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# Effect of Appropriate Technology Introduction to Farm Households in Vietnam for GHG Emission Reduction

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**Abstract**

In June 2015, carbon credits amounting to 446 t of $CO_2$ were issued for a Clean Development Mechanism (CDM) project developed and implemented in Vietnam's Mekong Delta aimed at reducing greenhouse gas (GHG) emissions through the introduction of biogas digesters (BDs) to farm households. Subsequently, the project was evaluated in terms of GHG emission reductions (i.e., carbon credits issued), receptiveness of farm households to the technology, and economic benefits to these families. Findings confirmed that BDs provide concrete reductions in GHG emissions and are beneficial to install in such scenarios. Currently, a new international framework for post-2020 global warming mitigation is being considered by the United Nations Framework Convention on Climate Change (UNFCCC), in which all signatory countries would participate, including the developing countries that have not yet been mandated to make reductions. These evaluation results present a potential policy direction for developing countries to reduce their GHG emissions.

**Keywords:** biogas digester, carbon credit, CDM, GHG emission reduction, sustainable development

## 1. Introduction

### *1.1 Background*

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concludes that the "warming of the climate system is unequivocal," and predicts that by the end of the 21$^{st}$ century the global mean temperature could increase by up to 4.8ºC and sea levels could rise by up to 82 cm (IPCC, 2014). The same report predicts, "given the strong dependence in rural areas on natural resources, the impacts of climate change on rural livelihoods and incomes are *likely* to be especially serious." For developing countries highly reliant on primary industries, the effects of climate change are substantial. Meanwhile, the UNFCCC Conference of the Parties (COP), which assesses global warming mitigation measures, is considering a new post-2020 international framework in which all countries would participate, including developing countries that have not yet been obligated to reduce GHG emissions, with an agreement expected in 2015 at the convening of COP21 in Paris.

Established under the UNFCCC Kyoto Protocol, the Clean Development Mechanism (CDM) is a system to trade emission reduction units created through emissions reduction projects established in developing countries. The CDM also aims to contribute to the sustainable development of developing countries. Most CDM projects thus far have emphasized efficient GHG reductions (WB, 2014) and few projects have taken root in rural areas of developing countries where developmental challenges such as poverty are prevalent. However, analyses of CDM projects to date conclude that they either do not contribute to sustainable development (Olsen, 2007) or have no effect on reducing poverty in rural areas (Sirohi, 2007). A primary reason for the reluctance of developing countries to participate in GHG emission reduction frameworks is that the usefulness of such frameworks within these countries is not evident to them. However, rural areas within developing countries are not only the most vulnerable to the impacts of global warming but are also the primary source of these countries' GHG emissions. Therefore, it is essential to clarify the benefits of reducing GHG emissions in rural parts of developing countries (Izumi et al., 2014).

In June 2015, the UN CDM Executive Board issued Certified Emission Reductions (CER, or carbon credits) for the CDM Project "Farm Household Biogas Project Contributing to Rural Development in Can Tho City." The project was created and implemented with the participation of the Japan International Research Center for Agricultural Sciences (JIRCAS), Can Tho University (CTU), and Can Tho City Government, Vietnam (UNFCCC, 2015b). The goal of the project is to reduce GHG emissions by providing biogas digesters (BDs), utilizing anaerobic fermentation of pig excreta, to farm households in Can Tho. This is the first Japanese designed CDM project targeting biogas utilization by low-income farm households (Izumi et al., 2013).

The BDs supplied through the project are made of thick plastic (Figure 1) and are financially affordable by farm households (Matsubara et al., 2014). The major structure, the fermentation tube, is composed of three layers of thick vinyl 0.9 m in diameter and 10 m in length. For safety reasons, when pressure is too high, surplus biogas will be emitted to the atmosphere through a safety valve made from a PET bottle. Excreta from pigs weighing a total of 200 kg will provide enough biogas for cooking for 3-5 family members (Vo et al., 2002). Previous financial and economic evaluations of BDs have been based on pre-existing information or limited results of rural surveys, and most have focused on concrete BDs. Some evaluations conclude that insufficient know-how among farm households and the lack of essential technical support hinder the implementation of BDs and point to the need for increased farmer training and government and non-government organizational support. Since these evaluations are not based on observations of actual projects, the quantitative effects and the feasibility of increasing the use of plastic BDs remain unclear.

