Greenhouse gas emissions from piggery and biogas digesters in the Red River Delta of Vietnam

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Contents

List of tables

List of figures

List of abbreviations

AGI	Agricultural Genetics Institute
ANOVA	Analysis of Variance
AW	Average Weight
MONRE	Ministry of Natural Resources and Environment of Viet Nam
EM	Effective Microorganisms
FTIR	Fourier Transform Infrared Multicomponent Trace Gas Analyser
GHG	Greenhouse Gas
GSO	General Statistics Office of Vietnam
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
MARD	Ministry of Agriculture and Rural Development of Vietnam
NA	Not Available
NDC	Nationally Determined Contributions
OM	Organic Matter
PVC	Polyvinyl Chloride
PP	Polypropylene
QCVN	National Technical Regulation of Vietnam
STP	Standard temperature and pressure
SD	Standard deviation
TCVN	Vietnam Standards

Executive summary

High demand for pork consumption in Vietnam has led to a shift of pig production systems from smallholder to industrial-scale farms, particularly in the Red River Delta. This production intensification also produces massive manure and urine quantities, leading to water, air, and soil pollution. The use of biogas plants has been seen as efficient to achieve in the same time a decrease in pollution, and a provision of biogas resources and bio-organic fertilizers. However, increasing pig head density has been causing great pressure on biogas digesters, as their size is not big enough for treatments anymore. Inappropriate utilization and management of biogas digesters can not only cause losses from pig wastes, but also contributes to increase greenhouse gas (GHG) emissions such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). This case study aims to identify the role and contributions of biogas digesters to better manage the sources of GHG emissions from pig wastes for different types of pig farms. Four provinces of the Red River Delta were selected to test the pig waste management efficiency of biogas digesters and measure GHG emissions from these systems. The findings show that CO_2, CH_4 and N_2O emission rates from pig manure are at least twice as much what is allowed under the Vietnam national technical regulation on ambient air quality. However, the GHGs emission rate does not significantly differ between smallholder and industrial-scale farms in the four surveyed provinces. Sampling position (between inside piggeries and outside the outlet of biogas digesters) did not affect significantly GHG emissions rate. These results confirm that the pig waste management of biogas digesters for both smallholder and industrial-scale pig farms is not efficient and that efforts need to be invested to mitigate GHG emissions in pig production.

Reducing pig density per piggery is highly recommended. The modification of biogas digester structure to separate solid pig manure and urine should also be considered. Otherwise, the application of other alternative aerobic or anaerobic digestion technologies should also be encouraged and promoted. Biogas digesters in pig production have a significant role to play in Vietnam government's mitigation strategies, as well as from the perspective of biosafety and animal husbandry policies.

1. Introduction

Livestock is one of the fastest growing sub-sectors of agriculture in Vietnam. In the past, livestock raising activities based on feeding agricultural by-products were popular in all agro-ecological zones. However, these have been sharply shifting from smallholder to industrial levels during the last decade. Under the orientations of livestock production development strategies of the Ministry of Agriculture and Rural Development Vietnam (MARD) from 2008 to 2020, the herd size and growth rate of livestock in general has quickly advanced towards industrial productions in areas where appropriate conditions for livestock raising are met (Bình et al., 2014). Consequently, the pig population has remarkably increased by 27.4 million heads in 2017. Growth rate of pig heads has increased by 2.3% per year since 2013. More than 14,858 of intensive pig farms in different production levels are nationally listed (GSO, 2017). Two-thirds of the intensive farms are in the Red River Delta and the rest is in the South.

Manure management is one of the mitigation components of agriculture under the Nationally Determined Contribution (NDC)'s framework that Vietnam government undertakes to implement during the period of 2020-2030. To achieve its mitigation goals, Vietnam government has planned specific actions to develop additional 300,000 biogas digesters which are expected to mitigate 1.92 million tons CO_2-equivalent (CO_2-eq), and improve animal feeds which are expected to mitigate 0.13 million tons CO_2-eq. Because its improvements are important to contribute to Vietnam government's policy implications and international commitments on climate change prevention, global warming and GHG mitigations.

However, the livestock population intensification is linked to an increase in waste production, reaching 26.5 million tons and 33.7 million m^3 for solid and liquid waste, respectively (Bo, 2017). Waste disposal is not yet organized, with only about 60% of wastes treated and used effectively through technologies as such biogas digester, composting (Bo, 2017). The actual proportion may be lower than reported. The rest remains untreated and is directly released to the environment. The dumping and inappropriate management before discharging into surrounding environment have caused varying degrees of water, soil, and air pollution and epidemic diseases to human and animal habitats. These not only causes losses from recycling wastes for use as fertilizers and biogas, but also increase greenhouse gas (GHG) emissions such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Previous reports showed that manure management practices contributed by 15.1% out of total agricultural emissions between 1992 and 2012 (Misselbrook et al., 1996; USAID, 2012). It is predicted that the amount of GHG emissions continues to raise in coming years. In order to reduce the negative environmental impact from animal wastes, the use of treatment technologies should be encouraged, focusing on the most popular, low-cost and convenient ones. Several options are at hand to reduce GHG emissions and provide bio-fertilizer sources, e.g. the addition of crop residues or bio-materials (biochar, effective microorganisms (EMs)) to manure, composting techniques or anaerobic digestion technology from biogas digesters.

Among these, biogas digesters are interesting for their multi-purpose nature, treating waste and producing energy in the same time. Biogas and digestate produced through the anaerobic digestion of organic matters inside the digester is important products to feed trees and improve environmental issues. Biogas could also replace other energy sources as fossil fuel, firewood, agriculture residues that commonly used for households in rural areas (Muller, 2007; Amigun et al., 2008; Molino et al., 2013; Adu-Gyamfi et al., 2012; Hinh, 2017).

