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GREENHOUSE GASES EMISSIONS FROM PIG HUSBANDRY: A CASE STUDY IN BAC GIANG PROVINCE, VIETNAM

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ABSTRACT

Recently, greenhouse gas emissions (GHG) have become a major concern. Consequently, most countries are focusing on the estimation and development of solutions for specific sectors. This study aimed to evaluate the current status of greenhouse gas (GHG) emissions from pig farming in Viet Yen district, Bac Giang province, Vietnam. The study was conducted from January 2022 to December 2023. The methodology used for estimating emitted GHGs is based on the Intergovernmental Panel on Climate Change (IPCC) guidelines. The GHGs including NH_4, N_2O, and NH_3 were estimated at farm and household scales. The field survey results indicate that the farm size consists of 2560 ± 550 pigs whereas the household consists of 135 ± 29 pigs. The estimated CH_4 generation per pig is 0.012 ± 0.001 tons/year for large-scale farms and 0.000104 ± 0.00002 tons/year for small-scale farms and households. The inventory revealed that the total energy used in pig production is approximately 102.27 tCO_2/month, equivalent to 0.00189 tCO_2/head/month. The digestion process of swine feed emitted about 127.18 tCO_2/month, equivalent to 0.0023 tCO_2/head/month. Considering the current integrated pig manure management system, the average amount of GHGs released into the atmosphere from manure is about 899.09 tCO_2/month. The average emission for integrated waste management methods is approximately 0.2001 tCO_2/head/year. This inventory data is crucial to supporting environmental protection strategy in pig waste management. Based on the current status of livestock production and greenhouse gas emissions, it is recommended to propose waste management policies that include collecting, classifying, and reusing manure and by-products to minimize greenhouse gas emissions.

Key words: circular economy, greenhouse gases, pig production, emission inventory, waste management

INTRODUCTION

Pig husbandry contributes to greenhouse gas emissions mainly through the anaerobic digestion of synthetic waste. The high-organic wastewater generated from pig raising and feeding is a significant factor in environmental pollution due to release of toxic gases and greenhouse gases which include, ammonia (NH_3), hydrogen sulfide (H_2S), dinitrogen monoxide (N_2O), methane (CH_4) and carbon dioxide (CO_2). It was reported that integrated manure management systems have been responsible for approximately 18% of the total global greenhouse gas emissions from the livestock industry, with a particular impact from pig raising (Conor et al. 2017). Among these gases, CH_4 and CO_2 are the most significant. Pig manure, characterized by its high content of total nitrogen, total carbon, and total solids, contributes to the emissions of CH_4 and CO_2 (Xie et al. 2012).

CH_4 is primarily generated through the fermentation of feed in the rumen of ruminant animals, including pigs (Diem et al. 2011; Hung and Lien 2014; Thuan et al. 2017). Unlike ruminants, pigs have a single stomach, resulting in feces with a higher concentration of biodegradable carbon (Amon et al. 2007). Therefore, pig manure is considered the main source of CH_4 emissions, particularly when treated under anaerobic conditions, such as in biogas tanks. In this process, acid-producing bacteria convert the available carbon into acetate, hydrogen, and CO_2 in the initial stage of transformation. These products are then digested by methanogenic archaea, which specialize in the production of CH_4 (Tchobanoglous et al. 2002).

Inventory is a highly effective tool for estimating GHG emissions from various sources such as energy consumption, transportation, agriculture cultivation, and waste treatment. This approach has been recognized as both economically efficient and scientifically reliable (Thuan et al. 2017). In Vietnam, the Law on Environmental Protection has incorporated GHG emissions inventory, including greenhouse gas inventory, as a part of GHG emission reduction efforts in Article 91 (Vietnamese Environmental Law 2020). However, the steps involved in implementing GHG inventory, including data collection, information synthesis, and data processing, are still lacking standardization and synchronization. This study focused on analyzing the total emissions and greenhouse gases (NH_3, N_2O, CH_4) from pig-raising activities, specifically tailored to match the actual conditions of the survey area. The selected area for fieldwork and conducting the GHG inventory is Viet Yen District, Bac Giang Province. The study also incorporates the process of inventorying livestock production data in 2021, including herd quantity, distribution of pig types in the area, households engaged in pig farming, evaluation of management practices, and calculation of the total amount of the aforementioned gases.

