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Economic Benefit and Greenhouse Gas Emission Reduction Potential of A Family-Scale Cowdung Anaerobic Biogas Digester

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ABSTRACT. The objective of this research is to evaluate economic benefit and greenhouse gas (GHG) emission reduction potential of a family-scale anaerobic cowdung biogas digester. Research was conducted at two villages in Lampung Province, namely Marga Lestari, District of South Lampung and Pesawaran Indah, District of Pesawaran. Economic benefit and GHG emission reduction potential were evaluated based on LPG saving due to biogas utilisation for cooking and slurry digestate utilisation for fertilizer substitution. Results showed that a family-scale anaerobic cowdung biogas digester demonstrated a good potential to reduce GHG emission, but not in economic. A digester with 5 heads of cow produced biogas at a rate of 1582 L/day. With average methane content of 53.6%, energy value of the biogas was equivalent to 167 kg LPG and able to substitute 52 bottles LPG annually. A family-scale biogas digester contributed 111.6 USD/year and potentially reduced GHG emission by 2674.8 kg CO_2e/year. Development of family scale biogas-digesters should be integrated with organic fertilizer production and smallholder agriculture.

Keywords: biogas; cowdung; greenhouse gas; economy; benefit.

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1. Introduction

Lampung has a great potential to develop family-scale biogas digesters due to significant growth on household animal husbandry, especially for cow fattening. The population of beef cattle in Lampung has slightly increased from 573,483 heads in 2013 to 660,745 heads in 2016 (BPS, 2016). Generally, farmers raise 3 to 5 heads of cow as a secondary activity. Household animal husbandry poses a significant role for farmers in villages. The cows can be used for power traction during land preparation (ploughing and harrowing) and transportation of farm products from the fields. In a needy situation, these animals can also be used as a cash animal.

The cow produces a significant amount of manure. According to ASAE Standard D384.1 the quantity of manure excreted by a cow is 5.8% (wet basis) of its weight (ASAE, 2003). Cow manure is primarily composed of organic materials and water. With no proper treatment, this manure may emit methane (CH_4), one of important greenhouse gases (GHGs), to the atmosphere (Bird and Sumner, 2011). Under anaerobic conditions, the organic materials will be decomposed by anaerobic and facultative bacteria. The end products of anaerobic decomposition are methane, carbon dioxide, and stabilized organic materials. The emitted methane can be captured by constructing lids or caps for lagoons, tanks, or digesters to keep manure anaerobically. The recovered methane can be used as a fuel for many application such as cooking, lighting, or electricity generating engine.

Traditionally, most farmers in Indonesia handle the manure by simply collecting and stacking it nearby the pen. The manure is then picked up after six months and used as compost by spreading it on the fields. During the stacking period, anaerobic process undergoes inside

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the piled manure that emits methane. With a sound management, however, cow manure can be used to produce renewable energy in form of biogas through anaerobic digestion. Cow manure can be explored to produce renewable energy (biogas) and fertilizer (compost) through anaerobic digestion process. The biogas can be used to substitute traditional cooking fuels such as fuelwood and kerosene as happened in India (Kandpal *et al*., 1991), Nepal, and Bangladesh (Kabir *et al*., 2012). Whilst, slurry digestate can be utilized as a good compost. In fact, cow manure presents an important potential of renewable sources for energy and fertilizer. Regarding the socio-economic features of villagers in less developing countries, the biogas produced from renewable sources is the right option in meeting both energy and environmental requirements (Kabir *et al*., 2013).

In Indonesia, household biogas is applied mainly as substitute for LPG (liquefied petroleum gas) following kerosene-to-LPG conversion program initiated by government in 2007. The policy of this conversion program was regulated under President Regulation No. 104/2007 on The Rules, Distribution, and Price Determination for 3 kg LPG bottle, Regulation of Ministry of Energy and Mineral Resources No. 021/2007 on The Implementation, Supply, and Distribution of 3 kg LPG bottle, and President Regulation No. 28/2008 on The Price of 3 kg LPG Bottle for Domestic and Micro Scale Business (Lie, 2009).

