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Greenhouse gas emission of household plastic biogas digester using life cycle assessment approach

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Greenhouse gas emission of household plastic biogas digester using life cycle assessment approach

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Abstract. Biogas is one of renewable energy sources capable to reduce greenhouse gas (GHG) emission. Plastic biogas digester is a popular type adopted by people due to its low cost and simplicity. The utilization of materials for digester fabrication, however, positively contributes to GHG emission. The purpose of this research is to evaluate GHG emission of household scale plastic biogas digester by using life cycle assessment (LCA) approach. The boundary system consists of fabrication of the digester, operation and maintenance, and utilization of the biogas. The research is conducted by making an inventory to collect related information on the quantity of materials utilized to construct a household size plastic biogas digester along with emission factor of each material. Other important parameters include biogas yield and its methane content. Emission reduction is calculated from LPG saving due biogas utilization to fuel kitchen stove. Result showed that a household size plastic tube biogas digester system potentially reduced GHG emission by 1400.78 kg CO_2eq/year for a five years of service life time. The GHG emission (in kg CO_2eq/year) is comprised of 59.11 for digester construction, 7.83 for biogas production, (-456.14 for biogas utilization, and -1011.58 for slurry digestate utilization.

1. Introduction

Biogas is mainly composed of 45-70% methane (CH_4) and 30-45% carbon dioxide (CO_2) [1]. Biogas can be used to substitute several fuels, such as fuelwood, kerosene, and liquefied petroleum gas (LPG) for cooking and gasoline or diesel fuel for running engines either to generate electricity or mechanical power. It is one of renewable energy sources because biogas is produced from organic matters through anaerobic digestion process. Household scale biogas technology has been applied and played important role to supply clean energy in many countries such as China [2, 3], India [4, 5], Nepal [6], Bangladesh [7], and Vietnam [8-11]. Household biogas digesters have also been initiated in other parts such as Africa [12-14] and Latin America [15, 16]. These digesters are suitable for rural areas where peoples live scattered far apart [17].

Household biogas digester is a biogas facility with a capacity to serve a single family, mostly for cooking. The digester has been introduced in Indonesia since 1970s with floating drum digester type [18]. Presently household biogas plants applied in Indonesia are dominated by fixed dome and plastic tube digesters. Until the end of last decade, very little success is achieved and many household digesters was abandoned. This could be resulted from lack of effective operational maintenance, insufficient gas storage facilities, and low cost of kerosene at that time. Since 2009, household biogas digester regained its popularity thanks to an Indonesia Domestic Biogas Program called BIRU (Biogas Rumah) sponsored by SNV (*Stichting Nederlandse Vrijwilligers*) with exclusively fixed dome type. The cost of constructing a fixed dome digester, however, is still expensive for farmers. Therefore, development of plastic tube digester technology was targeted to reduce construction costs. With a good maintenance, the life of the plant made of a good quality plastic may go up to 5 years [16]. Some plastic bags such as PVC, polypropylene and high quality polyethylene are estimated to last to 10 years [19]. In normal conditions, however, the life is about two years and in some cases even shorter than 6 months because of their susceptibility to mechanical damage [20, 21].

Tubular digesters are characterized by the ease of implementation and handling, since they do not require specialized skills for the construction and maintenance [8, 17]. Eventhough high quality pre-fabricated bags may not be locally available, all construction materials can be easily transported [20]. The main disadvantage of the plastic bag digester is that the plastic tube is very susceptible to leakage because of mechanical damage due to foldaway during transport or damage by sharp objects such as claws of hens, cats, and rats passing over the bag. Unprotected underground plastic digester can also be penetrated by plant root growing around. Some farmers protect the plastic bag digester using a masonry structure and a roof, resulting in higher installation costs. The main necessary tasks are daily feeding, digestate management, removal of sludge in the bottom of the digester, and control of biogas leakage [19]. A lot of works on plastic tube household biogas digester have been reported by Garfi and co-workers [22-26]. Other works on plastic digester were also reported in Vietnam [8, 10].

The installation and operation of household biogas digesters provides multiple benefits to the family [27, 28]. First of all, it is an effective way to decompose cow dung with high energy output [29]. Rural household digester provides an important source of renewable energy (biogas) as an healthier and environmentally friendly cooking fuel. Construction and operation of biogas digester can also be integrated to other farm systems such as livestock [30], aquaculture [31, 32], agrosystem [33], production and processing [34] that maximize environmental advantages. Therefore, household biogas system is an important alternative to overcome energy scarcity, reduce environmental loads and to realize a sustainable agriculture in the rural areas [35].

