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Manure management practices on biogas and non-biogas pig farms in developing countries – using livestock farms in Vietnam as an example

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ABSTRACT

This survey was carried out to study animal manure management on livestock farms with biogas technology (biogas farms) and without (non-biogas farms) in the areas surrounding the Vietnamese cities Hanoi and Hue. The objective of the study was to assess the contribution of biogas production to a better environment as well as to recognize the problems with livestock manure management on small-scale farms. On all the farms included in the study more than one manure management technology was used, i.e. composting, separation of manure, biogas production and discharge of liquid manure to recipients such as public sewers or ponds. On biogas farms, most of the manure collected was used for bio-digestion. The farmers used the fermented manure (digestate) as a source of nutrients for crops, but on more than 50% of the interviewed biogas farms digestate was discharged to the environment. On non-biogas farms, manure was in the form of slurry or it was separated into a liquid and a dry-matter-rich solid fraction. The solid fraction from separation was used for composting and the liquid fraction usually discharged to the environment. The survey revealed that there is a need to improve methods for transporting the manure to the field, as transportation is the main barrier to recycling the liquid manure fraction. Farmers in developing countries need financial and technical support to install biogas digesters and to overcome the problems involved in utilizing the manure. Information about how to pre-treat manure before adding it to the digester is urgently needed. At present too much water is used, and the high volume of slurry reduces the retention time and is a disincentive for transporting and applying the digestate to fields. The users need to be informed about the risk of loss of methane to the environment, how to prevent cooker corrosion and the discharge to recipients. In addition, the study reveals that in developing countries manure management legislation needs to be tightened to control environmental pollution.

1. Introduction

Biogas produced from animal waste is widely used as a renewable bio-fuel source. This source of energy is regarded as cheap and clean and is also known to produce a residue with a high fertilizer value for crop production (Albihn and Vinneås, 2007; Lantz et al., 2007; Masse et al., 1997; Møller et al., 2004; Sommer et al., 2004). In developed countries, the biogas technology is used on a large scale for power and heat production. It is also one of the technologies supported by governments and the international organizations UN and EU (Eriksson and Olsson, 2007), because it reduces GHG emissions from manure and produces renewable energy (Møller et al., 2004; Sommer et al., 2004).

In developing countries, there are currently millions of household biogas digesters of the Chinese dome design (Maithel, 2009). There are 3.8 million of these in India, 60,000 in Bangladesh, 30 million in China and an increasing number in Africa and Peru (Ramachandra and Shruthi, 2007; Amigun and von Blottnitz, 2009; Walekhwa et al., 2009; Chen et al., 2010; Jiang et al., 2011). An increase in population densities and livestock production in

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developing countries enhances environmental problems that are gradually becoming a barrier for development. Biogas technology is considered as one of the solutions to environmental problems caused by manure management. Of benefits can be mentioned that biogas is renewable and clean and can be used for heating and cooking, which saves trees, thus reducing deforestation, it improves the working environment for women and reduces odor, pathogens and flies. The use of biogas will also reduce the workload for farmers, who would otherwise have to collect firewood (Xiaohua et al., 2007). Therefore, the biogas technology can help reduce poverty and support a sustainable development (Teune, 2007). It is also particularly suitable for remote areas where there is no energy infrastructure.

On a global scale Vietnam is a poor country, which has seen an impressive economic development. This has caused livestock production to increase and also to become more specialized. Vietnam is facing many problems associated with animal waste management such as air and water pollution, lack of hygiene and inappropriate use of manure resources. Fermentation of manure in biogas reactors is regarded as a helpful tool to solve some of these problems, and since 2003 the government has supported the construction of biogas digesters together with international organizations such as Netherlands Development Organisation (SNV; Anonymous, 2010a). In 2011, this organisation constructed 110,000 biogas plants and the plan is to construct a further 200,000 plants in the period 2013–2018 (Anonymous, 2011). Through SNV support biogas has become a technology that is affordable and suitable for small-scale farming.

This survey set out to investigate the current situation of manure management in Vietnam with the objective of identifying the major associated risks. Vietnam is considered an example for developing countries facing similar problems. This study intends to contribute with in-depth knowledge about problems and solutions for the development of the safe and sustainable recycling of manure on livestock farms in Vietnam and fellow developing countries in Asia. The results will contribute to the development of a tool for policy-makers in the promotion of a sustainable and environmentally safe development of the livestock production.

2. Method

The interviews were carried out in two provinces representative of medium and small-scale farming in peri-urban areas of the northern and central regions of Vietnam. Peri-urban regions were selected, because pig productions in Asia are situated near large cities (Gerber et al., 2005). Small-scale pig production is by the Vietnamese government defined as farms housing fewer than 19 fattening pigs or fewer than five sows, and medium-scale production is defined as ranging from 19 to 99 fatteners and 5–19 sows (Vu et al., 2007).

In the red river region of Hanoi in Northern Vietnam, the survey was carried out in Quoc Oai district, about 30 km from Western Hanoi. In Hue province, central Vietnam, the survey was carried out in Huong Tra district, 10 km from the center of Hue. These districts were chosen because they represent regions, which have a well developed pig production compared to other districts in the provinces. In Quoc Oai and Huong Tra districts, the four communities Sai Son, Dong Yen and Huong Toan, Huong Xuan were selected by random sampling from a total number of 46 communities.

In all communities, pig farms with and without biogas digesters were included in the survey. Lists of all pig producers in the selected communities were provided by local community veterinary groups. Randomly 96 non-biogas farms and 85 biogas farms was selected for interview in Ha Noi from a total of 120 non-biogas farms and150 biogas farms. In Hue 50 non-biogas farms and 50 biogas farms was selected randomly for the interview from a total of 100 biogas farm and 98 non-biogas farms. Thus, in total 281 farms were interviewed by a group from the SUSANE project. As mentioned the farm was selected by simple random sampling method.

The questionnaire for this study was prepared during workshops involving specialists in manure management, plant nutrition and epidemiology. The experiences from the survey carried out by Vu et al. (2007) were also incorporated when developing the questionnaire. The 62 questions focused on the following five main areas: information about the household, animal production, manure management, biogas digester design and management, and use of biogas (Table 1).