The circular economy approach is commonly used in livestock farming in developing countries, including Vietnam, to manage solid waste. This approach proved to be relatively effective, thanks to waste auditing techniques that calculate inputs and outputs. It was found that the average nitrogen and phosphorus use efficiency in animal waste was 28% (Wei et al. 2016). Waste and manure were utilized for biogas production (35%), used directly as fertilizer for plants (61.06%), used as earthworm feedstuff (3.06%), and accounted for 0.01% in fishing (Hen et al. 2021). In our previous study, it was found that earthworm compost has a higher nutritional content compared to fresh cow manure, with nitrogen content fluctuating around 0.49% (Cong and Hang 2019). Earthworm raising significantly contributes to waste treatment and odor control in livestock farming. However, the circular economy approach has limitations in terms of greenhouse gas control. Auditing techniques are unable to calculate greenhouse gas emissions. Therefore, conducting a greenhouse gas inventory could potentially be a feasible contribution.

Viet Yen District is located in the Southwest midland of Bac Giang Province. It is one of the two main pig farming areas in Bac Giang province, accounting for 13.3% of the province's total herd and contributing about 0.48% of Vietnam's total herd by 2020 (Department of Bac Giang Statistics 2020). Pig farming is primarily conducted by households and some large-scale farms. Waste management in these areas is mainly done through biogas construction and direct discharge into the environment. In this context, the inclusion of GHG emissions inventory data is essential for general statistical data on environmental quality assessment in the locality. This data will enable local authorities to propose an appropriate Environmental Protection Plan (EPP). Based on this, the study conducted an inventory of GHG emissions in 60 farms and households in the selected area. The GHG inventory data from farms will be used for annual EPPs. This data could likewise be used to encourage households to adopt better husbandry practices aimed at reducing emissions at the source.

RESEARCH METHODOLOGY

Study area. Viet Yen district is situated along the Cau River, approximately 25 km from Bac Giang city and 60 km from the center of Hanoi (Fig. 1). The total natural area of this district is 171.01 km², with a population of 219,089 people as of 2020. The population density reaches 1,281 people/km². Viet Yen district focuses on the development of high-tech agriculture, integrating farming and breeding in bio-safe farms. The outsourcing model for pig raising is still quite prevalent in this area (Hien 2013)). In 2019, pig farms in Viet Yen district aimed to raise high-quality breeding pigs according to organic standards, with a target of 89,600 pig heads in total (People's Committee of Viet Yen District 2022). However, the waste generated, including emissions from farms and households, has not been adequately treated and utilized, resulting in resource waste and environmental pollution (Ha et al. 2020).

