The potential of energy production and greenhouse gases emissions reduction of dairy farm biogas production

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Abstract. Dairy farming continues to grow in Indonesia as a result of high demand of meat and dairy products. On the one hand, dairy farming has the potential benefits for farmers, rural development and national food security. On the other hand, dairy farming generates the amount of waste causing adverse impact on environment. The uptake of biogas technology provides an effective method in managing waste as well as producing sustainable energy. In addition, biogas technology has the potential to reduce greenhouse gases emissions due to dairy farming activities. Biogas adoption in dairy farming potentially prevents greenhouse gases emission through manure management and fuel substitution. This paper analysed emission reduction and energy production of 5 biogas digesters which is installed in dairy farming in Pati regency, Indonesia. Results show potential energy from all biogas digesters was estimated 266,286.6 MJ year\(^{-1}\) while greenhouse gases emissions reduction was estimated to be 0.084 GgCO\(_2\)-eq year\(^{-1}\) due to biogas utilization. The emission consisted of 0.028 GgCO\(_2\)-eq year\(^{-1}\) from manure storage and 0.084 GgCO\(_2\)-eq year\(^{-1}\) from fuel replacement. Producing less emission can be an indicator that biogas is a cleaner and more efficient method compared to previous methods used by farmers in managing waste as well as in using fuels.

Keywords: anaerobic digestion, biogas, dairy farming, emission reduction, greenhouse gases

1. Introduction
Indonesia, a home of more than 260 million people, has the potential for developing cattle farming due to population growth and high demand of meat and milk. Most of cattle farming in Indonesia are operated by small scale farmers and located in rural areas. It means that the development of cattle farming benefits for supporting national self-sufficiency in food, increasing farmer’s income and encouraging rural development. However the expansion of cattle farming generates huge number of animal waste. Dairy cattle can produce about 30 kilograms of faeces and 80-100 litres of liquid waste [1].

Poor management of cattle waste causes adverse impact on the environment. Livestock manure contains a diverse range of pathogens polluting water body that can lead to disease for human [2]. Uncontrolled decomposition of organic material from livestock manure generates air pollution (odour) and greenhouse gases emissions. Methane (CH\(_4\)) is the most emitted gas in the livestock sector and waste management is one of main sources of GHG emissions [3]. With global warming potential 25 times higher than CO\(_2\) places CH\(_4\) emission in livestock as a significant contributor to global warming IPCC.
Anaerobic digestion is a promising method to tackle problems related to animal husbandry and it is also a method for producing sustainable energy. Anaerobic digestion prevents greenhouse gases emission by changing waste management and replacing dirtier fuel into biogas. Organic materials contained by livestock manure can be converted into biogas, a combustible gas, through the process of anaerobic digestion. Biogas consists of big portion of methane (40-70%), carbon dioxide (25-40%) and small quantities of other gases [4]. Slurry, a by-product of biogas plant, is returned to the agricultural land as a nutrient rich fertiliser containing nitrogen, phosphorus, and other minerals [5].

Small scale biogas digester is preferable type of biogas digester in Indonesia. Digester with small size 4-30 m³ requires small land, less investment, simpler management and fewer animals for feeding. This study investigates the GHG emissions reduction potential of household biogas digesters which are used in dairy farming located in Pati regency. This paper only focuses on estimating avoided GHG emissions from manure management and energy replacement.

2. Methods and materials

2.1 Study site

This study was carried out in dairy farms in Sukoharjo village, Pati regency, Indonesia (6°75'S, 111°01'E). In Pati regency, dairy farms are operated in Sukoharjo village and all of them are small scale farming which has an average of six cows per farm. The village covers an area of 3.77 Km² and the population is 6,522. It is located in lowland areas with elevations 10 meter above sea level with annual rainfall ranging from 0 to 330 mm.

There are 5 digesters in this study site and all of them are communal digesters. Communal digesters mean that digesters are managed by the group of farmers and the biogas produced from the digesters is delivered to member of the group. The size of these digesters varies from 6 to 30 m³. Of 5 biogas digesters, 1 digester with size 6 m³ uses fiberglass dome design while the rest use concrete-fixed dome design. Biogas is mostly for cooking and only in certain period (blackout) households uses it for lighting because electricity is available in the area. Not all of farmers experience to cook using biogas due to the number of digesters. Of 21 dairy farmers, only 10 farmers get benefits from the operation of biogas digesters in respect with the distance of their home from digester.