Initially, all specialists involved in interviewing farmers met and jointly interviewed 10 farmers. This ensured that all interviewers were carrying out the individual interviews as similarly as possible and the experience from this initial joint interview study was used to improve the questionnaire.

2.1. Data analysis

Prior to the analysis of data, all the obtained data were rechecked by two specialists to ensure that the data were correct. If information was considered inconsistent, the interviewer returned to the farm and asked the farmer again. If reliable data could not be obtained, the information was omitted from the data analysis. After the control of data, the final survey included information from 181 Hanoi farms of which 96 had installed biogas and 100 farms near Hue of which 50 farms had installed biogas (Table 2).

The data collected included economic and production characteristics of the farms, which could be broadly grouped into physical, socio-economic and technical aspects. Data were analyzed by using

Table 1
Main categories of the 62 questions in the survey.

Category	Questions
Household	Name, education, occupation, number of members in family, total land area (livestock land and field land), distance from pigpen to field.
Animal production	Animal category Number of animals Weights of animals Diets and feeding methods
Manure management	Cleaning of animal house (How many times/day, how much water used (m^3 day^{-1}) Distance from pigpen to kitchen and drinking water resource Bactericidal agents used for cleaning, if any Technology for manure collection (liquid manure, solid manure or a mixture of liquid and solid manure, i.e. mixed manure) End use of manure (crop, fish pond, biogas, discharge to waterways)
Biogas	Source of information about biogas technology Rationale for installing biogas digester or for choosing not to install biogas digester Type of biogas digester installed Overall function of the biogas digester Main problem when using biogas Cost of installing biogas Donor support Source of biomass used to feed the digester, pig manure only or supplementation of other biomasses Use of biological additives to biogas digester How often were sediment removed
Use of biogas. economy, benefits	End use of biogas (cooking, lighting, heating..) Release of excess gas production How much money can be saved from installing a biogas digester Additional benefits, hygiene, odour, flies etc.

Table 2
Number of farmers involved in the survey.

Commune	Hanoi (April, 2010)			Hue (June, 2010)		
	Sai Son	Dong Yen	Total	Huong Toan	Huong Xuan	Total
Biogas	37	59	96	26	24	50
Non-biogas	44	41	85	26	24	50

statistical techniques with the aid of the Statistical Package of the Microsoft Office Excel 2007 software.

3. Results and discussions

3.1. Household

Average size of a family is 4–5 persons of which 2–3 work on the farm, the remaining family members being either too young or too old to contribute to farm work (Table 3). This number corresponds to the official statistics about the population, showing that the average number of persons per family is 3.5 in the rural Red-river region in Vietnam, and in the rural central Vietnam it is 3.9 persons per family (General Statistic Office of Vietnam, 2009). In China, farming households also number 4–5 persons (Xiaohua and Jingfei, 2005).

The field area of biogas farms is 1942 m^2 in Hanoi and 3385 m^2 in Hue. On non-biogas farms, the average field area is 1713 m^2 in Hanoi and 3289 m^2 in Hue (Table 3). The field area in Hue is larger than in Hanoi because the population density in Hue is lower than in Hanoi. The soil quality in Hue is also poorer than in Hanoi, i.e. mainly acrisol. Consequently, only one crop of rice can be grown per year in Hue compared to two crops per year in Hanoi. Most of the agricultural land is used for rice cultivation in both Hanoi and Hue provinces, as this is the main source of food in Vietnam. The survey showed that maize, sweet potato and cassava are also produced by farmers. The animal manure that was transported to fields was done so in barrels on rudimentary vehicles such as hand-pulled carts or motorbikes. The distance from the animal house to the field is about 860 m in Hanoi and 1500 m in Hue. Farmers identified the lack of adequate manure transportation vehicles and high labor input as the main barriers to manure utilization; hence, instead of using manure for crops, they discharged it to the environment. This finding is in agreement with the report of Jackson and Mtengeti (2005).

The average number of pigs per farm in the Hanoi region was 39 and 11 in Hue including sows, fatteners and piglets (Table 3). It is noteworthy that farms in Hue had a very small number of sows and piglets, indicating that the farmers had chosen to raise fatteners, which is less demanding than sow and piglet production. The amount of manure transported to the fields is inadequate to meet crop demand, partly because only some of the total amount of manure produced was applied to fields. This was due to the transport distances involved, the farmers have difficulties in transporting the manure to the fields; therefore, farmers instead have to use relative high amounts of inorganic fertilizer. This is especially the case in the Hue province where transport distances are long.

The surveyed data also indicate that there is a relation between the presence of a biogas plant and the amount of land available for the construction of the digester. One must bear in mind that the farm buildings are situated in villages and not within the fields, and thus on some farms there may not be room for a biogas digester near animal houses. Still, only six of the non-biogas farmers gave too little land for the plant as the rationale for not installing digesters (Fig. 1).

Table 3
Information about farm size, households size, number of persons working on the farm and number of animals. Mean values and standard deviations (in brackets).

	Hanoi		Hue	
	Biogas ($N = 96$)	Non-Biogas ($N = 85$)	Biogas ($N = 50$)	Non-Biogas ($N = 50$)
Land used for livestock, m^2	78 (61.0)	64.9 (61.1)	54.7 (82.5)	22.7 (10.7)
Field area, m^2	1942 (1837)	1713 (1376)	3385 (3251)	3289 (2328)
No. persons working on the farm	2.2 (0.7)	2.4 (1.2)	2 (0.7)	2.08 (0.6)
No. persons in the household	5.2 (1.4)	5.1 (1.8)	4.9 (1.4)	5.4 (1.5)
Sows per farm	3.3 (4.6)	2.5 (1.6)	1.7 (1.4)	1.5 (0.9)
Fatteners per farm	15.8 (11.8)	16.31 (12.4)	8.6 (8.1)	6.1 (5.5)
Piglets per farm	19.6 (23.6)	13.4 (6.3)	0.5 (2.0)	0.1 (0.9)

3.2. Animal production

Diets fed to the pigs were a commercial high protein and carbohydrate feed, a local feed or a mixture of a local and a commercial feed. The local feed consisted of agricultural residues such as rice bran mixed with cassava leaves, water spinach, banana tree, water hyacinth, sweet potatoes or soybean. The local ingredients are traditionally cooked before feeding. The mixed feed consisted of different rations of local and commercial feeds. Biogas is an obvious energy source for preparing the local feed, but this was not reflected in a higher proportion of mixed feed used on biogas farms.