Several studies have demonstrated the economic and GHG mitigation benefits of household biogas. Zhang [36] reported that CO_2 emission reduction potential of 8 m^3 biogas system is 1.25 tons based on 20-year operation. In addition, to achieve a positive reduction of CO_2 emission, the minimum lifetime of the household biogas system should be at least 1.78 years. Lansche [29] also reported that in terms of greenhouse gas emissions, biogas systems demonstrate an environmental advantage as compared to dung drying and combustion. In addition the digestate can be utilized as organic fertilizer that contributes more saving on greenhouse gas emissions. Therefore, development of biogas digester in rural areas is considered as an effective way to reduce GHG emission [37].

During construction and operation of the digester, however, may produce positive GHG emissions from the use of materials, fuel, and machinery. Mezzullo *et al*. [38] showed that the manufacture of small farm digester contributes very little to the whole environmental and energy impacts. However, Wang and Zhang [39] reported that the net CO_2 emission of a household biogas digester in rural China is 1558.91 kg resulted from 2878.30 kg CO_2 for one year of operation and emission reduction by fuel substitution (1078.59 kg) and fertilizer conservation (240.80 kg). Poorly designed and operated household digester will increase more GHG emissions [28]. Bruun *et al*. [40] questioned whether small-scale biogas digesters can be a right option for global warming mitigation. It is important, therefore, to conduct GHG emission evaluation for household biogas digester development. This paper aims at presenting results from GHG emission analysis of the application of household biogas digester technology made from polyethylene plastic tube. The LCA (life cycle assessment) approach is used to evaluate environmental impacts of household biogas system. Recently, the LCA perspective has been adopted to evaluate energy and environmental aspects of biogas systems [10, 29, 38, 41].

2. Materials and methods

As portrayed in figure 1, a LCA comprises four phases: (i) goal and scope definition, (ii) life cycle inventory analysis, (iii) impact assessment, and (iv) interpretation of results [42](ISO, 2006).

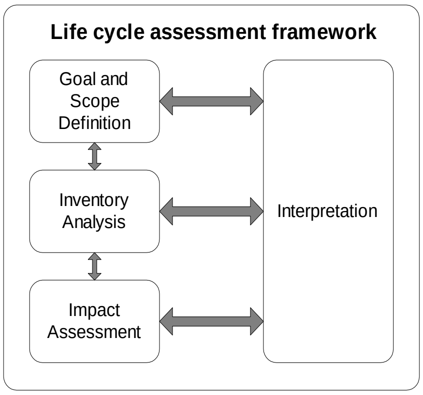

Figure 1. Steps in a LCA framework [42]

2.1. Goal, scope and boundary system

The goal of this work was to identify and evaluate environmental impact in term of GHG emissions from cattle dung household-scale anaerobic digestion. The objective was to identify the most important factors that affected the environmental load of a household biogas digester. From these factors, the GHG emissions caused by the process were analyzed, including the GHG emission avoided from the displacement of a fossil fuel (LPG in this case). By determining the environmental load of biogas production, it was possible to identify whether the process had beneficial or detrimental effects. The assessment examined the digester construction, biogas production (digester operation and maintenance), and biogas and by-product utilization (figure 2). The by-product slurry digestate, used as a source of organic fertilizer, was also examined as a displacement of chemical fertilizers.