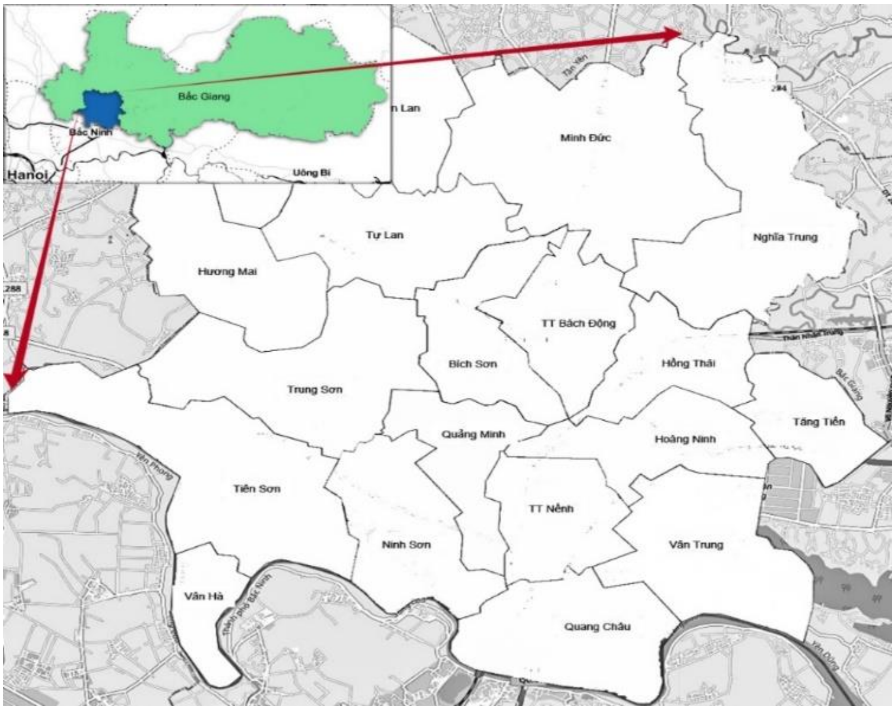

Figure 1. Location of Viet Yen District, Bac Giang Province

Data collection. Data were collected using structured questionnaires. The data on pig production included farm area, number of pigs, type of pig growing periods, manure and solid waste generation at household and farm scales. For pig farms, interviews were conducted with staff in charge of pig farm management. On the household level, either male or female householders were interviewed. A total of 47 staff members from 47 different farms, and 13 householders from 13 different households, were interviewed. All interviewees were contacted through Viet Yen authorities to arrange face-to-face interviews. Priority was given to those with preliminary or advanced knowledge of GHG emissions in their livestock farming. The general information on livestock production and its development strategies at the provincial and district were collected at the district people committee. The study was conducted from January 2022 to December 2023.

The sample size for the structured interview was calculated using the Yamane formula with a 95% confidence interval (Israel 2009).

$$n = \frac{N}{1+N_e^2} \quad (1)$$

where, n: number of samples to collect, N: total number of samples, *e*: expected error

With an expected error of 10% and the total number of pig-raising establishments in Viet Yen district was 142, including 47 farm - scales and 95 household - scales, the sample size was determined to be 58 for formula (1). To increase the reliability of data processing as well as the accuracy of the study, the sample size was selected as 60.

Emissions estimation. To calculate the amount of emissions generated, the general formula (2) used in this study is (IPCC 2006):

$$E = N_i \times EF_i \quad (2)$$

where: E: The amount of emissions *(kg/year);* N_i: number of pigs *(head);* EF: emission coefficient* *(kg/head/year).*

Greenhouse gas emissions estimation. This study applied the methodology of the Intergovernmental Panel on Climate Change (IPCC) to calculate GHG emissions from pig production and the wastes generated (IPCC 2006). The general formula for the calculation of CO_2 emission is indicated as Equation 3. The greenhouse gas emission estimation for electricity use (Equation 4), feed digestion (Equation 5), calculating the coefficient of greenhouse gas emissions from the digestion of feed by pigs (Equation 6).

$$CO_{2(emission)} = N \times EF \quad (3)$$

Where: $CO_{2\ (emission)}$: greenhouse gas emissions *(tCO_2);* N: number of pigs *(head);* EF: emission coefficient *(tCO_2/head).*

Greenhouse gas emissions from electricity use

$$CO_{2\ (1)} = M_1 \times EF_1 \quad (4)$$

Where: $CO_{2\ (1)}$: Amount of greenhouse gases generated from electricity use *(tCO_2/month);* M_1: Amount of power consumed *(kWh/month);* EF_1: Emission coefficient for Vietnam's electricity grid is equal to 0.8458 in 2019 *(tCO_2/MWh)* (Department of Climate Change 2021).

Greenhouse gas emissions from pig's feed digestion

$$CO_{2\ (2)} = \sum \frac{EF_{2T} \times N_T \times GWP_{CH_4}}{1000} \quad (5)$$

Where: $CO_{2\ (2)}$: GHG emissions from pig feed digestion *(tCO_2/month);* EF_{2T}: CH4 emission factor of pigs that belong to group T *(tCH_4/head/month). Note:* Groups T include 1: mating boars, 2: sows (gilts), 3: pregnant sows, 4: nursing sows, 5: suckling piglets, 6: weaning piglets, 7: post-weaning piglets, 8: mature swine)*;* N_T: Number of pigs of group T *(head);* GWP_{CH4}: The 100-year global warming potential of CH_4 compared to CO_2 is equal to 23.

Calculation of coefficient of greenhouse gas emissions

$$EF_{2.T} = \frac{GE_T \times \frac{Y_m}{100} \times 30}{55.65} \quad (6)$$

where: GE_T: Crude energy input in the day of pigs of group T *(MJ/head/day);* Ym: Methane conversion factor, in this case, it is 0.6 for pigs.

Calculation of raw energy intake per day

$$GE_T = m_{feed} \times MJGE/kg_{feed} \quad (7)$$

Where: m_{feed}: the amount of food taken per day *(kg/day);* $MJGE/kg_{feed}$: total crude energy in 1 kg of food taken in 1 day.