In light of the issuance of CERs from the CDM project, this paper evaluates the effects of the introduction of plastic BDs on GHG emission reductions (CERs issued), the receptiveness of farm households to the technology, and the economic benefits to these households. On the basis of this evaluation, this study will also examine the possibilities for and direction of increased future BD implementation.

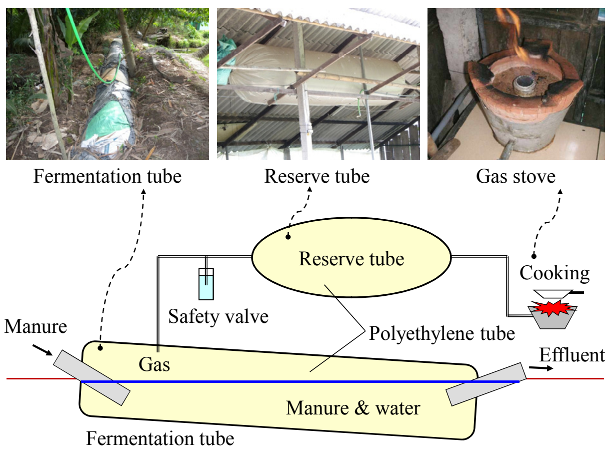


Figure 1. Plastic biogas digester (BD) system

### *1.2 CDM Project Background*

From 2008, JIRCAS and CTU have worked on a CDM project to substitute cooking fuel used by farm households in Vietnam's Mekong Delta with biogas from BDs (Matsubara et al., 2011). CDM projects are divided into a planning stage, in which the project is designed and registered with the UN CDM Executive Board, and an implementation stage. The implementation stage involves the installation of GHG emissions reduction technology, monitoring of the amount of emissions reduced, and the issuing of CERs corresponding to the amount of emissions reduced. The CDM project plan in question provides for annual monitoring of GHG emission reductions.

The chronology of the CDM project developed by JIRCAS and CTU is outlined in Table 1. After project initiation in 2008, all data required to produce a Project Design Document (PDD) were collected through various surveys and experiments. In January 2011, a validation of the PDD was conducted by the Designated Operational Entity (DOE). Issues highlighted by the DOE were resolved, and the project was registered with the CDM Executive Board in August 2012 with the approval of the Japanese and Vietnamese governments. It took approximately four years from project initiation to registration. Prior to project registration, starting in November 2011, a number of BDs had already been installed in households and farmers had been trained on the technology.

The first monitoring period occurred between June 1, 2013 and May 31, 2014, and biogas usage from BDs installed by farm households was recorded. A Monitoring Report (MR) was then compiled and in October 2014 the DOE reviewed the results. The MR was revised in light of issues flagged by the DOE and CERs were issued in June 2015.

Table 1. The chronology of a household biogas Clean Development Mechanism project

| Month | Year | Item |
|---|---|---|
| Oct. | 2008 | Launch of project activities |
| | | Data collection, preparation of PDD |
| Jan. | 2011 | Validation of PPD by DOE |
| Sept. | | Approval by the gov. of Japan |
| Nov. | | Start BD installation |
| Feb. | 2012 | Approval by the gov. of Vietnam |
| Aug. | | Registration with UNFCCC (CDM-EB) |
| June | 2013 | Start 1$^{st}$ monitoring period |
| May | 2014 | End 1$^{st}$ monitoring period |
| June | | Start 2$^{nd}$ monitoring period |
| Oct. | | Verification by DOE |
| May | 2015 | End 2$^{nd}$ monitoring period |
| June | | Issuance of CER (for 1$^{st}$ monitoring period) |

*Note*.

PDD Project Design Document

DOE Designated Operational Entity

BD Biogas Digester

UNFCCC United Nations Framework Convention on Climate Change

CDM Clean Development Mechanism

EB Executive Board

CER Certified Emission Reductions

## 2. Method

Actual BD installations and biogas usage were monitored to evaluate the reduction in GHG emissions, the receptiveness of farm households towards the technology, and the economic benefit to households participating in the project. GHG emission reductions were calculated, and sampling surveys and financial analyses of farm households were conducted, as detailed below.

### *2.1 Installation of Biogas Digesters*

The 961 households participating in the project were located in 17 wards, communes and town within three districts of Can Tho (Izumi et al., 2013). One-half of the cost of installation of each BD was borne by the project promoter while the other half was borne by the participating household (Matsubara et al., 2014). Training sessions were conducted to introduce the technical aspects of the BDs, and Key Farmers (KFs) trained to provide guidance to households within each hamlet supervised the installation of the BDs. With the support of the KFs, BDs were installed in each farm household through the following process:

(1) Prioritization of households

After consultation with the People's Committee representative from each ward and commune in which participating households were located, CTU staff prioritized households for BD installation. The order of installation was determined primarily by considering household requests and resources (number of pigs, land area, etc.).