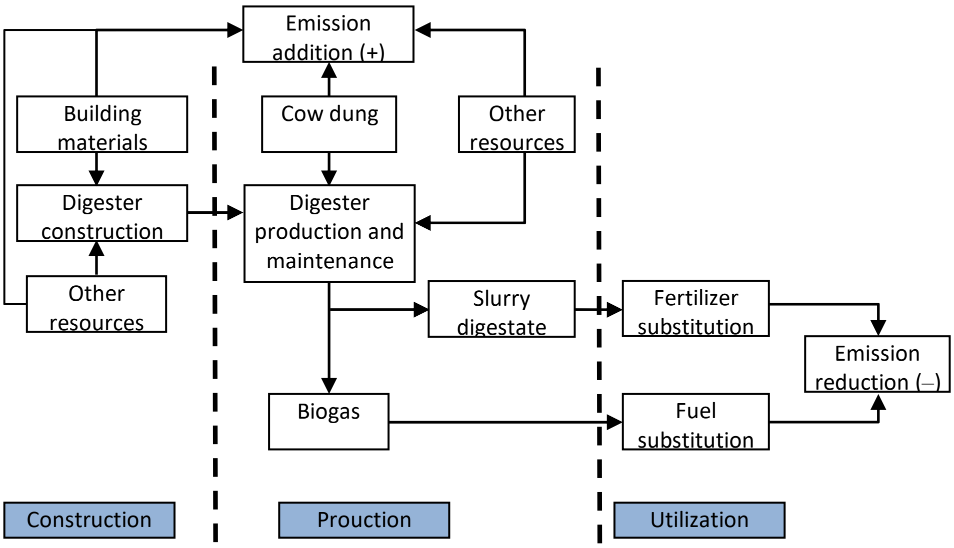

Figure 2. Life cycle framework of a household biogas digester (from construction to utilization)

2.2. Household-size digester description

A household biogas digester was constructed to handle dung of 3 to 5 heads of cattle. This number is common and is easily found in many villages in Lampung. The size of plastic tube biogas digester complies this condition was 4 m length with a diameter of 0.9 m and thickness of 0.20 mm. Two plastic bags were used to construct this digester: one bag is for digester (placed in the cemented ground surface near the pen) and another bag (usually placed in the ceilling) is used to store the biogas. To construct this digester we used two pieces of LDPE plastic tube with length of 5 m (one meter excess is wrapped to connect the plastic tube to 4” PVC pipe in both inlet and outlet). The plastic is strong enough, but to ensure digester stability a box made from clay bricks and mortar cement was built to house the digester bag. The digester is schematically depicted in figure 3.

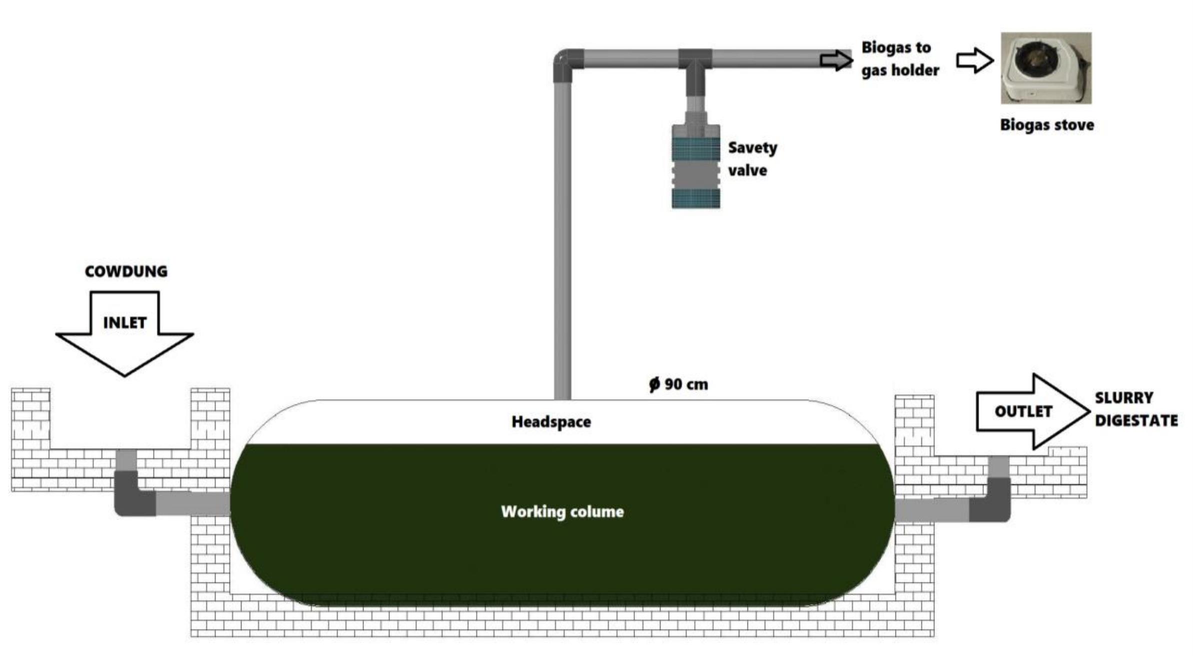

Figure 3. Scheme of plastic tube digester (4 m length, 90 cm diameter) system

2.3. *Life-cycle inventory*

All inventory inputs required for biogas digester system was recorded and compiled. Outputs produced from the biogas system were measured and a laboratory analysis was conducted to get such important data as biogas yield, biogas composition, and digestate amount. Additional data (GHG emission factors) were collected from literatures. Inventory data are grouped into three according to its steps:

2.3.1. Digester construction. Materials and sources used to construct biogas digester includes LDPE plastic tube, PVC pipe, connectors, etc. Indirect inputs is fuel for transportation truck. Table 1 presents all inputs required for biogas digester construction, digester operation, and product utilization.

2.3.2. Biogas production. The anaerobic digester was fed using fresh cow dung diluted with water at substrate into water ratio of 1:1 (total solid content of around 8%). Additional inputs, therefore, included water and electricity to run the water pump. Normally, household digesters work at ambient temperature with hydraulic retention time of around 40 days. Under normal operating conditions, the household size digester is fed at a loading rate of 120 L/d.

2.3.3. Product utilization. In this research, the biogas was used to fuel kitchen stove, substituting LPG. In this case, an LPG stove was modified to be able to work with solely biogas at low pressure.

To control biogas pressure, a weight is placed on top of the biogas storage bag. Slurry digestate was considered to substitute a part of chemical fertilizer.

Table 1. Materials and resources used in household biogas digester system

No	Item	Qty	Mass or other	Remark
1	Plastic tube 5-m (LDPE) 0.20 mm	1 pc	2298 g	Construction
2	Plastic tube 4-m (LDPE) 0.12 mm	1 pc	1355 g	Construction
3	Pipe 4" (PVC)	1 pc	17.152 kg	Construction
4	Pipe 1/2" (PVC)	5 pcs	3050 g	Construction
5	Pipe 3/4" (PVC)	1 pc	1.684 kg	Construction
6	90^o elbow S×S connector 4" (PVC)	2 pcs	2.480 kg	Construction
7	90^o elbow S×S 1/2" (PVC)	5 pcs	185 g	Construction
8	Tee connector S×S×S 1/2" (PVC)	1 pc	50 g	Construction
9	Male adapter Mpt×S 3/4" (PVC)	1 pc	25 g	Construction
10	Female adapter S×FT 3/4" (PVC)	1 pc	35 g	Construction
11	Ball valve 1/2" (PVC)	2 pcs	140 g	Construction
12	Stang ball valve (besi/baja)	2 pcs	54 g	Construction
13	Coupling connector 1/2" (PVC)	1 pc	29 g	Construction
14	Reducing coupling S×S 3/4"×1/2" (PVC)	3 pcs	102 g	Construction
15	Flexible thread plastic hose 1/2" (PU)	1 m	64 g	Construction
16	Flexible thread plastic hose (PU)	1 m	178 g	Construction
17	Rubber band rope @2 m length	8 pcs	560 g	Construction
18	Plastic bottle (PET)	1 pc	16 g	Construction
19	Clay bricks	1000 pcs		Construction
20	Cement PC	3 sacks	150 kg	Construction
21	Sand	1 box	1000 kg	Construction
22	PVC glue	1 pc	45 g	Construction
23	PTFE seal tape case (PET)	1 pc	3.2 g	Construction
24	Polytetrafluoroethylene (PTFE) seal tape	2 m	1.8 g	Construction
25	Transportation (light duty trucks)	2 times	5 km	Construction
26	Gas stove (tin)	1 pc	2.032 kg	Operation
27	Polypropylene (PP r) plastic jar (20 L)	1 pc	840 g	Operation
28	Fresh cow dung	40 kg	40 kg	Operation
29	Electricity	125 W	10 min/d	Operation
30	Water	100 L	120 L/d	Operation

2.4. Calculation and analysis

The GHG emitted during digester construction and operation (GHG_p) is positive value, calculated by:

$$GHG_p = \sum C_i \times EF_i \tag{1}$$

where C is input quantity and EF is the respective emission factor as presented in table 2.