Calculation of greenhouse gas emissions from pig manure management

$$CO_{2\,(3)} = EF_{3T} \times N_T \times GWP_{CH4} \quad (8)$$

Where, $CO_{2\,(3)}$: GHG emissions from pig manure management system *(tCO_2/month);* EF_{3T}: Monthly methane emission factor from pig manure group T *(tCH_4/head/month);* N_T: Number of pigs in group T.

RESULTS AND DISCUSSION

Pig production characteristics. The total number of pigs in the surveyed breeding facilities is about 53,905 heads which includes the groups mentioned above (6,5% of the total number of pigs in Bac Giang province in 2020: 830,700 heads) (GSO 2020). Farms and households used electricity and gas as the main energy sources for pig husbandry. The estimated total electricity usage for 60 facilities is 120920 kWh/month. Crude Energy (GE) is different among different pig production periods (Table 1). The sows needed the largest source of crude energy (72.63 ± 2.43 MJ/head/day). The suckling piglets needed the least crude energy (0.67 ± 0.06 MJ/head/day). Mature swine had crude energy consumption ranging from 30 to 45 MJ/head/day (Fig. 1). The amount of food to be fed therefore also varied with the required energy requirements. For pregnant sows, the amount of feed and energy required was constantly changing, especially in the calving period when fiber was always added to the diet (Phuong and Gia 2017).

Table 1. Current status of pig husbandry in Viet Yen District.

Pig production period	Number (head)	MJGE/Kg	mfeed (kg/head/day)	GE (MJ/head/day)
Mating boars	19	17.58 ± 0.54	1.65 ± 0.26	28.87 ± 0.88
Sows (gilts)	2826	16.04 ± 0.57	2.06 ± 0.21	33.14 ± 1.15
Pregnant sows	2101	15.66 ± 0.56	2.76 ± 0.15	43.32 ± 1.57
Nursing sows	603	18.23 ± 0.61	3.98 ± 0.84	72.63 ± 2.43
Suckling piglets	1462	5.99 ± 0.59	0.11 ± 0.03	0.67 ± 0.06
Weaning piglets	5918	20.03 ± 0.45	0.25 ± 0.08	5.11 ± 0.115
Post-weaning piglets	12198	18.22 ± 0.32	0.52 ± 0.05	9.48 ± 0.17
Mature swines	28778	18.40 ± 0.54	2.48 ± 0.47	45.66 ± 1.36
TOTAL	53905			

Gas emissions from entire pig production process. Emissions from pig husbandry, both on a farm scale and household scale, showed significant fluctuations. Among the emissions, NH_3 was generated the most, while N_2O was generated the least (Table 2). The estimated CH_4 generation was 28.87 ± 7.82 (tons/year) for large-scale farms and 0.014 ± 0.005 (tons/year) for households. Similarly, the amount of NH_3 and N_2O generated by household pig farming was 0.0006 ± 0.0002 (ton/year) and 0.01 ± 0.004 (ton/year) respectively. These air pollutant emissions can originate from the activities of pigs and even the decomposition of pig manure in the pigsty. These results are about 2% higher compared to similar inventory data (Eszter et al. 2022).

Table 2. Estimated emissions from pig husbandry.

Emission	Coefficient*	Farms (ton/year)			Household (ton/year)
		Large-scale	Medium-scale	Small-scale	
CH_4	4	28.87 ± 7.82	11.81 ± 2.15	0.21 ± 0.07	0.014 ± 0.005
NH_3	0.18	1.29 ± 0.35	0.53 ± 0.09	0.0091 ± 0.0032	0.0006 ± 0.0002
N_2O	1.5	11.18 ± 3.31	4.86 ± 1.76	0.07 ± 0.02	0.01± 0.004

* source: Le et al. 2017.