In some countries such as China (Chen *et al*., 2014), India (Singh and Sooch, 2004), Nepal (Forte, 2011), Bangladesh (Khan *et al*., 2014), and Vietnam (An *et al*., 1997), family sized biogas technologies play a significant role to fulfill energy need, especially in the rural areas. By the end of 2010, China has installed 41.18 million household biogas digesters in rural areas with an annual biogas output of 15.5 billion m^3 (Feng *et al*., 2014). In India, the National Biogas and Manure Management Program implemented by Ministry of New and Renewable Energy has successfully installed more than 4 million biogas plants in the country as of 2010 (Schmidt and Dabur, 2014). Barnhart (2014) reported that Nepal has installed around 250,000 units of biogas digester that saved 239,386 tons of fuelwood per year and 3,830,000 liters of kerosene. The total number of installed biogas digesters in Vietnam accounted for about 200,000 units (Nguyen, 2011). Recently, Bangladesh has installed more than 40,000 domestic biogas plants using cow dung or poultry litter (Khan *et al*., 2014). Domestic biogas is also growing in Africa thanks to support from Netherlands Development Organization SNV (Stichting Nederlandse Vrijwilligers). In 2009, a total of 53,617 biogas plants were installed in Africa (Ghimire, 2013).

Adoption of household biogas digesters in Indonesia is quite slow compared to those mentioned countries. Since 2009, Indonesia has received support from Netherlands Government to promote domestic biogas through a program called Indonesia Domestic Biogas Program, popularly called BIRU (Biogas Rumah). As of March 2015, the number of digesters has reached 14,478 across nine provinces (Vorley *et al*., 2015). Slow adoption of biogas technology in Indonesia may be resulted from its unclear benefit.

The objective of this research is to evaluate economic and environmental benefits of family size cowdung biogas digester.

2. Materials and Methods

2.1. Location description

Research was conducted at two villages in Lampung Province, namely Marga Lestari Village, Subdistrict of Jati Agung, District of South Lampung and Pesawaran Indah Village, Subdistrict of Padang Cermin, District of Pesawaran (Figure 1). In these villages, farmers prefer to raise mostly PO (Peranakan Ongole) cattle. The reason is that PO cattle has such advantages as high adaptability to tropical climate, resistant to heat, resistant to parasites disorders like mosquito bites, and also good tolerance to feed containing high crude fiber. These cattle also good for dual purpose as beef cattle and working cow as well. Generally farmers allow the cattle for grazing during day time. The both villages were intentionally selected because there were a number of families got involved in the biogas digester installation and operation. The biogas was used solely for cooking in those two areas.

A total of 4 biogas digesters were observed in detail to evaluate their performance (Table 1). All digesters at Marga Lestari were constructed using polyethylene (PE) tubular plastic (Figure 2a) with a diameter of 90 cm and length of 4 to 5 m and equipped with separated gas holder to collect and store the biogas. The digesters in Pesawaran Indah were fixed-dome type constructed using cement concrete with a capacity of 4 and 6 m^3 without separated gas holder (Figure 2b). In both villages, fresh cowdung was mixed with water at a ratio of water to cowdung 1:1 (v/v) prior to loading in the digester. This is purposed to increase flow-ability and to reduce TS of the substrate.

Table 1
Description of digesters used in the experiment.

Digester	Location	Capacity (m^3)	Number of cow (head)	Loading Freq.	Loading Amount (L/day)
A (Tubular plastic)	Pesawaran Indah	3.5	3	Twice a week	80
B (Tubular plastic)	Marga Lestari	4.7	4	Daily	80
C (Fixed dome)	Pesawaran Indah	6	6	Daily	150
D (Fixed dome)	Pesawaran Indah	6	5	Twice a week	120

