MANURE MANAGEMENT IN PIG PRODUCTION IN VIETNAM

Tran Thi Bich Ngoc, Tran Viet Phuong, Tran Thi Thanh Thao, Nguyen Thanh Trung, Le Thi Thanh Huyen and Pham Doan Lan

National Institute of Animal Science (NIAS), Ha Noi, Viet Nam

Corresponding author: Tran Thi Bich Ngoc; Tel: 0972708014; Email: bichngocnias@gmail.com

ABSTRACT

Pig farming in Vietnam has expanded rapidly, leading to a significant increase in manure production. Greenhouse gases (GHG) including methane, nitrous oxide and carbon dioxide emissions from pig manure production occupy a large portion in total GHG emission from livestock production. GHG inventory from manure management in Vietnam has been estimated by Tier 1 method with basic characterization for livestock populations so far. A more complex Tier 2 method for the inventory of GHG emissions referenced from IPCC (2019) provides a better estimation based on country-specific emission factors that allows to apply for different manure management systems and requires detailed information in animal performance, diet composition and manure management system. Preliminary observations presented in this review showed that the crude protein levels in commercial feed for pig are higher than nutrient requirement in diet recommended by NRC (2012) while the metabolizable energy levels and fiber levels are not much in difference. Intensive pig production has raised environmental concerns due to improper waste management, including direct discharge and inefficient treatment methods. While biogas digestion is a promising solution, challenges such as overloading and suboptimal decomposition hinder its effectiveness. To mitigate these issues and reduce greenhouse gas emissions, further research, technological advancements, and stricter regulations are necessary to improve manure management practices.

Keywords: *pig production, manure management, greenhouse gas inventory, emission factor, diet composition*

INTRODUCTION

Livestock manure is a substantial source of the three greenhouse gases (GHG)-methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). The highest CH_4 emissions are typically associated with liquid-based manure management system (MMS), where a large portion of manure decomposes anaerobically. In contrast, N_2O emissions vary significantly between individual MMS, and can also originate indirectly from nitrogen (N) that is lost during manure storage and handling (i.e. volatilization and leaching). Carbon dioxide (CO_2) emissions from livestock are not estimated because annual net CO_2 emissions are assumed to be zero – the CO_2 photosynthesized by plants is returned to the atmosphere as respired CO_2.

In Vietnam, the GHG inventory from manure management is estimated based on Tier 1 (IPCC, 2019), therefore the accuracy of inventory data is limited. This review will concern on the gap data in Vietnam in order to determine CH_4 and N_2O emission factors from manure management following Tier 2 approach.

TIER 2 CALCULATION OF CH_4 AND N_2O EMISSIONS FROM MANURE MANAGEMENT

Tier 2 calculation of CH_4 emissions from manure management

A more complex method to estimate CH_4 emissions from manure management should be used where a particular livestock species/category represents a significant share of a country's emissions. This method requires detailed information on animal characteristics and manure management practices, which is used to develop emission factors specific to the conditions of the country. The main difference between the Tier 1 and Tier 2 calculations is whether default information or country-specific information is used in the calculation of emissions from manure management system. The Tier 2 approach provides a much wider group of options for the estimation of emissions from different manure management systems.

Development of Tier 2 emission factors involves the determination of a weighted average methane conversion factor (MCF) using the estimates of the manure managed by each waste system within each climate region. The average MCF is then multiplied by the daily volatile solids (VS) excretion rate and the B_0 for the livestock categories. In Equation 10.23 of IPCC (2019), the estimate is as follows:

$$\mathbf{EF_{(T)} = VS_T \times 365 \times B_{0(T)} \times 0.67 \times \Sigma_{Sk}\, MCF_{Sk}/100 \times AWMS_{TSk}}$$

Where:

$EF_{(T)}$ = annual CH4 emission factor for livestock category T, kg CH4 animal^{-1} yr^{-1}

$VS_{(T)}$ = daily volatile solid excreted for livestock category T, kg dry matter animal^{-1} day^{-1}

365 = basis for calculating annual VS production, days yr^{-1}

$B_{0(T)}$ = maximum methane producing capacity for manure produced by livestock category T, m^3 CH4 kg^{-1} of VS excreted

0.67 = conversion factor of m3 CH4 to kilograms CH4

MCF(S,k) = methane conversion factors for each manure management system S by climate region k, percent

$AWMS_{(T,S,k)}$ = fraction of livestock category T's manure handled using animal waste management system S in climate region k, dimensionless

VS are the organic materials in livestock manure and consist of both biodegradable and nonbiodegradable fractions. The value needed for the Equation 10.24 (IPCC, 2019) is the total VS (both degradable and nonbiodegradable fractions) as excreted by each animal species since the Bo values are based on total VS entering the systems. The best way to obtain average daily VS excretion rates is to use data from nationally published sources. If average daily VS excretion rates are not available, country-specific VS excretion rates can be estimated from feed intake levels. Feed intake for cattle and buffalo can be estimated using the 'Enhanced' characterization method with a good practice to collect data to describe animal's typical diet and performance, and to estimate feed intake required from animal performance and diet data (IPCC, 2019). This ensures consistency in the data underlying the emissions estimates. For swine, country-specific swine production data may be required to estimate feed intake. The VS content of manure equals the fraction of the diet consumed that is not digested and thus excreted as fecal material which, when combined with urinary excretions, constitutes manure.

The VS excretion rate is estimated as equation 10.24 IPCC (2019):

$$\mathbf{VS = [GE \times (1 - DE/100) + (UE \times GE)] \times [(1\text{-}ASH)/18.45]}$$

Where:

VS = volatile solid excretion per day on a dry-organic matter basis, kg VS day^{-1}

GE = gross energy intake, MJ day^{-1}

DE = digestibility of the feed in percent (e.g. 60 percent)

(UE • GE) = urinary energy expressed as fraction of GE. Typically, 0.04GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85 percent or more grain in the diet or for swine). Use country-specific values where available.

ASH = the ash content of feed calculated as a fraction of the dry matter feed intake (e.g., 0.06 for sows: Dämmgen et al. 2011). Use country-specific values where available.