For all pig categories, mixed diets are the most commonly ration used on both biogas and non-biogas farms (Table 4).

Commercial diets are fed to sows on biogas and non-biogas plants on an average 10% of all farms. Piglet productions on farms in Hue are fed a mixed diet. In the Hanoi region, 28 and 34%, respectively, of non-biogas and biogas farms use commercial feeds for fattening pigs, whereas these numbers are, respectively, 0 and 8% in the Hue province. Pigs fed commercial diets grow faster than pigs fed mixed and local feeds due to the higher level of easily digestible protein and carbohydrate. However, mixed diets are preferred by most farmers because these diets are cheaper and the growth rate can still be acceptable. In most developing countries mixed diets are common, for example in African countries like

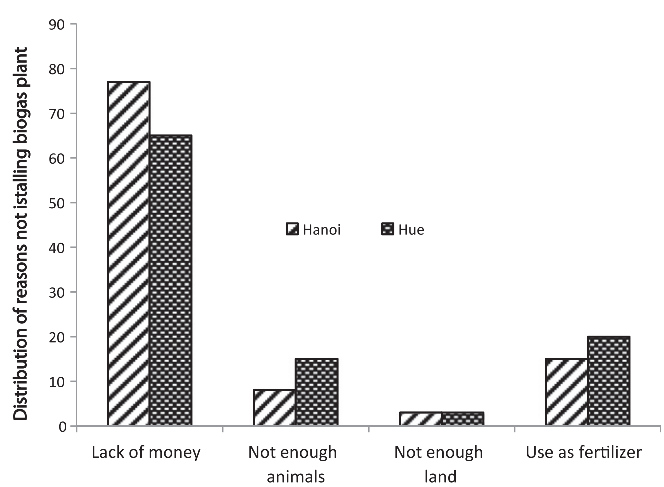

Fig. 1. The rationale given by farmers for not installing biogas digester. The total percentage for the reasons given exceeds 100% because some farmers gave more than one reason for not installing biogas plants on their farms.

Table 4
Livestock feeding system on biogas and non-biogas farms in Hanoi and Hue.

Animals	Feeding mode	Hanoi				Hue			
		Biogas ($N = 96$)		Non-Biogas ($N = 85$)		Biogas ($N = 50$)		Non-Biogas ($N = 50$)	
		N	%	N	%	N	%	N	%
Sows	Commercial	16	16.7	9	11.0	6	12.0	0	0.0
	Mix	52	54.2	53	62.9	39	78.0	42	84.0
	Traditional	28	29.1	23	27.1	5	10.0	8	16.0
Fattening Pigs	Commercial	33	34.4	24	28.2	4	8.0	0	0.0
	Mix	58	60.4	59	69.4	41	82.0	47	94.0
	Traditional	5	5.2	2	2.4	5	10.0	3	6.0
Piglets	Commercial	38	40.0	31	36.4	0	0.0	0	0.0
	Mix	55	57.5	46	54.1	50	100.0	50	100.0
	Traditional	2	2.5	8	9.4	0	0.0	0	0.0

N: Number of households.

Tanzania, Nigeria, South Africa, and mixed feeding is considered most valuable for an economic and sustainable agriculture based on organic farming (Lekule and Kyvsgaard, 2003).

Different types of feeding practices lead to different manure compositions, and result in different qualities and quantities of gas produced in biogas digesters. This should be kept in mind when assessing biogas production on a farm. With the feeding practices in developing countries being much different from those in industrialized countries, there is an urgent need for assessing and revising the biogas potential of manure and other biomasses in these countries (Møller et al., 2004; Tuan et al., 2006). Beside nutrients such as nitrogen and phosphorus at high concentrations, commercial feed also contains growth hormone, antibiotics and some heavy metals. These nutrients in animal manure can degrade water quality if they are over-applied to land or enter water resources (Ribaudo et al., 2003). Thus, high N, P, heavy metals and pharmaceutical is of concern in Vietnam due to discharge or runoff of manure to recipient water. There is a need of more focus on feeding practice in relation to manure management in order to achieve environmentally friendly manure management practice (Gollehon et al., 2001).

3.3. Manure management

Manure management is affected by the use of biogas digesters for the treatment of manure on many farms. On non-biogas farms in Hanoi 65% of the manure was separated into a dry-matter-rich and a liquid fraction (Table 5). The dry-matter-rich fraction was then normally composted in a corner of the garden or in the field. After around 3–4 months or longer it was applied to crops as a fertilizer (55 farms). The liquid fraction, urine and cleaning water are stored in uncovered containers and also used to fertilize the crop in the growing season. When the container reaches capacity, the excess is discharged to the environment. On 62 non-biogas farms, the liquid was discharged to recipients during periods when the container could not accommodate the liquid manure produced. This is a source of water pollution. In Vietnam a total of 442.000 tons of nitrogen and 212.00 tons of phosphorus was discharged to public water resources in 2004, hereof 38% of nitrogen 92% of phosphorus was from pig farms (Anonymous, 2010b). Visual observations indicate increasing pollution of water in regions with high density of animal production. Vietnam currently has no regulations for BOD or COD levels of manure discharged to the public sewers by small and medium-sized livestock farms. In Malaysia, effluent with a BOD level lower than 20 mg O_2 l^{-1} may legally be discharged to rivers (Sommer et al., 2005). In China, there is a daily maximum BOD level for slurry of 150 mg O_2 l^{-1} (Wang, 2005). Legislation for pollution with livestock manure varies considerably from country to country due to the difference in socioeconomics or culture. In some developed countries like Denmark, England and the Netherlands, livestock manure legislation is very strict and the discharge of manure to the environment is prohibited (Petersen et al., 2007; Oenema, 2004).

Table 5
Manure management methods on biogas and non-biogas farms in Hanoi and Hue provinces.