With the technical and financial supports of the Vietnamese government and international donors, about 0.5 million biogas plants have been introduced to livestock raisers until 2018 (Hinh, 2017). Under Vietnam Nationally Determined Contributions (NDCs)'s commitment, the biogas digester projects will continue to be applied with additional 0.3 million plants in period of 2021-2030. Unfortunately, recent findings show that the quality of manure decomposition of these systems is limited, with animal density causing high pressure on the biogas digester's volume, as their size is not big enough for treatments anymore. Especially, biogas digester volumes which are common from 7-12 m^3 in smallholder livestock farms are less significant to treat animal wastes (Hinh, 2017). In addition, GHG emissions from biogas digesters were not quantified, neither for smallholders nor for industrial pig production systems. Therefore, this study aims at quantifying GHG emissions from biogas digester in different types of pig production systems and at different locations in the biogas digesters.

2. Materials and methods

2.1. Study sites and pig production characteristics

2.1.1. Description of study sites

This study was carried out in four districts under four provinces: Thanh Hoa (TH), Phu Tho (PT), Thai Binh (TB) and Vinh Phuc (VP). These provinces represent the areas of the Red River Delta and the northern midlands and mountain areas where the largest pig populations and densities are observed per farm. Since 2013, the number of livestock farms has increased 3.8 times in PT, 2.7 times in TB and 1.9 times VP and TH, respectively (Table 1).

Table 1. Number of livestock farms in the study provinces

Study provinces	2013	2014	2015	2016	2017
Vinh Phuc (VP)	532	534	628	944	1,021
Thai Binh (TB)	279	474	573	696	744
Phu Tho (PT)	66	93	126	224	248
Thanh Hoa (TH)	342	498	509	644	661

Source: (GSO, 2018)

2.1.2. Pig production characteristics

The rapid increase is not only seen in the number of pig farms, but also in pig populations in the surveyed provinces. Thai Binh province had the highest number of pigs with over one million heads, accounting for 3.6% compared to the total nationwide pig populations. Of which, the number of fatteners was around 800 thousands heads accounted for 3.4%. In addition, the number of sows is twice that of other surveyed provinces by 185 thousand heads. The number of raisers in the surveyed provinces have sharply increased by respectively 69,022 households (Vinh Phuc), 94,101 households (Thai Binh), 120,706 households (Phu Tho) and 186,758 households (Thanh Hoa) (General Statistical Office, 2016). The distribution of pig raisers by pig head size is shown in Figure 1. In which, the largest proportion of households who have from 1 to 2 herd size accounts for ranging from 36% to 53%. Households have from 3 to 5 pig herd size and from 10 to 49 pig herd size also account for a large proportion by 20% on average. In contrast, the proportion of households with more than 50 pig herds were less than 5%. This study focuses on two groups of pig raisers with pig farm scales of 3-5 heads per farm and 10-49 heads per farm.

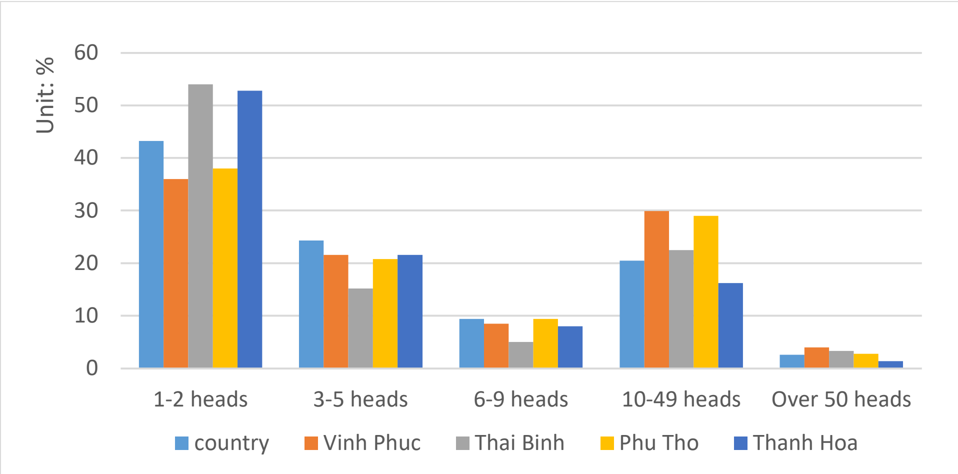

Figure 1. Number and structure of pig raisers by scale and by province (Source: Rural and Agricultural Census, 2016)

2.2. Experimental design

2.2.1. Sampling design

A convenience sampling method based on suggestions from the Department of Livestock Production, Ministry of Agriculture and Rural Development Vietnam was applied to select pig farms. Six pig farms were randomly sampled in each district of the four provinces, and are named as TH farms, TB farms, VP farms and PT farms according to the initials of the provinces. A total of 24 farms were selected, among which 16 were small-scale farms and 8 were large-scale farms. The farm category is defined according to the number of fattened pig heads per farm as shown in Figure 1. Farms fall in the large-scale category when the total pig heads are above 10 pigs per farm. The farms that have less than 10 pigs per farm as classified as small-scale farms (Rural and Agricultural Census, 2016). The study was done on three types of biogas digesters, specifically

KT1, KT2, composite plastic structures[1]. These biogas digesters are usually built underground of the piggery. The digester is filled in through the inlet tank and the inlet pipe. The produced biogas is accumulated at the upper part of the digester.