18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg^{-1}). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

According to IPCC (2019), digestible energy of feed ranges from 70-80% in mature pigs and from 80-90% in growing pigs.

Tier 2 calculation of N_2O emissions from manure management

This section describes how to estimate the N_2O produced, directly and indirectly, during the storage and treatment of manure before it is applied to land or otherwise used for feed, fuel, or construction purposes. The approach is based on N excretion, emission factors for N_2O emissions, as well as volatilization and leaching factors.

Direct N_2O emissions occur via combined nitrification and denitrification of nitrogen contained in the manure. The emission of N_2O from manure during storage and treatment depends on the nitrogen and carbon content of manure, and on the duration of the storage and type of treatment. Nitrification (the oxidation of ammonia nitrogen to nitrate nitrogen) is a prerequisite for the emission of N_2O from stored animal manures. Nitrification is likely to occur in stored animal manures with a sufficient supply of oxygen. Nitrification does not occur under anaerobic conditions. Nitrites and nitrates are transformed to N_2O and dinitrogen (N2) during the naturally occurring process of denitrification, an anaerobic process. There is general agreement in the scientific literature that the ratio of N_2O to N2 increases with increasing acidity, nitrate concentration, and reduced moisture. In summary, the production and emission of N_2O from managed manures requires the presence of either nitrites or nitrates in an anaerobic environment preceded by aerobic conditions necessary for the formation of these oxidized forms of nitrogen. In addition, conditions preventing reduction of N_2O to N2, such as a low pH or limited moisture, must be present.

Indirect emissions of N_2O result from volatile N losses in the form of ammonia (NH3) and nitric oxides (NOx) that are lost during manure storage and management and deposited somewhere else, where those subsequently can lead to additional N_2O emissions. Ammonia emissions stem from the volatilization of NH4 +, which in turn is produced during decomposition of organic N. This can be urea (mammals) and uric acid (poultry), that can be rapidly mineralized to NH4 +, or more complex organic N substrates such as proteins. NH3 is highly volatile and can contribute substantially to manure N losses. Nitrogen losses start after the excretion in animal confinements or pastures, continue through manure storage and treatment, and after application of manure onto fields. In addition to gaseous losses, N can also be lost via runoff and leaching into soils around animal confinements, on pastures, and at the location of manure storage and management. Nitrogen that is lost from manure decreases the amount of remaining N that is available for soil fertilization (FAO 2018). The Tier 2 calculations of N_2O emissions from manure management are based on total amount of

N excreted from all livestock categories that is handled in different MMS and which is multiplied with specific emission factors for each MMS.

Direct N_2O emissions from manure management is estimated as Equation 10.25, IPCC (2019)

$$N_2O_{D(MM)} = [\Sigma_S[\Sigma_T(N_T \times Nex_T \times MS_{T,S})] \times EF_{3,S}] \times 44/28$$

Where:

$N_2O_{D(MM)}$ = direct N_2O emissions from manure management in the region [kg N_2O yr^{-1}]

N_T = number of head of livestock species/category T in the region

Nex_T = annual N excretion rate per head of livestock category T [kg N $animal^{-1}$ yr^{-1}]

$MS_{T,S}$ = fraction of Nex for livestock category T in manure management system S

$EF_{3,S}$ = emission factor for direct N_2O emissions from manure management systems S in the region [kg N2 O-N kg^{-1} N]

S = manure management system

T = species/category of livestock

44/28 = conversion of N_2O-N to N_2O emissions (two N atoms per N_2O molecule)

Estimation of annual N excretion rates (Nex) as Equation 10.31 IPCC (2019). Annual N excretion rates should be determined for each livestock category as they vary greatly between livestock species and diets.

$$Nex_T = N_{intake(T)} \times (1 - N_{retention\_frac(T)}) \times 365$$

Where:

$Nex_{(T)}$ = annual N excretion rates, kg N $animal^{-1}$ yr^{-1}

$N_{intake(T)}$ = the daily N intake per head of animal of species/category T, kg N $animal^{-1}$ day^{-1} $N_{retention\_frac(T)}$ = fraction of daily N intake that is retained by animal of species/category T, dimensionless

365 = Number of days in a year.

Equation IPCC 10.31A (2019): $Nex_T = (N_{intake(T)} - N_{retention(T)}) \times 365$

Where:

$Nex_{(T)}$ = annual N excretion rates, kg N $animal^{-1}$ yr^{-1}

$N_{intake(T)}$ = the daily N intake per head of animal of species/category T, kg N $animal^{-1}$ day^{-1} $N_{retention(T)}$ = amount of daily N intake by head of animal of species/category T, that is retained by animal of species/category T, kg N $animal^{-1}$ day^{-1},

365 = Number of days in a year.

PIG PRODUCTION IN VIETNAM

Pig population in Vietnam

Pig production plays an important role in livestock production in Viet Nam. Pork accounts for the largest proportion (52.3%) of protein in Vietnamese meals (OECD, 2023). Pork is the most important source of protein for the Vietnamese population and the main ingredient of many dishes in its gastronomy. Possibly, for these reasons, Vietnam has positioned itself as the largest consumer of pork per capita in Southeast Asia.

Vietnam is one of the most important pork markets in the world. It is the second-largest pork producer in Asia, and the seventh worldwide. In turn, it is the largest per capita consumer of pork in Southeast Asia and the sixth in the world. However, Vietnam has had to face adverse situations such as the arrival of African swine fever diseases (ASF) or the Covid-19 pandemic in recent years. The pig population and herd characteristics in recently years are showed in Table 1.

Table 1. Pig population in Vietnam in recently years

Year	2022	2021	2020	2019	2018
Total (not including suckling piglets) (head)	28 800 000	23 327 648	22028091	19615526	28151948
Fattening pig (head)	-	20 047 333	18937643	17058342	24102605
Sow (head)	-	3 213 266	3025817	2499353	3974529
In which: Farrowing sow (head)	-	2 458 656	2275874	57831	-
Boars (head)	-	67 049	64631	42192969	74814
Suckling piglets (head)	-	4 374 777	3912390	3328822	-
Market hog (head)	-	47 892 659	46346028	2343092	49743746
Quantity of live market hog (ton)	-	4 174 255	4020105	18472	3816414
Piglets for roasted pigs (head)	-	1 956 138	1995269	19615526	2439399
Quantity of piglets for roasted pigs (ton)	-	16 342	16594	17058342	19073.8

Source: GSO (General Statistics Office), Vietnam 2023

The 2019 outbreak of African swine fever diseases (ASF) in the country caused dramatically decreased pig population, from around 28.1 million heads reducing to 19.6 million heads; recorded the lowest volume of pig production in the country within the observed timeline (Table 1). Thereafter, pig population has been recovered strongly since 2020 to 2022; from around 19.6 million up to around 28.8 million heads in 2022 (Table 1).