2.2 Data collection and analysis

Survey method with a face-to-face interview is used to collect primary data from biogas users as respondents. Data are collected by doing a census survey instead of a sample survey since the whole population is quite small (10 respondents). For this study, respondents are asked to answer few questions including digester size, number of cattle for feeding the digester and type of fuel used by respondent before using biogas. Secondary data are collected from literatures. For instance, data and formula to calculate the amount of emission reduction from manure management are provided by IPCC [6]. Data and formula to calculate the amount of emission avoided due to fuel replacement mostly are provided by Bruun [7].

3. Result and discussion

3.1 The potential of biogas production

In order to calculate the amount of GHGs reduction due to biogas utilization, it is obligation to know digester volume, gas production and the number of cattle needed to feed each biogas digester. Data related to digester volume and the number of cattle is collected by observation
while volume of biogas produced each digester is assumed 30% of digester volume [7]. In this study site, farmers own 2-10 dairy cows therefore mostly cow dungs were collected from several farmers. In smallest digester (6 m³) cow dungs were collected from single farmer. An advantage of installing biogas in dairy farming is related to water availability. Water is an important material in one of processes making biogas called hydrolysis process. Ratio for water and cow dung is expected 1 : 1. For example, an 18 m³ biogas digester is fed by mixture of 240 kg of dung and about 240 litres of fresh water per day to obtain maximum biogas volume. Dairy farms consume lots of water for cleaning and later, water can be used for feeding biogas digester.

Table 1. Characteristic of biogas digester

| Biogas plants code | Digester volume (m³) | Gas production (m³ day⁻¹) | Number of dairy cattle needed (head) |
|--------------------|----------------------|---------------------------|-------------------------------------|
| A                  | 25                   | 7.5                       | 16                                  |
| B                  | 18                   | 5.4                       | 12                                  |
| C                  | 18                   | 5.4                       | 12                                  |
| D                  | 6                    | 1.8                       | 4                                   |
| E                  | 30                   | 9                         | 20                                  |
| Total              | 97                   | 29.1                      | 46                                  |

From Table 1, the total amount of biogas was potentially produced in study site to be 29.1 m³.day⁻¹ or 10,621.5 m³.year⁻¹ (1 year = 365 days). The amount of biogas produced from all biogas digesters was delivered to households or no biogas lost. Assuming caloric value of biogas was 5,992 Kcal.m⁻³ [8]. The amount of energy from biogas that can be delivered to households per year was 63,644,028 Kcal or 266,286.6 MJ. Each household was delivered 26.6 GJ of energy per year since there were 10 households as biogas recipients. Salunkhe et al. [8] denoted that efficiency biogas stove was estimated 62% therefore 16.5 GJ of energy per year can be potentially used for cooking.

3.2 Potential emission avoided from manure management

Total of dairy cattle is needed to produce dung for feeding biogas digester (N) is 64 (Table 1). Formula and the value of every variable to calculate the emission are taken from IPCC [6]. GHG emissions reduction from manure storage and emission factor (EF) was calculated using Equations 1 & 2. GHG emission in the form of CH₄ manure is presented in Giga grams CO₂eq.year⁻¹. Global warming potential of CH₄ is 25 GgCO₂eq.GgCH₄⁻¹:

\[
CH₄_{\text{manure}} = EF \times N \times 10^{-6} \times 25
\]  
\[
EF = (VS \times 365) \left[B_0 x 0.67(\text{kg. m}^{-3}) \times \frac{MCF}{100} \times MS\right]
\]

Whereas:

\[\text{VS} = \text{the daily volatile solid excreted by dairy cattle (kg dry matter.head}^{-1}.\text{day}^{-1})\]
\[365 = \text{basis for calculating annual VS production, (days year}^{-1})\]
\[B_0 = \text{maximum methane producing capacity for manure produced by dairy cattle (m}^3 \text{ CH}_4 \text{ kg}^{-1} \text{ of VS excreted)}\]
\[0.67 = \text{conversion factor of m}^3 \text{ CH}_4 \text{ to kilograms CH}_4\]
\[MCF = \text{methane conversion factors for each manure management system S by climate region k, (}\
\%
]
MS = fraction of dairy cattle’s manure handled using manure management system S in climate region k, dimensionless

From Equations 1 and 2, the reduction contribution of manure management was estimated to be 0.028 GgCO$_2$-eq, year$^{-1}$. Anaerobic digestion of dairy waste provides less GHG emission and better sanitation. Prior to using biogas technology, farmers dump waste from their farms in their backyards or in the rivers because of cost, insufficient regulations and lack of knowledge. Poor sanitation creates problems on health of both farmer’s family and their neighbours surrounding the farming because Sukoharjo village as location of dairy farming is a densely populated area.