2.2.2. Gas sampling procedure

Gas was sampled from 1st October to 11th November 2018 from manure collected at two locations per farm, inside the piggery and outside the biogas digester. Inside the piggery, a composite sample was obtained from fresh solid manure or slurry taken at two random positions, while at the outlet of the biogas digester, one sample of digested wastes was taken directly. Pig manure were then kept by white plastic plates (radius = 9.25 cm). Plates with pig manure then were weighed to note the initial mass using an electronic scale (Model-HY K17, 5kg). Fresh solid pig manure was sampled in the same locations, weighted and dried in the microwave until stable mass. A pH and humidity tester (model DM-15, Takemura) was used to measure pH levels. Ambient conditions such as temperature, pressure, moisture, precipitation, wind speed, GPS were taken before gas flux measurements. The starting and ending times of a measurement process were specified as soon as the attachment between the chamber and sample disks was sealed to measure GHG emissions. Environmental parameters were recorded at the time of measurement for each sampling duration. Data on ambient conditions such as temperature and humidity, wind speed were updated from Google's a weather forecast application on the mobile device connecting GPS with satellites.

2.2.3. Description and operation of static chamber and gas emission measurement

The static chamber method has been applied extensively to measure rates of trace gas emission sources (Hutchinson and Livingston, 1993; Hutchinson and Mosier, 1981; Kusa et al., 2008), and allows to detect gases emitted from a surface of a volatile solid within a known volume during a known period of time. In this study, a static chamber system was designed following the GHG emission measurement protocol that developed by Arévalo at el., (2018). This system was connected to a Gasmet DX-4040 Fourier Transform Infrared Multicomponent Trace Gas Analyser. The chamber was programmed to be closed for fifteen minutes (one observation), with three observations performed in one hour. The total number of repeats were 72 observations. The FTIR gas analyser measures main greenhouse gases at low concentrations in parts per million unit per seconds ($ppm.s^{-1}$) including CO_2, CH_4, N_2O and other gases as CO, NH_3, water vapour. The response time of the analyser is 20 seconds for one reading and the flow speed of sample pump is 1.5 litters/minute. The gas analyser was calibrated with pure nitrogen N_2 (2 liters/minute) prior to each measurement at the Agricultural Genetics Institute (AGI) in Hanoi. For each

[1] KT1 and KT2 are small-scale types of biogas plants defined by Nguyen Quang Khai – Director of Biogas Technology Center, Vietnam Union of Science and Technology Associations (see more http://tietkiemnangluong.com.vn/tin-tuc/tai-lieu/t14293/tu-sach-khi-sinh-hoc.html)
Composite is a composition material used for biogas plant construction. It replaces other common materials as bricks, cement and sand.

measurement, the chamber was inserted to the base and sealed with a black rubber ring while the base was inserted to the sample and sealed with water (see in the appendices A1, A2).

2.3. Data analysis

2.3.1. Calculation of GHG emission fluxes

Emission fluxes were computed from the change in gas concentration with time. There are two main approaches of GHGs calculation based on static chamber method including linear and non-linear models (Anthony et al., 1995). For linear model, the gas concentration within the container headspace increased linearly with time. As such, fluxes were calculated from the slope of the linear regression between gas concentrations versus time (Whalen, 2000). The equation is described as follow:

$$F = \frac{\Delta C}{\Delta t} \frac{P}{P_0} \frac{273.15}{T_{Kelvin}} \frac{v}{A} \frac{M}{V_s} \quad (1)$$

Where:

- F is the flux rate (mass unit. $m^{-2}.h^{-1}$)
- P is the measured ambient pressure (mbar)
- P_0 is the standard pressure (1013.25 mbar)
- v is the total system volume (L), ($\sum V = V_{\text{headspace}} + V_{\text{tubing}} + V_{\text{Cell of gas analyzer}}$)
- V is the volume occupied by 1 mol of the gas at standard temperature and pressure (STP) (0.024 m3, or 22.4 L)
- A is surface area of the chamber over the emission source (m^2)
- T is the ambient temperature in degrees celsius (°C),
- T_{Kelvin} is the temperature T in Kelvin (K) = (273.15 + T_c)
- $\Delta C/\Delta t$ is the change in concentration in time interval *t* or the slope of the gas concentration curve ($ppm.s^{-1}$)
- M is the molecular weight of the gas ($gmol^{-1}$)

However, the linear model is dependent on various (solid, slurry) characteristics of manure sources, which might vary from one sample to another within the same sampling event. An alternative is proposed by (Hutchinson and Mosier, 1981) using exponential model based on diffusion theory to correct for the decreasing concentration gradient within the static chamber headspace. This approach has advantage of not depending on the sampling time or conditions of gas sources. However, its limitation is that only three gas concentrations can be used and its goodness of fit, the statistical significance of the flux based on those three data points cannot be tested (Anthony et al., 1995).

The equation is described as follow:

$$F = \frac{\Delta C}{\Delta t} \frac{P}{P_0} \frac{273.15}{T_{Kelvin}} \frac{v}{A} \frac{M}{V_s} \quad (2)$$

The difference between (1) and (2) equations is the method which the concentration gradient with time $\Delta C/\Delta t$ is calculated. Three following cases show the calculation of this approach (Ginting et al., 2003).