(2) Preliminary survey

CTU staff and KFs visited selected households beforehand and determined the feasibility of BD installation in light of current conditions (number of pigs, land area, cooking fuel, etc.). In cases where BD installation was deemed appropriate, an installation schedule was created in consultation with the household.

(3) Preparation

Prior to the installation date, a farm household prepared for the BD installation by digging a ditch with dimensions 10 m × 0.8 m × 0.8 m for installation of the fermentation tube. In addition, KFs arranged for the materials and tools required for the BD installation.

(4) BD installation

CTU staff, KFs, and farm households jointly installed the BDs. In most cases, installation was completed in approximately one day.

*2.2 Monitoring of Biogas Usage*

Monitoring of biogas usage started when farm households first utilized the biogas produced by the BD. The first monitoring period occurred between June 1, 2013 and May 31, 2014. During this period, record sheets were distributed to all BD-installed households and they were asked to record their cooking fuel usage, including biogas. Monitoring components included the hours of biogas usage (none, less than two hours, more than two and less than four hours, more than four hours); firewood usage (kg); liquefied petroleum (LP) gas usage hours and electricity usage hours (i.e., for rice steamers). Households were also asked to record changes in domestic livestock numbers or any problems while operating their BD. As a general rule, records were kept by the farm households under the direction of CTU staff and KFs, although in some cases KFs recorded data they had gathered from the households. The monitoring records were collected every three months by KFs, submitted to CTU, and compiled into a database.

The amount of emission reduction is either the amount of biogas production from the BDs or the amount of non-renewable fuel replaced by biogas. It was necessary to install an expensive gas meter for each BD to measure biogas production. Therefore, to keep costs low, the measurement method selected was the estimation of non-renewable fuel replaced by biogas. For this reason, the monitoring parameter required by PDD is the number of operating BDs (UNFCCC, 2015a), and to confirm this, biogas use hours were monitored on a daily basis. Electricity usage hours were monitored to confirm the effect of biogas usage on electricity usage. Electricity is supplied from a national grid; and was therefore, excluded from the emission calculation.

*2.3 Calculation of Emission Reductions*

The reduction in GHG emissions during the first monitoring period was calculated based on the results of biogas usage among farm households. The CDM project focused on reducing emissions from non-renewable firewood (woody biomass) and LP gas used by households for cooking (Matsubara et al., 2014). The amount of GHG emissions reduced can be estimated by multiplying the quantity of cooking fuel displaced by biogas by its net calorific value and emission factor. In the AMS-I.E CDM methodology, emission reductions from non-renewable firewood are 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 $tCO_2$

$B_y$ = Quantity of woody biomass that is substituted or displaced during year $y$ in tonnes

$f_{NRB\text{-}y}$ = Fraction of woody biomass used in the absence of the project activity in year $y$ that can be established as non-renewable biomass using survey methods

$NCV_{biomass}$ = Net calorific value of the non-renewable woody biomass that is substituted ($TJ\ t^{-1}$)

$EF_{pf}$ = Emission factor for the substitution of non-renewable woody biomass by similar consumers ($tCO_2\ TJ^{-1}$).

In addition, emission reductions from LP gas are obtained by the following formula from the AMS-I.C CDM methodology (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 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 $Gg^{-1}$)

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

According to Matsubara et al. (2014), from IPCC default values and baseline surveys, the current CDM project assumes $ER_y$ = 1.407 $tCO_2$/household, $BE_{fg}$ = 0.053 $tCO_2$/household and $BE$ (annual baseline emissions) = 1.46 $tCO_2$ $year^{-1}$/household.

The annual emission reductions (*ER*) are calculated by subtracting from *BE*, emissions from the project activity during the year (*PE*) and emissions increasing outside of the project boundary due to project activity (*LE*). Within the current project, *PE* did not occur, although it was necessary to consider *LE* during monitoring (Matsubara et al., 2014). In order to define *LE*, all households within the CDM project area that had been using BDs before the project commenced were identified, and a survey was conducted to ascertain if any of the households had ceased their use of biogas and returned to using firewood (woody biomass) after the project commenced. After calculating *LE*, the value was subtracted from *BE* to arrive at *ER*.

