Anaerobic biodigester as a community-based food waste processor (case study: canteen area of PT PLN Nusantara Power UP Muara Karang)

Tania Revina Yasin[1] , *Iman Dimassetya Yanuar* Yusuf[1] , and *Aulia* Rahmanissa[1]

[1]PT PLN Nusantara Power UP Muara Karang, Jl. Pluit Karang Ayu Barat 01 Penjaringan North Jakarta, 14450, Indonesia

Abstract. In 2022, DKI Jakarta disposed of ± 8,000 tons/day of waste to the Integrated Waste Processing Site (TPST) Bantar Gebang. Among them, 3,761.90 tons/day of organic waste were generated from domestic activities. Considering the amount of organic waste, the potential to convert it into biogas through anaerobic biodigester was feasible. As the organic waste decomposes, it produces methane (CH_4) gas, which holds value as a renewable alternative energy source. Processing food waste into biogas is not only perceived as an effective way to reduce CH_4 hazards but also provides economic benefits for the community. PT PLN Nusantara Power UP Muara Karang, located in Pluit - North Jakarta, attempted to make a breakthrough in waste management, especially in the Pluit Sub-district, through a methane capture and processing facility. Employing quantitative methods with primary data, this research was conducted from May to August 2023 and focused on the canteen area whose tenants came from the Pluit neighborhood. The anaerobic biodigester facility has a design capacity of up to 5 m^3 or 800 kg of food waste. In its initial operation (May to August 2023), the food waste processed 363.5 kg and produced 40.7 m^3 of methane gas, or 1.4009 GJ, and was used by canteen tenants for their daily operations. Annually, based on its initial condition, the activity conducted in this research can reduce greenhouse gases by 690 kg CO_2e and provide economic benefits of Rp 16,000,000.

1 Introduction

Based on Indonesian Law Number 18 of 2018 about Waste Management, waste is the remains of daily human activities and/or natural processes in solid form. Based on these regulations, the waste managed consists of household waste, household-like waste and specific waste. Household waste is waste originating from daily activities in the household, excluding feces and specific waste. Meanwhile, household-type waste is waste originating from commercial areas, industrial areas, special areas, social facilities, public facilities, and/or other facilities [1].

Management of household and similar household waste is carried out through waste reduction and handling. Waste can be reduced by minimizing waste generation, recycling waste, or reusing waste. Waste handling can be done through sorting, collection from the source to temporary shelters or integrated processing sites, waste transportation, waste processing, and final waste processing.

Based on data from the National Waste Management Information System or SISPN KLHK RI, the composition of Indonesia's waste in 2022 consisted of 40,81% food waste, 17,75% plastic waste, 13,18% wood/twig waste, 11,17% waste paper/cardboard, and others [2]. Based on the 2021 food loss and waste in Indonesia study report, the total generation of food waste during the period 2000 – 2019 reached 115 – 184 kg/capita/year. The value of CO2 emissions resulting from food waste is estimated at 1,702.9 metric tons/year or equivalent to 7,29% of Indonesia's greenhouse gas emissions [3]. It causes a loss of food which is the same as a portion for 61-125 million people per year. Reducing food waste generation was reported to be the most significant effort to reduce greenhouse gas emissions[3]. Reducing food waste by 5% can reduce greenhouse gas emissions by 2,98% [3]. Other than that, economic loss was reported around IDR 213-551 trillion/year or about 4-5 percent of Indonesia's GDP per year [3].

Waste generation in DKI Jakarta in 2022 was 8.527,07 tonnes/day or 3.112.381,4 tonnes/year [2]. For the North Jakarta city area, the total waste produced in 2022 was 499.480,75 tons/year with a waste reduction percentage of 26,02% and waste handling of 73,53%. Food waste does not only come from household consumption but also comes from retail and food service [4]. Most food waste is not managed at the source but is thrown directly into the landfill. Food waste that is not processed and thrown into landfills will decompose naturally and produce methane gas. This will have a negative impact on the environment [17].

Anaerobic digestion is one of the methods that is reliable for processing food waste. Considering the negative environmental impacts such as but not limited to landfilling, incineration, or composting of food waste [5][6], anaerobic digestion has been proposed as a relatively cost-effective technology for renewable energy production and waste treatment of this high-moisture and energy-rich material [7][8].

PT PLN Nusantara Power UP Muara Karang employed this technology to manage waste generated from the canteen area. Before this research was conducted, waste management in the PT PLN Nusantara Power UP Muara Karang canteen area was still limited to placing it in the temporary storage site to then be taken to the final disposal site or landfill by waste transport officers.