- Case 1: If $\Delta C_1 > \Delta C_2$ and $C_0 < C_1 < C_2$ or $C_0 > C_1 > C_2$

$$\frac{\Delta C}{\Delta t} = \left[\frac{(\Delta C_1)^2}{\Delta t\,(2C_1 - C_2 - C_0)} ln\left(\frac{\Delta C_1}{\Delta C_2}\right)\right] \quad (3)$$

- Case 2: If $\Delta C_1 \leq \Delta C_2$ and $C_0 < C_1 < C_2$ or $C_0 > C_1 > C_2$

$$\frac{\Delta C}{\Delta t} = \left[\frac{\Delta C_1 + \Delta C_2}{2\Delta t}\right] \quad (4)$$

- Case 3: If $\Delta C_1 \leq \Delta C_2$ and $C_0 < C_1 > C_2$ or $C_0 > C_1 < C_2$

$$\frac{\Delta C}{\Delta t} = \left[\frac{\Delta C_1}{2\Delta t} + \frac{\Delta C_3}{4\Delta t}\right] \quad (5)$$

Where $\Delta C_1 = (C_1 - C_0)$; $\Delta C_2 = (C_2 - C_1)$; $\Delta C_3 = (C_2 - C_0)$; C_0, C_1, and C_2 are gas concentrations (ppm) within the static chamber after time periods t_0, t_1 and t_2 respectively where $t_2 = 2t_1$. Case 1 is based on the diffusion approach considering gas flux saturation with time (Ginting et al., 2003; Anthony et al., 1995; Hutchinson and Mosier, 1981). Case 2 is based on the average of the two slopes between concentrations when there is no gas flux saturation; that is, the gas concentration gradient is linear over time (Hossler and Bouchard, 2008; Ginting et al., 2003). Case 3 is based on the average of the slopes between the first and second and between the first and third gas concentrations, respectively (Ginting et al., 2003).

In this study, time intervals (Δt) after each sampling were defined as 0, 5, and 10 minutes. C_0, C_5, C_{10} were concentrations measured at the corresponding intervals. Based on the concentration gradients, most of N_2O samples had steady increase at sampling times of 0, 5, and 10 minutes ($C_0 > C_5 > C_{10}$). In addition, there were 85.2% of N_2O flux concentrations out of 72 samples followed case 1 ($\Delta C_1 > \Delta C_2$ and $C_0 > C_5 > C_{10}$), 14.0% of those followed case 2 ($\Delta C_1 < \Delta C_2$ and $C_0 > C_5 > C_{10}$) and the remaining of 0.8% followed case 3. Therefore, N_2O emissions were calculated by case 1

2.3.2. Statistical analysis

Data of GHG fluxes were first tested for normality using the univariate procedure in R package. The GHG emissions rates were determined from linear regressions, using the goodness of fit and the significant level for model selection. The significance of the differences between emission fluxes in different piggeries was tested by an one-way ANOVA. As N_2O gas fluxes were nonlinearly distributed, the concentration C_0, C_1, C_2 corresponding at the time intervals 0, 5 and 10 minutes were used for calculations.

3. Results

3.1. Pig raising characteristics in the study provinces

Characteristics of piggery structure and pig population are shown in Table 2. TB farms had the largest number of fattened pigs and sows while number of piglets were the greatest in TH farms. The average area of piggeries in TB and TH farms were twice larger than the one of farms from the other two provinces. The largest volume (m^3) of biogas digester was found in TH farms. Feces and urine were gathered in the same inlets of biogas digester without separation. The period of manure storage inside a biogas digester was usually one year. However, the biogas digester sizes, commonly ranging from 10.8 to 13.5 m^3, and the treatment duration were not large and long enough to digest and decompose the amount of produced manure. Digested wastes after biogas digesters which were discharged into the surrounding environment of piggery and pig raiser's residences still provided odour emissions and water and soil pollution.

Table 2. Average pig production characteristics by province and by farm size

Pig production characteristics	Unit	PT farms		TB farms		TH farms		VP farms	
		Small	Large	Small	Large	Small	Large	Small	Large
Sample size	farm	4	2	4	2	4	2	4	2
Number of sow	Head	2.2	0.0	3.7	5.0	1.3	2.8	2.2	2.6
Number of fattened pig	Head	7.8	25.5	8.6	52.5	6.7	41.4	6.5	23.0
Number of piglet	Head	10.3	20.4	14.3	24.0	18.1	72.5	8.8	30.0
Piggery's area	m^2	35.6	84.5	51	136.3	57.8	640.4	68	137.7
Volume of biogas digester	m^3	8.4	14.5	9.0	13.5	9.0	16.0	8.5	14.3

3.2. GHG emissions from piggery and manure management

CO_2 and CH_4 concentrations increased linearly over time within the chamber headspaces (Table 3). The R-squared of these two gases were significant in all surveyed sites. R-squared was lower for N_2O because the curve was non-linear (quadratic, exponential). Therefore, equation 2 was applied for N_2O concentration. N_2O concentration increased in PT and TB farms and decreased in TH and VP farms.

Table 3. GHG concentrations from 24 pig farms in 4 study provinces

Concentration (ppm)	PT farms		TB farms		TH farms		VP farms	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CO_2	1162	428	1078	403	1259	311	1257	679
R-squared	0.994^{***}		0.861^{***}		0.928^{***}		0.848^{***}	
CH_4	33.3	25.1	28.7	22.8	47.6	25.5	45.6	31.3
R-squared	0.995^{***}		0.844^{***}		0.862^{***}		0.845^{***}	
N_2O	0.5	0.3	0.5	0.1	0.3	0.07	0.4	0.03
R-squared	0.658^{**}		0.703^{***}		0.459^{ID}		0.471^{**}	

Note: (SD) is standard deviation in the parenthesis; ***, ** are 1% and 5% significant levels, ID is insignificant difference, sampling time is 15 minutes.

CO_2 and CH_4 emission rates did not vary significantly between the selected provinces (Table 4). However, these rates were much higher than the standard levels under national technical regulation on industrial emission of inorganic substances and dusts in Vietnam for emissions of CO_2 and CH_4 (QCVN 19: 2009/MONRE). On their side, N_2O emissions were within the ranges of the national regulation. The combined contribution of CH_4 and N_2O emissions in CO_2eq reached around 25 $kg.ha^{-1}$on average.