Farming system (different farm scales with specific number)

In 2017, Viet Nam has 11,737 commercial pig farms with 16.6 million pigs, 2,982 contracted farms with 3.9 million pigs, pig production chain (cooperative group) with 937 chains including 1.2 million pigs, and 2.5 million households (Pham Thanh Long, 2018).

Table 2. Pig farm scale in Viet Nam in year 2021

Items	Total	Farm scale (facilities)				
		Keeping from 1 to 9 animals	Keeping from 10 to 29 animals	Keeping from 30 to 99 animals	Keeping from 100 to 299 animals	Keeping more than 300 animals
Whole country	2050944	1710949	279346	49962	6380	4307
Red river delta	337197	252173	65767	15849	2274	1134
Northern midland and mountainous	828332	735832	82332	8899	872	397
North Central & South central coast	546723	472253	62458	10207	1003	802
Central highland	117739	99004	14452	3187	590	506
Southeast	42867	24158	12055	4495	857	1302
Mekong River Delta or Southwest	178086	127529	42282	7325	784	166

Source: GSO (General Statistics Office), Vietnam 2023

There were around 2.0 million pig production facilities in Viet Nam in 2021. In which, householders accounts 85.5% (1.71 millions), facilities keeping from 10 to 29 animals occupy 14.0%; and farms raising from 30 to 99 animals, 100 to 299 animals, and more than 300 animals only account 2.5, 0,3 and 0,2%, respectively (Table 2). Total numbers of pig facilities mainly locate in the Northern Midland and Mountainous and the North Central & South Central Coast regions, where there are some advantages for pig production such as large square areas of lands, low human density population, v.v. The Red River delta stands at the third largest number of pig production facilities region with the highest number of large pig farm (1134), accounting 26.3% of whole country (Table 2). At the farm scale, there are about 11.0% of model farms and 40% of mechanically ventilated farms (DPA, 2020).

CURRENT STATUS OF NUTRITION AND FEED FOR PIG IN VIETNAM

The relationship between diet composition and manure emission in pig

Nutrition is one of principle factors that influences GHG emissions from pig houses along with manure management and floor type (Philippe and Nicks, 2014; Aarnink and Verstegen, 2007). Numerous studies demonstrated the impact of diet composition on manure composition, properties and microbial ecology and thereby gas emission (Canh et al., 1998a, 1998b, 1998c; Kerr et al., 2006, 2018; Le et al., 2005; Mroz et al., 2000; Panetta et al., 2006; Trabue & Kerr, 2014, Clark et al., 2005; Shriver et al., 2003). Pig nutrition is assumed to affect both the emissions of CH_4 and N_2O especially in terms of N excretion and digestibility of feed organic matter (Dourmad et al., 2013). According to IPCC (2019), emission of N_2O is calculated based on N excretion and other specific emission factors regarding manure management. Also, the emission of CH_4 has been shown to influenced by diet crude protein (CP), in particular, a reduction of CH_4 emission was observed in pig fed with low CP in diet, that is better related to volatile fatty acids (VFA) content than to total C content (Misselbrook et al., 1998). Reducing N excretion from pigs and slurry VFA content by decreasing CP in diet has been previously established by Hobbs et al (1996). Otto et al. (2003) reported that the retention of dietary N was only ranging from 30-60% of the intake of the pigs. This observation is in line with other studies that CP is often fed in excess with the excess nutrients being excreted, about 40 to 60 % for dietary N (Peu et al., 2010; Kerr et al., 2020). The high density of pig population in combine with their protein-rich feeding synergically generate high gas emission. On the other hand, the emission of CH_4 from stored manure is likely to be influenced by dietary fiber content. According to IPCC (2019), emission of CH_4 is calculated based on volatile solids in excreta, considered as amount of organic matter excreted. Volatile solids excreted depend on the digestibility of feed organic matter and is mainly affected by dietary fiber content (Lee et al., 2022). This was illustrated by the study of Jarret et al. (2012) that higher volatile solids excreta and CH_4 emission per pig is observed in pigs treated with a high fiber diet when comparing with a conventional diet. Velthof et al. (2005) also showed that a decrease in the CP content reduced production of CH_4, while the increase of diet fiber content increases it. In general, two main dietary factors including crude protein level and fiber content are important to take into consideration for nutritional strategy proposed for the abatement of manure pollutant gas emissions. According to Jongbloed and Lenis (1993), the most substantial excretion of nitrogen, about 60-70% of total nitrogen excretion from pig farming originates from the growing-finishing pigs. Furthermore, the fattening period accounts for more than 70% of total emissions, while the gestation, lactation and weaning periods each contribute to about 10% of total emissions of GHG (Philippe and Nicks, 2014). It is to say the growing and fattening pigs should be the primary target of GHG inventory activities.