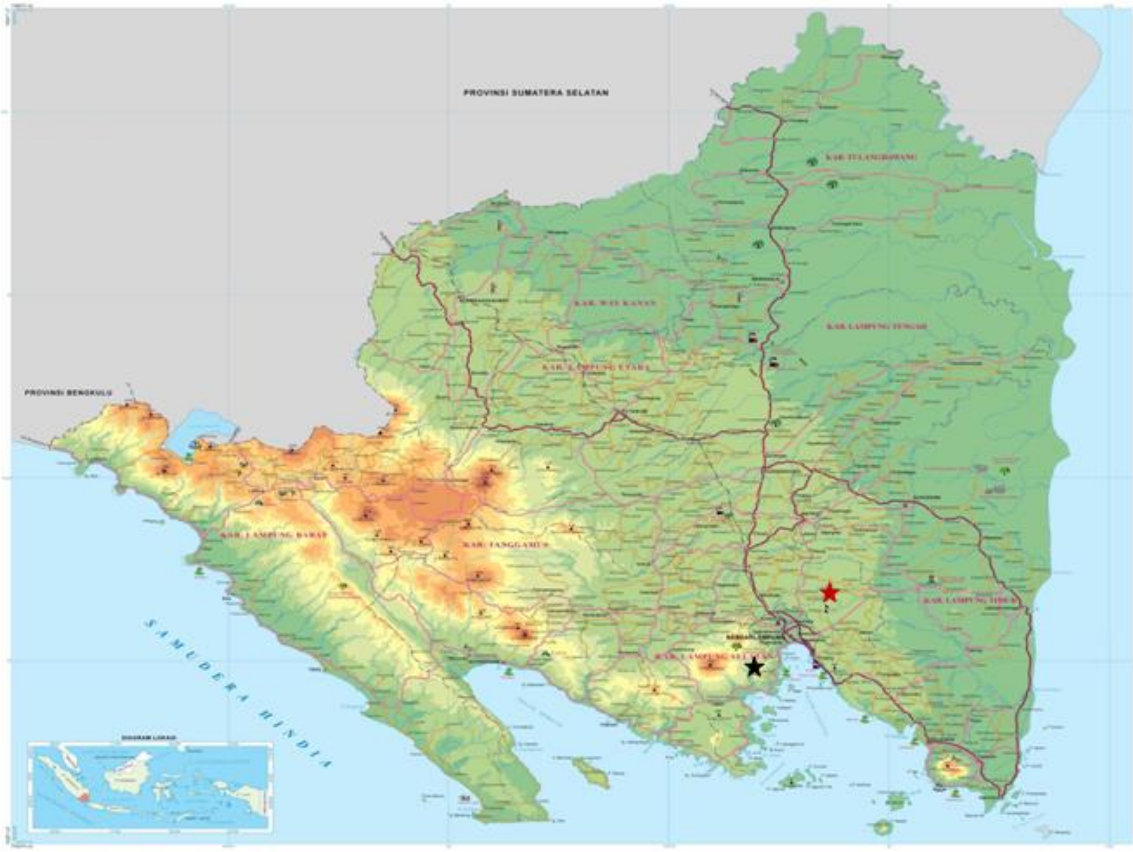

Figure 1. Research locations: Pesawaran Indah (black star) and Marga Lestari (red star).