The aims of this study were to implement anaerobic digesters to process food waste in PT PLN Nusantara Power UP Muara Karang canteen area; evaluate the results by observing waste input, gas production, emission reduction, potential energy; promote the application of anaerobic digester technology.

2 Methodology

This study took place in the canteen area managed by PT PLN Nusantara Power UP Muara Karang which is located in the Pluit sub-district, North Jakarta. The research was conducted in a quantitative method by collecting primary data obtained directly from each canteen tenant. The primary data covered waste input and gas production. The analysis and discussion of this study were supported by literature studies on the applications of anaerobic digesters for food waste management.

https://doi.org/10.1051/e3sconf/202448505003

2.1 Emission reduction

Calculation of the emission reduction value resulting from waste processing using an anaerobic digester uses the following formula:

$$CO_2 \text{ mitigation} = \text{baseline emission} - \text{anaerobic digester emission} \tag{1}$$

The baseline condition in this study is emissions resulting from conditions when food waste is transported to a landfill and undergoes decomposition as well as emissions resulting from burning LPG. Anaerobic digester emission is calculated from emissions resulting from burning biogas. To calculate CO_2 emissions from waste disposal activities to the landfill, use the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories Chapter 5 Waste as a reference with the following formula:

$$DDOCm = Wi \times DOC \times Total\ DOC_f \times MCF \tag{2}$$
$$CH_4 \text{ emission} = [(DDOCm \times F \times 16/12) - R_T] \times (1 - OX_T) \tag{3}$$
$$CO_2 \text{ emission} = 45/55 \times CH_4 \text{ emission} \tag{4}$$
$$\text{Organic waste emission} = CH_4 \text{ emission} + CO_2 \text{ emission} \tag{5}$$

where $DDOC_m$ is total degradable organic carbon, Wi is weight, DOC_f is degradable organic carbon factor (value = 0,48), MCF is methane correction factor (value =1) , F is the fraction by volume of CH_4 in landfill gas (value = 0,5), R_T is recovery rate CH_4 over time (value = 0), OX_T is oxidation factor over time (value = 0).

The formulas to calculate CO_2 emissions from LPG consumption are [9]:

$$CO_2\ LPG = Vol\ biogas \times density \times EF\ CO_2\ LPG / eff\ LPG \tag{6}$$
$$CH_4\ LPG = Vol\ biogas \times density \times EF\ CH_4\ LPG / eff\ LPG \tag{7}$$
$$N_2O\ LPG = Vol\ biogas \times density \times EF\ N_2O\ LPG / eff\ LPG \tag{8}$$
$$CO_2e\ LPG = CO_2\ LPG + (CH_4\ LPG \times GWP\ CH_4) + (N_2O\ LPG \times GWP\ N_2O) \tag{9}$$

where *vol biogas* is the volume of biogas consumption, *density* is the density of biogas (1.2 kg/m^3), $EF\ CO_2\ LPG$ is CO_2 emission factor from burning LPG (3.075 g/kg), $EF\ CH_4\ LPG$ is CH_4 emission factor from burning LPG (0.137 g/kg), $EF\ N_2O\ LPG$ is N_2O emission factor from burning LPG (1.88 g/kg), *eff LPG* is combustion efficiency of LPG (60%), *GWP* is global warming potential (CO_2 = 1, CH_4 = 21, N_2O = 310).

The formulas to calculate CO_2 emissions from biogas consumption are [9]:

$$CO_2\ bio = Vol\ biogas \times density \times EF\ CO_2\ bio / eff\ bio \tag{10}$$
$$CH_4\ bio = Vol\ biogas \times density \times EF\ CH_4\ bio / eff\ bio \tag{11}$$
$$CO_2e\ bio = CO2\ bio + (CH_4\ bio \times GWP\ CH_4) \tag{12}$$

where $EF\ CO_2\ bio$ is the CO_2 emission factor from burning biogas (748 g/kg), $EF\ CH_4\ bio$ is the CH_4 emission factor from burning biogas (0.023 g/kg), *eff bio* is the combustion efficiency of biogas (60%).

2.2 Potential energy

$$Potential\ energy = Energy \times 0{,}0036 \tag{13}$$

where *Energy* is conversion from biogas volume to energy (kWh) with the assumpstion that 1 m^3 biogas equals to 6 kWh of energy [11]. *0,0036* is used to convert kWh to GJ.