The biogas process was considered as a multi-output process and the second output (digestate) had a functional unit of kilogram (kg). An equivalent amount of chemical fertilizer replaced by digestate was based on N, P, K content in the slurry digestate. The functional unit of the analysis was a cubic meter (m^3) of biogas. An equivalent cubic meter of methane was calculated by multiplying the methane content to the biogas amount. Likewise, an equivalent kg LPG was calculated by comparing energy value of methane and LPG. Greenhouse gas emission (GHG_n) from biogas and digestate utilization is saving (negative value). The GHG saving was calculated by:

$$GHG_n = (LPG_{eq} \times EF_{LPG} + N \times EF_N + P \times EF_P + K \times EF_K) \tag{2}$$

The total GHG emission was calculated by subtracting GHGn from GHGp:

$$GHG_{total} = GHG_p - GHG_n \quad (3)$$

Table 2. GHG emission factor (kg CO_2/unit) of inputs and outputs used in household biogas system

No	Item	Unit	GHG Emission Factor	Reference
1	Electricity power	kWh	0.832	[42]
2	Clay bricks (248 mm×121 mm×70 mm)*	1000 pcs	428.0	[43]
3	Transportation (light duty trucks)	km	0.307	[44]
4	Polyvinile carbon (PVC) Pipe	kg	2.22	[45]
5	Polypropylene (PP r) plastic	kg	1.5	[46]
6	Polyurethane (PU) plastic	kg	4.99	[45]
7	Rubber	kg	3.18	[45]
8	Cement PC	kg	0.89	[45]
9	Sand	kg	0.01	[45]
10	Polyethilene (PET) plastic	kg	5.44	[45]
11	Low density polyethilene (LDPE) plastic	kg	2.06	[45]
12	Ferrochromium	kg	1.3	[47]
13	Tin (for kitchen stove)	kg	1.6	[47]
14	LPG	kg	3.00	[48]
15	Nitrogen fertilizer production	kg	1.3	[49]
16	Phosphorous fertilizer production	kg	0.2	[49]
17	Potassium fertilizer production	kg	0.2	[49]
18	N_2O factor from N fertilizer application	kg	0.07	[49]

*) Our local bricks have a smaller dimension of (170 mm×90 mm×35 mm)

3. Results and discussion

Based on table 1 and table 2 we have calculated GHG emission of all materials and other resources used for digester construction and digester operation (biogas production). The result presented in table 3 assumes for one year of service life. The GHG emission is 306.36 kg CO_2eq comprises of 295.52 kg CO_2 eq for digester construction and 10.84 kg CO_2eq for biogas production.

Table 3. GHG emission for a household biogas digester and biogas production

No	Item	Amount and unit	GHG emission (kg CO_2 eq)	Remark
1	Clay bricks	1000 pcs	84.864	Construction
2	Transportation (light duty truck)	5 km	1.535	Construction
3	PVC pipes	24.977 kg	54.949	Construction
4	PU plastic	242 g	1.208	Construction
5	Rubber band rope	560 g	1.781	Construction
6	Cement PC	150 kg	133.500	Construction
7	Sand	1000 kg	10.000	Construction
8	PET plastic bottle	16 g	0.087	Construction
9	LDPE plastic	3653 g	7.525	Construction
10	Ball valve handle (Ferrochromium)	54 g	0.070	Construction
11	PTFE seal tape case (PET)	3.2 g	0.007	Construction
12	PTFE seal tape	0.36 g	0.000	Construction
13	Electricity power	7.60 kWh	6.327	Operation, annually.
14	Gas stove (tin)	2.032	3.251	Construction
15	PP plastic jar (20 L)	840 g	1.260	Operation

16	Fresh cowdung and water	140 kg	0.000	Operation
	TOTAL (GHG_p)		306.364	

Even though household digester built using good plastic tube and with good maintenance may have service life time up to 10 years [19], in this work we analyze GHG emission till five years life time. Figure 4 shows effect of service life time on the GHG emission for digester construction and operation. In this case the GHG emission is divided by the respective life time to get annual amount of GHG emission. It should be noted, however, that electricity is consumed everyday during the all life time operation so that only this item has been treated on the annual basis already. The GHG emission decreases significantly from 306.36 with one year life time to 66.33 kg CO_2eq if the service life time of five years can be realized. It implies that good maintenance has to be mandated to the digester owner or operator.