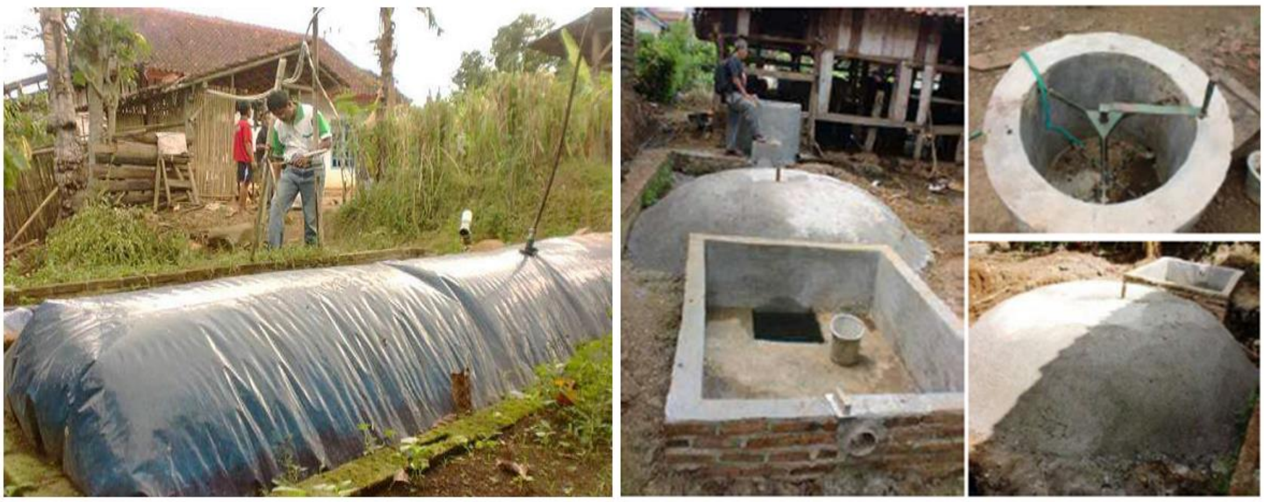

Figure 2. (a) Tubular plastic digester, and (b) fixed dome concrete digester.

Table 2.
Fresh cowdung and substrate characteristic (all parameters are presented in % wet basis).

Digester	Water content		Total solid		Volatile solid		Ash	
	inlet	Outlet	Inlet	Outlet	inlet	outlet	inlet	Outlet
A (plastic)	92.23	94.17	7.77	5.83	5.66	3.80	2.11	2.03
B (plastic)	91.70	94.92	8.30	5.08	5.27	2.23	3.03	2.85
C (dome)	90.89	95.21	9.11	4.79	5.49	1.29	3.62	3.50
D (dome)	91.61	95.06	8.39	4.94	6.28	2.88	2.12	2.03
Fresh dung	77.82		22.19		16.72		5.47	

Table 2 showed characteristic of fresh cowdung used as substrate to operate the digesters. Substrate input is fresh cowdung mixed with water at a cowdung-to-water ratio of 1:1 (v/v). Substrate output is spent substrate or digestate flowing out of the digester outlet.

2.2. Analysis and Measurements

Proximate analysis was performed for fresh and spent substrate (cow dung) in order to determine water, total solid (TS), volatile solid (VS), and ash content. Water content was determined gravimetrically by drying sample in an oven at 105 ºC for 24 hours. Ash content of fresh and spent cowdung was analyzed by burning the material in a furnace (Barnstead Thermolyne 1300) at a temperature 500 ºC for 2 hours. Chemical oxygen demand (COD) of fresh and spent substrate was analyzed using closed reflux method. Samples to be analysed for COD concentration include fresh cowdung taken from the pen, substrate input or fresh substrate (a mixture of cowdung and water just before loading into the digester), and spent substrate or digestate taken from the outlet of the digester. Hydraulic retention time (HRT) is calculated by dividing total load of each digester by loading rate.

The quantity of biogas production was estimated using pressure difference read at a simple U-tube water manometer equipped in the digester system. Biogas samples were collected using gas sampling bag. Biogas composition was analyzed using a gas chromatograph (Shimadzu GC2014) with TCD detector and Shincarbon column (4.0m length, 3mm inner diameter).

2.3. Calculation

The amount of methane emission was calculated by considering Methane Producing Potential (Bo) and methane conversion factor (MCF). The Bo is defined as the maximum amount of methane that can be produced from a given quantity of manure. IPCC (2006) suggested Bo value of 0.1 m^3 CH_4/kg VS (volatile solid) of manure for non dairy cattle in developing countries. Methane conversion factor reflects the portion of Bo that is achieved. The MCF value varies with the climate (especially temperature) and the type of manure treatment. IPCC (2006) recommended MCF value of deep bedding of cattle dung for a long time (> 1 month) is 80% for warm climate (greater than 25° C). Methane emission is estimated as the following:

$$CH_4 = Bo \times MCF \times VS \quad (1)$$

Environmental benefit of digester was evaluated using total GHG emission reduction potential (GHG_{TOT}):

$$GHG_{TOT} = GHG_{CH4} + GHG_{LPG} + GHG_{FERT} \quad (2)$$

Units for all terms in Equation 2 are represented in kilogram CO_2 equivalent (kg CO_2e). GHG_{CH4} is calculated by multiplying the amount of methane estimated from pilled manure (Eq. 1) and the global warming potential of methane (GWP_{CH4}):

$$GHG_{CH4} = CH_4 \times GWP_{CH4} \quad (3)$$

GHG_{LPG} is calculated by multiplying the amount of saved LPG (kg) due to biogas utilization for cooking and global warming potential of LPG burning:

$$GHG_{LPG} = LPG \times GWP_{LPG} \quad (4)$$

GHG_{FERT} is calculated from equivalent amount (in kg) of N, P, and K fertilizer in the compost from spent slurry digestate and global warming potential of respected fertilizer production. In addition, global warming potential of nitrogen fertilizer application in form of N_2O is also considered.