### 3.3 Potential emission avoided from energy substitution

Greenhouse gases were emitted directly from biogas digester as well as from the combustion of biogas. Poor construction and maintenance quality of biogas digester can be sources of biogas lost before it is used as fuel. In this study, the construction and maintenance was assumed well managed meaning no biogas lost from digesters. Since biogas was used to replace fuel wood and LPG for cooking, the emission during combustion for biogas, fuel wood and LPG must be calculated and compared in order to know the emission avoided due to energy replacement. The potential of biogas emissions and the replaced fuels were estimated using in Equation 3 and 4 [7].

\[
\text{IPB}_{GW} = M_i(f_i) \cdot CF_{CH_4} + ECR_{CH_4} \cdot CF_{CH_4} + ECR_{N_2O} \cdot CF_{N_2O} + ECR_{CO_2} \cdot CF_{CO_2} + ECR_{CO} \cdot CF_{CO}
\]

(3)

\[
\text{IPB}_{GW} = \text{Impact potential of biogas emissions per unit of energy delivered (g CO$_2$-eq) } \\
M_i(f_i) = \text{Amount of methane that is lost from biogas digester (value is 0 because no biogas lost from digesters).} \\
CF = \text{Characterization factor for CO, CO$_2$, N$_2$O and CH$_4$ (g CO$_2$-eq g$^{-1}$)} \\
ECB = \text{GHG emissions during combustion of biogas (g GHG)}
\]

\[
\text{IPR}_{GW} = ECR_{CH_4} \cdot CF_{CH_4} + ECR_{N_2O} \cdot CF_{N_2O} + ECR_{CO_2} \cdot CF_{CO_2} + ECR_{CO} \cdot CF_{CO}
\]

(4)

\[
\text{IPR}_{GW} = \text{Impact potential of emissions from the replaced fuels (g CO$_2$-eq) } \\
ECR = \text{Certain GHG emissions during combustion of the replaced fuel (g GHG)}
\]

Characterization factor value for CO, N$_2$O, CO$_2$, and CH$_4$ are 1.9 gCO$_2$-eq g$^{-1}$, 295 gCO$_2$-eq g$^{-1}$, 1 gCO$_2$-eq g$^{-1}$ and 25 gCO$_2$-eq g$^{-1}$, respectively. Value for ECB and ECR were provided by Table 2.

### Table 2. Emissions per MJ delivered energy

| Energy type | CO$_2$ (g) | CH$_4$ (mg) | CO (g) | N$_2$O (mg) |
|-------------|------------|-------------|--------|-------------|
| Biogas      | 81.5       | 57.0        | 0.1    | 5.4         |
| Fuel wood   | 532.0      | 600.0       | 14.0   | 4.3         |
| LPG         | 139        | 8.9         | 0.82   | 6.0         |

### Table 3. GHG emissions of biogas and fuel wood combustion (kg CO$_2$-eq kg$^{-1}$)

| Energy type | CO$_2$ (kg) | CH$_4$ (kg) | CO (kg) | N$_2$O (kg) | Total     |
|-------------|-------------|-------------|---------|-------------|-----------|
| Biogas      | 13,021.4    | 9.1         | 16.0    | 0.86        | 13,533.97 |
| Fuel wood   | 84,998.7    | 95.9        | 2,236.8 | 0.69        | 91,847.89 |

Based on survey, 6 households used fuel wood and 4 households used LPG prior to using biogas for cooking. Hence, the amount of delivered energy to replace the usage of fire wood was 159,772 MJ year$^{-1}$ or 60% of total amount of energy from biogas (266,286.6 MJ year$^{-1}$). GHG emission from biogas combustion and fuel wood as replacement of biogas in the same value of delivered energy...
(159,772 MJ year⁻¹) was shown in Table 3. With similar calculation, it was estimated 106,514.6 MJ year⁻¹ energy from biogas used for LPG replacement and the emission was shown in Table 4.