Annual emission reductions for the entire project ($ER_y$) were calculated by totaling *ER* from the number of days of BD operation within each BD household in the given year, using the following formula:

$$ER_y = \sum_{i=1}^{n} ER \times (1/365) \times ODi \quad (3)$$

where

$ER_y$ = Annual emission reductions for the entire project ($tCO_2$)

$ER$ = Unit emission reduction of BD ($tCO_2$ $year^{-1}$)

$OD_i$ = Operation days of BD use by household $i$ (days $year^{-1}$)

$n$ = Number of monitored households operating BD

*2.4 Sampling Surveys*

From the 961 households participating in the project, 100 were randomly selected to ascertain their usage of cooking fuels prior to BD installation through surveys conducted via a questionnaire. From these 100 households, the 66 that had completed BD installation before the end of the first monitoring period (May 31, 2014) were revisited after their BD installation; when interviews were conducted and questionnaires filled out to confirm their biogas usage. Changes in cooking fuel usage due to the introduction of BDs were analyzed by comparing the survey results pre- and post-BD installation. The surveys focused primarily on the type and amount of fuel used for cooking, the time required to collect firewood, and expenditure on fuel purchase. Surveys were conducted by JIRCAS and CTU researchers.

*2.5 Financial Analyses of Farm Households*

In order to conduct a cost-benefit analysis of the introduction of BDs to farm households, data obtained from the sampling surveys regarding cooking fuels pre- and post-BD installation, as well as project performance, provide the basis for a calculation of net present value (NPV) using the following parameters:

・ Initial costs: BD cost = USD140; household labor cost = USD20; labor and transportation costs for KFs providing technical support = USD20; Total = USD180

・ Maintenance costs: Labor and transportation costs for biannual inspection by KFs = USD20

・ Benefit of BD installation to farm households: Annual savings on fuel costs according to sampling surveys

・ Useful life of BD: 7 years (UNFCCC, 2015a)

・ Discount rate: Interest rate of 6.0%/year if deposited for 12 months with Joint Stock Commercial Bank for Foreign Trade of Vietnam (Vietcom Bank)

Prior to BD installation, the conventional treatment of pig excreta was flushing with water and discharge into a pond or canal through a PVC pipe. After BD installation, the pig excreta are flushed using water and discharged into the fermentation tube through a PVC pipe. Thus, there is no change in labor cost for the collection of pig excreta before and after BD installation. Therefore, labor cost for collection of pig excreta is not considered in this study.

Decreases in the useful life of BDs, cost increases, and varied subsidies for initial costs were considered for the purposes of sensitivity analysis.

## 3. Results

### *3.1 Number of BD Installations*

BD installation began in November 2011, with 301 units installed by the beginning of the project's first monitoring period (June 1, 2013). The following year, 134 units were installed; bringing the total of installed units to 435 by the end of the first monitoring period. During the second monitoring period, an additional 80 units were installed, with a total of 515 units installed as of May 31, 2015 (Figure 2).

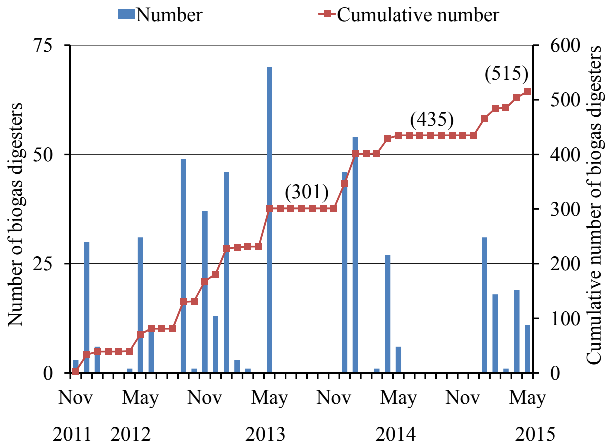


Figure 2. Progress of biogas digester (BD) installations

### *3.2 Results of Biogas Usage Monitoring*

Biogas usage by farm households during the first monitoring period is shown in Table 2. Of the total number of monitored days in the period (122 296), biogas was used during 117 062, or 95.7%, of these days (unit operating days). The average usage time during this period was 2.9 h. Figure 3 shows the rates of post-installation BD operation based on the number of elapsed years (proportion of BD operating days to total number of days). Observations show operating rates tended to decrease over time after BDs were installed.