Manure management	Hanoi ($N = 181$)				Hue ($N = 100$)			
	Biogas ($N = 96$)		Non-Biogas ($N = 85$)		Biogas ($N = 50$)		Non-Biogas ($N = 50$)	
	N	%	N	%	N	%	N	%
No treatment	0	0.0	30	35.3	0	0.0	45	90.0
Composted	0	0.0	30	35.3	0	0.0	0	0.0
No treatment + composted	0	0.0	25	29.4	0	0.0	5	10.0
Fermented	82	85.4	0	0.0	50	100.0	0	0.0
Fermented + no treatment	8	8.3	0	0.0	0	0.0	0	0.0
Fermented + compost	6	6.3	0	0.0	0	0.0	0	0.0
Discharge	56	58.3	62	72.9	30	60.0	22	44.0

N: Number of households.
Manure management method: No treatment means unfermented manure. Compost is the solid fraction from separation of manure that has been stored in heaps for a minimum of two months before using. Fermented manure means manure that has been fermented in a biogas digester (may also be called digestate).
Discharged manure is manure that is discharged to the environment (ditches, canals, lakes, rivers). On biogas farms discharged manure is fermented liquid manure, and on non-biogas farms discharge is usually washing water and urine.

On 16 out of 25 farms where both untreated manure and compost was produced (Table 5), the untreated manure was applied to fishponds on the farm. During the survey, we noticed that on two farms the fish died, because the farmer used too much manure to nourish the fish pond.

Further the manure was not treated on 30 out of 85 farms, and was typically stored in a pit behind the pigsty before being applied to fields. Manure stored in uncovered containers may be a significant source of odor and ammonia emission (Martinez et al., 2003; Vu et al., 2007). Most of the surveyed pig farms do not use bedding in the pigpen due to the difficulty in cleaning them and due to the heat created by the composting, which is unwanted in the hot climate. Only a few farmers used bedding for the sows giving birth in the winter period. According to Smith et al. (2000), 45% of the pig manure in England and Wales is managed as slurry and 55% as farmyard manure, but in countries like Denmark and the Netherlands more than 90% of the manure are managed as slurry. In Vietnam and other Asian countries, manure is managed as slurry, and as liquid and solid manure from in-house separation.

On non-biogas livestock farms in the Hue province, most of the manure is handled as slurry (45 out of 50 farms). The farmers scrape the manure into an uncovered container at the back of the pigpen. Slurry is stored until it is spread onto fields. Five farms in Hue produced both liquid manure and compost types. One difference between Hue and Hanoi is that farmers in Hue tended to use mineral fertilizer for rice and maize crops in fields far from their house. The pig slurry was used only for vegetables grown closer to home. This may be because the quality of the soil is very low and there is a need of adding organic matter to improve soil quality where high value vegetables are grown. On most of the biogas farms in Hanoi all the manure was used for fermentation in biogas digesters (82 of 96 farms); the manure was not separated before feeding into the digester but scraped off the concrete floor of the pen directly into the digester together with washing water. If the farm had a fishpond (eight of the farms surveyed), then some solid manure was retained to feed the fish. Six farms composted the manure because manure production was in excess of the digester's capacity. These six farms bred cows or buffaloes, and the pig manure was composted together with cow and buffalo manure. On all 50 biogas farms in the Hue province, all the manure was used to feed the biogas digester.

The digestate from biogas digestion was discharged directly to a recipient on 56 out of 96 farms in Hanoi and 30 out of 50 farms in Hue. There are two reasons for this – farmers put a low value on the plant nutrient content of the digestate, because the manure is diluted when added to the digesters and the distance of transporting the liquid manure to fields and gardens is long. Farmers do not have the means of transporting the large volumes of digestate over long distances. Thus, there is a need for the development of new manure transport technologies for farms that install biogas digesters.

3.4. Biogas

3.4.1. Farmers' attitude to the biogas technology

A large number of Vietnamese farms have installed biogas digesters in recent years (Teune, 2007). The increase is a reflection of the financial subsidy given for the construction of biogas plants. Farmers tend to accept new technology when this brings about a clear improvement in their life or their economy (Jackson and Mtengeti, 2005). Farmers are well aware of the problems caused by animal manure management, and find that biogas treatment of the manure can reduce these problems (Fig. 2). At present odor is considered the largest problem and problems with hygiene are associated with odor. However, the most common reason associated with not installing biogas plants is lack of money (Fig. 1). There is a greater willingness of households with higher income to adopt the biogas technology than of the poorer counterparts (Walekhwa et al., 2009).

Most farmers in Hanoi learn about biogas technology through neighbors (36%) and in Hue via the extension service (52%) (Table 6). Public media such as television and newspapers also play an important part with 26% of households in Hanoi and 20% in Hue learning about biogas through these. As the Vietnamese government wishes to expand the use of the biogas technology (Anonymous, 2010a), the method used by the Hue extension service may be used to propagate knowledge about the technology among farmers.

Other considerations given by farmers for their decision on whether or not to adopt the biogas technology are whether they have enough animals to support a biogas production or enough land for constructing the digester (Fig. 1).

The brick dome digester predominated, having been installed on 74 out of 96 biogas farms in Hanoi and 50 out of 50 biogas farms in Hue (Fig. 3). The standard volume of these digesters is 6–8 m^3 (Fig. 4). The farmers consult SNV in the process of installation. SNV pays USD 60 of the USD 200–400 cost of constructing the digester, and the organization gives technical advice and instructions during the construction. The composite biogas digester is a new type of bio digester in Vietnam (Nguyen, 2010, Fig. 4), having been introduced in Vietnam about three years ago, because it is durable, there is no gas leaking, it is easy to construct and use. The intention is to use it on large-scale pig farms. As the number of large-scale pig farms is set to increase in the future, the composite biogas digester will probably be much used in the future (Anonymous, 2010b). Therefore, research and development in biogas digester technology should also aim to adapt this technology to Vietnamese conditions. Besides using the gas for cooking and heating, these digesters will probably also be used for electricity production to be sold to the national grid.

Table 6
Source of information on biogas for farmers in Hanoi and Hue.

Source of information	Hanoi ($n = 96$)		Hue ($n = 50$)	
	N	%	*N*	%
Public media	25	26.0	10	20.0
Neighbors	34	35.5	13	26.0
Extension service	25	26.0	26	52.0
Others	12	12.5	1	2.0

N: Number of farms.

