Quantifying the potency of greenhouse gas emission from manure management through anaerobic digester in Central Java

Sarah, H L Susilawati and A Pramono

Indonesian Agricultural Environment Research Institute, Pati, Indonesia
E-mail: sarahsoedarma@gmail.com

Abstract. Indonesia has committed to reduce 29% of national greenhouse gas (GHG) emissions by its own efforts and 41% with international support by 2030. The livestock releases methane (CH\textsubscript{4}) and nitrous oxide (N\textsubscript{2}O) from enteric fermentation and manure management. The anaerobic digester can capture CH\textsubscript{4} emission from manure and it can be used for bio-energy to replace LPG and kerosene. This study aims to estimate GHG emission from manure management and its reductions through anaerobic digestion in Central Java Province during 2010–2015. The data were collected through questionnaire surveys, interviews, and institutional data collections. GHG emissions from livestock and its mitigation were estimated using the IPCC 2006 Tier 1 method. The results showed that Central Java has GHG emission from the livestock of 1,546.26, 1,658.38, 1,775.99, 1,708.46, 1,745.37, and 1,817.52 Gg CO\textsubscript{2} from 2010 to 2015, respectively. The anaerobic digestion avoided CH\textsubscript{4} emission approximately 11.55 - 117.43 Gg CO\textsubscript{2} per year. Methane avoidance could substitute the energy around 0.50 - 5.08 Gg CO\textsubscript{2} per year. Anaerobic digesters are processes that convert cow manure into biogas rich in methane, which can reduce indirectly GHG emissions from animal waste. Manure management through a digester produces biogas that can be used to replace non-renewable energy such as LPG and kerosene.

1. Introduction
Indonesia has committed to reduce 29% of national greenhouse gas (GHG) emissions by its own efforts and 41% with international support by 2030, while still maintaining the economical-growth target of 7% [1]. Methane and nitrous oxide emissions contribute to global warming, which the agricultural sector provides 10 to 12% and the livestock sector provides 18 to 51% of total anthropogenic GHG emissions. These gases are produced during the digestion process of ruminants compared to non-ruminants. Livestock produces methane gas from the digestion of feed in the rumen (CH\textsubscript{4} enteric fermentation) and CH\textsubscript{4} from livestock manure. N\textsubscript{2}O gas is produced from the management of livestock manure [2].

The livestock sector produces more than 1 million t of manure annually. Most of this waste is dumped in containers or stored outdoors until it decomposes. This method will generate methane and N\textsubscript{2}O gas which has global warming potential of 21 and 310 times greater than CO\textsubscript{2} respectively [3].

From 2010 to 2015 the population of beef cattle in Central Java was accounted for 2 million cows [4]. This has an impact on the potential for global warming due to increased methane so that methane emissions from livestock are highly importance. Energy diversification is the key to overcome energy scarcity, which is starting to occur. The saving and developing renewable energy is an energy
One of the renewable energies is biogas. Biogas comes from livestock manure, industrial waste, or household organic waste. Biogas has a prospect as an alternative fuel that can be developed, considering that existing fuels are increasingly scarce and have high costs [5]. The digesters produce biogas at average rates of 0.30 to 0.48 L g\(^{-3}\) volatile solid from swine, bovine, and poultry slurries. The digesters can produce the CH\(_4\) concentration of 60 to 80% [6]. Burning 1 t of methane is equivalent to eliminating about 24 t of CO\(_2\) [7]. In China, about 5.43 million digesters can handle about 15 million t of organic waste per year with 1.345 billion m\(^3\) of biogas production. Biogas can substitute for coal and electricity for lighting so the 15 m\(^3\) digester and conveyance system is about 2,000 - 3,000 yuan RMB [8]. The purpose of this paper is to determine the contribution of GHG emissions from the livestock after the biogas procurement program in Central Java Province from 2010 to 2015.

