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Reduction of Greenhouse Gas Emissions in Vietnam through Introduction of a Proper Technical Support System for Domestic Biogas Digesters

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Abstract

A domestic biogas digester (BD) is a household-sized system that produces biogas from organic waste under anaerobic conditions. By substituting conventional cooking fuel with biogas, greenhouse gas (GHG) emissions can be reduced. In addition, improved livestock manure management from use of the BD system can lead to further GHG emission reductions. However, because the main component of biogas is methane (CH_4), with 25 times the global warming potential of carbon dioxide (CO_2), leakage of biogas from the BD system can counteract the benefits of this system. Thick vinyl-type BDs were introduced to farming households in a rural area of Vietnam's Mekong Delta in an effort to reduce GHG emissions as a Clean Development Mechanism project. In this project, selected farmers were trained as Key Farmers (KFs). These farmers acquired knowledge about appropriate techniques relating to the BD system and provided technical support to households. Then, biogas usage was monitored in the households where the BD technology was installed. The average proportion of operational BDs reached as high as 92.3%. Therefore, the technical support system provided by the KFs was regarded as practical and effective. Additionally, leakage of biogas from the BD systems was monitored. The average leakage was estimated at 8% of the produced biogas. Including emission reductions from improved livestock manure management, the total GHG emission reductions from the introduction of BD systems was calculated as 2.95 tonnes of CO_2 per year per household. Overall, the emission reduction effects can only be achieved with appropriate installation, operation, and maintenance of the BD systems.

Keywords: domestic biogas digester, GHG emission reduction, leakage, technical support system

1. Introduction

A domestic biogas digester (BD) is a household-sized system that produces biogas from organic waste, such as livestock manure, under anaerobic conditions. A BD system supplies renewable cooking fuel to households, which allows for better manure handling, resulting in reductions in greenhouse gas (GHG) emissions. A BD system also provides regional environmental benefits such as limiting malodors and poor water quality issues. Households employing a BD system benefit from cost savings on cooking fuel expenses (Izumi et al., 2015). Because of these environmental and economic benefits, BDs have been promoted widely in rural areas of developing countries, especially Asian countries such as China, India, Nepal, and Vietnam, and supported by governments and development aid donors.

Introducing and monitoring GHG emission reduction technologies such as BDs in rural areas of developing countries has been regarded as difficult, because GHG emission reductions are small and distributed over large areas. Tubiello et al. (2009) indicated that targeting the rural poor for GHG emission reduction activities is problematic, due to a number of barriers related to governance, technical capability, high transaction costs, lack of appropriate baseline, and monitoring methodologies.

For sustainable BD use, appropriate management, operation, and maintenance of the BD system is required, especially because the main component of biogas is methane (CH_4), a greenhouse gas with global warming potential 25 times greater than that of carbon dioxide (CO_2) (IPCC, 2006). Biogas leaking from a BD system due to poor management can significantly limit the effectiveness of the system in providing reductions in GHG emissions. A previous study pointed out that biogas leaks from poorly maintained BD systems can cancel out the advantages of BDs in terms of global warming mitigation (Bruun et al., 2014). Roubik et al. (2016) conducted a survey in central Vietnam to identify the problems with biogas technology. They reported that the most frequently encountered problem is leakages from BDs, leading to undesired CH_4 emissions.

The Japan International Research Center for Agricultural Sciences (JIRCAS) and Can Tho University (CTU) in Vietnam implemented the Clean Development Mechanism (CDM) Project "Farm Household Biogas Project Contributing to Rural Development in Can Tho City" as part of a collaborative research project. The goal of the project was to reduce GHG emissions by providing thick vinyl-type BDs (Figure 1) to utilize anaerobic fermentation of pig manure at farming households in Can Tho. Selected farmers were trained as Key Farmers (KFs), who acquired knowledge on appropriate techniques relating to the BD systems and provided technical support to households. As of May 2015, 515 BD units had been installed. In June 2015, the United Nations (UN) CDM Executive Board issued Certified Emission Reductions (CER, or carbon credits) for this CDM Project (Izumi et al., 2015; UNFCCC, 2015b).

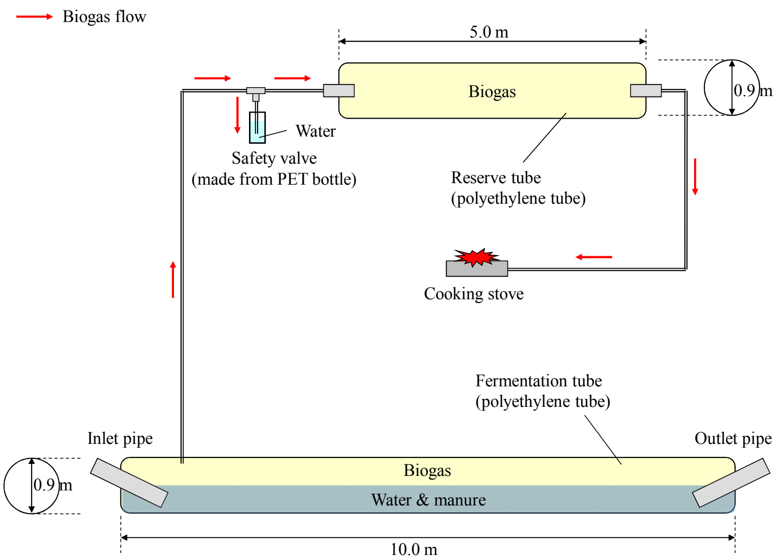

Figure 1. Structural outline of a thick vinyl-type domestic biogas digester (BD)