3.4.2. Biogas production

The efficiency of gas production in biogas digesters depends on temperature, retention time, continuous input to the digester and the composition of the manure (An and Preston, 1999; Vindis et al., 2009). The digesters on the surveyed farms were not heated; therefore they operate at the temperature of the surrounding soil as they are dug into the ground. In the summer, the average air temperature is around 34 °C, which is very suitable for bacterial fermentation, but during winter the temperature is 10–15 °C and at these temperatures methane production is much lower than at temperatures above 20 °C (Zeeman et al., 1988). Therefore, biogas production during winter may be low in especially mountainous regions, and may not be sufficient for the needs of the people living on the farms.

Advice about the construction of digesters is provided by the extension service (SNV) and by neighbors who already have a biogas digester installed. This is probably the reason why the volume of digesters within each of the respective regions is very similar (Table 7). In Hanoi, the volume of digesters ranges between 11–16 m^3 and in Hue between 6 and 8 m^3, a difference between

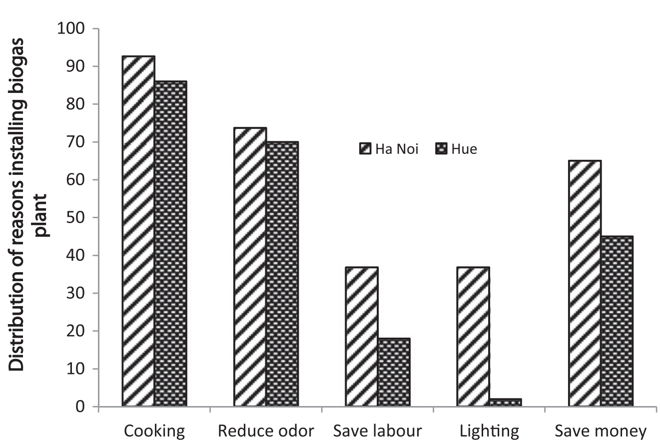

Fig. 2. Purpose of using biogas in Hanoi and Hue provinces. Percentage of reasons exceeded 100% because some farmers gave more than one reason for installing a biogas plant.

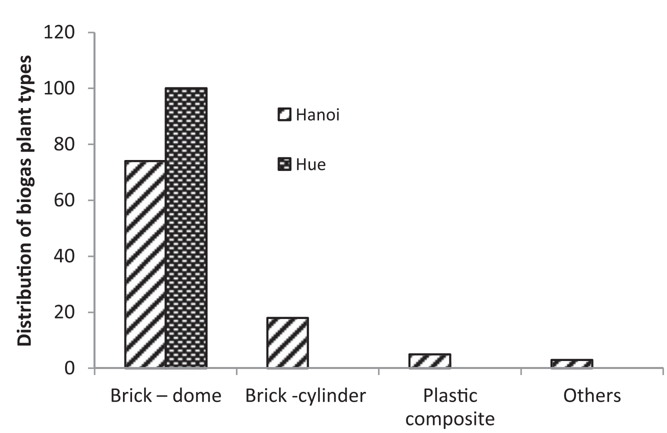

Fig. 3. Biogas digesters installed on the farms in Hanoi and Hue.

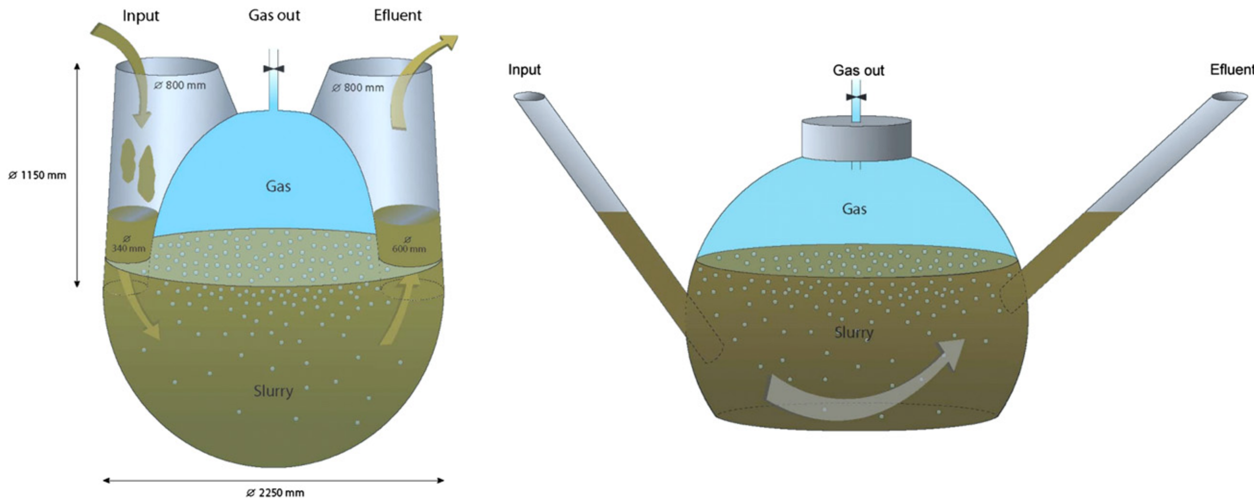

Fig. 4. *Left*) bio-digester design constructed by composite material and *Right*) Dome bio-digester design build with bricks.

Table 7
Relationship between retention time (days), volume of biogas digester (m^3) and loading rate (m^3/day) in biogas households.

Regions	RT (days)	1–10	11–20	21–30	31–40	>40
Hanoi	Average RT (days)	7.7	14.5	25.7	35.4	95.4
Hanoi	Number of farms	24	31	11	5	25
Hanoi	% of farms	25.0	32.3	11.4	5.3	26.0
Hanoi	Digester volume (m^3)	11.2	15.2	15.3	15.6	13.4
Hanoi	Average loading rate (m^3 day^{-1})	1.6	1.1	0.6	0.5	0.2
Hue	Average RT (days)	6.5	15.2	26.9	33.7	66.1
Hue	Number of farms	16	14	4	4	12
Hue	% of farms	32.0	28.0	8.0	8.0	24.0
Hue	Digester volume (m^3)	7.4	7.5	7.3	6.5	7.9
Hue	Average loading rate (m^3 day^{-1})	1.5	0.5	0.3	0.2	0.1

RT: Retention time.

regions that reflects that farms in Hue have fewer animals. Most family-size digesters in countries supported by SNV such as Uganda, Nepal, Kenya, and Tanzania have a bio-digestion capacity volume of 6–16 m^3 (Walekhwa et al., 2009; Mwirigi et al., 2009).