Of the 301 households that had installed BDs when monitoring began, four households did not utilize biogas at all during the monitoring period. Of those households that had installed a BD towards the end of the monitoring period, 15 were unable to begin using biogas by the end of the monitoring period. Therefore, there were 416 operational units and 19 non-operational units during this monitoring period.

The reasons for nonuse of biogas during the first monitoring period are shown in Figure 4. The most common reason was an interruption in the raising of pigs (54.5%) resulting in temporary shortages of BD input, due to the sale of adult pigs or disease, as well as the abandonment of pig farming due to disease, falling sale prices, or labor shortages. On the other hand, BD malfunction led to 29.6% of non-utilization.

Table 2. Breakdown of biogas usage by farm households during the first monitoring period

| Time (h) | 0 | 0-2 | 2-4 | 4+ | Total |
|---|---|---|---|---|---|
| Days | 5 234 | 15 469 | 67 605 | 33 988 | 122 296 |
| (%) | 4.3 | 12.6 | 55.3 | 27.8 | 100.0 |

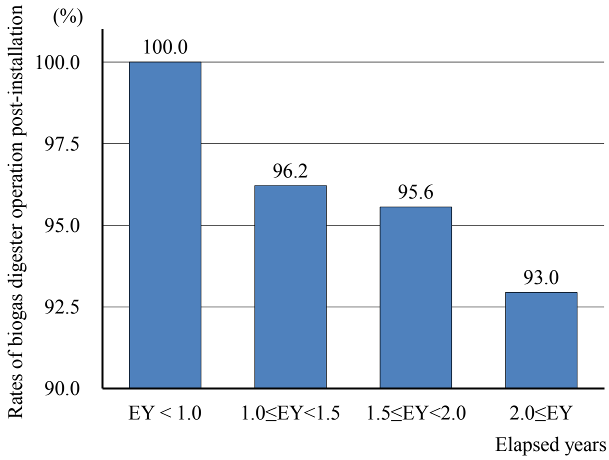


Figure 3. Rates of biogas digester (BD) operation post-installation based on number of elapsed years (EY)

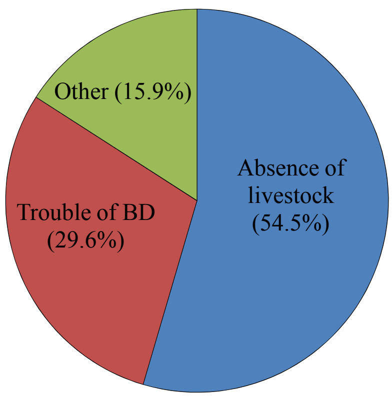


Figure 4. Reasons for nonuse of biogas during first monitoring period

*3.3 GHG Emission Reductions*

From biogas usage monitoring data, entering the number of BD operating days in the first monitoring period into formula (3) shows a reduction of emissions of 468 $tCO_2$ $year^{-1}$ for the project as a whole.

Ascertaining pre-existing BD numbers for the purposes of evaluating *LE* showed that, among the 130 hamlets within the CDM project area, 280 BD units were installed in 46 hamlets, with 216 in operation. The operation of these pre-existing BDs was not affected by more easily available firewood due to the increase of biogas use by other households under the project, and their continued use or abandonment occurred for other reasons. Survey results indicated that $LE$ = 0; however, from a conservative standpoint, *LE* was set at 5% of the emission reductions from displacing non-renewable firewood as shown in the AMS-I.E. CDM methodology (UNFCCC, 2011a). Multiplying $B_y$ obtained from formula (1) by 5% and subtracting the result from *BE*, $ER$ = 1.39 $tCO_2$ $year^{-1}$/household. From this, using formula (3), the annual emission reductions for the entire project during the first monitoring period were calculated at 446 $tCO_2$ $year^{-1}$.

*3.4 Changes to Cooking Fuel Usage*

Pre-BD installation surveys of 100 farm households revealed that firewood, LP gas, and electricity were the main sources of energy for cooking, while rice husks and sawdust were also used (Table 3). Besides cooking applications, fuel was also used to prepare pig feed and to make processed goods such as alcohol, with 57% and 29% of households consuming fuel for these purposes, respectively. To obtain firewood, 69% of households collected it themselves while 21% purchased firewood, and 10% engaged in both activities.