Table 4. GHG emission rate of pig manure by province

Emission rates	**PT farms**	**TB farms**	**TH farms**	**VP farms**	**Chi-squared**
($mg.m^{-2}.h^{-1}$)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
CO_2	1400 (347)	1806 (1036.04)	1644 (481.43)	1365 (1022.23)	1.7964^{ID}
CH_4	18.6 (16.5)	23.5 (19.89)	26.2 (18.58)	23.9 (19.97)	1.4764^{ID}
N_2O	0.2 (0.54)	0.02 (0.27)	-0.03 (0.04)	0.01 (0.06)	NA
CO_2-eq ($kg.ha^{-1}$)	24.1	23.9	22.9	26.3	

Note: (SD) is standard deviation in the parenthesis; ID is insignificant difference, NA is not available

Per pig head and per feed input, CO_2 was by far the larger contributor to GHG emissions in terms of mass, although with a wide variation between farms (Table 5). However, when transformed in CO_2-eq, the contribution is mainly from CH_4 emissions.

Table 5. Emission rate of pig manure by pig head and feed inputs

Emission ($mg.m^{-2}.h^{-1}$)	**Total pig (head)**		**Feed input (kg/day)**	
	Mean	SD	Mean	SD
CO_2	91.84	124.53	64.02	88.02
CH_4	1.51	2.15	1.06	1.52
N_2O	0.0021	0.0140	0.0015	0.0098
CO_2-eq ($kg. ha^{-1}$)	1.30		0.91	

Note: (SD) is standard deviation in the parenthesis

The emission rates did not vary significantly between the sampling locations, whether inside the piggery or outside the outlet of the biogas digester at sampling points (Figure 2), although emissions were slightly higher inside.

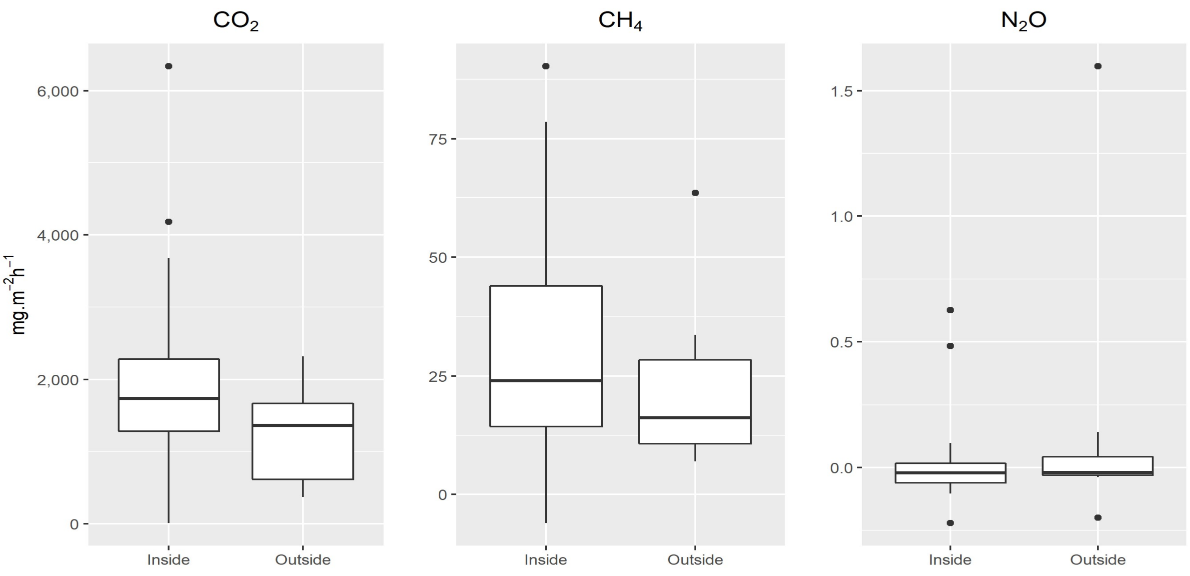

Figure 2. Emission rate of pig manure inside piggery and outside storage

In order to detect an effect of feed components on emissions, GHG emissions rates tended to increase slightly with manure dry matter (Figure 3), but variation was very large.

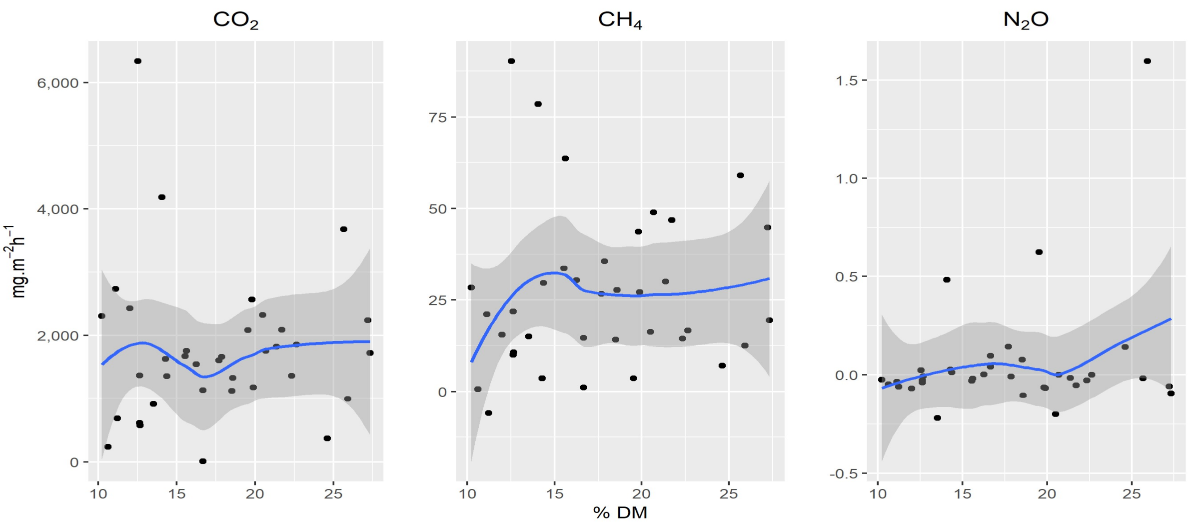

Figure 3. Relationship between GHG emission rate and dry matter in pig manure

The GHG emission rates showed higher variation in smallholder farms than in industrial farms (Figure 4). CH_4 emission rates were significantly greater in industrial-scale pig farms compared to smallholder pig farms.