Generally, agricultural extension systems (agricultural advisory services) do not work well in developing countries. There is limited information available to farmers on extension, operation, and maintenance of BDs. Because of this, a new extension system using KFs to provide technical support on installation, operation, and maintenance of BDs to participants was examined in this study. In addition, to assess the impact of the introduction of thick vinyl-type BD systems on GHG emissions accurately, the effects from biogas leakage and improvements in pig manure handling were included in the assessment.

2. Materials and Methods

2.1 Monitoring of Household Biogas Usage

In CDM projects, monitoring of GHG emission reductions resulting from the project is required to obtain the CERs. For this current CDM project, biogas usage from all households with installed BD systems has been monitored since June 1, 2013 (UNFCCC, 2015a). All households with installed BD systems were asked to record by time category (i.e., none, less than two hours, between two and four hours, or more than four hours) the biogas usage per day. Monitoring records were collected from the households every three months by the KFs, submitted to CTU, and compiled into a database. Based on the monitoring data collected over a period of 2 years and 3 months (June 1, 2013 to August 31, 2015), the monthly proportion of operational BDs was calculated and biogas usage was determined.

In addition, a questionnaire was distributed among participating households to evaluate their satisfaction with their BD system, the perceived effects of introducing GHG emission reduction technology, and the performance of the KFs. From the 515 households that had installed BDs as of May 31, 2015, 257 households (around 50%) were selected randomly for interviews to further evaluate the performance of the KFs.

2.2 Impacts on Greenhouse Gas Emissions after Introduction of a Biogas Digester

GHG emissions before and after BD installation are summarized in Table 1. The most important GHGs from (1) burning of conventional cooking fuel, (2) conventional livestock manure management, (3) leakage from a BD, and (4) leakage from use of nonrenewable woody biomass by nonproject households/users who previously used renewable energy, were estimated by methods further described below. Total reductions in GHG emissions by a BD system were calculated as the sum of the main emission constituents from each activity.

The GHGs targeted in this study were CO_2, CH_4, and nitrous oxide (N_2O). These gases are defined as GHGs in the Kyoto Protocol. This study did not include carbon monoxide (CO), emissions from chemical fertilizer usage, or emissions from using BD effluent as fertilizer. The latter two are affected by many conditions such as soil properties and crop and field management practices.

Table 1. Greenhouse gas emissions before and after biogas digester (BD) installation

	Source	Gas	Included/ Excluded	Justification/Explanation
Baseline scenario	Emissions from the burning of conventional cooking fuel	CO_2	✓	Major constituent of emissions
		CH_4		Excluded for simplification, this is conservative
		N_2O		Excluded for simplification, this is conservative
	Emissions from conventional livestock manure management	CO_2		Excluded as emissions from livestock manure are CO_2 neutral
		CH_4	✓	Major constituent of emissions
		N_2O		Excluded for simplification
	Emissions from chemical fertilizer usage	CO_2		Excluded for simplification
		CH_4		Excluded for simplification
		N_2O		Major constituent of emissions
Project scenario	Emissions from the burning of biogas	CO_2		Excluded as emissions from the burning of biogas are CO_2 neutral
		CH_4		Excluded for simplification
		N_2O		Excluded for simplification
	Leakage from a BD	CO_2		Excluded as emissions from a BD are CO_2 neutral
		CH_4	✓	Major emission constituent for project activity
		N_2O		No N_2O generated from a BD
	Leakage from use of nonrenewable woody biomass by nonproject households/users that previously used renewable energy	CO_2	✓	Leakage from use of nonrenewable woody biomass by non-project households/users that previously used renewable energy is a source according to AMS I. E.
		CH_4		Not a source
		N_2O		Not a source
	Emissions from the usage of effluent as fertilizer	CO_2		Excluded as emissions from effluent are CO_2 neutral
		CH_4		Excluded for simplification
		N_2O		Major constituent of emissions

✓: Target of this analysis

(1) Emissions from the burning of conventional cooking fuel

GHG emissions can be estimated by multiplying the quantity of cooking fuel by the fuel's net calorific value and emission factor. The quantities of cooking fuel used before and after BD installation were obtained from a survey of 66 households conducted between November 2012 and May 2014 (Izumi et al., 2015). Emissions from the burning of nonrenewable firewood, taking into account reductions in emissions resulting from substitution of nonrenewable firewood as an energy source, can be obtained using the following formula (UNFCCC, 2011a):

$$ER_y = B_y \times f_{NRB\text{-}y} \times NCV_{biomass} \times EF_{pf} \quad (1)$$

where

ER_y = emission reductions during year y in tonnes of CO_2 (tCO_2),

B_y = quantity of woody biomass that is substituted during year y in tonnes,

$f_{NRB\text{-}y}$ = fraction of nonrenewable woody biomass used in year y,

$NCV_{biomass}$ = net calorific value of the nonrenewable woody biomass that is substituted in tetrajoules/tonne (TJ t^{-1}), and

EF_{pf} = emission factor for the substitution of nonrenewable woody biomass (tCO_2 TJ^{-1}).