3 Results and discussion

3.1 Food digester

The food digester that is used in this study is an anaerobic digester reactor. The principle of anaerobic digester is to process food waste anaerobically by utilizing anaerobic bacteria to decompose food waste. Food waste contains high moisture content which makes it easy to decompose [10]. The flow of the waste processing process using a food digester in the study area can be seen in the following picture.

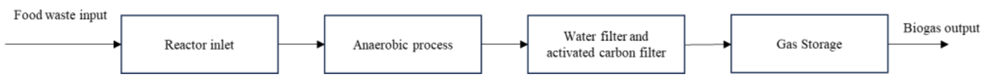

Fig. 1. Food waste digester processing flow

Before being put into the reactor, the waste is first weighed and recorded. After that, food waste will be put into the reactor through the inlet tube. In the reactor tube with a total capacity of 5,000 L, the waste will be decomposed anaerobically and observed in four months (May to August 2023). From the results of this anaerobic reaction, a chemical reaction will occur and methane/biogas gas will be produced. Apart from that, this process will also produce by-products in the form of liquid waste which can be used as liquid fertilizer. It is a high-value fertilizer as it is odorless, free from weeds, and contains nutrients which is beneficial for plants [13]. The gas formed will be filtered first. In this unit, there are water filters to trap undesirable gases such as carbon dioxide and activated carbon filters to remove odors. From the filtration process, the gas will enter a storage tube to be stored when not in use. There are 2 flowmeters installed to record gas production and gas usage.

Table 1. Food waste input and gas production in May-August 2023

Month (2023)	Food Waste Input (kg)	Gas Production (m^3)
May	100.9	11.3
June	346	25.9
July	386	34.9
August	416	40,9
TOTAL	**1,248.9**	**113**

The total waste processed and gas production produced using the anaerobic digester can be seen in Fig. 2. The food waste input was increased from 100.9 kg in May which produced 11.3 m^3 of biogas to 416 kg in August 2023 which produced 40.9 m^3 of biogas. From Fig. 2, it can be concluded that biogas production can be expanded by rising food waste input. The comparison of food waste input and gas production can be seen in Fig. 3. Linear regression (0.0856 x waste (kg) + 1.5346) revealed that 1 kg of waste can produce 1.6202 m3 of biogas. The formula needs further research to yield a more representative calculation.

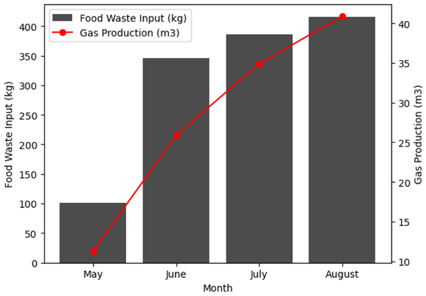

Fig. 2. Food waste input and gas production May to august 2023

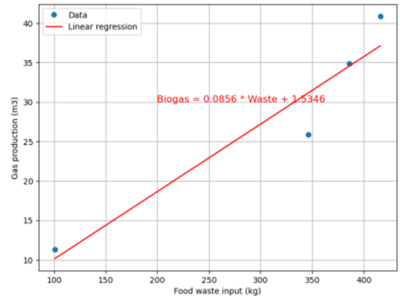

Fig. 3. Food waste input vs gas production

3.1.1 Factors influencing gas production

The anaerobic digestion process in this reactor is greatly influenced by the characteristics of waste input, such as the size and hardness of food waste, food ingredients, and chemical elements. It is highly recommended to crush the food waste before entering the reactor to speed up the production process as they are difficult to decompose [14]. Apart from that, there are also types of food ingredients that are not recommended to enter the reactor, such as thickener, orange peel [15], used cooking oil [16], and plastic or chemical contamination [14]. Hence, it is vital to distinguish a ready-to-process waste with the above-mentioned elements before starting this anaerobic digestion process.

3.2 Emission reduction & potential energy

3.2.1 Emission reduction

Utilizing organic waste to produce biogas will certainly reduce emissions produced from organic waste. These emissions are from waste that is taken into landfills (TPA). Compared to standard LPG the use of biogas has fewer emissions as it reduces the emissions. Calculations for CO_2e emission mitigation from waste processing using an anaerobic biodigester can be seen in Table 2.

Table 2. CO_2e emission reduction using anaerobic biodigester

Baseline emission		Project emission	**CO_2e emission mitigation (kg)**
CO_2e Emission from food waste (kg)	CO_2e Emission from LPG usage (kg)	CO_2e Emission from biogas usage (kg)	
2,622.7	701.8	169.2	**3,155.3**

CO_2e emission from food waste that was not processed is 2,622.7 kg, CO_2e emissions when cooking used LPG was 701.8 kg CO_2e, meanwhile, CO_2e emissions when cooking used biogas was 169.2 kg CO_2e. Thus, using formula (1) it was reported that the greenhouse gas mitigation from May to August 2023 was 3,155.3 kg CO_2e.