In addition to temperature, other problems that affect gas production and collection are broken digester caps and gas valves that are not airtight, leaving gas escaping to the atmosphere. This is a significant environmental problem as biogas production then may increase GHG emissions to the environment.

At the low temperatures the retention time should be at least 20 (Thy et al., 2003) and better 30–50 days). For comparison large-scale mesophilic digestors (37 °C) typically have a retention time of 15–20 days. About 55% of the digesters in Hanoi and 60% of the digesters in Hue have a retention time of between 1 and 20 days (Table 7). In these biogas plants the organic matter is not efficiently transformed to biogas. This will also cause problems with odor emission from fermented manure. The organic matter discharged to water sources lead to a high oxygen demand causing anaerobic conditions in recipient waters, and pathogens like E-coli and parasite eggs may proliferate in the discharged manure due to the short treatment time and may spread disease (Campagnolo et al., 2002., Gerba and Smith, 2004). In contrast, with a long retention time, little methane is produced during the last days of fermentation, and that is not economical. Figs. 5 and 6 shows that there is a difference in number of animals between households, however volume of digesters is quite similar in both Hanoi and Hue. So there is a need to develop models and decision support that includes advice on the most appropriate size of biogas digesters in relation to the soil temperature and the amount of manure produced on the farms.

The SNV organization advises farmers to feed the digesters with manure and water at a ratio of 1–3. This advice had not reached all farmers, and they therefore used an arbitrary amount of water for cleaning the pigpen and flushing manure into the bio-digesters –;

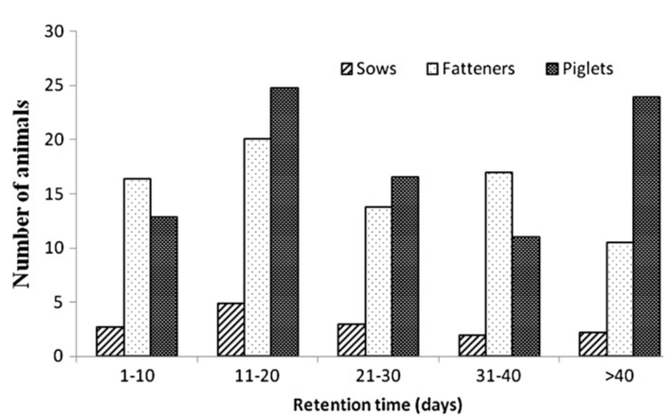

Fig. 5. Number of animals on pig farms and relationship with retention time of slurry in biogas digesters in Hanoi.

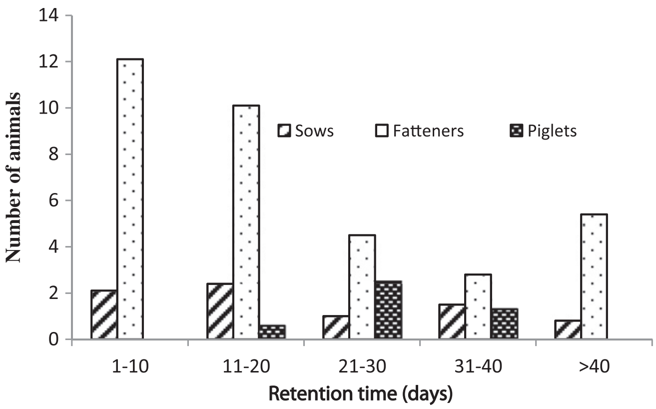

Fig. 6. Number of animals on pig farms and relationship with retention time of slurry in biogas digesters in Hue.

they stopped adding water when the pigpen was clean (Table 8). In Hanoi, the average ratio of manure to water was about 1:9 in the summer and 1:8 in the winter, and in Hue the numbers were 1:20 and 1:16, respectively. Consequently the manure is very dilute and biogas production is low due to a low retention time.

Almost all farms used chemicals to clean pigpens. The chemicals such as powdered lime, iodine and chloramine are used to clean the pigpen after a batch of fattening pigs has been removed to avoid spreading disease to the new batch of pigs. Farmers are aware that chemicals can affect the fermentation process and have installed a separate pipeline that carries washing water with chemicals around the digester. It was noticed that some farmers did not know that chemicals can effect fermentation, and on their farms washing water mixed with chemicals was fed to the bio-digester and the biogas production was significantly reduced on these occasions. Powdered lime is a popular disinfectant due to its cheapness. Lime may increase the temperature in the digester because of a powdered lime-water reaction. Sudden changes in temperature are a hazard to the biogas production. Further lime addition may also cause an increase in pH above the optimal pH of 7, which is detrimental to the fermentation process especially sudden increases as will be caused by occasional addition of lime. Other disinfectants like iodine and chloramine are also often used, and these chemicals will kill the microorganism in the digester, stopping the biogas production. There is a need to test how a disinfectant affects the biogas process and to provide advice on how to adjust its use to ensure that the fermentation process is not negatively affected.

3.5. Biogas consumption

Most farmers answered that their biogas digesters produced gas at a rate that fulfilled their needs for cooking and lighting. On some farms too much biogas was produced, which was then emitted to the atmosphere or made available for their neighbors to use. However, the biggest problem that we saw on farms was that the gas cooker rusted very fast and was unusable after 2–4 years. The reason for this was that the farmers did not use a filter to absorb the dihydrogen sulphide (H_2S) in the biogas before using the gas for cooking. The H_2S in combination with water forms an acid which is corrosive.

Table 8
Volume of water used in biogas and non -biogas households in summer and winter.