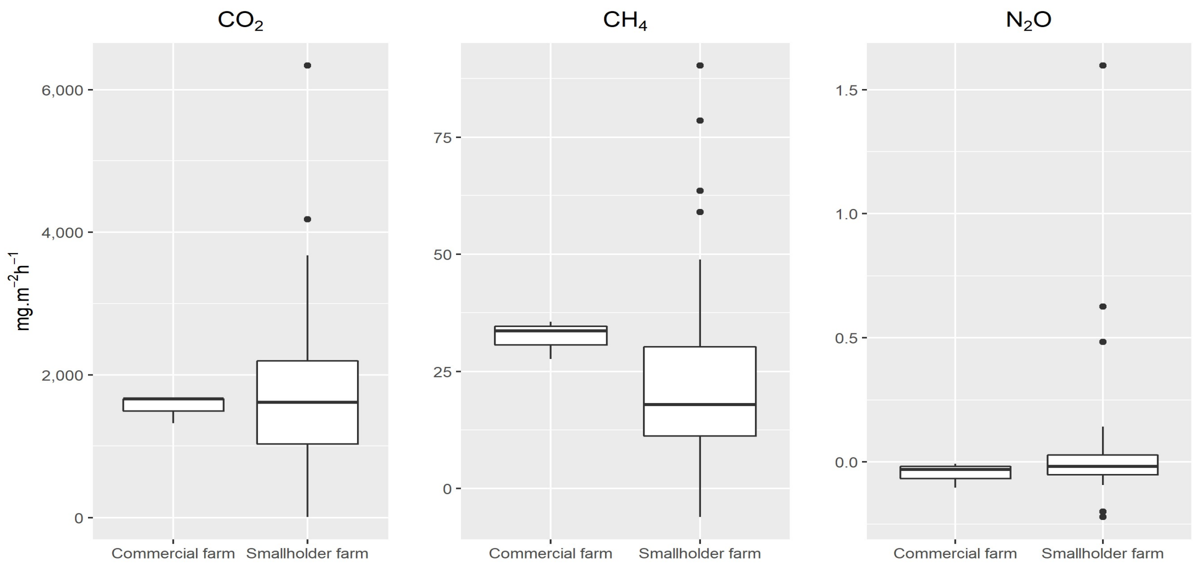

Figure 4. Emission rate of pig manure by farm scales

3.3. Environmental parameters affecting GHG emissions

The average temperature in TB and TH provinces was higher than in Phu Tho and Vinh Phuc provinces by 6 - 7^{0}C, but humidity was 15 to 20% lower. Pig manure samples were slightly acid, with an average moisture of 80.15%, with no significant differences in provinces.

Table 6. Environmental indicators and sample characteristics in selected sites

Variables	Unit	PT farms	TB farms	TH farms	VP farms
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Ambient temp	^{0}C	21.9 (0.8)	27.9 (2.0)	28.6 (1.4)	20.6 (0.5)
Ambient humidity	%	90.5 (1.4)	70.4 (5.6)	75.5 (5.9)	94.4 (2.3)
Sample weight	g	401.0 (107.5)	471.4 (110.4)	485.4 (128.0)	499.0 (169.9)
Sample moisture	%	83.4 (4.1)	77.6 (9.6)	80.6 (5.0)	79.0 (7.2)
pH		6.5 (0.3)	6.2 (0.2)	6.4 (0.3)	6.4 (0.2)

Note: (SD) is standard deviation in the parenthesis

4. Discussion

4.1. Pig farm location and structure characteristics affecting the GHG emissions

Although the structure of the pig house does not directly affect GHG emissions, it determines how manure is handled, stored, processed, and used. For the pig house location, this study found that most of the small-scale farmers built the pig houses near or inside their residential area in a very close distance (around 17 to 67 m). Piggeries are placed within farmers' residences. This could be explained because pig raising conditions and infrastructures were similar in all these provinces. This means that the capacity of biogas digesters in piggeries to decompose organic matters and digest pig manure was not completely efficient. Otherwise, the biases of sampling selection, standards of pig farm classification based on Vietnamese regulations and heterogeneity among selected sites were factors that could explain the difference in GHG emissions between these types of pig farms.

The location of pig farms are commonly seen at small-scale pig farms while large-scale pig farms were required to arrange outside far away from community's residences. This is convenient in cleaning and taking care of pig herds. However, there are risks of water and air contamination, as well as epidemic diseases. The exchange between GHG and odor emissions of excreta indoor and the atmosphere outdoor was restrained by the surrounding infrastructures. In conditions of high temperature, the emissions were stronger than, especially for CO_2 and CH_4. These results agreed with the findings of Ngwabie et al., (2011). For this reason, the manure management method using biogas digester should be appropriate to deploy under the floor or outside near the pig house. In addition, pig house type and structure play an important role in CO_2, CH_4 and N_2O emission intensification. The most frequent problems with structural components were related to the floor characteristics. The natural ventilation pig house structure and flatted floor were popular for both large-scale and small-scale farms in the study sites. Housing systems with slatted floors were realized to be easy to accumulate manure in liquid or slurry form. Depending on the floor type, how to design that could increase or decrease GHG emissions. Different types of floor have varying effects to GHG emissions. The effect of slatted floor areas on GHG emissions has also shown conflicting results, especially CH_4 and N_2O emissions (Fitamant et al., 1999; Guingand et al., 2010; Philippe et al., 2014). Pig houses with fully slatted floor systems were observed to reduce CO_2 production by 7-13% (Guingand et al., 2010; Sun et al., 2008). In comparison, bedded systems combine a wide range of raising techniques that impact the level of emissions. Bedded floor systems are usually associated with reduced CH_4 emissions, but increased CO_2 and N_2O emissions. Therefore, the selection of suitable materials is significant not only for raising conditions of pig, benefits of production cost, but also practical issues as manure storage, drainage. Together with the pig house site arrangement, the floor type and structure system also determines the feasibility of using anaerobic digestion or composting to treat the manure with its associated effects on GHG emissions. However, more evidences of different floor types are needed to confirm their effects on gas emissions in pig houses in the North.

