of manure in Norway or information on the manure storage period on Norwegian farms. For these reasons, unfortunately, values of these important parameters were estimated by use of a mechanistic model (Sommer et al., 2004). The obtained results from the model were neither investigated in the light of sensitivity nor tested on the basis of actual conditions, but the model was used to envisage the reduction potential of introducing anaerobic treatments in agriculture.

The model also demonstrated the GHG effects of transporting manure from farms to centralized plants. The sensitivity of GHG emissions due to manure transportation was evaluated by choosing three distances (as 10, 20 and 30 km) from farms to biogas plants and three different truck sizes (as 10, 20 and 30 mg).

A number of recent publications such as governmental reports and literature, which were previously discussed, were used for acquiring appropriate data as well as for obtaining additional inputs for the model such as animal types and their units. Apart from these explanations, the challenges in building a GHG emissions model for Norway should not be underestimated. For example, the many factors that influence N_2O emissions result in considerable uncertainty (60%) according to Hoem (2006), and consequently, the estimates are very tentative.

4.2 Discussion of the results

The equations used in the model were run with predominantly actual data as explained previously, because there was no information available on GHG emission measurements from animal farms in Norway (Figure 1). Compared to estimates of the methane emissions from the Norwegian Pollution Authority, our calculation differed by 33.5%. There might be at least four reasons for the differences:

1) It might be that this study's model takes into account emissions occurring from animal facilities (Figure 1), which were not reduced by AD.

2) It might be that methane emissions from methane storage areas were calculated separately for winter and summer in the model. These sources had a considerable influence on the seasonal variations in GHG emission from agricultural activities. Approximately 23% of the loss occurred during the winter period, while 73% occurred during the summer period.

3) It might be that GHG emissions during the grazing period results in reduced GHG emissions. When taking into account the grazing period, the summer loss decreased to 62%. Moreover, the value of the Arrhenius parameter with effects on temperature changes was calculated based on the use of various types of animals in the model by the equation. This result is similar to that obtained by Sommer et al. (2004). There might be at least two explanations for this. First, we deduced that the temperature in the manure should be used rather than air temperature, and therefore, different temperatures were used. Second, manure is kept in houses only for 12 h (scraping of gutters two times per day) in our model and therefore, the amount of stored manure at high temperatures was less in this study than that reported by other studies. The estimates could be improved by measuring the temperature of slurry in gutters and stores more accurately.

4) It might be that the lower GHG emissions estimated by the Norwegian Pollution Authority may have an operational impact on the chosen technology for manure storage on the farm. The results of GHG emissions from animal facilities and storage in the present model indicates that emissions decreased by almost 65% (Table 7).

On the basis of the GHG emissions, as observed by the value obtained from the transportation portion of the model, the results were comparable to those of other studies in terms of the effect of manure transportation on GHG emissions. The results show that transportation contributes slightly to GHG emissions. This was also the findings of Briseid et al. (2010). The reduction potential of GHG emissions from Norwegian agriculture is heavily dependent on which energy source the biogas will substitute. There are also differences between fossil fuel types. The greatest potential is when biogas can substitute petroleum, but this also holds for other vehicles and additional infrastructure for fuel supply because one needs to convert from liquid to gas-driven cars. The model is not very detailed, and improvement of this sub-model is important for the results.

The performance of treated manure and untreated manure of the present model was compared not only with GHG emissions data but also with NH_3 emissions data. Because the treatment results in exposure of stored slurry to the atmosphere, and possible NH_3 emissions, it is necessary to cover the storage tanks; therefore, the model also shows that anaerobic treatment could also lead to decreased NH_3 emissions from stores.

It was neither reported in this study, nor by other studies, that the actual measured quantity of manure on fields in Norway was comparable to results obtained from computer estimates based on the present model application. An estimate on the reduction potential of GHGs from manure management in this model was much (55%) lower than that found earlier (Briseid et al., 2010). In the proposed model, emissions can be determined more accurately by a calculation of the contributions from the pre-storage period, and also from the non-stored amount of manure during pasturing, which is subtracted from the total amount (Figures 1 and 2).

4.3 Discussion of the Arrhenius parameter

Sommer et al. (2004) provided figures for the Arrhenius value for cattle and pigs. In this study, emissions from all animal types were calculated based on figures from SSB (2010). These calculations gave a significantly higher calculated Arrhenius parameter than that calculated by Sommer et al. (2004). The differences could be due to the unscientific estimation method for estimating the Arrhenius parameter. On the other hand, this method made it possible to correlate our results to results obtained by the SSB's method. The differences call for an improvement in the SSB's method, which could give additional information on the emissions related to the management of manure. By using this type of model, it was possible to calculate emissions from animal facilities and storage tanks, which could vary from different storage periods and temperatures.

5 Conclusions

The model presented made it possible to divide methane outlets from storage of manure in summer and wither seasons. This was based on Sommer et al. (2004). The submodel for emission of nitrous oxide was based on the model from IPCC (1997a), which could be improved if more accurate data were available. The emissions were modeled and the key conclusions from this study were as follows:

1) Biogas could reduce greenhouse gas emission from manure management by 64%.

2) Transportation of manure yielded only minor GHG emissions compared to the reduction that could be achieved.

3) The reduction potential of GHG emissions depends on the use of the gas (i.e., which type of energy it substitutes). The potential was highest when methane substituted oil, at roughly 610 - 650 Gg CO_2-eq. depending on the transportation distance between the farms and the biogas plant.

This study tried to simulate Norwegian farm conditions. However, for future studies, either data estimated according to our observations in the field or some values acquired from other similar studies in the literature should be used. Future work is needed to determine the correct value (E_{CH_4}, B_0, etc.) for Norwegian farms.

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