	Hanoi		Hue	
	Biogas	Non-biogas	Biogas	Non-biogas
Cleaning water in summer (l/day/household)	380	230	220	189
Cleaning water in winter (l/day/household)	300	180	180	140

The main purpose for installing biogas is to use the gas for cooking (Fig. 2), which replaces energy sources that must otherwise be purchased or collected, i.e. propane gas, coal or firewood. As mentioned above, farmers also find that the fermentation of manure in biogas digesters reduces odor emissions significantly, that there are fewer flies on the farm and that the pigpens are cleaner. Not least do the farmers save money from using biogas. The cost of installing a biogas digester in Hanoi is around US $ 400 and US $ 200 in Hue province. Biogas digesters can reduce annual energy costs by US $ 120–150 per farm, and the payback time is estimated at two-three years. In China, the investment costs for a biogas plant is US $ 264–442 for size from 6 to 10 m^3 (Mi, 2008). It is more expensive in Uganda at US $ 700–1200 for 8–16 m^3 plants (Walekhwa et al., 2009) and in Kenya at around Kshs 72.000 ~ US $ 790(Mwirigi et al., 2009).

Countries like Vietnam can also benefit from selling CO_2 reduction through the Clean Development Mechanism (CDM; Teune, 2008).

4. Conclusions

The biogas technology can potentially contribute to solve Vietnam's current problems with animal manure management. It offers additional energy, environmental and economic bonuses. The results of the survey showed that nearly all farmers realized that biogas digesters provide multiple benefits, but that the main stumbling block to them installing one was lack of money. Currently, the SNV organization contributes 10% of the cost, with farmers having to pay the remainder themselves. Ninety percent of non-biogas farmers answered that if they had enough money they would install a biogas digester. Moreover, farmers need advice and technical support to optimize biogas production on a number of concerns such as ratio of water to manure input, how to use disinfectants without decrease in gas volume produced, how to maintain biogas digester. In particular, farmers are very much in need for techniques to prevent gas cooker corrosion due to sulfuric acid. The survey results also indicate that difficulties in transporting the liquid manure to the fields limit the usability of the manure. There is a need to improve the vehicles to make it easier and more comfortable for farmers to transport manure.

Finally, the legislation covering small and medium-scale livestock farms is very inadequate. Farmers can, for example, freely discharge manure into public waterways. This manure is the source of eutrophication, odor pollution and constitutes a risk for the spread of disease and is a challenge for the maintenance of hygiene.

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References

Albihn, A., Vinnerås, B., 2007. Biosecurity and arable use of manure and biowaste — Treatment alternatives. Livest. Sci. 112, 232–239.
Amigun, B., von Blottnitz, H., 2009. Capital cost prediction for biogas installations in Africa: Lang factor approach. Environ. Prog. Sustain. Energy 28, 134–142.
An, B.X., Preston, T.R., 1999. Gas production from pig manure fed in different loading rates to polyethylene tubular biodigesters. Livest. Res. Rural Dev. 11.

Anonymous, 2010a. Press conference on Ashden Award in Vietnam 12/7/2010. (http://biogas.org.vn/english/Tin-tuc-Su-kien/Tin-hoat-dong/Le-cong-bo-giai-thuong-Ashden-Award-ngay-12-7-2010.aspx. access date: 4.12.11).

Anonymous, 2010b. Kiem soat o nhiem tai cac vung dong dan cu ngheo. (Environmentally Sustainable Development in Poor Urban Areas). Vietnam-Denmark cooperation development in the Environment. http://www.niaslinc.dk/gateway_to_asia/nordic_webpublications/x506033537.pdf access date: 4.12.11.

Anonymous, 2011. Summary of the Biogas Program for Animal Husbandry sector of Vietnam. http://biogas.org.vn/english/getattachment/Tin-tuc-Su-kien/Tin-hoat-dong/Biogas-Programme-for-the-Animal-Husbandry-Sector-o/BP-Summary-Eng.pdf.aspx access date 15.12.11.

Campagnolo, E.R., Johnson, K.R., Karpati, A., Rubin, C.S., Kolpin, D.W., Meyer, M.T., Esteban, J.E., McGeehin, M.A., 2002. Antimicrobial residues in animal waste and water resources proximal to large-scale swine and poultry feeding operations. Sci. Total Environ. 299, 89–95.

Chen, Y., Yang, G., Sweeney, S., Feng, Y., 2010. Household biogas use in rural China: a study of opportunities and constraints. Renew. Sust. Energ. Rev. 14, 545–549.

Eriksson, P., Olsson, M., 2007. The Potential of Biogas as Vehicle Fuel in Europe-as Technological Innovation Systems Analysis of the Emerging Bio-Methane Technology. Chalmers University of Technology. Report No 6, ISSN: 1404–8167.

General Statistic Office Of Vietnam, 2009. Vietnam Population and Housing Census 2009. Website. http://www.gso.gov.vn/default_en.aspx?tabid=515&idmid=5&ItemID=11082, access date: 15.12.11.

Gerba, C.P., Smith Jr., J.E., 2004. Sources of pathogenic microorganisms and their fate during land application of waste. J. Environ. Qual. 34 (1), 42–48.

Gerber, P., Chilonda, P., Franceschini, G., Menzi, H., 2005. Geographical determinants and environmental implications of livestock production intensification in Asia. Bioresource Technol. 96, 263–276.

Gollehon, N., Caswell, M., Ribaudo, M., Kellogg, R., Lander, C., Letson, D., 2001. Confined Animal Production and Manure Nutrients. Agriculture Information Bulltin No 771. Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. http://www.ers.usda.gov/publications/aib771/aib771.pdf.

Jackson, H.L., Mtengeti, E.J., 2005. Assessment of animal manure production, management and utilization in Southern Highlands of Tanzania. Livest. Res. Rural Dev. 17 (10).

Jiang, X., Sommer, S.G., Christensen, K.V., 2011. A review of the biogas industry in China. Energy Policy 39, 6073–6081.

Lantz, M., Svensson, M., Bjornsson, L., Borjesson, P., 2007. The prospects for an expension of biogas systems in Sweden-Incentives, barriers and potentials. Energ. Policy 35 (3), 1830–1843.

Lekule, F.P., Kyvsgaard, N.C., 2003. Improving pig husbandry in tropical resource-poor communities and its potential to reduce risk of porcine cysticercosis. Acta Trop. 87, 111–117.