3.2.2 Potential energy

Energy value is obtained from the total volume of biogas that is successfully produced and utilized. From the data obtained from daily flowmeter recordings, it was found that the volume of biogas produced from processing from May to August 2023 was 113 m^3.

With the assumption that there was a minimum of 60% methane in the biogas, it was forecasted that the total energy production was equivalent to 6 kWh [11]. With a volume of 113 m^3, the total energy production was predicted around 2.44 GJ. However, further research is required to verify the calculation reliability.

3.3 Economic benefit

Economic benefits are obtained from the profits obtained by canteen tenants through the use of biogas as a substitute for LNG. The number of stoves that have been installed is 8 out of 16 stove units.

$$W\,biogas = Vol\ biogas\ x\ \ Calorific\ value\ biogas\ /\ Calorific\ value\ LPG \qquad (13)$$

where *W biogas* is weight of biogas (kg), *Vol biogas* is volume of biogas (m^3), *Calorific value biogas* (4,810 kcal/m^3), and *Calorific value LPG* (11,254.6 kcal/kg).

Total biogas utilization during the period May – August 2023 is 113 m^3. If converted to a 5.5 kg gas cylinder using formula (13), biogas consumption can save the use of 9 gas cylinders. The current price of a 5.5 kg gas cylinder is IDR 95,000,-, so the savings that can be obtained is IDR 855,000,-.

This program is a form of the company's commitment to reducing environmental degradation due to waste. Calculation of the benefits of this program through calculating the Social Return on Investment (SROI) for this program has not been carried out. The economic benefits discussed in this paper only calculate the value of the economic benefits received by canteen tenant from the use of biogas.

3.4 Implementation review

Sustainable food management is a systematic approach that seeks to reduce wasted food and its associated impacts over the entire life cycle, starting with the use of natural resources, manufacturing, sales, and consumption and ending with decisions on recovery or final disposal [4]. The application of anaerobic digestion and the gas produced depends on the amount of waste being processed. Food waste generated from canteens usually results from leftover food from visitors, waste from food processing, and food that is no longer fit to be served. This shows that visitor consumption patterns, food portions, food processing, and the food storage process are important factors in the generation of food waste. It is reported that small-scale household anaerobic digesters can produce gas ranging from 0.31 – 6.13 m^3/day and methane composition 63.1- 66.8%. Based on that report, a digester reactor with 6 m^3 capacity can produce gas on average of 3.065 m^3/day, with a methane composition of 64.7% [12]. The average gas production from May to August in the Muara Karang canteen is 0.911 m^3/day. Compared to the result, there is still a gap to increase its gas production.

Active participation from canteen tenants plays a significant role in the success of this program. Tenants' participation includes sorting waste, collecting waste, inputting waste into the reactor, and weighing and recording the amount of waste processed. The first step taken was to provide information regarding the benefits of anaerobic digesters for tenants. The benefits approach through calculating economic value makes tenants interested in participating. Tenants are given knowledge about how to properly sort waste and the types of waste that can be processed through anaerobic digesters. Waste that can be processed includes vegetables, broth, food waste, egg shells, and other organic waste. Waste that should not be included includes orange peels because orange peels have disinfectant properties which can affect the performance of the microorganisms in the digester tank. Each tenant gets 1 special trash bin for their organic waste. After the waste is collected, the tenants ought to put the organic waste into the anaerobic digester unit. Biogas from the anaerobic digester will be used by cafeteria tenants to support daily trading activities.

The implementation carried out in the study was still limited to a small scale. It can be said that the installed anaerobic capacity is still sufficient to accommodate and process more organic waste. Utilization of the biogas produced is currently limited to only a few tenants. This is related to the technicalities of the biogas distribution system. The application of anaerobic digesters at the study location has the potential to be developed. In the future, this waste processing unit is expected to be able to process waste from residential areas or restaurants around the study location. However, a firm concept and system are required to ensure the operations and sustainability of waste processing. The application of anaerobic digestion can be carried out on a larger scale in commercial areas such as restaurants, markets, malls, and hotels or at the RW scale where the amount of organic waste produced is greater and the benefits of biogas will be felt by more people. This program, which was initiated by the private sector- PT PLN Nusantara Power UP Muara Karang, shows a strong commitment from the business world to contribute to the reduction of waste, reduction of greenhouse gas emissions, increase of renewable energy in order to achieve sustainable development goals.