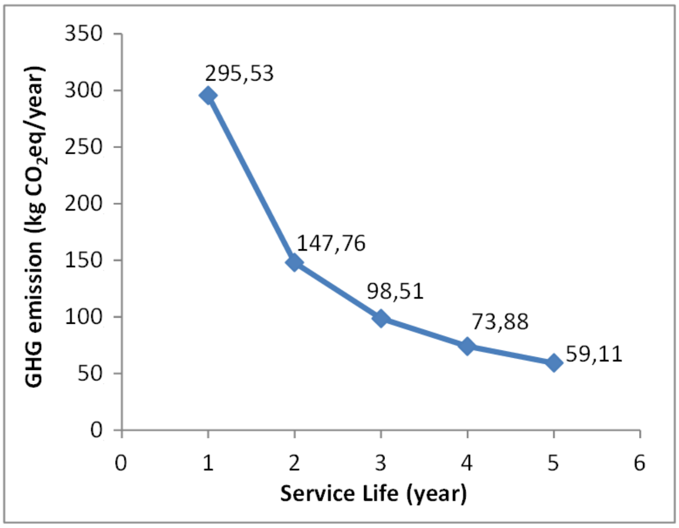

Figure 4. Effect of service life time on the GHG emission for digester construction and operation

Household plastic tubular digesters operated in a typical Indonesia's climate can produce biogas at around 0.478 m^3/m^3 of digester working volume [50]. Based on the digester size described in previous section we have calculated that working volume of the digester is 2.036 m^3. The digester produces daily biogas at a rate of 0.972 m^3 with an average methane content of 55.75% (volume based). Using calorific value of methane 35.82 MJ/m^3, it can be showed that the biogas is equivalent to 0.416 kg of LPG a day. GHG emission due to biogas utilization to replace LPG, therefore, is equal 456.14 kg CO_2eq/year. This is a saving so that it is a negative value.

Slurry digestate can be used to replace chemical fertilizer because it contains sufficient N, P, and K. Assuming steady state operation, the amount of digestate is equal to the substrate loading rate, that is 120 kg. At 8% TS content, this is equal to 9.636 kg dry matter a day or 3517.14 kg/year. With N, P, K content of 1.24%, 0.19%, and 1.05% (w/w, dry basis), respectively, the slury digestate is equivalent to annual amount of 94.81 kg UREA (46% N), 18.56 kg SP36 (36% P), and 61.55 kg KCl fertilizer (60% K). Our calculation reveals that utilization of slurry digestate as organic fertilizers reduce GHG emission by 1011.58 kg CO_2eq/year.

Based on our calculations, a typical household biogas digester potentially reduces GHG emissions by 1161.36 kg CO_2eq/year for one year life time, comprised of digester preparation (295.53), biogas production (10.84), biogas utilization (-456.14), and slurry digestate utilization (-1011.58) as presented in figure 5. Assuming 5 years life time can be realized, the GHG emission reduction becomes 1400.78 kg CO_2eq/year. Figure 5 also shows that slurry digestate utilization for organic fertilizer surprisingly save more GHG emission as compared to the contribution of biogas utilization. This is important to note because biogas is the main product of a digester system, while slurry digestate is a by-product that is frequently ignored by farmers.