Intensive pig farming is considered one of the relatively highest sources of dinitrogen monoxide (N_2O), methane (CH_4), and ammonia (NH_3) (Conor et al. 2017; Dumont 2018; Webb et al. 2014). It is the generation of such a large amount of harmful emissions that has caused potential environmental harm. First, it seriously affects the atmosphere. Second, it disturbs the daily life of residents living nearby and, most dangerously, causes unpredictable diseases for the health of mankind (Thuan et al. 2017). The NH_3 and N_2O that are generated from swine manure and pig waste have a very tie-knot interaction with the farm-to-household waste management system (Diem et al. 2011; Yamaji et al. 2004). N_2O is one of the GHGs that persists for the longest time in the surrounding atmosphere and is also one of the factors that has a relatively significant influence on the destruction of O_3 in the stratosphere. Ammonia (NH_3) is not a GHG because it has a relatively short time in the atmosphere - only a few hours to a few days (Arogo et al. 2003). NH_3 directly contributes to the acidification and eutrophication process of ecologically sensitive areas (Dise et al. 2011) and relies on secondary transformation reactions to transform into molecules that contribute to increased climate change (Calidonna et al. 2004). NH_3 molecules are also highly likely to have a direct impact on human health (Brunekreef and Holgate 2002). CH_4 belongs to the group of GHGs and is also a photochemical agent in the troposphere and stratosphere.

GHG emissions from feed digestion. In livestock production, CH_4 is mainly emitted from the fermentation of feed in the rumen of ruminants and manure from cattle (Thuan et al. 2017; Dung et al. 2016). Table 3 shows the results of GHG emissions from feed digestion of each group of pigs. The coefficient of greenhouse gas emissions due to feed digestion is different between groups of pigs, especially nursing sows and suckling piglets. For pigs raised for meat, the emission factor increases in each period. This difference in emission factor is considered to be due to the nutrition of each group of pigs to ensure normal growth and development (Thuan et al. 2017). On average, the coefficient of greenhouse gas emissions due to the digestion of feed by pig groups is about 0.0023 tCO_2/head/month, equivalent to 1.2 $kgCH_4$/head/year. These results are consistent with other studies conducted in Vietnam and other parts of Asia (Thuan et al. 2017; Yan et al. 2023).

Table 3. GHG emissions from pig feed digestion

Pig production period	Number (head)	$EF_{2.T}$ ($kgCH_4$/head/month)	$CO_{2(2)}$ (tCO_2/month)	GWP_{CH4}
Mating boars	19	0.093 ± 0.0028	0.04	23
Sows (gilts)	2826	0.107 ± 0.003	6.95	23
Pregnant sows	2101	0.14 ± 0.005	6.77	23
Nursing sows	603	0.23 ± 0.007	3.19	23
Suckling piglets	1462	0.002 ± 0.0002	0.07	23
Weaning piglets	5918	0.01 ± 0.0003	2.18	23
Post-weaning piglets	12198	0.03 ± 0.0005	8.70	23
Mature swines	28778	0.15 ± 0.004	99.28	23
TOTAL	53905		127.18	

GHG emissions from waste management systems. The total GHG emissions from the current manure management system of the surveyed livestock establishments are 899.09 tCO_2/month, and the average emission factor for all 9 pig groups is 0.0166 tCO_2/head/month, equivalent to 0.2001 tCO_2/head/year (Table 4). This emission factor is within the range of the default emission factor value set by IPCC for Asia (2-7 kg CH_4/head/year) (Emission Inventory Guidebook 2007). It is similar to studies conducted in Vietnam and other parts of Asia (Yan et al. 2023).

Although biogas is used in this management system, the gas generated has not been recovered because the biogas cellar has been built but there is no filter device, leading to the use of biogas plants. Using this gas for cooking will cause corrosion of metal structures. In addition, no farm has installed biogas generators yet, so biogas has not been used to convert biogas into electricity. Therefore, all the greenhouse gases produced above go into the atmosphere. It can be seen that the construction of a biogas tank, besides the benefits of environmental pollution treatment, increases the relatively high amount of greenhouse gases if biogas is not recovered for other uses.

Table 4. GHG emissions from integrated waste management systems.

Pig production period	Number (head)	Direct discharge (%)	Biogas (%)	Selling (%)	GHGs (tCO_2/month)
Mating boars	19	11	65	26	0.28
Sows (gilts)	2826	12.17	64.5	23.32	49.95
Pregnant sows	2101	11.11	65.05	23.84	46.48
Nursing sows	603	10.45	66	23.55	21.84
Suckling piglets	1462	12.65	66.17	21.17	0.53
Weaning piglets	5918	11.25	65.05	23.69	15.52
Post-weaning piglets	12198	12.55	64	23.45	63.39
Mature swine	28778	12.09	65.1	22.81	701.09
TOTAL	53905				899.09

GHGs emissions from electrical energy. Applying Equation 2, which represents the monthly electricity consumption from the survey, the GHG emissions from this activity were calculated as CO_2 (1) = 102.27 tCO_2/month. With a total of 53,905 pigs surveyed, the greenhouse gas emission factor due to the use of electric energy is estimated at 0.00189 tCO_2/head/month.