$$GHG_{FERT} = (N \times GWP_N) + (N \times N_2O\text{-}N \times GWP_{N2O}) + (P \times GWP_P) + (K \times GWP_K) \quad (5)$$

Table 3 lists global warming potential values for various sources used for calculating greenhouse gas emission reduction potential of a family-sized cowdung biogas digester.

Table 3.
Global warming potential factors to calculate GHG emission reduction.

Parameter	Description	Value	References
GWP_{CH4}	Global warming potential for methane burning (CO_2e/kg)	21	Guinée (2004) [23]
GWP_N	Global warming potential for nitrogen fertilizer production (CO_2e/kg)	1.3	Pathak *et al.* (2009)
GWP_P	Global warming potential for phosphorous fertilizer production (CO_2e/kg)	0.2	Pathak *et al.* (2009)
GWP_K	Global warming potential for potassium fertilizer production (CO_2e/kg)	0.2	Pathak *et al.* (2009)
N_2O-N	N_2O emission factor from N fertilizer application (kg/kg)	0.07	Pathak *et al.* (2009)
GWP_{N2O}	Global warming potential for N_2O (CO_2e/kg)	310	Guinée (2004)
GWP_{LPG}	Global warming potential for LPG burning (CO_2e/kg)	3.00	Suhedi (2006)

Economic benefit was estimated from LPG saving due to biogas utilization for cooking and slurry digestate utilization for replacing chemical fertilizers.

3. Results and Discussion

Fresh cow manure has high potential to be used as a substrate in the process of digestion anaerobic because it contains high organic matter (16.72%, w/w). It is also evident from the high COD value, ranging from 82,553 to 104,038 mg/L with an average of 91,498 mg/L. Fresh cow dung contains high total solid, TS (22.19%, w/w), so it is not optimum for the anaerobic digestion process. In addition, with the water content of 77.82% (w/w), the cowdung forms a paste-like substance which is difficult to flow. These conditions are not ideal for wet anaerobic digestion process that requires a TS maximum level of 9% (Yavini *et al*., 2014) to ensure an optimum process. Therefore, in practice the cow dung should be diluted with water at a ratio of cow dung to water of about 1: 1 (v/v). By using the dilution, substrate contains 8.39% of TS and ready to be loaded into the process of anaerobic digestion.

Comparing influent and effluent characteristic as in Table 2, it is revealed that TS, VS, and ash content of the substrate decreased, while water content increased during biogas process. During anaerobic digestion process, a portion of VS is converted into stable gases such as CO_2 and CH_4. Therefore, VS and TS decreased during biogas process. Another explanation is that for digesters with no stirring mechanism there is a problem related to settling process. Solid settling causes the effluent become more dilute so that TS and VS contents decrease while water content increases. This process also explains why ash content decreases even though ash is considered as inert material.

Methane forming reaction from CO_2 and H_2 route also produces H_2O:

$$CO_2 + 4H_2 \rightarrow CH_4 + H_2O \quad (6)$$

The water, however, is usually carried in the biogas and should not increase water content of the effluent.

3.1. Digester performance

Table 4 presented operating condition of digesters. Anaerobic digesters in this research work were in conditions close to normal with an average pH of 7.83 to 8.32. This is a good condition for the process of anaerobic digestion. Yadvika *et al*. (2004) reported the optimal pH for anaerobic digestion process is as narrow as the range between 6.8 and 7.2. Other research reported the range between 5.5 and 8.5 (RISE-AT, 1998). Anaerobic digestion process destroys organic matter (volatile solid) to produce biogas and a more stable material (digestate). With an average hydraulic retention time (HRT) of 35 days, digesters capable to decompose organic material and decrease the COD value from 45,749 to 22,476 mg/L. Thus, the COD removal reached an average of 51.32%. COD removal can be improved by increasing the HRT (size of the digester). It is not easy to be executed, however, because of the limited space.