In formula (1), B_y refers to an absolute dry weight of the woody biomass. However, firewood consumption values obtained from the survey refer to an air-dried weight. To account for this difference, the air-dried weight of firewood reported in the survey was converted to absolute dry weight by multiplying by a conversion factor (0.844), specifically developed for this CDM project (Matsubara et al., 2014; UNFCCC, 2015a). Similarly, a conversion factor of 0.7 was developed for f_{NRB-y} (Matsubara et al., 2014; UNFCCC, 2015a).

Emissions from the burning of liquefied petroleum (LP) gas can be obtained using the following formula (UNFCCC, 2011b):

$$BE_{fg} = F_{fg} \times N \times NCV_{fg} \times EF_{fg} \times 10^{-6} \quad (2)$$

where

BE_{fg} = baseline emissions from the burning of fossil fuel for household cooking needs (tCO_2 $year^{-1}$),

F_{fg} = annual amount of fossil fuel used for cooking in an average household participating in the project (kg $year^{-1}$),

N = number of BDs,

NCV_{fg} = net calorific value of fossil fuel (TJ Gg^{-1}), and

EF_{fg} = emission factor of fossil fuel (tCO_2 TJ^{-1}).

GHG emissions from the burning of conventional cooking fuel prior to and following BD installation were estimated by the sum of GHG emissions determined using formulas (1) and (2).

(2) Emissions by conventional livestock manure management

GHG emissions from conventional livestock manure management can be obtained using the following formula (IPCC, 2006):

$$EF_{(T)} = (VS_{(T)} \times 365) \times (B_{o(T)} \times 0.67 \times \sum_{S,K} \frac{MCF_{S,K}}{100} \times MS_{(T,S,K)}) \quad (3)$$

where

$EF_{(T)}$ = annual CH_4 emission factor for livestock from category T (kg CH_4 $animal^{-1}$ $year^{-1}$),

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

365 = basis for calculating annual VS production (day $year^{-1}$),

$B_{o(T)}$ = maximum CH_4 production capacity for manure from livestock from category T (m^3 CH_4 kg^{-1} of VS excreted),

0.67 = conversion factor for m^3 CH_4 to kg CH_4,

$MCF_{(S, K)}$ = CH_4 conversion factor for each manure management system S by climate region K (%), and

$MS_{(T, S, K)}$ = fraction of livestock manure from category T using manure management system S in climate region K (dimensionless).

Baseline emissions (BE_y) in tCO_2 $year^{-1}$ can be calculated using the following formula:

$$BE_y = EF_{(T)} \times N_{(T)} \times GWP_{CH4} \quad (4)$$

where;

$EF_{(T)}$ = annual CH_4 emission factor for livestock from category T (kg CH_4 $animal^{-1}$ $year^{-1}$),

$N_{(T)}$ = number of livestock from category T, and

GWP_{CH4} = global warming potential of CH_4.

The livestock count and conventional livestock manure handling methods were determined based on survey results from 66 households. Total GHG emissions from conventional livestock manure management prior to and following BD installation were estimated using formulas (3) and (4).

(3) Leakage of biogas from a biogas digester

In a thick vinyl-type BD system, produced biogas is stored in a reserve tube and used as fuel for daily cooking. The reserve tube is composed of two thick vinyl layers and measures 0.9 m in diameter and 5 m in length. Due to these space requirements, ordinary BD systems only have one reserve tube. Consequently, when the amount of biogas that is used is less than the amount of produced biogas, excess biogas is emitted into the atmosphere through the safety valve (Figure 1).

To determine the amount of emitted biogas from the safety valve, a gas flow meter was installed on the pipe before and after the safety valve. The volumes of produced biogas (measured by the meter installed before the safety valve) and stored biogas (measured by the meter installed after the safety valve) were monitored for 25 weeks, from March to September 2013. Five households were selected for this monitoring. During the monitoring period, the households recorded the value of the gas flow meters twice a day, in the morning (before cooking) and in the evening (after cooking). The CTU survey team visited the households once a week to collect the monitoring data and to ensure that the gas flow meters were functioning and that the data were recorded correctly.

(4) Leakage from use of nonrenewable woody biomass by nonproject households/users in the project area that previously had BDs

Leakage (*LE*) is defined as the unintended increasing emissions caused by project activity. Within the current CDM project, it was necessary to consider *LE* (Matsubara et al., 2014) because an increase in the availability of firewood was achieved due to the substitution of firewood for biogas. It became necessary to determine whether a conversion from biogas to firewood use occurred in households that had installed a BD prior to the project and, therefore, were not included in the BD installation project. To define *LE*, all households within the CDM project area that had been using BDs prior to the commencement of the project were identified and a survey was distributed to these households to investigate if any of them ceased their use of biogas and returned to using firewood (woody biomass) after the project commenced.