2. Materials and methods
This activity uses the Tier-1 method. The Tier-1 method is the easiest and simplest method. The data required is the livestock population in one year in an area and the emission factor (FE) value for each CH\(_4\) and N\(_2\)O gases from each type of livestock [2]. The study was conducted at Indonesian Agricultural Environment Research Institute (IAERI), Pati-Central Java during January-May 2020. The method used in this research was data collecting activity and processing based on literatures.

2.1. Materials
The data are collected by recapitulating several districts that have implemented the digester program in Central Java Province. Central Java Province located between 5\(^°\)4’- 8\(^°\)3’ South Latitude and 108\(^°\)30’- 111\(^°\)30’ East Longitudes. Central Java Province has 29 districts and six municipalities with Semarang City as the capital city [9]. This study uses primary data and secondary data. Primary data such as the number of the digester was carried out by surveying locations where the digester was present. Meanwhile, secondary data such as the livestock population were obtained from statistical data from the Ministry of Agriculture in 2013 and 2017. This paper used data from 2010 to 2015.

| Species          | Population (head) |
|------------------|-------------------|
|                  | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   |
| Beef Cattle      | 1,554,008 | 1,936,501 | 2,047,882 | 1,496,777 | 1,587,988 | 1,638,003 |
| Dairy Cattle     | 122,489  | 149,931  | 154,398  | 103,794  | 122,566  | 134,670  |
| Buffalo          | 111,097  | 75,674   | 79,667   | 62,032   | 66,860   | 64,913   |
| Sheep            | 2,146,760 | 2,226,709 | 2,429,132 | 2,458,303 | 2,395,671 | 2,304,131 |
| Goats            | 3,691,096 | 3,724,452 | 3,889,878 | 3,922,159 | 3,957,917 | 4,069,797 |
| Swine            | 150,821  | 150,292  | 163,377  | 158,883  | 136,495  | 122,653  |
| Horses           | 15,152   | 15,872   | 17,763   | 15,559   | 13,462   | 12,550   |
| Native Chicken   | 36,908,672 | 38,296,383 | 40,868,263 | 39,313,232 | 40,753,808 | 40,717,553 |
| Broiler          | 64,332,799 | 66,239,700 | 76,906,291 | 103,964,760 | 108,195,894 | 126,102,735 |
| Layer            | 17,712,776 | 18,395,051 | 19,881,430 | 21,630,154 | 20,293,547 | 21,865,087 |
| Duck             | 5,006,163  | 5,451,474  | 5,713,260  | 5,582,225  | 5,654,845  | 4,978,129  |

Source: [4,10].

2.2. Methods
The carbon of livestock manure is a result from autotrophic fixation which produces CO\(_2\) into the atmosphere in a relatively short time so the CO\(_2\) from the process of storing livestock manure is not considered a source of global warming. However, CO\(_2\) together with CH\(_4\) and N\(_2\)O emissions are
measured to see any aerobic decomposition activity. GHG emissions from livestock are calculated using the IPCC 2006 Tier-1 method. This method requires two data, namely livestock population data and the FE values of methane gas and N₂O for each type of livestock. The formula for calculating greenhouse gas emissions using the Tier-1 method is as follows:

- CH₄ Manure = N(T) * EF(T) * 10⁻⁶ (IPCC 10.22 Equation, 2006) (1)
- Direct N₂O (mm) = NE₃MMS * EF₃ (S) * 44/28 (Equation 10.25 IPCC, 2006) (2)
- Indirect N₂O (mm) = NE_volatileization-MMS * EF₄ * 44/28 (Equation 10.27 IPCC, 2006) (3)

Methane avoidance biogas = number of digester x number of livestock involved in biogas x volume of gas from cow dung per day in digester x digester pressure x 365 days x conversion of CH₄ to CO₂e

Energy substitution = substitution to LPG + substitution to kerosene

Table 2. Emission factor in Asian.