Results from a survey of 66 households after they had begun using biogas are summarized in Figure 5, which shows changes in cooking fuel usage pre- and post-BD installation. Conventional BDs are normally connected to cooking stoves and are thus not accessible for use in preparing pig feed or producing alcohol. Therefore, looking only at cooking applications, of the 66 households surveyed, 50 (75.8%) used firewood, 48 (72.7%) used LP gas, and 54 (81.8%) used electricity prior to BD installation. Following BD installation, these figures dropped to 19 (28.8%), 13 (19.7%), and 39 (59.1%), respectively, with 58 (87.9%) of the households using biogas.

Eight households did not use biogas for cooking. Among these, two (3.0%) experienced trouble with their BDs and were unable to utilize the gas, while the remaining six (9.1%) households only used biogas to prepare pig feed. The households using biogas for pig feed had installed their own custom-built stoves for this application.

Reasons for the continued use of conventional fuels after BD installation included BD malfunctions, insufficient amounts of biogas for cooking that required supplementing with firewood or LP gas, and usage of biogas to prepare pig feed. In the second instance, households utilized biogas to replace some firewood or LP gas consumption. In the third instance, some households were hesitant to use biogas in preparing food and continued to use firewood and LP gas for cooking. In households using biogas for pig feed preparation, biogas replaced firewood for this application.

Prior to BD installation, an average of 1.59 t of firewood (dry weight) and 27.3 kg of LP gas were used annually for cooking. After BD installation, these quantities decreased to 0.32 t and 2.4 kg, respectively. The average annual amount of firewood used to prepare pig feed was 1.5 t prior to BD installation and dropped to 0.38 t post-installation.

From these reductions in non-renewable fuel use, annual savings on fuel expenditures due to BD installation were calculated at USD13 for firewood and USD41 for LP gas, for a total savings of USD54. Furthermore, a 66 h annual reduction in the time required to collect firewood was projected, resulting in a savings of USD41, assuming a local average daily wage of USD5. Accordingly, if the labor savings associated with firewood collection are taken into account, the total annual savings per household in fuel expenses were estimated to be around USD95.

Table 4 summarizes the changes related to farm household cooking fuels prior to and following BD installation as identified by sampling surveys.

Table 3. Type of fuel used for cooking by farm households

| Item | Firewood | LP gas | Electricity | Rice husk | Sawdust |
|---|---|---|---|---|---|
| Used (%) | 94 | 74 | 78 | 28 | 12 |
| Unused (%) | 6 | 26 | 22 | 72 | 88 |

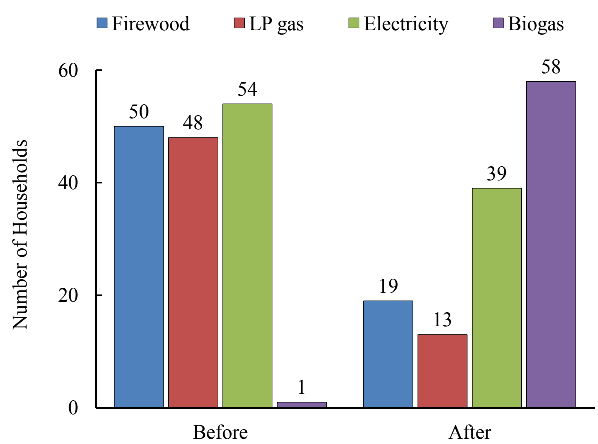


Figure 5. Changes in cooking fuel usage before and after biogas digester (BD) installation

Table 4. Changes related to farm household cooking fuels before and after biogas digester (BD) installation

| Item | | | Before | After | Difference |
|---|---|---|---|---|---|
| Amount of cooking fuel used | Firewood ($t\ year^{-1}$) | Cooking | 1.59 | 0.32 | -1.27 |
| | | Pig feed | 1.50 | 0.38 | -1.12 |
| | | Total | 3.09 | 0.70 | -2.39 |
| | LP gas ($kg\ year^{-1}$) | | 27.3 | 2.4 | -24.9 |
| GHG emissions ($tCO_2\ year^{-1}$) | Firewood | Cooking | 1.20 | 0.24 | -0.96 |
| | | Pig feed | 1.13 | 0.29 | -0.84 |
| | | Total | 2.33 | 0.53 | -1.80 |
| | LP gas | | 0.08 | 0.01 | -0.07 |
| | Total | | 2.41 | 0.54 | -1.87 |
| Expenses for cooking fuel ($USD\ year^{-1}$) | Firewood (purchase) | | 14 | 1 | -13 |
| | Firewood (collection) | | 53 | 12 | -41 |
| | LP gas | | 45 | 4 | -41 |
| | Total | | 112 | 17 | -95 |

*3.5 Financial Analysis of Farm Households*

The cost-benefit analysis of cash flow for farm households that installed a BD, based on the findings of sampling surveys and project records, is shown in Table 5. Accordingly, the NPV is calculated at USD214, demonstrating a clear benefit to farm households employing BD technology.