3. Results

3.1 Monitoring of Household Biogas Usage

The monthly percentage of operational BDs from June 2013 to August 2015 is presented in Figure 2.

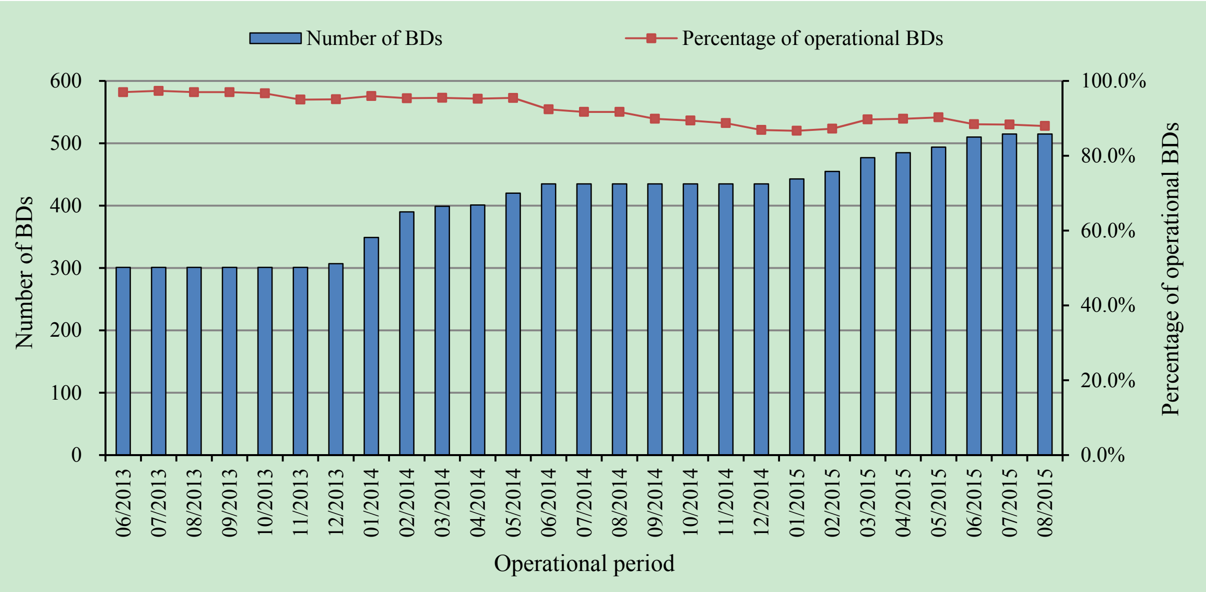

Figure 2. Number and percentage of operational domestic biogas digesters (BDs)

The average percentage of operational BDs during this period was 92.3%. The percentage of operational BDs decreased over time. In August 2015, 453 out of 515 units were in operation (88.0%). The percentages of operational BD units based on years since installation (up to August 2015) are illustrated in Figure 3. The first 39 BDs were installed in December 2011. In August 2015, 32 of these were still operational (82.1%).

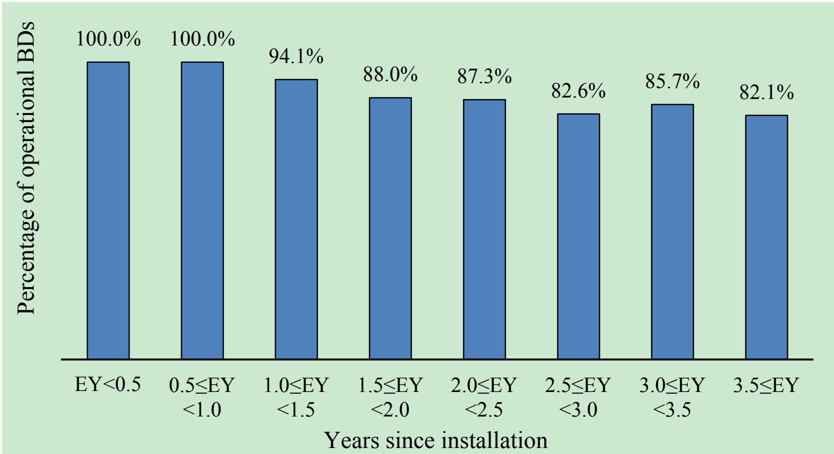

Figure 3. Percentage of operational biogas digesters (BDs) based on years since installation (EY)

The reasons the users were not using biogas as an energy source as of August 2015 are presented in Figure 4. The most common reason was an interruption or cessation in the raising of pigs because of disease, falling sale prices, or labor shortages. BD malfunctioning, which included outlet drainage problems and polyethylene tubing damage from mice or chickens, accounted for approximately 40% of the reasons for not using biogas..