Effectiveness of GHG reduction follow circular approach. The total amount of manure is treated by a biogas digester, about 613.35 tCO_2/month will be recovered which is equivalent to 0.0114 tCO_2/head/month and 0.136 tCO_2/head/year (Table 5). If all of the generated gas is recovered and converted into energy to serve the operation of the farm, the amount of gas emitted into the atmosphere will be significantly reduced. These findings are similar to studies conducted in Vietnam and other parts of Asia (Yan et al. 2023).

Every 1 m^3 of biogas is equivalent to 4.6 - 6.2 kWh of electricity, 0.45 m^3 of natural gas, 0.6 liters of gasoline, 0.48 liters of industrial gas, 0.91 kg of charcoal, and 0.6 kg of coal (Thanh et al. 2015). In the case of greenhouse gas emissions from 100% biogas waste management, the calculated electricity consumption is approximately 120,920 kWh per month. To meet this electricity demand, 24,184 m^3 of biogas is needed. However, the amount of biogas obtained from 100% biogas treatment is only 347 m^3 per month. This indicates an excess of gas compared to the demand, resulting in the discharge of this excess gas into the environment, with an emission of 324.33 tCO_2 per month. This corresponds to an emission factor of 0.006 tCO_2 per head per year.

Table 5. GHGs recovered by biogas digester

Groups	Number (head)	VST (kg/day)	$EF_{3.T.4}$ (kgCH$_4$/head/month)	Recoveries (tCO_2/month)
Mating boars	19	0.78 ± 0.02	0.45	0.20
Sows (gilts)	2826	0.896 ± 0.03	0.52	33.95
Pregnant sows	2101	1.172 ± 0.04	0.68	33.01
Nursing sows	603	1.965 ± 0.06	1.15	15.89
Suckling piglets	1462	0.018 ± 0.001	0.01	0.35
Weaning piglets	5918	0.138 ± 0.003	0.08	10.95
Post-weaning piglets	12198	0.26 ± 0.004	0.15	42.52
Mature swines	28778	1.235 ± 0.03	0.72	476.49
Average		0.81 ± 0.02	0.47 ± 0.38	
TOTAL	53905			613.35

The potential application of circular economy at farms and household scales in Viet Yen district will be thoroughly considered from both technical and economic perspectives. However, due to an imbalanced distribution between farms and households in the surveyed area, it may not be feasible for small-scale operations to implement circular economy due to a lack of facilities, capital, and labor. For example, the cost of removing impurities in raw gas immediately after biogas processing is still high, making it unaffordable for most small pig farms in the surveyed area. Additionally, some farmers are not yet aware of CE due to a lack of information and training, which hinders their ability to implement it in practice. Despite the significant potential of utilizing greenhouse gases (GHG) through CE, the support of policies and institutions from local authorities is necessary to facilitate its implementation.

CONCLUSION

The study shows GHG emissions from pig husbandry, both on a farm scale and household scale, showed significant fluctuations. The estimated CH_4 generation was 28.87 ± 7.82 (tons/year) for large-scale farms and 0.014 ± 0.005 (tons/year) for households. Similarly, the amount of NH_3 and N_2O generated by household pig farming was 0.0006 ± 0.0002 (ton/year) and 0.01 ± 0.004 (ton/year) respectively. These air pollutant emissions can originate from the activities of pigs and even the decomposition of pig manure in the pigsty. The GHGs were also estimated for different sources such as energy consumption, feedstuff, and waste management systems.

The circular economy approach was proposed to apply in this study via a scenario of biogas digester decomposition of high organic contents and gas recovery. In case the total amount of manure is treated by a biogas digester, about 613.35 tCO_2/month will be recovered which is equivalent to 0.0114 tCO_2/head/month and 0,136 tCO_2/head/year. However, the circular economy approach shows an advantage at large-scale pig production since the farmers have more resources for investment. It is suggested that more solutions for small-scale farms should be studied to reduce the GHGs.

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