Current status of feed utilization and feeding standard for different type of pigs in Vietnam

Recommendations of nutritional requirement for pigs have been globally announced by NRC, INRA, ARC or DEGUSA, ect. However, research on nutritional requirements for pigs which are suitable for production conditions and pig breed system within the country is important. In Viet Nam, researches on nutrient requirement including metabolizable energy (ME), protein and amino acids of standardized ileal digestible basis (SID) for fattening pigs (Ninh Thi Len et al., 2011) and gilts (Tran Quoc Viet., 2014) have been implemented under Viet Nam production condition and the obtained results are beneficial references for nutritionists to establish diet formula for pigs. For the production of commercial feeds of pig, the Government establish the Vietnamese standard TCVN1547:2020 for animal feed stuffs-Compound feeds for pig that is compiled by the National Standards Technical Committee TCVN/TC/F17 Animal feed, appraisaled by Directorate for Standards, Metrology and Quality, and announced by Ministry of Science and Technology. The Vietnamese standard for animal feed stuffs TCVN1547:2020 is the recommendation for nutritionists to apply in practice, not obligatory regulation. The information in detail for feeding standard in compound feeds for pig as well as pig nutrient requirements by research in Viet Nam in comparison with NCR (2012) is provided in Table 3 (growing and fattening pigs) and Table 4 (sow, gilt and boar). Growing-fattening pigs are fed *ad libitum* and the estimated feed intake per day was shown in Table 3. Previous researches on nutrient requirement of growing and fattening pigs in Vietnam just indicated the requirement for amino acids in total basis (Tran Quoc Viet et al., 2001; Vu Thi Lan Phuong and Do Van Quang., 2001). Study of Ninh Thi Len et al. (2011) indicated the requirement for amino acids in Standard Ideal Digestible (SID) basis that is more applicable when utilizing different types of feed ingredients and closer to real nutritional need of the pigs specifically for two types of seasons Summer-Autumn and Winter-Spring under Viet Nam pig production condition. In general, the requirement for crude protein for growing and fattening pigs in all feeding periods obtained from Viet Nam's research is higher than NRC (2012), while ME requirement is lower than that of NRC (2012). One potential nutritional approach that has gained interest of researchers and can be used to improve the efficiency of N utilization in pigs and consequently to reduce N excretion is to improve the dietary amino acid balance along with the reduction of the required CP content of the diet by a combination of different protein sources and/or substitution of protein by the supplement of synthetic amino acids. This approach was shown to reduce the amount of N excreted in feces and urine and GHG emission (Osada et al., 2011). The SID amino acid requirement of pig under Vietnam production condition obtained will be important data base for future researches on this approach. Besides studies on nutrient requirement for growing-fattening pigs, chemical composition, total tract digestibility and energy values of several feedstuffs used for this pig type has also been published (Ninh Thi Len et al., 2010). These results are necessary for nutritionists to build up proper feeding formula for growing-fattening pigs to achieve a better agreement between nutritional supply and requirement of pigs that go along with the reduction of GHG emission.

The animal feed industry in Viet Nam has undergone fundamental changes, with a marked increase in the efficiency of livestock production. In the 1960s and 1970s, the whole country only had more than a dozen industrial feed production establishments with a negligible output. According to Department of Livestock Production (2022), the number of factories producing industrial animal feed has reached 290 in total in 2021 including foreign companies (33%) and local companies (67%). Total industrial feed production in 2021 reached 21.9 million tons with 12.2 million tons of pig feed accounting for 55.8% (Department of Livestock Production, 2022). It is implicated that industrial animal feed production is one of the most dynamic production sectors in the field of agriculture, which has a great influence on the development of the livestock industry. This is also illustrated by a survey of Alltech (2024) that Viet Nam is one of few countries with a dynamically developing animal feed industry in Asia which ranks 8th of the world output. Nutrient contents in diet for growing-fattening pigs in commercial feed in Viet Nam are shown in Table 5. The nutritional data of diets are collected from animal feed company with high production output. These preliminary data show that the CP level in diet for all feeding periods of commercial feed is higher than nutrient requirement in diet recommended by NRC (2012), TCVN1547:2020 as well as Viet Nam's research while the ME levels and fiber levels are not much in difference. In particular, the average CP levels in diet for different periods of growing-fattening pigs including less than 15kg, 15-25 kg, 25-50 kg and 50-finish in Viet Nam commercial feed are 19.8%, 18.4%, 17.5% and 16%, respectively. Soybean meal and soybean full fat are major feed ingredients for protein source, whilst popular ingredients for energy source are corn, wheat, rice bran, wheat bran, broken rice in almost Viet Nam commercial feed for pigs. In 2022, the animal feed industry had to spend nearly 2.7 billion USD to import corn and soybean (Department of Livestock Production, 2024). It is implicated the predominant use of these two basic feed ingredients in animal production in general and pig production in particular.

All information above gives the overall picture of the current status of feed utilization and feeding standard for different types of pigs in Vietnam. This is the basic background to design pig diets for determining CH_4 and N_2O emission factors. To have the experimental diets closed to the practical diets, the collection of pig diet samples from different ecological areas is necessary.

The calculation of DE in diet

According to IPCC 2019, the calculation of CH_4 emission factors following Tier 2 method is based on VS. The VS excretion rate can be estimated from feed intake levels with country specific production data. According to the study on nutrient requirement for growing-fattening pigs of Viet Nam’s research, Ninh Thi Len et al. (2011) reported that daily feed intake of growing-fattening pigs in two production period from 20-50kg and from 50 kg to finish under the condition of feeding *ad libitum* is 1.74kg and 2.46 kg in Summer-Autumn time and 1.93 kg and 2.7 kg in Winter-Spring time (Table 3).

The VS can be estimated based on Gross energy (GE) and Digestibility of the feed (%) that can be derived from Digestible energy (DE). According to Noblet and Perez. (1993), the DE value can be predicted from dietary chemical composition by the equation presented below:

$$\mathbf{DE = 1161 + (0.749 \times GE) - (4.3 \times Ash) - (4.1 \times NDF)}$$

NDF: Neutral detergent fiber (g/kg dry matter)

In addition, the DE and ME values and digestibility of several feed stuffs used for growing-fattening pigs in Viet Nam were identified in study of Ninh Thi Len et al. (2010). Specifically, the DE and ME values (kcal/kg dry matter) of maize, cassava root meal, broken rice, rice bran 10% CP, rice bran 7.5% CP, soybean meal and fish meal are 3882-3779, 3630-3561, 3965-3870, 2383-2294, 1811-1733, 3887-3681, 3694-3483, respectively. From the obtained results, this study demonstrated the linear relationship between DE and ME, and between DE and dietary chemical compositions with the coefficient of determination $R^2 > 0.95$ illustrated by equations presented in Table 6. These results are beneficial reference database for the calculation of emission factor for CH_4 emission inventory.