Maithel, S., 2009. Biomass Energy. Resource of Assessment Handbook. Solution Centre for Renewable Energy Cooperation Network for the Asia Pacific Asian and Pacific. Centre for Transfer of Technology. http://recap.apctt.org/Docs/Biomass.pdf.

Martinez, J., Guiziou, F., Peu, P., Gueutier, V., 2003. Influence of treatment techniques for pig slurry on methane emissions during subsequent storage. Biosyst. Eng. 85, 347–354.

Masse, D.I., Droste, R.L., Kennedy, K.J., Patni, N.K., Munroe, J.A., 1997. Potential for the psychrophilic anaerobic treatment of swine manure using a sequencing batch reactor. Can. Agr. Eng. 39, 25–33.

Mi, Z., 2008. Financing of domestic biogas plants in China. The International Workshop on Financing of Domestic Biogas Plants, pp. 22–23.

Mwirigi, J.W., Makenzi, P.M., Ochola, W.O., 2009. Socio-economic constraints to adoption and sustainability of biogas technology by farmers in Nakuru Districts, Kenya. Energ. Sust. Dev. 13, 108–115.

Møller, H.B., Sommer, G.S., Ahring, B.K., 2004. Methane productivity of manure, straw and solid fractions of manure. Biomass Bioenerg. 26, 485–495.

Nguyen, A., 2010. Economic Benefits from Using Biogas Composite Tank. Ministry of industry and Trade-National program on energy efficiency and conservation. http://tietkiemnangluong.com.vn/en/hot-news/economic-benefits-from-using-composite-biogas-tank-42003-9019.html, access date: 4.12.11.

Oenema, O., 2004. Governmental policies and measures regulating nitrogen and phosphorus from animal manure in European agiculture. J. Anim. Sci. 82, E196–E206.

Petersen, S.O., Sommer, S.G., Béline, F., Burton, C., Dach, J., Dourmad, J.Y., Leip, A., Misselbrook, T., Nicholson, F., Poulsen, H.D., Provolo, G., Sørensen, P., Vinnerås, B., Weiske, A., Bernal, M.P., Böhm, R., Juhász, C., Mihelic, R., 2007. Recycling of livestock manure in a whole-farm perspective. Livest. Sci. 112, 180–191.

Ramachandra, T.V., Shruthi, B.V., 2007. Spatial mapping of renewable energy potential. Renew. Sust. Energ. Rev. 11, 1460–1480.

Ribaudo, M., Gollehon, N., Aillery, M., Kaplan, J., Johansson, R., Agapoff, J., Christensen, L., Breneman, V., Peters, M., 2003. Manure Management for Water Quality: Cost to Animal Feeding Operations of Applying Manure Nutrients to Land. Agriculture Economic Report 824. Department of Agriculture, Economic Research Service, Resource Economics Division. http://www.ers.usda.gov/publications/aer824/aer824fm.pdf.

Smith, K.A., Brewer, A.J., Dauven, A., Wilson, D.W., 2000. A survey of the production and use of animal manures in England and Wales. I. Pig manure. Soil Use Manage. 16, 124–132.

Sommer, S.G., Petersen, S.O., Møller, H.B., 2004. Algorithms for calculating methane and nitrous oxide emissions from manure management. Nutr. Cycl. Agroecosys., 69,143–69,154.

Sommer, S.G., Mathanpaal, G., Dass, T., 2005. A simple biofilter for treatment of pig slurry in Malaysia. Environ. Technol. 26, 303–312.

Teune, B., 2007. The Biogas Programe in Vietnam; Amazing Results in Poverty Reduction and Economic Development. Boilling Point 53. http://www.docstoc.com/docs/42581979/The-Biogas-Programme-in-Vietnam-Amazing-results-in-poverty, access date: 4.12.11.

Teune, B., 2008. Vietnam Biogas Program – Making Money Out of Green House Gas Reduction by Sustainable Development. http://biogas.org.vn/english/Tin-tuc-Su-kien/Tin-hoat-dong/Chuong-trinh-khi-sinh-hoc-Viet-Nam-voi-doanh-thu-tu-giam-phat-thai-khi-nha-kinh-thong-qua-phat-trien-ben-vung.aspx, access date: 4.12.11.

Thy, S., Preston, T.R., Ly, J., 2003. Effect of retention time on gas production and fertilizer value of biodigester effluent. Livestock Res. Rural Dev. 15 (7). http://www.lrrd.org/lrrd15/7/sant157.htm.

Tuan, V.D., Porphyre, V., Farinet, J.L., Toan, T.D., 2006. Composition of animal manure and co-products. In: Porphyre, V., Coi, N.Q. (Eds.), Pig Production Development, Animal Waste Management and Environmental Protection: A Case Study in Thai Binh Province. Northern Vietnam PRISE Publication, France, pp. 127–143.

Vindis, P., Mursec, B., Janzekovic, M., Cus, F., 2009. The impact of mesophilic and thermophilic anaerobic digestion on biogas production. J. Achievement Mater. Manufacturing Eng. 36, 192–198.

Vu, T.K.V., Tran, M.T., Dang, T.T.S., 2007. A survey of manure management on pig farms in Northern Vietnam. Livest. Sci. 112, 288–297.

Walekhwa, P.N., Mugisha, J., Drake, L., 2009. Biogas energy from family-size digesters in Uganda: critical factors and policy implications. Energy Policy 37, 2754–2762.

Wang, X., 2005. Diffuse pollution from livestock production in China. Chin. J. Geochem. 2 (2), 189–193. doi:10.1007/BF02841165.

Xiaohua, W., Jingfei, L., 2005. Influence of using household biogas digesters on household energy consumption in rural areas- a case study in Lianshui in China. Renew. Sust. Energ. Rev. 9, 229–236.

Xiaohua, W., Chonglan, D., Xiaoyan, H., Weiming, W., Xiaoping, J., Sangyun, J., 2007. The influence of using biogas digesters on family energy consumption and its economic benefit in rural areas-comparative study between Lianshui and Guichi in China. Renew. Sust. Energ. Rev. 11, 1018–1024.

Zeeman, G., Sutter, K., Vens, T., Koster, M., Wellinger, A., 1988. Psychrophilic digestion of dairy cattle and pig manure: start-up procedures of batch, fed-batch and CSTR-type digesters. Biol. Wastes 26, 15–31.