4.2. Biogas digester volume and design affecting GHG emissions

Biogas digester volume calculation depends on the volume of manure produced. In case of North Vietnam, small-scale biogas digesters are still predominant, with the most common sizes from 6 m^3 to 12 m^3 (Roubík et al., 2016). However, results from this study shows that for an average quantities of 5 sows, 58 market pigs and 59 piglets per farm, the manure produced would be … m^3, which is a lot for the average size of biogas digester (12.6 m^3) to handle pig wastes. Another key finding is that there is no significant difference between the amount of GHG emissions produced before and after the use of biogas digesters, showing the inefficiency of the process. This leads to a lack of OMs in the digestate, usually caused by the use excessively high water per manure ratios (Roubík et al., 2016; Thu et al., 2012). Indeed, the imbalance between the manure and water ratios promotes the digester filling faster and reduces the retention time of feces. Thien Thu et al., (2012) showed that 55%-60% of the digesters had the retention time between 1 and 20 days. In these biogas digesters the OMs were inefficiently transformed to biogas. This means that the waste decomposition process continuously happens after discharging into the environment.

Overall, the consequences of this inefficient process are a poor GHG emissions mitigation, the lack of organic matters (OMs) in digestates, poor quality of biogas, spreading smells of biogas and loss of nutrients to the environments.

5. Opportunities for future studies

This case study has shown that waste management and treatment processes are moderately effective in mitigating GHG emissions and improving fertilizer utilization, as the level of GHG emissions before and after the use of biogas digesters remains high. Several gaps in knowledge could be addressed by future studies.

(i) The study initially evaluates the efficiency of GHG emission reduction in biogas digester systems. Comparisons with other waste management technologies are needed, such as composting technology, solid and liquid manure separation technology, EM technology, etc. This knowledge will be helpful to target interventions for different manure management technologies and prioritize them for government programs.

(ii) Care should be taken when extrapolating research results to other regions, and more assessments are needed in industrial and smallholder pig farms in different geographical zones, to consolidate findings of emission levels at different production scales.

(iii) Feed sources play an important role in total GHG emitted. Most households use currently concentrated feed, and the comparative emissions following feeding with alternative products should be investigated.

(iv) This study analyzes emissions at the time of sampling, but has not evaluated emissions over longer time period, especially changes in seasonal emission rates. Future studies could focus on the impact of seasonal environmental changes, such as the fluctuation of temperature and humidity, on emission rates over time.

(v) These results were restricted to specify which type of pig (market pig, sow and piglet) had high GHGs emission rates per pig head. Similarly, the results did not identify GHGs emission rates for specific type of feed input. Further research is needed to provide additional data of GHG emission and feed intakes to confirm these results.

6. Conclusion

This case study provides additional knowledge of the pig waste management efficiency from biogas digesters in both small-scale and large-scale farms in four study provinces in the Red River Delta. The study confirms that due to the current high pig densities, biogas digesters are overloaded and the quality of manure decomposition are not optimal. The CO_2 and CH_4 emission rates ($mg.m^{-2}.h^{-1}$) from pig wastes inside and outside of biogas digesters are at least twice as much what is allowed under the Vietnam national technical regulation on ambient air quality. However, the GHGs emission rate does not significantly differ between smallholder and industrial-scale farms in four surveyed provinces. Sampling position (between inside piggeries and outside the outlet of biogas digesters) did not affect significantly GHGs emission rate. These results confirm that the pig waste management of biogas digester systems for both smallholder and industrial-scale pig farms is not efficient and that efforts need to be invested to mitigate GHG emissions in pig production. This case study suggests that adjustments of pig populations, density of pig heads per piggery floor area unit during a pig production cycle are highly recommended. The modification in biogas digester structure is also necessary to separate solid pig manure and urine. Otherwise, the application of other alternative aerobic or anaerobic digestion technologies should also be encouraged and promoted when economic and environment benefits are met. Biogas digesters in pig production have a significant role to play in Vietnam government's mitigation strategies, as well as from the perspective of biosafety and animal husbandry policies.