Table 3. Feeding standard and nutrient requirement of fattening pigs in Viet Nam

Item	**TCVN1547:2020** *Vietnam Standard of compound feed*				**NCR (2012)** *Nutrient requirements (90% dry matter)*				**Vietnam's research[a]** *Nutrient requirements (88% dry matter)*	
	Weaning	**Starter**	**Grower**	**Finisher**	**5-25 kg BW**	**25-50 kg BW**	**50-75 kg BW**	**75-135 kg BW**	**20-50kg BW**	**50 kg BW-finish**
ME content of diet (kcal/kg)	3200	3000	2900	2900	3383	3300	3300	3300	3050	2950
Crude Protein (%)	18.0	17.0	14.0	13.0	15.7	13.8	12.1	10.4	16	13
Total Lysine (%)	1.1	1.0	0.8	0.6	1.45	1.12	0.97	0.77	-	-
Total Methionine and cysteine (%)	0.6	0.5	0.4	0.3	0.87	0.65	0.57	0.46	-	-
Total Threonine (%)	0.66	0.6	0.5	0.45	0.95	0.72	0.64	0.52	-	-
Crude fiber (%)	4.0	5.0	7.0	7.0	-	-	-	-	-	-
Crude ash (%)	7.0	7.0	8.0	8.0	-	-	-	-	-	-
Calcium (%)	0.7-1.0	0.6-0.95	0.5-0.9	0.5-0.9	0.78	0.66	0.59	0.49	-	-
Phosphorus (%)	0.65-1.0	0.6-1.0	0.5-0.9	0.4-0.9	0.65	0.56	0.52	0.45	-	-
SID lysine (%)	-	-	-	-	1.36	0.98	0.85	0.67	0.89 & 0.98*	0.74 & 0.83*
SID methionine and cysteine (%)	-	-	-	-	0.75	0.55	0.48	0.39	0.53 & 0.64*	0.44 & 0.50*
SID threonine (%)	-	-	-	-	0.8	0.59	0.52	0.43	0.60 & 0.71*	0.50 & 0.56*
SID tryptophan (%)	-	-	-	-	0.22	0.17	0.15	0.12	0.16 & 0.18*	0.13 & 0.15*
Estimate food intake (kg/day)	-	-	-	-	0.575**	1.582**	2.229**	2.784**	1.74 & 1.93*	2.46 & 2.7*

** Summer Autumn & Winter Spring; [a] Source data: Ninh Thi Len et al. (2011); ** Feed intake + feed wastage (assume 5% feed wastage); ME: metabolizable energy; SID: standardized ileal digestible; BW: body weight*

Table 4. Feeding standard and nutrient requirement of gilts, lactating sows, gestating sows and male pigs in Viet Nam

Item	**TCVN1547:2020** ***Vietnam Standard of compound feed***			**NCR (2012)** ***Nutrient requirements (90% dry matter)***				**Vietnam's research[a]** ***Nutrient requirements (90% dry matter)***	
	Gestating	**Lactating**	**Boar**	**Gestating**	**Lactating**	**Gilt***	**Entire males****	**Gilt *(50-80kg)***	**Gilt *(80kg to breeding)***
ME content of diet (kcal/kg)	2800	3000	2950	3300	3300	3300	3300	3265	3265
Crude Protein (%)	13.0	15.0	15.0	7.1-13.4	11.8-13.9	14.1-11.8	14.2-12.13	16.3	13.8
Total Lysine (%)	0.5	0.8	0.8	0.39-0.8	0.83-1.0	0.99-0.81	1.01-0.85	-	-
Total Methionine and cysteine (%)	0.35	0.40	0.40	0.29-0.54	0.46-0.55	0.58-0.49	0.59-0.50	-	-
Total Threonine (%)	0.50	0.63	0.50	0.34-0.58	0.56-0.67	0.65-0.55	0.66-0.56	-	-
Crude fiber (%)	9.0	7.0	6.0	-	-	-	-	-	-
Crude ash (%)	8.0	8.0	8.0	-	-	-	-	-	-
Calcium (%)	0.75-1.05	0.75-1.05	0.75-1.0	0.43-0.83	0.6-0.8	0.61-0.53	0.64-0.57	-	-
Phosphorus (%)	0.6-0.9	0.6-0.9	0.6-0.9	0.38-0.62	0.54-0.67	0.53-0.47	0.55-0.5	-	-
SID lysine (%)	-	-	-	0.32-0.69	0.72-0.84	0.87-0.7	0.88-0.73	0.71	0.55
SID methionine and cysteine (%)	-	-	-	0.23-0.4	0.38-0.47	0.49-0.41	0.50-0.42	0.42	0.33
SID threonine (%)	-	-	-	0.27-0.43	0.46-0.55	0.53-0.45	0.54-0.46	0.46	0.37
Estimate food intake (kg/day)	-	-	-	2.08-2.61***	5.93-6.61***	2.12-2.68***	2.06-2.75***	2.59	2.87

[a] *Source data: Tran Quoc Viet et al. (2014);* * *Gilt from 50-75kg and 75-135kg body weight;* ** *Entire males from 50-75kg and 75-135kg body weight;* *** *Feed intake + feed wastage (assume 5% feed wastage); ME: metabolizable energy; SID: standardized ileal digestible*

Table 5. Nutrient contents in diet for growing-fattening pigs in commercial feed in Viet Nam