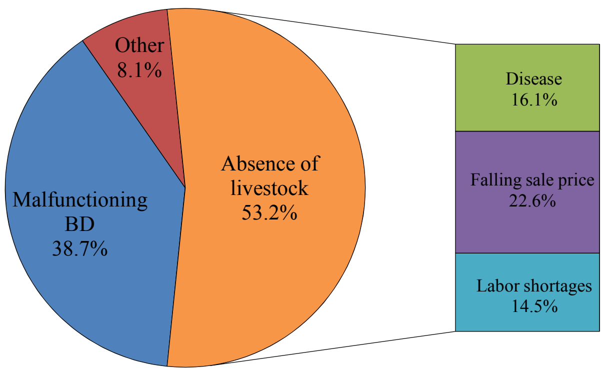

Figure 4. Reasons for not using biogas (as of August 2015)

Questionnaire results from 257 households (response rate 100%) indicated that more than 99% of the households were satisfied with the introduction of the BDs. Only 0.8% (2 households) answered “not satisfied.”

Participating households evaluated the effects associated with the introduction of the BDs. The evaluated effects included cost savings on cooking fuel (firewood and LP gas), time savings from less firewood collection/decreased cooking time, using BD effluent as fertilizer for gardens and ponds, health benefits of avoiding smoke/soot generated from cooking with firewood, and environmental enhancements such as avoiding malodors and poor water quality issues (Figure 5).

Many of these effects were recognized by participating households, particularly the cost and time savings and health and environmental improvements. However, only 30% of participating households recognized the fertilizer value of the BD effluent. This suggests that usage of BD effluent was not popular in the target area. It is possible that this is due to a shortage of land area for gardens and ponds and the requirement of additional labor for transporting and applying the effluent (especially for gardens). In households who did use the effluent as fertilizer, 47% used it for aquaculture, 33% used it for crop production, and 20% used it for both activities. Effluent application in aquaculture is easy and affordable because effluent can be supplied by gravity flow from the BD outlet to the pond. Therefore, it was assumed this was the reason why the number of households using the effluent for aquaculture was higher than it was for crop production.

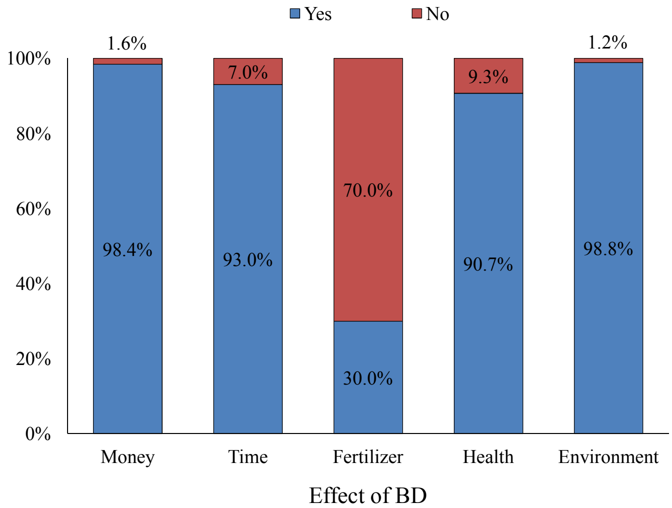

Figure 5. Perceptions of participating households regarding the effects of biogas digester (BD) installation

Money = costs savings on cooking fuel; Time = time savings associated with less firewood collection and cooking time; Fertilizer = using BD effluent as fertilizer for gardens and ponds; Health = health benefits from avoiding smoke and soot generated from cooking by firewood; Environment = Environmental enhancement through limiting malodors and poor water quality issues.

The performance evaluations of the KFs indicated that most households approved of the KFs' activities. The majority of participating households graded their performance as "Good" (Figure 6).

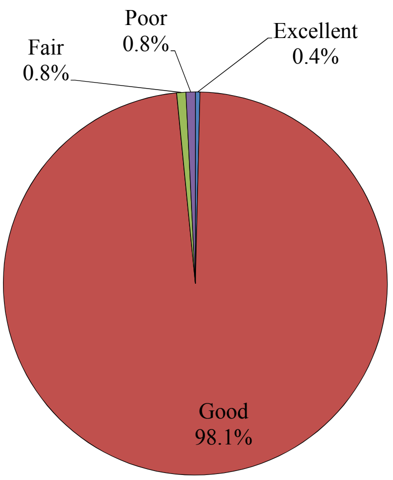

Figure 6. Evaluation of key farmers' (KFs) performance by participating households

3.2 Impact on Greenhouse Gas Emissions after Introduction of Biogas Digesters

(1) Emissions from the burning of conventional cooking fuel

According to Izumi et al. (2015), the quantities of firewood and LP gas consumed prior to BD installation were 3.09 t year^{-1} household^{-1} and 27.3 kg year^{-1} household^{-1} respectively. Following BD installation, these figures dropped to 0.70 t year^{-1} household^{-1} and 2.4 kg year^{-1} household^{-1} respectively (Table 2). The reductions in firewood and LP gas consumption were 77.3% and 91.2% respectively. These values were entered into formulas (1) and (2) to determine GHG emissions prior to and following BD installation (Table 2). The annual reduction in emissions was calculated as 1.87 tCO_2 year^{-1} household^{-1}.