4 Conclusion

The application of anaerobic digesters to process organic waste on a regional scale was feasible. The study that was conducted from May to August 2023 at PT PLN Nusantara Power UP Muara Karang's canteen area reported several plausible results which were the reduction of organic waste by 1,248.9 kg, a reduction of CO_2 greenhouse gas emissions by 3,155.3 kg CO_2e, and a potential of a new renewable energy source in the form of biogas amounting to 2.44 GJ. It was also reported that rising food waste input to the anaerobic digester system would expand biogas production. Other than that, the financial advantage was also feasible as the produced biogas can be utilized as an LPG alternative replacement. The study provided insights and a call to action for the government and private sector entities to adopt anaerobic digester technology to manage food waste on a larger scale to create a sustainable city and also a better quality of life for the community.

References

1. Government of Indonesia, Law 18-Solid waste management,(2008)
2. www.sipsn.menlhk.go.id
3. Bapenas, Study Report Food Loss and Waste in Indonesia, (2021)
4. F.A. Cahyani, P. Wulandari, N.A. Putri, Food waste management regulation in Indonesia to achieve sustainable development goals, *IOP Conference Series: Earth and Environmental Science*, **978**, (2022)
5. Lin, C., Pfaltzgraff, L., Herrero-Davila, L., Mubofu, E., Abderrahim, S., Clark, J., Koutinas, A., Kopsahelis, N., Stamatelatou, K., Dickson, F., Thankappan, S., Mohamed, Z.,Brocklesby, R., Luque, R., Food waste as a valuable resource for the production of chemicals, materials and fuels, Current situation and global perspective, *Energy Environ. Sci*, **6**, 426–650, (2013)
6. Posmanik, R., Labatut, R., Kim, A., Usack, J., Tester, J., Angenent, L., Coupling hydrothermal liquefaction and anaerobic digestion for energy valorization from model biomass feedstocks, *Bioresour Technol*, **233**, 134–143, (2017)

https://doi.org/10.1051/e3sconf/202448505003

7. Romero-Güiza, M., Vila, J., Mata-Alvisz, J., Chimenos, J., Astals, S., The role of additives on anaerobic digestion: A review. *Renew. Sustain. Energy Rev.*, **58**, 1486-1499, (2016)
8. Xu, F., Li, Y., Wang, Z.W., Mathematical modeling of solid-state anaerobic digestion, *Prog. Energy Combust. Sci*. **51**, 49–66, (2015)
9. J. Wahyudi. Potensi Produksi Biogas dan Mitigasi Emisi Gas Rumah Kaca di Industri Tahu. *Prosiding SNST* ke-**8**, (2017)
10. C. Zhang, H. Su, J. Baeyens, T. Tan, Reviewing the anaerobic digestion of food waste for biogas production, *Renewable and Sustainable Energy Reviews*, **38**, 383-392, (2014)
11. T. Vintila, S. Neo, C. Vintilă, Biogas Production Potential from Waste in Timis County, *Scientific Papers: Animal Sci Biotechnol*, **45**, 366-373, (2012)
12. X.F. Lou, J. Nair, G. Ho, Field performance of small scale anaerobic digesters treating food waste, *Energy for Sustainable Development*, **16**, 509-514, (2012)
13. B. Bharathiraja, T. Sudharsana, J. Jayamuthunagai, R. Praveenkumar, S. Chozhavendhan, J. Iyyappan, Biogas production – A review on composition, fuel properties, feed stock and principles of anaerobic digestion, *Renewable and Sustainable Energy Reviews,* **90**, 570-582, (2018)
14. S. Mirmohamadsadeghi, K. Karimi, M. Tabatabaei, M. Aghbashlo, Biogas production from food wastes: A review on recent developments and future perspectives, *Bioresource Technology Reports,***7**, 1-10, (2019)
15. B. Ruiz, X. Flotats, Effect of limonene on batch anaerobic digestion of citrus peel waste, *Biochemical Engineering Journal,* **109**, 9-18, (2016)
16. R. Sandriaty, C. Priadi, S. Kurnianingsih, A. Abdillah, Potential of biogas production from anaerobic co-digestion of fat, oil and grease waste and food waste, *E3S Web of Conferences,* **67**, 1-5, (2018)
17. E. Amir, S. Hophmayer-Tokich, T.B.A. Kurnani, Socio-Economic Considerations of Converting Food Waste into Biogas on a Household Level in Indonesia: The Case of the City of Bandung, *Recycling,* **1**, 61-88, (2015)