| Livestock category | CH₄ (kg heads⁻¹ year⁻¹) | Direct N₂O (kg heads⁻¹ day⁻¹) | Indirect N₂O (kg heads⁻¹ day⁻¹) |
|--------------------|--------------------------|--------------------------------|---------------------------------|
| Beef Cattle        | 0.72                     | 0.0144                         | 0.007                           |
| Dairy Cattle       | 23.25                    | 0                              | 0.008                           |
| Buffalo            | 1.44                     | 0.0144                         | 0.007                           |
| Sheep              | 0.20                     | 0.02                           | 0.01                            |
| Goats              | 0.22                     | 0.02                           | 0.01                            |
| Swine              | 7                        | 0.02                           | 0.01                            |
| Horses             | 2.19                     | 0.02                           | 0.01                            |
| Native Chicken     | 0.02                     | 0.001                          | 0.01                            |
| Broiler            | 0.02                     | 0.001                          | 0.01                            |
| Layer              | 0.02                     | 0.001                          | 0.01                            |
| Duck               | 0.02                     | 0.001                          | 0.01                            |

Source: [11].

3. Results and discussion
Agricultural activities in Central Java Province are including horticulture, fisheries, plantations, animal husbandry, and food crops. The livestock sub-sector contributes to the greenhouse gases that come from enteric fermentation and manure management. GHG emissions cause global warming which will have an impact on extreme weather which affects crop yields and productivity, food availability, and food prices [12]. The average growth of livestock population in Central Java from 2010 to 2015 has increased for the types of beef cattle, dairy cows, buffalo, goats, sheep, native chickens, broilers, and layer chickens. The types of pigs and horses have decreased on average each year [4,10].
Figure 1. Emission from manure management.

Animal manure is a product produced of animals that can be recycled as plant nutrition. They produce an essential substrate required for $\text{N}_2\text{O}$ and $\text{CH}_4$ gas-producing microbes. This GHG can be produced and emitted in manure management activity, such as manure storage, manure processing, and spreading manure on the land. Land conditions can affect the magnitude of emissions such as temperature and water availability for microbial activities (nitrification, denitrification, methane formation, and $\text{CH}_4$ oxidation) [13]. Microbial production in the soil is a major source of $\text{N}_2\text{O}$ and has increased with the increased use of nitrogen fertilizers [14]. Livestock produces greenhouse gases in the form of $\text{CH}_4$ from enteric fermentation, $\text{N}_2\text{O}$ from the use of nitrogen fertilizers from livestock manure, and $\text{CH}_4$ and $\text{N}_2\text{O}$ from manure management and deposition of livestock manure in the pasture. Some $\text{CO}_2$ is also produced in animal husbandry from the use of fossil fuels and energy [15].

According to figure 1 goats contribute the most to GHG emissions from manure management. From Figure 1 it can be seen that the highest emission comes from goats with the amount of GHG emission load depending on the number of livestock population, because of the linear relationship between population size and methane and $\text{N}_2\text{O}$ emissions [2]. Another source states that GHG emissions depend on the livestock population [1]. The results showed that Central Java has GHG emission from the livestock of 1546.26, 1658.38, 1775.99, 1708.46, 1745.37, and 1817.52 Gg CO$_2$ from 2010 to 2015.

The effort to mitigate methane from livestock manure is manure management using digesters. Animal manure stored in digesters is a suitable environmental condition for methane bacteria. The bacteria in the digester will break down organic waste to produce methane which can be used as a source of electricity. This process will reduce odors and pathogens that commonly occur on the process of storing animal waste [16].

Digesters can reduce greenhouse gas emissions through utilizing as renewable energy for consumption. Through the anaerobic process, digesters reduce the organic content of the waste into methane ($\text{CH}_4$), carbon dioxide ($\text{CO}_2$), $\text{H}_2$, $\text{NH}_3$, and $\text{H}_2\text{S}$. Capture and combustion of $\text{CH}_4$ in digesters can reduce greenhouse gas emissions compared to traditional manure management [17]. The existence of conducive conditions to the growth of methane bacteria will shorten the time required for bacteria to digest waste and increase the production of biogas [18].