Table 4. GHG emissions biogas and LPG combustion (kg CO₂eq kg⁻¹)

| Energy type | CO₂ (kg) | CH₄ (kg) | CO (kg) | N₂O (kg) | Total  |
|-------------|----------|----------|---------|-----------|--------|
| Biogas      | 8,680.9  | 6.1      | 10.7    | 0.58      | 9,022.64 |
| LPG         | 14,805.5 | 0.95     | 87.3    | 0.64      | 15,183.71 |

Fuel wood combustion generated GHG emissions far higher than that of biogas combustion at the same delivered energy (Table 3). Burning fuel wood emitted 91,847.89 KgCO₂eq Kg⁻¹.year⁻¹ that was about 7 fold of GHG emission from biogas combustion. Burning biogas also produce less emission compared to burning LPG (Table 4). The reduction of GHG emissions from fuel substitution was estimated using Equation 5.

Avoided GHG emissions = GHG emission of replaced fuel(fuelwood,LPG) − GHG emission of biogas  

Using Equation 5, utilization biogas to replace fuel wood and LPG reduced GHG emissions 0.078 GgCO₂eq.year⁻¹ and 0.006 GgCO₂eq.Year⁻¹, respectively. Total GHG emissions 0.084 GgCO₂eq.year⁻¹ was potentially prevented as a result of shifting from fuel wood and LPG to biogas for cooking. The amount of emission prevented from fuel substitution was approximately three times larger than the amount of emission prevented from manure management.

Burning fuel wood emits highest greenhouse gases compared to that of biogas and LPG. Theoretically, it can be predicted from data provided by Table 2 while the value of CO₂, CH₄ and CO emissions from burning fuel wood are far higher than that of biogas and LPG. High production of smoke from fuel wood burning is also not only an indicator for emission but also an indicator lower efficiency of fuel wood stove. The low efficiency of a stove means that much energy is wasted [5].

In rural areas, people use fuel wood fuel because it is cheap. In many cases, fuel wood is easy to collect because it is obtained from their backyard for free. However for fuel wood users, rainy season is the most difficult period because it is hard to find dry fuel wood. Wet fuel wood causes difficulties for making fire and creates abundant smoke and soot therefore cooking with biogas reduces burden for cleaning kitchen and appliances. Compared to fuel wood, biogas offers benefit on health by reducing indoor smoke pollution and prevents them from possibly getting respiratory diseases [5, 9].

Compared to biogas, LPG has relatively same in stove efficiency but it has caloric value higher than biogas [10]. However, cooking with biogas offers other environmental and economic benefits. Environmentally, burning biogas produces less emission. Economically, biogas users spend less money and it enables biogas users to save their money [11]. In some periods, LPG users experienced LPG shortage causing difficulties to buy LPG and the price increases sharply.

3.4 Total potential emission prevented

Total potential emission prevented is sum of the amount of emission avoided due to energy replacement and the amount of emission avoided due to change of waste management. The utilization of biogas digester to treat manure and to replace fuel in this study site was estimated 0.112 GgCO₂eq.Year⁻¹. In reality, the GHG emissions reduction can be either higher or lower than this result study depending on many factors. In manure management, prevented emission can be higher if farmers dump their animal waste to river before using biogas. In fuel replacement, the emission increases while the proportion of fuel wood users increase. The ability of anaerobic
digestion to reduce GHG emissions will decrease sharply when the amount of biogas lost increases through either digester cracking or intentional release [10].

4. Conclusion
This study results the ability of biogas to produce energy and to reduce GHG emissions. Potential energy from all biogas digesters was estimated 266,286.6 MJ year⁻¹. With regards the number of households as recipients and stove efficiency, it was estimated to be 16.5 GJ of energy per year that can be used for cooking per household. Total greenhouse gases emissions reduction was estimated to be 0.084 GgCO₂eq year⁻¹ consisting of 0.028 GgCO₂eq year⁻¹ from manure storage and 0.084 GgCO₂eq year⁻¹ from fuel replacement. Reducing GHG emissions is one of benefits to utilize biogas. It can be noted that only 10 of 21 farmers experienced benefits of biogas in managing waste and providing energy. It means many farmers still practise less efficient activities and produce more emissions.

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