By way of sensitivity analysis, calculations of NPV assuming a shorter useful life of BDs and increased costs are shown in Table 6. Assuming present costs, BDs will become profitable if they remain in use for four or more years. Assuming a 10% or 20% cost increase, they will remain profitable from the fourth year onwards. A 30% cost increase will produce a profit for households if the unit is used longer than five years.

Sensitivity analysis was also conducted to consider the effects of subsidization of initial costs (Table 7). Three different cases were compared. Case 1 assumes no subsidization of initial costs, Case 2 considers a 100% subsidization of KF labor and transportation costs, while Case 3 considers a 100% subsidization of KF labor and transportation costs and a 50% subsidization of material and labor costs to the household. As stated, BDs become profitable from the fourth year in Case 1, from the third year in Case 2, and from the second year after installation in Case 3. Subsidies assumed in Case 3 were made available to households participating in the current CDM project, hence the installation of BDs for these farmers may be profitable from an earlier point.

Table 5. Cost-benefit analysis of cash flow for farm households that installed a biogas digester (USD)

| Year | Cost | | | Benefit | Cash Flow |
|---|---|---|---|---|---|
| | Initial | O&M | Total | | |
| 1 | 180 | 10 | 190 | 47.5 | -142.5 |
| 2 | | 20 | 20 | 95 | 75 |
| 3 | | 20 | 20 | 95 | 75 |
| 4 | | 20 | 20 | 95 | 75 |
| 5 | | 20 | 20 | 95 | 75 |
| 6 | | 20 | 20 | 95 | 75 |
| 7 | | 20 | 20 | 95 | 75 |
| Total | 180 | 130 | 310 | 617.5 | 307.5 |

*Note*. O&M Operation and Maintenance

Table 6. Net present value of household by cost in sensitivity analysis (USD)

| | Useful life of biogas digester (year) | | | | |
|---|---|---|---|---|---|
| Cost | 3 | 4 | 5 | 6 | 7 |
| Present cost | -5 | 55 | 111 | 164 | 214 |
| Cost 10% up | -26 | 32 | 86 | 138 | 186 |
| Cost 20% up | -48 | 9 | 62 | 112 | 159 |
| Cost 30% up | -69 | -14 | 37 | 86 | 132 |

Table 7. Net present value of household by subsidy in sensitivity analysis (USD)

| | Useful life of biogas digester (year) | | | | | |
|---|---|---|---|---|---|---|
| Subsidy | 2 | 3 | 4 | 5 | 6 | 7 |
| Case 1 | -68 | -5 | 55 | 111 | 164 | 214 |
| Case 2 | -49 | 14 | 74 | 130 | 183 | 232 |
| Case 3 | 27 | 90 | 149 | 205 | 258 | 308 |

*Note*.

Case 1 No subsidization of initial costs

Case 2 A 100% subsidization of Key Farmers' labor and transportation costs

Case 3 A 100% subsidization of Key Farmers' labor and transportation costs and a 50% subsidization of material and labor costs to the household

**4. Discussion**

*4.1 Evaluating GHG Emission Reductions*

Monitoring results indicate a BD operation rate of 95.7% during the first monitoring period. Taking into account *LE*, the emissions reduction for one BD (*ER*) was 1.39 $tCO_2$ $year^{-1}$/household, while the annual emissions reduction from the project as a whole ($ER_y$) was 446 $tCO_2$; on the basis of which CERs were issued by the UN CDM Executive Board. As a general rule, CDM emission reductions are conservatively estimated. As such, the reduction figures from this project can be considered as the minimum certifiable amounts.

While the PDD envisaged that 100% of the firewood and LP gas used for cooking by households would be displaced by biogas (Matsubara et al., 2014); according to sampling surveys it was found that some households continued to use these conventional fuels while others utilized biogas to prepare pig feed rather than food for human consumption. The annual per household reduction in firewood consumption was 1.27 t (dry weight) and 24.9 kg for LP gas. Thus, comparing the reduction amounts used by the PDD of 1.58 t of firewood (1.87 t dry weight conversion) and 17.8 kg of LP gas per household, the actual reductions were slightly lower for firewood and higher for LP gas. However, if the 1.12 t/household reduction in firewood used to prepare pig feed is taken into account, the total reduction of 2.39 t/household is greater than the PDD value.