	Company Name	Body Weight (kg)	CP min (%)	ME (Kcal/ kg)	Fiber max (%)	Ca (%)	P (%)	Lysine total min (%)	Met + Cys min (%)
Foreign company	CP Feed	< 15	21	3300	3,5	0,6 - 1,2	0,4 - 0,9	1,3	0,7
		15 - 25	19	3300	5	0,5 - 1,2	0,4 - 0,9	1,1	0,6
		25-60	18	3150	6	0,5 - 1,2	0,5 - 1,0	1,0	0,6
		60-80	17	3050	6	0,5 - 1,2	0,5 - 1,0	0,9	0,5
		80 - finish	17	3000	8	0,5 - 1,2	0,5 - 1,0	0,9	0,6
	New Hope	< 15	20	3400	4	0,5 - 1,2	0,5 - 1,0	1,4	0,75
		15 - 25	18,5	3250	5	0,6 - 1,2	0,5 - 1,0	1,2	0,65
		25 - 60	16,5	3150	5	0,7 - 1,3	0,6 - 1,2	1	0,6
		60 - finish	14,5	2950	8	0,6 - 1,2	0,5 - 1,2	0,7	0,45
	Cargill	15-25	18	3000	7	0,5 - 1,8	0,4 - 1,2	0,85	0,45
		20 -40	17	2900	7	0,5 - 0,18	0,4 - 0,15	0,8	0,5
	De Heus	< 15	19	3350	3	0,4 - 1,0	0,45 - 0,8	1,2	0,7
		15 - 22	18	3150	5,5	0,6 - 1,25	0,5 - 0,8	1,0	0,5
		22 - 40	18	3120	5,5	0,6 - 1,25	0,5 - 0,8	1,0	0,5
		40 - 100	17	3000	5,5	0,6 - 1,25	0,5 - 0,8	1,0	0,5
	SUNJIN VINA	10 - 25	18	3190	6	0,4 - 1,2	0,4 - 1,0	1,2	0,7
		25 - 50	17	3150	6	0,4 - 1,2	0,4 - 1,0	1,0	0,6
		50 - finish	15	3100	10	0,4 - 1,2	0,4 - 1,0	0,76	0,5
Join venture	Proconco	9 - 20	19	3300	6	0,35 - 1,7	0,5 - 1,7	1,05	0,57
		20 - 50	18	3300	6	0,35 - 1,7	0,5 - 1,7	1,05	0,57
		50 - finish	15	3300	6	0,35 - 1,7	0,5 - 1,7	1,05	0,57

	Company Name	Body Weight (kg)	CP min (%)	ME (Kcal/kg)	Fiber max (%)	Ca (%)	P (%)	Lysine total min (%)	Met + Cys min (%)
Local company	Hoa Phat	< 15	20	3300	5	0,5 - 1,5	0,4 - 1,4	1,2	0,7
		12 - 25	19	3200	5	0,5 - 1,5	0,4 - 1,4	1,1	0,6
		25 - 50	18	3000	7,5	0,5 - 1,5	0,4 - 1,4	0,95	0,55
		50 - finish	17,5	3050	8	0,5 - 1,5	0,4 - 1,4	0,8	0,45
	VINA	< 20	20	3200	5	0,7 - 1,2	0,4 - 1,2	1,2	0,6
		25 - 50	18,5	3150	6	0,7 - 1,2	0,4 - 1,2	1,1	0,6
		50 - 80	17	3050	7	0,6 - 1,2	0,4 - 1,2	0,95	0,5
		80 - finish	17	3000	8	0,6 - 1,2	0,4 - 1,2	0,95	0,5
	US Feed	< 12	20	3200	5	0,7 - 1,2	0,4 - 1,2	1,15	0,63
		12 - 25	19	3150	6	0,6 - 1,4	0,3 - 1,2	1,08	0,6
		25 - 50	18	3100	6	0,6 - 1,2	0,3 - 1,2	1	0,5
		50 - finish	17	3050	7	0,6 - 1,2	0,3 - 1,2	1	0,5
	Dabaco	< 15	19,5	3300	3,7	0,9 - 1,1	0,8	1,1	0,6
		15 - 30	18	3000	5	0,8 - 1,0	0,7	1	0,6
		30 - 60	16	3000	7,5	0,9 - 1,1	0,65	0,8	0,5
		60 - finish	14	3000	7,2	0,9 - 1,1	0,75	0,8	0,4

CP: Crude protein; ME: Metabolizable energy

Table 6. Equations illustrated the relationship between energy (kcal/kg dry matter) and dietary chemical compositions (g/kg dry matter) (Compiled from Ninh Thi Len et al., 2010)

Equations	R^2	***P* value**
DE = 4000 + 1.52 CP – 9.7 CF	0.99	0.001
DE = 3926 + 3.42 CP + 7.97 EE – 1.95NDF – 16.7Ash	0.97	0.017
ME = -53.5 + 0.998 DE – 0.292 CP	1	0.001

DE: Digestible energy; ME: Metabolizable energy; CP: crude protein; CF: crude fiber; EE: ether extract; NDF: Neutral detergent fiber

MANURE MANAGEMENT IN PIG PRODUCTION

Situation of pig manure generation in Vietnam

Manure is made of a combination of feces and urine with a ratio of 60% feces and 40% urine. There are three types of pig manure: slurry, liquid, and solid, in which slurry is a combination of urine, faeces, and water; solid consists of faeces and litter scraped from the floor, and liquid is characterized by collectively joined urine, faeces remaining from scraping and cleaning water (Vu et al., 2007). The quantity of manure is influenced by the animal's feed intake and increases from piglets to slaughter pig weight. Recently, in Vietnam, the pig farming industry has grown rapidly, resulting in more economic efficiency, higher labor productivity, and higher farmer revenue, however, it also has a negative impact on the environment's quality since large amounts of solid, liquid, and gaseous wastes are generated that are not properly treated. Moreover, the shift from traditional extensive livestock farming to intensive animal production is also generating growing volumes of animal waste.

According to the calculation of Trinh (2021), based on the average number of pig heads for 2016-2020, the total amount of manure from livestock annually was 71.87 million tons of solid waste and 76.44 million tons of liquid waste per year. Specifically, in the report of the Ministry of Natural Resources and Environment of Vietnam on the status of the National Environment from 2016-2020, every year, the amount of solid waste from pig production across the country was about 18-21 million tons, which accounted for 34 % and took second place to cattle production (Figure 1) (MONRE, 2021; DLP, 2023). However, pig farming is considered the largest source of liquid waste, with an average of 84% volume of slurry waste generated during this period (Tong Xuan Chinh, 2015; Vu Chi Cuong et al, 2013; DLP, 2023). The African swine fever outbreak occurred in 2019, resulting in the total number of pig heads being reduced rapidly; however, by 2020, African swine fever had been well controlled, and pig production is gradually recovering, which led to an increasing tendency in the volume of manure in the following years. Figure 1 showed the amount of waste generated in pig farming, which indicated the total volume of solid and liquid waste reached a peak of 21.12 million tons and 254.94 million tons in 2021, respectively. Generally, about 75 percent of the manure is generated by smallholder farms, and the remainder comes from commercial farms (Cassou and Cao 2017).