Table 3. Methane avoidance and energy substitution in Central Java during 2010-2015.

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|------|------|------|------|------|------|------|
| Methane avoidance (Gg CO$_2$ yr$^{-1}$) | 11.55 | 26.95 | 90.48 | 84.7 | 119.35 | 117.43 |
| Substitution energy (Gg CO$_2$ yr$^{-1}$) | 0.5 | 1.16 | 3.91 | 3.66 | 5.16 | 5.08 |
The methanogen process is dominated by the formation of methane gas, while CO$_2$ gas is produced in limited quantities [19]. Anaerobic digestion of manure can reduce GHG emission into the atmosphere by avoiding methane emission from natural decomposition during storage [20]. Another opinion also explains that the use of biogas significantly contributes to the development of sustainable energy and the reduction of GHG emissions in China [21]. The methane avoidance and energy substitution in Central Java during 2010-2015 was shown in Table 3. The anaerobic digestion avoided methane emission approximately 11.55 – 117.43 Gg CO$_2$ per year. Methane gas in digesters can be substituted for energy around 0.50- 5.08 Gg CO$_2$ per year from 2010 to 2015.

Biogas is a biofuel with a high value and contains methane, which can be used as a renewable energy source as a substitute for natural gas or petroleum [19]. The potential of biogas energy produced in the digester is obtained from the rate of biogas production, namely the volume of gas, and the resulting methane gas composition [22]. The methane emitted from the digester storage is about 12% of the annual quantity of CH$_4$ produced in the digester. Digesters destroy 62% volatile solids of the manure and additional feedstock which will produce CH$_4$. Also, the captured biogas (88%) generates renewable electricity and heat [23].

4. Conclusions

Central Java has GHG emission from the livestock of 1,546.26, 1,658.38, 1,775.99, 1,708.46, 1,745.37, and 1,817.52 Gg CO$_2$ from 2010 to 2015. The anaerobic digestion avoided CH$_4$ emission approximately 11.55 – 117.43 Gg CO$_2$ per year (1-6% per year). Methane avoidance could substitute the energy around 0.50- 5.08 Gg CO$_2$ per year (0.03%-0.28% per year). Anaerobic digesters are processes that convert cow manure into biogas rich in methane, which can significantly reduce GHG emissions from animal waste. Manure management through a digester produces biogas can be used to replace non-renewable energy such as LPG and kerosene.

Acknowledgments

All the authors are the main contributor to this paper. The authors are very grateful to the Indonesian Agricultural Environment Research Institute for involving the authors in research activity.