Theoretically, every kg of COD removal may produce CH_4 as much as 0.350 Nm^3 (Manariotis *et al*., 2010) or 0.388 m^3 at a temperature of 30°C. Digesters evaluated in this research produced average 247.6 L CH_4/kg COD removal (Table 5). Based on this value, the digesters have a fairly good efficiency, reaching 63.8%.

Digesters were capable of producing daily biogas at rate of 1582 L/unit/day or 280.3 L/head of cow (Table 5). Average methane content of the biogas was 53.61% (Table 6), meaning that energy value produced from a family-scale digester was 1121.2 MJ/day or 7858.6 MJ/year. By taking low heating value (LHV) for LPG as much as 46.6 MJ/kg (Wright *et al*., 2009), the biogas is equivalent to 169 kg of LPG/year. For the purposes of domestic cooking, Indonesia has marketed 3 kg so that the biogas can replace 56 bottles of LPG per year. Our observation, however, showed that every unit of digester was capable of replacing one bottle LPG need per week or 52 bottles/year.

Table 4.
Digester operating condition.

Parameter*	Digester				
	A plastic	B plastic	C dome	D dome	Average
pH in	8.41	8.15	8.34	8.37	8.32
pH out	7.80	7.83	7.83	7.86	7.83
Number of cow (head)	3	4	6	5	5
Loading rate (L/head/day)	26.7	20.0	25.0	24.0	22.67
Total load (L/head)	715.7	883.6	750.0	900.0	812.3
HRT (day)	27	44	30	38	35
COD_{in} (mg/L)	46,964	41,276	42,736	52,019	45.749
COD_{out} (mg/L)	23,360	19,112	17,941	29,492	22,476
CDD removal (COD_r) (mg/L)	23,604	22,164	24,795	22,527	23,373
CDD removal (COD_r) (%)	50.26	53.70	58.02	43.31	51.32

Table 5.
Biogas and methane yield and digester efficiency.

Digester	No. of cow (head)	Biogas yield			CH_4 yield L/kg COD_r	Digester efficiency (%)
		L/d	L/head/d	L/kg COD_r		
C dome	6	2164	360.7	581.8	315.0	81.2
D dome	5	1000	200.0	369.9	180.2	46.4
Average		1582	280.3	475.9	247.6	63.8

3.2. GHG potential reduction

Total GHG emission potential was composed of biomethane potential of cowdung management (pilling up), GHG emission from LPG saving, and GHG emission from fertilizer saving. Pilling up the manure will result in an anaerobic process that emits methane to the atmosphere.

Table 6.
Biogas composition (%, v/v).

Parameter	Digester				
	A plastic	B plastic	C dome	D dome	Average
Methane (CH_4)	53.87	57.70	54.14	48.71	53.61
Carbon dioxide (CO_2)	25.79	31.99	34.90	32.72	31.35
Nitrogen (N_2)	20.34	10.30	10.95	18.56	15.04

With an average cow weight of 300 kg/head and using manure production 5.8% of living weight (ASAE, 2003), then every head of cow produces annual fresh dung of 6351 kg with VS content of 16.72% (Table 2). According to Equation (1), annual CH_4 emission potential is calculated to be 42.5 m^3/head. However, farmers usually let the cow to graze during the day, and the droppings are splattered over the field so that the potential of cow dung was one half of it (during night only). Thus, the annual GHG emission potential from piled cow manure reaches 21.24 m^3/head, equivalent to 308.6 kg CO_2e per head or 1592.8 kg CO_2e for every digester with 5 cows. This emission can be reduced by introducing manure into the digester and capturing the biogas for cooking fuel, replacing LPG.

As listed in Table 3, global warming potential for LPG burning is 3.00 kg CO_2e/kg. With LPG saving of 52 bottles per year, it follows that equivalent of GHG reduction due to LPG substitution by biogas was 468 kg CO_2e/year.