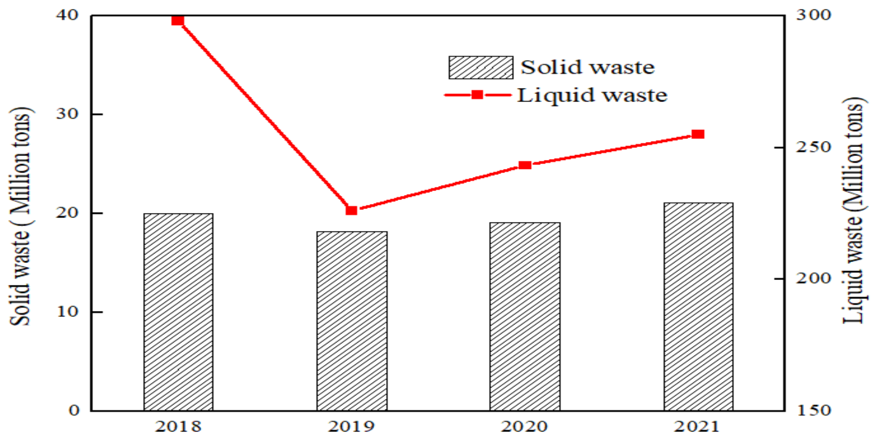

Figure 1. The amount of waste generated in pig farming. (Source: MONRE, 2021)

Basically, the chemical composition of pig manure depends on many factors, including the type and age of animals and a feeding method. Table 7 shows the difference in characteristics and amount of manure generated from different pig types, in which fattening pigs discharged the most significant volume of waste, corresponding to 3-5 kg/head/day, and the most difficult source to collect.

Table 7. Characteristics of pig manure from different types

Parameters	**Unit**	**Type of pig production**		
		Fattening pigs	**Sow**	**Piglet**
pH	-	6.73	6.55	6.41
TSS	mg/l	4.735	4,694	2.571
T-N	mg/l	106.03	67.16	65.03
NO3-	mg/l	4.21	3.13	2.94
NH4+	mg/l	97.72	65.81	73.68
T-P	mg/l	62.33	48.71	69.79
Total volume (*)	(kg/head/day)	3-5kg	0.94-1.79	0.6-1

*Source: (Thị et al., 2015), * (Bui Huu Doan et al., 2011)*

Current status of pig manure management

The manure management situation in Vietnam depends on the scale, areas…The study of Tua (2015) and Cassou et al. (2017) confirmed that 35.5% of pig farms have stored pig waste without treatment, whereas 40%- 42% of pig waste was discharged directly into the environment without treatment (Cassou & Cao, 2017; Tua, 2015). In all regions, smallholder farms discharge a larger volume of manure directly to the environment than intensive farms. Moreover, there are significant differences in the amount of waste contamination between regions as well as among provinces, which are partially reflected in the changes in livestock density (Table 8). In the Red River Delta, the region in Vietnam with the highest concentration of pigs, the amount of manure treated from extensive and intensive farming systems was 39% and 82% correspondingly (DLP-MARD, 2015). A survey was conducted in Ha Hoa district, Phu Tho Province (which belongs to the North Mountainous and Midland) to assess manure management practices and results showed that in pig farming households with less than 30 pigs, the ratio of waste treatment systems was 16%, partial systems were 46%, and no systems were present in 38%. By contrast, in households with a scale of more than 30 pigs, the ratio of waste treatment systems was 76%, and partial systems and no systems were 21% and 3%, respectively (Pham et al., 2018). The findings of a study in Binh Dinh province showed that 90% of farmers have no controlled and 51% of households have waste treatment systems (biogas), however, these systems are not effective (Dang & To, 2023). Another research was conducted in 22 pig farms in the Gia Lam district, Hanoi (Nguyen Thi Thuy Dung et al., 2015). The findings revealed that pig farms have used waste treatment techniques including composting or biogas; however, a significant amount of the waste was released into the environment without full treatment (Thị et al., 2015).

Table 8. The volume of pig waste discharged to the environment by the regions in Vietnam

Farm types / **Regions**	**RRD**	**NMM**	**NSCC**	**CH**	**SE**	**MRD**
Smallholder	2,469	2,993	1,901	334	554	1,140
Intensive	392	181	190	48	185	253

**RRD: Red River Delta, NMM: North Mountainous and Midland, NSCC: North and South Central Coast, CH: Central Highland, SE: Southeast, MRD: Mekong River Delta*

Composting, biogas, feeding fish, selling, and being used as fertilizer for plants are popular piggery waste treatment methods applied in Vietnam (Table 9). The proportion of applications for each method often depends on many factors such as farm scale, location, housing systems, etc. The results of Huong et al. showed that in intensive pig farms in several provinces, large farms deployed well in implementing waste treatment measures, with over 98% of farms applying biogas systems and 59% of farms separating or partly separating solid and liquid waste before treatment. Furthermore, about a third of the farms surveyed have bio-ponds for additional wastewater treatment following biogas tanks, and 28% of the farms have fishponds for wastewater treatment (N.T.H.Giang et al., 2021). 30 % of commercial farms reported using a separated method (solid and liquid wastes), whereas 60% of farms treat wastes as a mixture (Cassou & Cao, 2017). Composting is considered the common method in solid waste treatment, especially in smallholder farms. Solid wastes are collected and composted with rice straw and used as fertilizer for crops. On the other hand, biogas digesters are considered the most applicable solution for piggery liquid treatment. About 53% of pig farms in the south, 60% in the north, and 42% in the central regions were reported to use biogas digesters for waste treatment (Vu, 2014). According to Huong et al. (2021), biogas plants are preferred by small-scale farms by 78.8 % because of their low construction costs and less land use. The result of 120 surveyed households' pig farming in Ha Nam province showed that 70 % of these farms used biogas systems as the main method to treat swine wastewater (Pham et al., 2020). The concentration of pollutants in swine wastewater treatment after using biogas digestion was reduced significantly; however, compared to the Vietnamese National Technical Regulation on the Effluent of Livestock, the concentration of those was 2-3 times higher. Some reasons can be explained for the situation that the volume of the biogas tank was smaller than the volume of the influent, which leads to a decrease in the treatment efficiency of the biogas tank. According to Nguyen The Hinh (2017), on average, in the Northern, livestock farmers utilized 30–40 liters of water/ pig/day during the summer time, with a higher frequency of pen cleaning compared to winter.