Table 2. Changes in household cooking fuel consumption and greenhouse gas (GHG) emissions before and after biogas digester (BD) installation. Note that firewood consumption here includes firewood used to prepare pig feed

Item		Before BD installation	After BD installation	Difference
Cooking fuel consumption	Firewood (t $year^{-1}$)	3.09	0.70	-2.39
	Liquefied petroleum gas (kg $year^{-1}$)	27.3	2.4	-24.9
GHG emission (tCO_2 $year^{-1}$)	Firewood	2.33	0.53	-1.80
	Liquefied petroleum gas	0.08	0.01	-0.07
	Total	2.41	0.54	-1.87

(2) Emissions from conventional livestock manure management

The most important livestock in the target area was pigs, and the average number of pigs per household is summarized in Table 3.

Table 3. Average number of pigs per household

	Sows	Fattening pigs	Piglets	Total
Average number	1.87	9.67	4.95	16.49

The average number of pigs was 12 per household excluding piglets. The capacity for pig manure treatment in one BD system is limited by the size of the fermentation tube (approximately 10 m long and 0.9 m in diameter, (Figure 1)). Four pigs are assumed to provide sufficient manure for one BD system. In the target area, the conventional pig manure handling method consisted of disposal into a nearby waterbody such as a pond, canal, or river. This manure handling method was regarded as similar to deposition in lagoons (IPCC, 2006). Changes in pig manure handling before and after BD installation are summarized in Table 4.

Table 4. Changes in manure handling methods before and after biogas digester (BD) installation

Item		Before BD installation	After BD installation	Difference
Manure management system (manure from # of pigs)	Lagoon	12	8	-4
	BD	0	4	4
	Total	12	12	0
Greenhouse gas emission (tCO_2 $year^{-1}$)	Lagoon	5.11	3.40	-1.71
	BD	0.00	0.21	0.21
	Total	5.11	3.61	-1.50

Based on the numbers presented in Table 4, GHG emissions prior to and following BD installation were calculated using formulas (3) and (4). GHG emissions were estimated at 5.11 tCO_2 $year^{-1}$ prior to BD installation and 3.61 tCO_2 $year^{-1}$ following installation. The reduction in GHG emissions from the improvement of livestock manure management was estimated at 1.50 tCO_2 $year^{-1}$ (Table 4).

(3) Leakage from biogas digester

The weekly production, storage, and leakage of biogas from five selected households are illustrated in Figure 7. Biogas production fluctuates with factors such as quantity of feedstock, retention time, and temperature. The results of the survey showed that average daily production, storage, and leakage of biogas were 1.17 m^3, 1.08 m^3, and 0.09 m^3 respectively. This suggests that approximately 8% of the produced biogas leaked into the atmosphere during the monitoring period. The global warming potential of CH_4 is 25. Assuming the CH_4 content in biogas is 60%, and with CH_4's density at 0.67 kg m^{-3} (UNFCCC, 2012), this biogas leakage can be translated to 0.33 tCO_2 $year^{-1}$ $household^{-1}$.

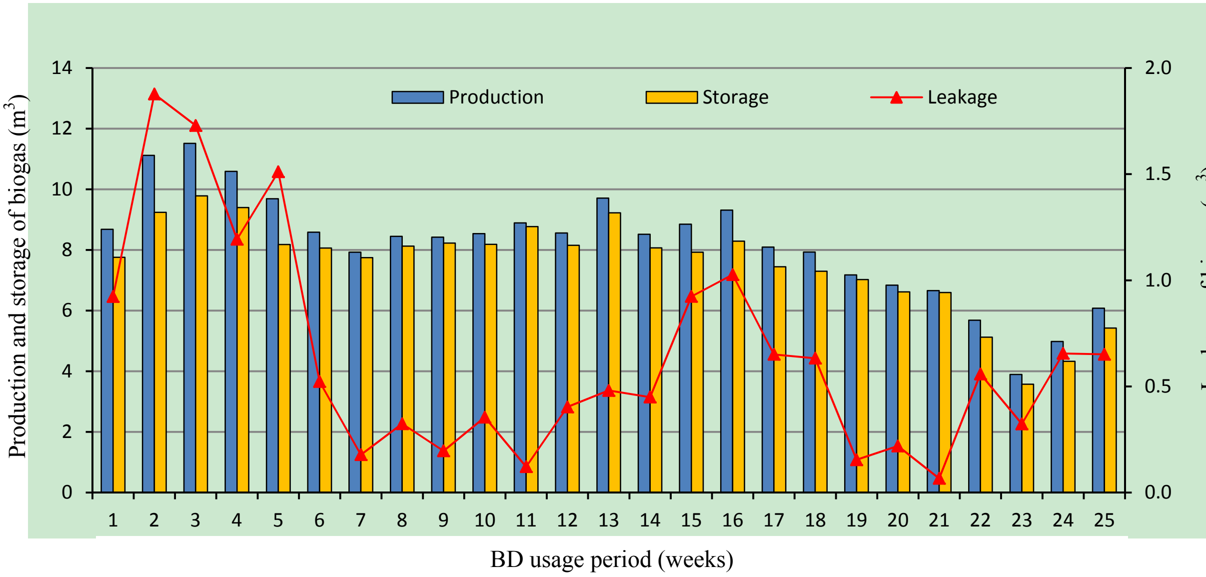

Figure 7. Production, storage, and leakage of biogas from a biogas digester (BD) system