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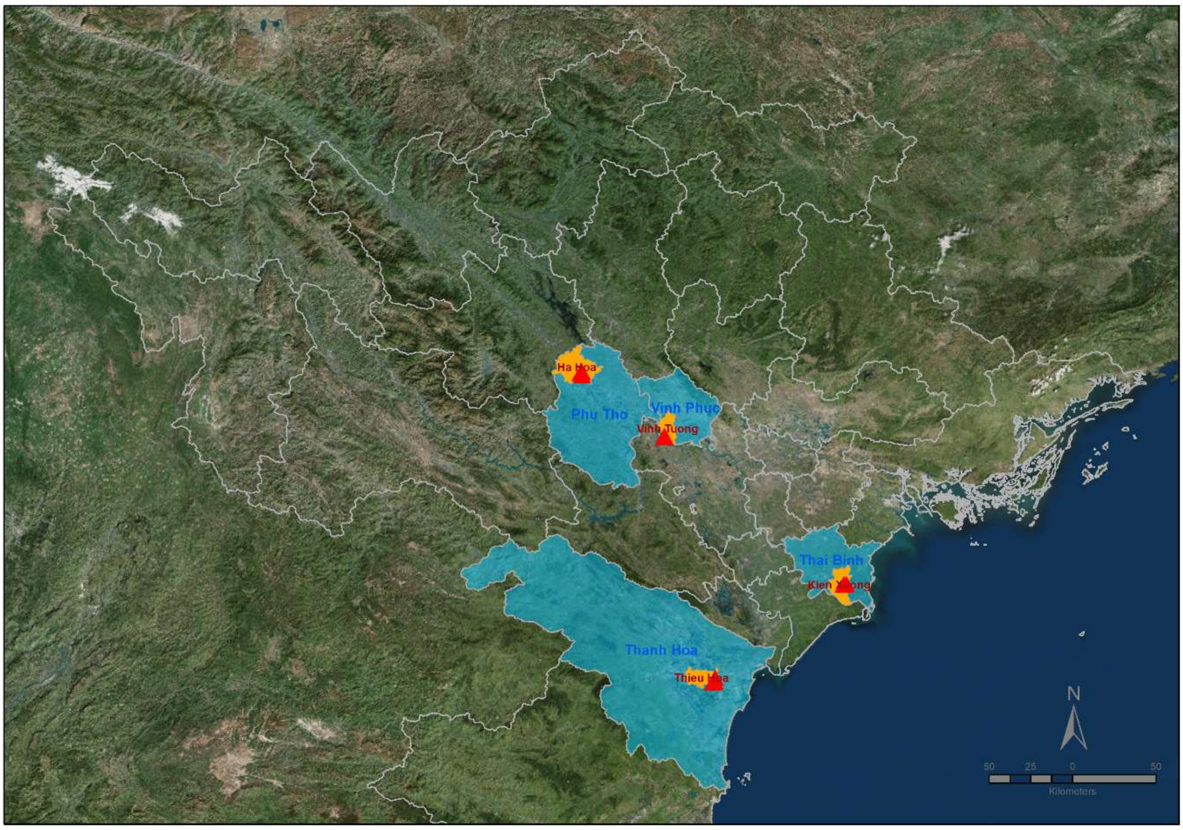
Appendices

Appendix A1. Study sites of greenhouse gas measurement in the North Vietnam



Appendix A2. The static chamber system application of GHG emission measurement

Appendix B. Environmental indicators at study sites

Name of interviewer:____

Address:____

ID:__________Date_______________

Details of the environmental indicator collected

Sample characterization*	Weight (g)	Sample moisture (%)	Sampling site@	Duration		Ambient temp (^0C)	Ambient moisture (%)	Wind speed (km/h)	Pressure (mbar)	GPS	pH
				From (h)	To (h)						

Note:

*) *Manure characterization*: At the time of sampling and measurement, manure is characterized in liquid, solid or slurry, etc,.

@) *Location*: At the point where manure samples are collected and measured (e.g. inside or outside the piggery, after biogas, etc.,)

Appendix C. Questionnaire

GHGs emissions from piggery and biogas digesters in the Red River Delta of Vietnam

Information on household head

Full name ________________________________

Address ________________________________

Tel ________________________________

Livestock raising activities

1. Current conditions of livestock raising

1.1. Current livestock farm classification? a) Commercial farm b) Smallholder farm

1.2. What kind of animal do you own? a) Pig b) Buffalo c) Cow d) Chicken e) Other (specify…………….)

2. Livestock herd characteristics and inputs

2.1. Animal breed a) Self-producing b) Purchase

Details of animal breed

Variables	*Unit*	*Pregnant sow*	*Fattener*	*Piglet*	*Boar*	*Dairy cow*	*Beef cow*	*Calf*	*Buffalo*
Total herd	*Head*								
Number of pig litter	*Litter/ year*								
fattening time to the present	*Month*								
Current average weight	*Kg/ head*								
Average weight for sale	*Kg/ head*								
Is there any pig to get sick, diarrhoea , disease during 1 month?	*1. Yes* *2. No*								

2.2. Animal feed components

Variables	*Pregnant sow*	*Fattener*	*Piglet*	*Boar*	*Dairy cow*	*Beef cow*	*Calf*	*Buffalo*
Feed type (a) Concentrated feed; (b) Mixed feed; (c) By-products (d) Grass, straw, etc.								

Number of feeding time/day (a) 2 times (b) 3 times (c) More than 3 times								
Total feed quantity (*kg/day*)								

2.3. Breeding facilities

Variables	Permanent breeding facilities	Temporary breeding facilities	Commercial farm
Number of breeding facilities			
Total flooring area (m2)			
Flooring type (a) concrete (b) brick (c) Ground floor (d) metal (e) Bio padding material (f) Other (…)			
Distance from animal stable to home (m)			
Stable type (a) Closed, with fan (b) Open, without fan			
Frequency of cleaning feces (time/day)			

3. Mode of livestock waste management

Variables	Pig	Cow	Buffalo
Method of waste management: (a) Biogas (b) Compost (Ủ) (c) Probiotics (d) Bio-bedded (e) Non-treatment (directly release to the environment) (f) Other (…			
Area/Volume of waste container *(*m2/m3*)*			
Type of material for biogas			
Waste decomposing duration (a) 1-3 month (b) 3-6 month (c) 6-12 month (d) Over 1 year			
Use of disinfectants for breeding facilities after each cycle (a) Yes (b) No			
Waste management and utilization (a) For sale (b) Use for fertilizer (c) Feeding for fish d) Other (…			

Recommendations:

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