*4.2 Evaluating Farm Household Receptiveness toward the Technology*

As of May 31, 2015, 515 units of BD emissions reduction technology were installed with a 50% subsidy for installation costs and the technical support of KFs. Of these, 467 units, or 91%, were in operation as of that date. Most farm households ceased their use of conventional firewood and LP gas and switched to biogas for cooking applications. Where BDs were not utilized, interruptions to pig-raising accounted for the majority of these cases, while BD malfunctions accounted for around one-third. Thus, only a small proportion of households did not use BDs for technical reasons. Regarding the lack of manure feedstock, author et al. presented that stable BD use was realized by using underutilized biomass resources like water hyacinth, which is generally available in the region, as feedstock (Bui et al., 2015). Households with the earliest installation of BDs continued to use them after 3.5 years. While the rate of BD utilization tended to decline with time after installation, even among BDs with a two-year post-installation period there was a high utilization rate of 93% (Figure 3). Therefore, provided there is assistance from KFs, the technology is easy for households to install and maintain and is suitable for reducing GHG emissions at the farm level.

### *4.3 Farm Household Economic Effects and the Role of Subsidies*

A savings of around USD95 per household was assumed by calculating the annual decrease in fuel expenditures from the reduced consumption of conventional cooking fuels owing to the introduction of BDs. From the NPV and sensitivity analysis, it is projected that a BD used for seven years will produce a profit of USD214. Additionally, BDs with a useful life of four or more years will produce a profit even in the absence of subsidies. This is a clear indication of the benefits to farm households from BD installation.

Subsidizing BD installation may therefore be considered unnecessary or it may be sufficient to subsidize only the labor and transportation costs of KFs. However, the present project subsidized 100% of KF labor and transportation costs and 50% of the material and labor costs of participating farm households. Owing to the fact that the project was a trial, all KF activities were included as project expenses, with an assumption of 50% of direct costs of BD installation based on the subsidy system of the biogas program promoted by the Vietnamese Ministry of Agriculture and Rural Development with the assistance of the Netherlands.

Ensuring the profitability of BDs will require lengthening their useful life, and the role of KFs is critical to this end. Bond et al. have discussed the fundamental factors behind the success or failure of biogas generator equipment for farmers, arguing that their failure is linked to improper maintenance and that investment and government contributions should therefore target operation and maintenance (Bond et al., 2011). From this perspective, in the future, Can Tho City Government and the People’s Committees at the district, ward, and commune levels should regard KFs as staff supporting extension workers and subsidize the labor and transportation costs involved in their provision of technical support at the time of BD installation. While the present analysis has focused on the private benefits to farm households in terms of fuel savings, the introduction of BDs also provides social benefits; mainly the reduction of GHG emissions. If the Vietnamese government were to introduce a scheme to support the development and activities of KFs, evaluating the external effects comprising the differences between social and private benefits, this could effectively increase BD use.

## 5. Conclusion

The “Farm Household Biogas Project Contributing to Rural Development in Can Tho City,” designed and implemented by JIRCAS and CTU in Vietnam’s Mekong Delta to reduce GHG emissions through the installation of thick plastic biogas digesters, was assessed in terms of GHG emission reductions, the receptiveness of farm households toward the technology, and the economic effects on those households. The BD technology utilized by the project was found to be effective in reducing GHG emissions, suitable in terms of required technical knowledge, and economically beneficial to farm households. The IPCC Fifth Assessment Report states that small-scale biogas production can contribute to GHG emission reductions as well as improved livelihood and health outcomes from a sustainable development perspective (IPCC, 2014). This has been confirmed by this study.

The UNFCCC is currently considering a new post-2020 international framework for global warming mitigation measures, in which all signatory countries will participate, including the developing countries that have not yet been obligated to reduce GHG emissions under the Kyoto Protocol. It is expected that while industrialized nations will again make international commitments to numerical reduction targets, developing nations will be more moderate in their approach by announcing voluntary targets. Nevertheless, for developing countries (excluding the newly emerging nations (BRICs)) with low per-capita emissions compared to developed countries, their commitment to voluntary targets must ensure that target attainment will not adversely affect economic development. In analyzing an actual CDM project from the perspective of the beneficiary households, the above evaluation has highlighted the positive outcomes of the project, and suggests a potential policy direction for developing countries to reduce their GHG emissions.

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