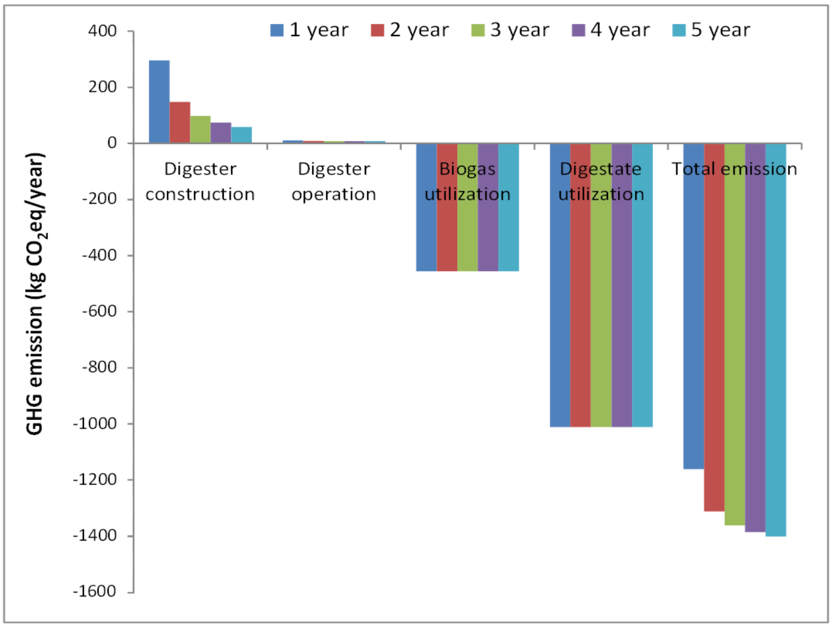

Figure 5. GHG emission of a plastic tubular household biogas system

4. Conclusion

A typical plastic tubular household-sized biogas digester system with 4 to 5 heads of cattle and 5 years of service life time potentially reduces GHG emission by 1400.78 kg CO_2eq/year. The GHG emission is affected by service life time, the shorter of life time, the higher the of GHG emission. Biogas digester construction and operation contributes positively to GHG emission by 59.11 kg CO_2eq/year for five years life time, while biogas production contributes very little. Conversely, biogas and slurry digestate utilization contributes negatively (saving) on GHG emission by 456.14 and 1011.58 kg CO_2eq/year, respectively. Digester life time duration contribute significantly on the total GHG emission saving. Therefore, good maintenance has to be mandated to the digester owner or operator.

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References

[1] Gomez C D C 2013 *Biogas as an energy option: an overview. The Biogas Handbook: Science, Production and Applications*, eds A Wellinger, J Murphy and D Baxter. (Cambridge: Woodhead Publishing Limited) pp 1–16.
[2] Chen Y, Hua W, Feng Y and Sweeney S 2014 *Renew. Sustain. Energy Rev.* **39** 679–85
[3] Feng Y, Guo Y, Yang Y, Qin X and Song Z 2012 *Renew. Sustain. Energy Rev.* **16** 5617–24
[4] Schmidt T S and Dabur S 2014 *Environmental Economics and Policy Studies* **16** 171–199.
[5] Singh K J and Sooch S S 2004 *Energy Conversion & Management* **45** 1329–41
[6] de Castro J F M 1995 *Energy for Sustainable Development* **I(6)** 37-40