Table 9. Waste treatment methods in intensive farms in Vietnam

Unit: %

Methods	**Provinces**			
	Hanoi	**Thai Binh**	**Ha Tinh**	**Dong Nai**
Solid/liquid separation	36.4	100	60	43
Compost	21.2	40	43.3	26.7
Biogas	78.8	96	100	100
Bio-pond	15	13	90	34
Fishpond	24	30	46	13

Source:N.T.H.Giang et al. (2021)

Situation of GHG emissions from pig production

Fundamentally, in pigs, enteric emissions account for only 11% of GHG emissions, whilst manure produces 89%: 69% of which is methane 20% is nitrous oxide, in which NH_3 and N_2O are produced from livestock waste and are closely related to the manure management system. N_2O is known as a greenhouse gas (GHGs) with long environmental retention times. In contrast, NH_3 has a relatively short atmospheric lifetime, only a few hours to a few days. CH_4 is a known gas belonging to the group of GHGs and is a photochemical agent in the troposphere and stratosphere (Yamaji et al., 2004). Recently, due to the growing demand for consumption and export, the number of pig heads has grown strongly, and the greenhouse gas emissions of pig production have also increased rapidly. Therefore, pig production is one of the important contributors to the atmospheric component that greatly influences climate change and local, national, and global environmental quality.

In Vietnam, according to data from the Department of Livestock Production in 2023, the amount of CO_2 tended to increase; especially, the volume of CO_2 raised sharply during the period 2016-2020 and reached 30.94 million tons of CO_2 equivalent at the end of the period (Figure 2) (DLP, 2023). GHG emissions also depend on the region, where the density of livestock and livestock production methods are different. The CO_2 emission was the highest from pig farming in the Red River Delta (Vu, 2013). In addition, the study of Truong et al. confirmed that pig farming in Northern Vietnam contributes significantly to the increase in greenhouse gases and NH_3 emissions, and it shows an upward trend in these emissions in the future (Truong et al., 2018). As reported data from the Vietnam report on National GHG Inventory for 2016, when comparing the total CH_4 emissions between species in manure management for 2016, the biggest emission subsector was swine, with 36.96 thousand tons of CH_4, and pig farming in North and Central regions accounted for a higher proportion than others (MONRE, 2020). However, the findings of Vu's study, NH_3 and H_2S gas concentrations in air emissions from pig farms in the North region were 7–18 times and 5–50 times higher than the allowed levels, respectively (Vu, 2014). Moreover, as reported by Dung et al, the structure and design of pig houses are key factors in the intensification of CO_2, CH_4, and N_2O emissions; housing systems with slatted floors made it simple to accumulate manure in the form of liquid or slurry (Dung et al., 2020).

Manure management is one of the agricultural mitigation components included in the

Nationally Determined Contribution (NDC) framework that the Vietnamese government plans to implement between 2020 and 2030. Besides, Vietnam has also signed a decision approving an action plan on reducing methane emissions to 2030 to cut methane emissions by at least 30% from 2020 at the UN climate change COP26. Therefore, there are several options available to minimize GHG emissions that should be prioritized at this stage.

Composting, anaerobic digestion technology from biogas digesters, or adding crop residues or biomaterials (such as charcoal or effective microorganisms (EMs)) to manure are common methods to reduce environmental problems from pig manure. Among them, biogas digesters are intriguing due to their dual functionality of treating waste and creating electricity. However, according to Dung et al., biogas digesters are currently overwhelmed, and the quality of manure decomposition is subpar because of the high pig density. Pig waste inside and outside of biogas digesters emits CO_2 and CH_4 at rates ($mg.m^{-2}.h^{-1}$) that are at least two times higher than those permitted by the Vietnam National Technical Regulation on Ambient Air Quality, and the GHG emission rate does not significantly differ between smallholder and industrial-scale farms in surveyed provinces (Dung et al., 2020). Therefore, in order to mitigate GHG emissions in pig production, further research needs to be invested in in the future.

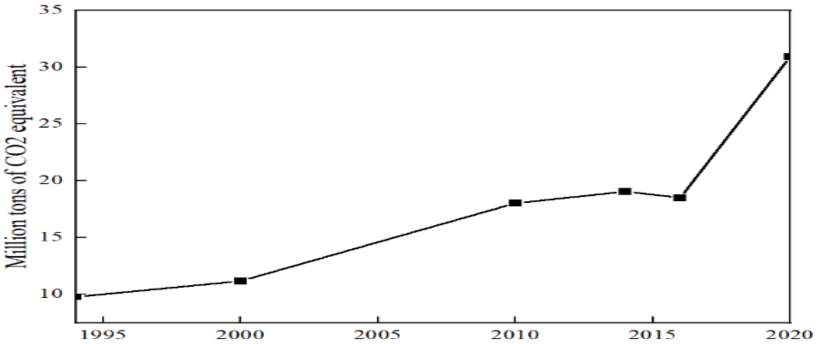

Figure 2. GHG emissions from livestock in the period 1994-2000 (million tons of CO_2-eq) (Source: DLP, 2023)

CONSTRAINS AND SUGGESTIONS

In Vietnam, some studies relating to GHG emissions in pig production are most concerned with mitigation solutions, there are no studies on tier 2 CH4 and N_2O emission factors from manure management in pig production. Thus, it is necessary to determine tier 2 CH4 and N_2O emission factors for improving the GHG inventory in Vietnam. The barriers in accessing tier 2 inventory are mainly the lack of information on the feed nutritional compositions and GE intake at different pig stages in different regions as well as types of manure management. In addition, methodology and methane emission measurement equipment are also limited.

Conflict of interest

The authors declare that there is no conflict of interest.

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