(4) Leakage from use of nonrenewable woody biomass by nonproject households/users that had biogas digesters installed prior to the project

The investigation into the numbers of pre-existing BDs for the purposes of evaluating *LE* showed that among the 130 rural communities within the CDM project area, 280 BD units were installed in 46 communities prior to the project. Of these 280 units, 216 were in operation during the investigation. Firewood became more easily accessible due to the increase in biogas use by the households where BDs were installed for this project. It was found that the operation of pre-existing BDs was not affected by the increased availability of firewood, and their continued use or abandonment occurred for other reasons. The results of the survey indicated that *LE* = 0; however, from a conservative standpoint, *LE* was set to 5% of the emission reductions (UNFCCC, 2011a). Thus, *LE* was calculated at 0.09 t CO_2 year^{-1}.

The total impact on GHG emissions from the introduction of the BD systems is summarized in Table 5. Reductions in GHG emissions, taking into account improved pig manure management and leakage of biogas from the BD system, were estimated at 2.95 tCO_2 year^{-1} per BD system. GHG emissions before and after BD installation are displayed in Figure 8.

Table 5. Changes in greenhouse gas (GHG) emissions before and after biogas digester (BD) installation

Item			Gas	GHG emission (tCO_2)			Source
				Before	After	Difference	
(1)	Conventional cooking fuel usage	Firewood	CO_2	2.33	0.53	-1.80	Measured
		Liquefied petroleum gas	CO_2	0.08	0.01	-0.07	
		Total		2.41	0.54	-1.87	
(2)	Conventional livestock manure management		CH_4	5.11	3.61	-1.50	Estimation based on Intergovernmental Panel on Climate Change default value
(3)	Leakage from BD		CH_4	0.00	0.33	0.33	Measured
(4)	Leakage from use of nonrenewable woody biomass		CO_2	0.00	0.09	0.09	Assumed as 5% of nonrenewable firewood
	Total			7.52	4.57	-2.95	