[7] Khan U K, Mainali B, Martin A and Silveira S 2014 *Sustainable Energy Technologies and Assessments* **7** 68–78
[8] An B X, Preston T R and Dolberg F 1997 *Livestock Research for Rural Development* **11(1)** http://www.lrrd.org/lrrd9/2/an92.htm (Accessed July 10, 2015)
[9] Nguyen V C N 2011 *Journal of Vietnamese Environment* **1(1)** 12–8
[10] Vu T K V, Vu D Q, *Asian Australas. J. Anim. Sci*. 28(5) 716–29
[11] Izumi T, Matsubara E, Dung D T, Ngan N V C, Chiem N H and Higano Y 2016 *Journal of Sustainable Development* 9(3) 224–35
[12] Adeoti O, Ilori M O, Oyebisi T O and Adekoya L O (2000) *Technovation* **20** 103–8
[13] Ghimire P C 2013 *Renewable Energy* **49** 90–4.
[14] Berhe T G, Tesfahuney R G, Desta G A and Mekonnen L S *Energy and Policy Research* 4(1) 10–20
[15] Ni J Q, Naveau H, Nyns E G 1993 *Renew Energy* **3** 763–79.
[16] Garfí M, Martí-Herrero J, Garwood A, Ferrer I 2016 *Renew Sust Energy Rev* **60** 599–614
[17] Song Z, Zhang C, Yang G, Feng Y, Ren G and Han X 2014 *Renew. Sustain. Energy Rev.* **33** 204–13
[18] SNV (Stichting Nederlandse Vrijwilligers) 2009 *Feasibility of a national programme on domestic biogas in Indonesia* (Final report).
[19] Martí-Herrero J, Chipana M, Cuevas C, Paco G, Serrano V, Zymla B, Heising K, Sologuren J, Gamarr A 2014 *Renew Energy* 71 156–65
[20] Pérez I A, Garfí M, Cadena E, Ferrer I E 2014 *Renew Energy* **62** 313–31
[21] Nzila C, Dewulf J, Spanjers H, Tuigong D, Kiriamiti H, van Langenhove H 2012 *Appl Energy* **93** 496–506.
[22] Garfí M, Gelman P, Comas J, Ferrer I 2011 *Waste Manage* **31** 2584–9
[23] Garfí M, Ferrer-Martí L, Perez I, Flotats X, Ferrer I 2011 *Ecol Eng* **37** 2066–70.
[24] Garfí M, Ferrer-Marti L, Velo E, Ferrer I 2012 *Renew Sust Energy Rev* **16** 575–81
[25] Garfí M, Cadena E, Pérez I, Ferrer I 2014 *Renew Energy* **62** 313–18
[26] Ferrer I, Garfí M, Uggetti E, Ferrer-Martí L, Calderon A and Velo E 2011 *Biomass Bioenerg* **35** 1668–74.
[27] Vorley, B., Porras, I., & Amrein, A. (2015) *The Indonesia Domestic Biogas Programme: can carbon financing promote sustainable agriculture*? IIED (International Institute for Environment and Development) and Hivos. London, UK: 10.
[28] Hou J, Zhang W, Wang P, Dou Z, Gao L and Styles D 2017 *Energies* **10**, 239 (14 pages)
[29] Lansche J and Müller J 2017 *J. Clean Prod.* **165**, 828–835.
[30] Chen R 1997 *Ecological Engineering* **8(1)** 19–29
[31] Edwards P, Polprasert C, Rajput V S and Pacharaprakiti C 1988 *Waste Management & Research* 6(1) 51–61
[32] Wu X F, Wu X D, Li J S, Xi X H, Mi T, Yang Q, Chen G Q, Chen B, Hayat T, Alsaedi A 2014 *Ecological Indicators* **47** 189–97
[33] Chen S and Chen B 2012 *Renew. Sust. Energy Rev.* **16** 3948–59
[34] Chen B and Chen S 2013 *Energy Policy* **62** 707–16
[35] Qi J, Chen B, Chen W and Chu X 2012 *Procedia Environ. Sci.* **13** 1902–6
[36] Zhang L X, Wang C B and Song B 2013 *J. Clean Prod.* **47** 415–21.
[37] Zhang P D, Jia G M and Wang G 2007 *Renew. Sustain. Energy Rev.* **8(11)** 1903-12.
[38] Mezzullo W G, McManus M C and Hammond G P 2013 *Applied Energy* **102** 657–664
[39] Wang C B and Zhang L X 2012 *Procedia Environ. Sci.* **13** 778–89
[40] Bruun S, Jensen L S, Vu V T K and Sommer S 2014 *Renew. Sustain. Energy Rev.* **33** 736–41
[41] Börjesson P and Berglund M 2007 *Biomass Bioenerg* **31** 326–44.
[42] Directorate General of Electricity 2016 http://www.djk.esdm.go.id/index.php/layanan-info-pub/2016-01-08-03-54-21/faktor-emisi-pembangkit-listrik (Visited June 16, 2018)
[43] Maheshwari H, Jain K 2017 *Indian Journal of Science and Technology* **10(16)** 1-12

[44] India Specific Road Transport Emission Factors 2015. 2017. http://indiaghgp.org/transport-emission-factors (Visited June 16, 2018)
[45] Winnipeg Sewage Treatment Program 2011 SEWPCC Process Selection Report. Appendix 7. https://www.winnipeg.ca/...Appendix.../Appendix%207.pdf
[46] Posen I D, Jaramillo P, Landis A E and Griffin W M 2017 *Environ. Res. Lett.* **12** 034024
[47] IPCC (The Intergovernmental Panel on Climate Change) 2008, *2006 IPCC Guidelines for National Greenhouse Gas Inventories – A primer*. Eggleston H S, Miwa K, Srivastava N and Tanabe K (eds). IGES, Japan.
[48] Suhedi F 2006 Keterkaitan aktivitas domestik dengan emisi CO_2. Presentation at Workshop "*Alternatif Rancangan Permukiman Perkotaan Berdasarkan Emisi CO_2*". Bandung, March 21, 2006. In Bahasa Indonesia.
[49] Pathak H, Jain N, Bhatia A, Mohanty S and Gupta N 2009 *Environment Monitoring Assessment* **157** 407-18
[50] Haryanto A, Cahyani D, Triyono T, Murdapa F and Haryono D 2017 *Int. Journal of Renewable Energy Development* **6(1)** 29-36.