References

[1] Nurhayati I S and Widiawati Y 2019 Mitigasi gas rumah kaca subsector peternakan di Kabupaten Subang, Jawa Barat (in Bahasa) Proc. Seminar Nasional Teknologi Peternakan dan Veteriner pp 226-236
[2] Syarifuddin H, Rahman S A and Devitriano D 2019 Inventarisasi emisi gas rumah kaca (CH$_4$ dan N$_2$O) dari sector peternakan sapi dengan metode tier -1 IPCC di Kabupaten Muaro Jambi (in Bahasa) Jurnal Ilmiah Ilmu-Ilmu Peternakan 22 pp 84-94
[3] Cuellar A D and Webber M E 2008 Cow power: the energy and emissions benefit of converting manure to biogas Environmental Research Letters 3 pp 1-8
[4] Pusat Data dan Sistem Informasi Pertanian 2013 Statistik Pertanian (in Bahasa) (Kementerian Pertanian) pp 1-360
[5] Widyastuti F R, Purwato and Hadiyanto 2013 Potensi Biogas melalui pemanfaatan limbah padat pada peternakan sapi perah Bangka Botanical Garden Pangkalpinang (in Bahasa) Metana 9 pp 19-26
[6] Masse D I, Talbot G and Gilbert Y 2011 On farm biogas production: a method to reduce GHG emission and develop more sustainable livestock operations Animal Feed Science and Technology 166-167 pp 436-445
[7] Key N and Sneeringer S 2011 Climate change policy and the adoption of methane digesters on livestock operations (US: United Stated Department of Agriculture) pp 1-47
[8] Erda L, Yue L and Hongmin D 1997 Potential GHG mitigation options for agriculture in China Applied Energy 56 pp 423-432
[9] Dinas Pekerjaan Umum Sumber Daya Air dan Tata Ruang Jawa Tengah 2020 Provinsi Jawa Tengah (in Bahasa) http://pusdataru.jatengprov.go.id/taturuang/profil-jateng.html#:~:text=Provinsi%20Jawa%20Tengah%20secara%20geografis,111o%2030%20Bujur%20Timur.&text=Jawa%20Tengah%20adalah%20sebuah%20provinsi,04%25%20dari%20luas%20pulau%20Jawa 28 Juli 2020

[10] Pusat Data dan Sistem Informasi Pertanian 2017 Statistik Pertanian (in Bahasa) (Kementerian Pertanian) pp 1-408

[11] IPCC 2006 Guidelines for national greenhouse gas inventories: emission from livestock manure management V4 Chapter 10 p 1

[12] Zervas G and Tsiplakou E 2012 An assessment of GHG emission from small ruminants in comparison with GHG emissions from large ruminants and monogastric livestock Atmospheric Environment 49 pp 13-23

[13] Chadwick D, Sommer S, Thorman R, Fangueiro D, Cardenas L, Amon B and Misselbrook T 2011 Manure management: Implications for greenhouse gas emissions Animal Feed Science and Technology 166–167 pp 514-531

[14] Davidson E A 2009 The contribution of manure and fertilizer nitrogen to atmospheric nitrous oxide since 1860 Nature Geoscience 2 pp 659-662

[15] O’Mara F P 2011 The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future Animal Feed Science and Technology 166–167 pp 7–15

[16] Zaks D P M, Winchester N, Kucharik C J, Barford C C and Reilly S J M 2011 Contribution of anaerobic digesters to emissions mitigation electricity generation under U.S. climate policy Environmental Science and Technology 45 pp 6735-6742

[17] Flesch T K, Desjardins R L and Worth D 2011 Fugitive methane emissions from an agricultural biodigester Biomass and Bioenergy 35 pp 3927–3935

[18] Carolyn B L and Charles K Ling 2013 Anaerobic digestion for energy generation and greenhouse gas reduction Agricultural Economists Rural Development pp 45–73

[19] Martins L C and Vessoni T C 2009 Biogas production: New trends for alternative energy sources in rural and urban zones Chem. Eng. Technol. 8 pp 1147–1153

[20] Nicolae S, Dallemend J F and Fahl F 2018 Biogas: Developments and perspectives in Europe Renewable Energy 129 pp 457–72

[21] Liu Yu, Yaoqiu K, Ningsheng H and W Zhifeng Xu Lianzhong 2008 Popularizing household-scale biogas digesters for rural sustainable energy development and greenhouse gas mitigation Renewable Energy 33 pp 2027-2035

[22] Iriani P, Suprianti Y and Yulistiani F 2017 Fermentasi anaerobik biogas dua tahap dengan aklimitasi dan pengkondisian pH fermentasi (in Bahasa) Jurnal Teknik Kimia dan Lingkungan 1 pp 1-10

[23] Baldé H, VanderZaag A C, Burt S D, Riddle C W, Crolla A, Desjardins R L and MacDonald D J 2016 Methane emissions from digestate at an agricultural biogas plant Bioresource Technology 216 pp 1-32