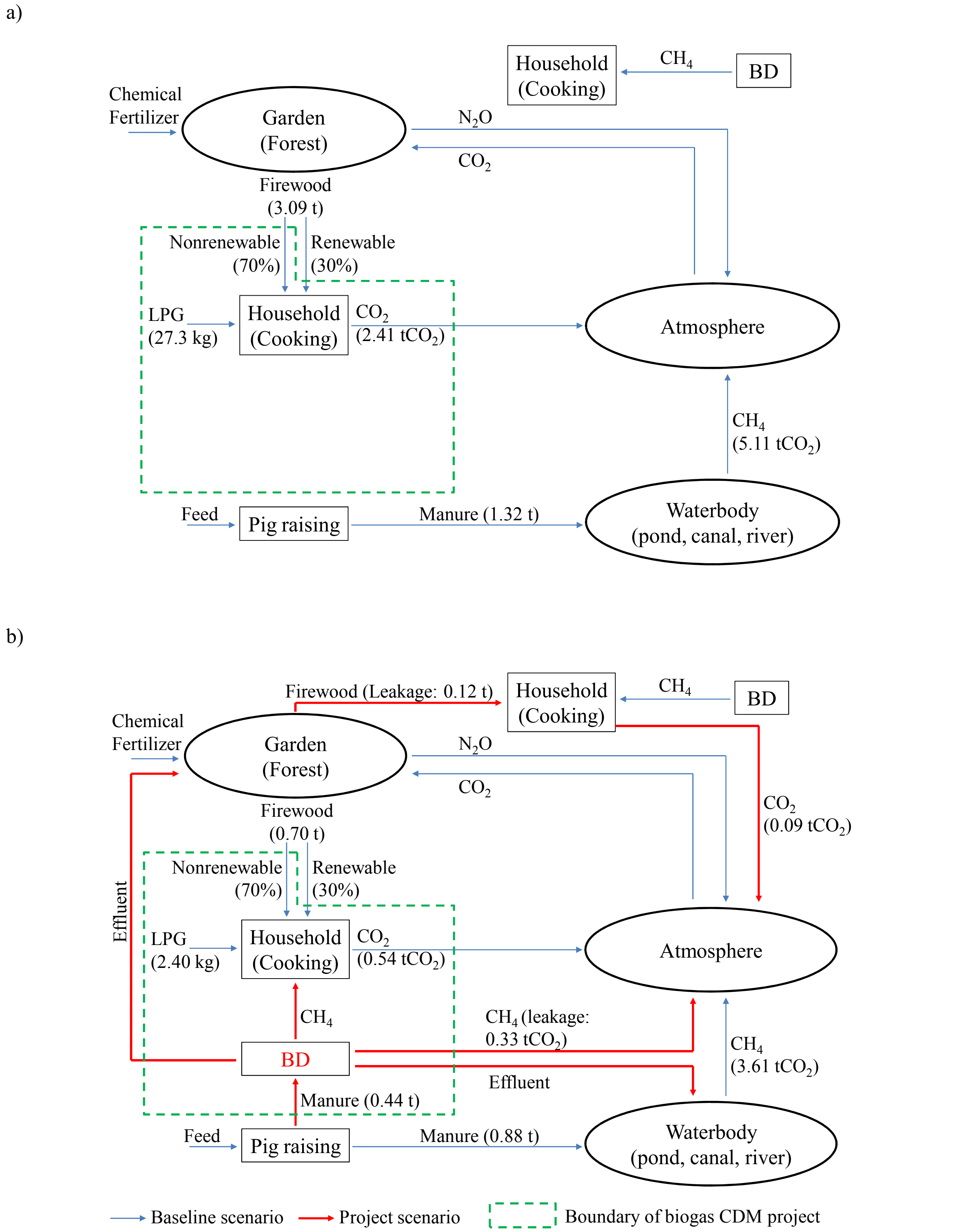

Figure 8. Greenhouse gas emission a) before and b) after biogas digester (BD) installation. Firewood: air-dried weight (t); Manure: volatile solid excreted (t)

4. Discussion and Conclusions

Biogas usage was monitored in households with introduced BD systems for a period of 2 years and 3 months. The results indicated that on average 92.3% of the BD systems were in operation during this time. Between 2008 and 2009, prior to the implementation of the CDM project, the status of 61 existing units of thick vinyl-type BDs was investigated. The proportion of farmers who were using them under favorable conditions was approximately 48% (Matsubara et al., 2014). Jiang et al. (2011) pointed out that the shortage of skilled workers in rural areas was leading to improper handling of BD systems. The ratio of BDs properly operated in China is approximately 60% (Zhang et al., 2006). Although a simple comparison is difficult, the installation of BDs by KFs, who providing a support system for maintenance, appeared to effectively improve the proportion of operating BD systems and increase the lifespan of the systems. This finding is corroborated by the KFs themselves. The KFs were satisfied with the installation of the BDs and recognized the system's good performance and effectiveness.

The amount of biogas leaking from the BDs was measured in the project. The leakage of biogas has the potential to offset the reductions in GHG emissions attributed to biogas use as an alternative for other cooking fuels (43.6%, 0.51 m^3 day^{-1}). These reductions equate to 1.87 tCO_2 per year. If biogas leakage exceeds this, the reduction in emissions is offset, leading instead to increased emissions. Bruun et al. (2014) estimated that leakage from BDs is approximately 40% and improper management of BDs, or use of biogas, is likely to counterbalance the effects of GHG emission reductions associated with BD installations. It should be noted that this analysis took into account the reduced amount of firewood used for preparation of livestock feed (replaced by biogas). According to Vu et al. (2015), Vietnamese pig farming is expanding, leading to increased amounts of waste and use of artificial feed. This could result in an increase in biogas generation when BDs are used. With the use of artificial feed, fuel used for preparation of livestock feed will no longer be needed. Ultimately, these changes will lead to a reduction in the consumption of biogas and potentially increasing biogas leakage.

To reduce excess biogas leakage, effective use of the biogas must be ensured. For this, two conceivable options are (1) supplying surplus biogas to neighbors, etc. (cooperative use); and (2) use for purposes other than for cooking fuel. Between these, a survey of 66 households confirmed that six households (9.1%) were using surplus gas cooperatively among relatives. When cooperatively used, gas is supplied by hoses fed from the reserve tube at the source. For this reason, cooperative use is limited to households in close proximity to the source. Currently, gas is supplied at no charge because the gas is utilized among relatives. However, an appropriate fee for gas usage could be collected in the future covering costs associated with the maintenance and management of the BDs, if the supply of gas is expanded beyond relatives.

The evaluation of the perceived effects of BD installation by households revealed that the usage of BD effluent as fertilizer is not progressing in the target areas. For this reason, GHG emissions from the application of chemical fertilizers and BD effluent as fertilizer were excluded from the analysis. However, to define the full potential for reduction of emissions from BD installations accurately, further analysis should include these factors.

Reduction of GHG emissions as a result of BD installation will be a reality only when BDs are properly installed, maintained, and managed. In this project, a support system for the maintenance and management of BD systems by KFs improved the percentage of operating BD systems, and suggested the possibility of increased lifespan of the systems. When promoting BD installation in any area, it is important to consider that the construction, maintenance, and management of the BD systems must be based on the local situation.

During the twenty-first session of the Conference of the Parties (COP 21) (United Nations Framework Convention on Climate Change) held in Paris, December 2015, the "Paris Agreement" was adopted. This is a new international framework for the mitigation of global warming, in which all countries, including developing countries, participated. It includes GHG emission reduction targets for all countries, which are submitted to the United Nations, and must be reviewed every five years (UNFCCC, 2015c). The results of this project provide suggestions for developing countries when creating and realizing future emissions reduction goals.

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