Fertilizer potential of slurry digestate (effluent) is represented by the amount of digestate as well as N, P, and K con-tent. In this case, the amount of digestate is assumed to be equal to the substrate loading rate. Because of high water content in the digestate, it is assumed that density of digestate is same as that for water (1 kg/L). The amount of slurry digestate was 22.7 kg/day per head of cow which was equivalent to dry matter of 2134.8 kg/year for a digester with 5 heads of cow. The content of N, P, K in the digestate was 1.24%, 0.19%, and 1.05% (w/w, dry basis), respectively. This meant the digestate was corresponding to 57.55 kg UREA (N fertilizer, 46%), 11.27 kg SP36 (P fertilizer, 36%), and 37.36 kg KCl (K fertilizer, 60%). Application of slurry digestate as compost reduced GHG emission by 614 kg CO_2e/year. Based on our calculations, family biogas digester with 5 heads of cow potentially reduced GHG emissions by 2674.8 kg CO_2e/year (Table 7). This value is lower than the study in India by Pathak *et al.* (2009). This can be resulted from a fact that digester in our study used cow dung collected during night time only.

Table 7.
Annual GHG potential reduction of a family-sized biogas digester

Parameter	Value (kg CO_2e)
GHG emission from biomethane potential resulted from manure management	1592.8
GHG emission from LPG saving	468.0
GHG emission from fertilizer saving	614.0
Total GHG emission reduction potential	2674.8

3.3 Economic Benefit

Economic benefit of a biogas digester was calculated based on LPG saving by biogas and fertilizer saving by slurry digestate. Biogas cost was assumed to be zero because all works related to digester operation and maintenance were conducted by a family members with no pay. In addition, all digesters evaluated in this study were developed by donors for free. Therefore, no interest and depreciation were made to evaluate economic benefit.

Recently, a bottle LPG @ 3 kg was marketed at a price of 20,000 IDR or 1.54 USD at a currency rate of 13,000 IDR/USD. Our observation found that a bottle of LPG @ 3kg is enough to meet a week of regular cooking. Therefore, every family spent about 1,040,000 IDR/year (USD 80.0 USD/year) for LPG. If the family operate a digester, LPG consumption is completely substituted by biogas. Economic benefit from biogas utilization is 1,040,000 IDR/year or 80 USD/year.

The price of UREA is 2850 IDR/kg, SP36 is 3350 IDR/kg and KCl is 5600 IDR/kg. This meant that slurry digestate produced from a biogas digester potentially contribute to economic benefits from fertilizer saving by 410,970 IDR/year or 31.61 USD/year at a currency of 13,000 IDR/USD.

The total economic benefit of biogas digester was 1,450,970 IDR/year or 111.6 USD/year. This was not a great value, however, so it can be understood if people were not eager in operating biogas digester. When compared to the cost of installation, which reached 2,000,000 IDR/unit (153.85 USD/unit) for plastic digester (Haryanto and Triyono, 2011) and 6,500,000 IDR/unit (500 USD/unit) for 6 m^3 concrete fixed-dome digester (Hariyanto, 2012), obviously that biogas construction was not impressing to villagers. This explains why dissemination of family-sized biogas digesters are developing slowly.

3.4 Future Prospect of Biogas in Lampung

Biogas digester has triple advantages: producing fuel, producing organic fertilizer, and reducing greenhouse gas emissions. Therefore, the household scale biogas digester has good prospects to be developed in Lampung. In addition, we also observed that farmers raising cattle of three or more heads can be found easily. Three is the minimum number of cow to operate a family size digester with biogas production sufficient for cooking.

Nevertheless, we also observed that more than 50% of biogas digester that has been installed from a variety donors was collapsed within 1 to 3 years of installation. Plastic digesters, though less expensive, are generally more breakable than concrete digesters. One way to solve this problem is developing biogas digester with multi purposes, and is not merely to produce biogas fuel. Slurry digestate is an important link between biogas and agriculture (Vorley *et al*., 2015). Therefore, biogas installation must be accompanied by organic fertilizer production and smallholder agriculture.

4. Conclusion

A family size anaerobic cowdung biogas digester with 5 heads of cow potentially reduced greenhouse gas emission by 2674.8 kg CO_2 equivalent per year compiled of 1592.8 kg from CH_4 saving due to manure management, 468 kg from LPG saving, and 614 kg from fertilizer saving. In addition, the biogas utilization also provided annual economic benefit of 1,450,970 IDR/year 111.6 USD/year. Development biogas digester has to be integrated with organic fertilizer production and smallholder agriculture.

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