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# Pemanfaatan Sampah Sisa Makanan dengan Kotoran Sapi sebagai Ko-Substrat untuk Produksi Energi Listrik

## *(Utilization of Food Waste with Cow Manure as a Co-Substrate for Electricity Generation)*

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Food Waste; Biogas; Methane Gas; Anaerobic Digestion; Thermoelectric Generator

**ABSTRACT.** Food waste is the dominant component of organic waste generation in Indonesia and drives environmental pollution via greenhouse gas release, particularly methane. This research is conducted to examine the potential of food waste as a biogas feedstock, the influence of the influence of different ratios of food waste and cattle manure on methane yield ($CH_4$) production, and assess the potential conversion of biogas into electrical energy using a Thermoelectric Generator (TEG). The research was conducted on a laboratory scale using a 15 L batch-type anaerobic digester with food waste to cattle manure ratios of 50:50 and 74:26. The analyzed parameters included C/N ratio, pH, temperature, methane concentration, biogas volume, and electrical power generated from thermal energy conversion through biogas combustion using a SP1848 Thermoelectric Generator. The results indicate that substrate composition significantly affects fermentation pH stability, temperature, and methane content, with certain compositions producing higher $CH_4$ percentages and greater potential for electricity generation. Although the energy conversion efficiency of the Thermoelectric Generator remains relatively low, this study demonstrates that food waste has promising to be developed as a sustainable alternative energy resource and can contribute to sustainable waste management and environmentally friendly energy production.

## INTRODUCTION

According to Regulation of the Ministry of Environment and Forestry of the Republic of Indonesia No. 6 of 2022, food waste constitutes one of the main components of municipal solid waste. Indonesia currently ranks second globally as a producer of food waste based on data from the Economist Intelligence Unit (EIU). Based on records from the Sistem Informasi Pengelolaan Sampah Nasional (SIPSN) in 2023, the total national waste generation reached 38,795,897.60 tons, with food waste dominating at 39.82%. The household sector is the largest contributor, accounting for approximately 63.64% or equivalent to 77 kg per capita per year, and this figure is projected to increase by 31% by 2030 (Barilla Center for Food and Nutrition; Badan Pangan Nasional). Food waste generation negatively impacts the environment and climate as it contributes to greenhouse gas emissions, particularly carbon dioxide and methane [1].

Food waste that is not properly managed will undergo decomposition and produce methane emissions, which contribute to global warming [2]. Therefore, effective treatment methods that minimize negative environmental impacts are required. One applicable technology is the biodigester, which utilizes anaerobic microorganisms to decompose organic matter in the absence of dissolved oxygen, thereby producing biogas [3]. A study by Ardinal et al. (2015) demonstrated that processing food waste with cow manure as a co-substrate produced methane gas of 23,297.59 mg/L, which has the potential to be converted into electrical energy amounting to 0.582 kWh.

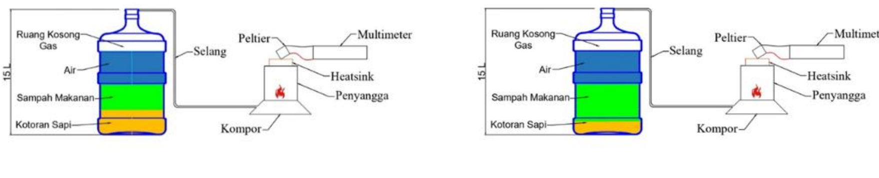
The development of biogas as a New and Renewable Energy (NRE) source holds strategic prospects because it is clean, environmentally friendly, and sustainable [4]. Biogas is generated through anaerobic fermentation and typically contains around 45% methane, which can be utilized as fuel for cooking and electricity generation [5]. The utilization of biogas also serves as an alternative solution to reduce dependence on fossil fuels, whose availability is gradually declining, although it still faces challenges such as relatively long processing times and sensitivity to environmental conditions, particularly temperature.

Based on this potential, this study utilizes food waste from the canteen of UPN "Veteran" Jawa Timur as feedstock for a biodigester to produce biogas, which is subsequently converted into electrical energy. The location was selected due to its high activity level and significant waste volume, thereby offering potential to reduce unutilized waste while supporting sustainable environmental management. The energy conversion medium used in this study is a Thermoelectric Generator (TEG), a device that converts heat energy into electrical energy through the Seebeck effect [6]. The use of TEG was chosen due to its compact and flexible design, which is expected to support the implementation of renewable energy systems based on waste management.

## RESEARCH METHODS

### Reactor Design

Based on Figures 1 and 2, the reactor used in this study was a 15 L gallon container, with each reactor having a different substrate composition. The first reactor consisted of food waste and cow manure at a 50:50 ratio, while the second reactor used a 74:26 ratio (food waste to cow manure). Both reactors were equipped with a gas outlet positioned at the top of the gallon cap and connected to a small stove to ensure proper methane gas flow. The methane gas collected in the stove hose was then subjected to a combustion test to generate heat for the Thermoelectric Generator (TEG), allowing the measurement of the electrical energy produced.




(a) (b)

**Figure 1**. (a) Reactor design of ratio 50 FW : 50 CD and (b) Reactor design of ratio 50 FW : 50 CD

### Primary Research

Food waste was fed into an airtight 15 L drum digester. Cow manure was added as an inoculum with mass variations of 3 kg and 1.85 kg in each digester. All substrates were mixed with 100 mL of EM4 solution and water at a ratio of 0.67:1 to maintain the substrate condition so that it was neither too diluted nor too dense. After mixing, the digester was tightly sealed to create anaerobic conditions. The anaerobic fermentation process was carried out in batch mode for 7–28 days to produce biogas. The stages of the biogas research were as follows: (a) loading the substrate and water according to the composition variation; (b) sealing the digester airtight; and (c) conducting anaerobic fermentation for 7–28 days.

The substrate composition in each digester was as follows:

a. Food waste : cow manure ratio = 50 : 50

- D1 = 60% rice and side dishes + 40% vegetables and fruits + 3 kg cow manure
- D2 = 50% rice and side dishes + 50% vegetables and fruits + 3 kg cow manure
- D4 = 40% rice and side dishes + 60% vegetables and fruits + 3 kg cow manure

b. Food waste : cow manure ratio = 74 : 26

- D3 = 60% rice and side dishes + 40% vegetables and fruits + 1.85 kg cow manure
- D5 = 50% rice and side dishes + 50% vegetables and fruits + 1.85 kg cow manure
- D6 = 40% rice and side dishes + 60% vegetables and fruits + 1.85 kg cow manure

## RESULTS AND DISCUSSION

### C/N Results

This study utilized organic materials in the form of cow manure and food waste, both of which have the potential to produce biogas through anaerobic fermentation. The major component of biogas with the highest percentage is methane ($CH_4$), whose formation is primarily influenced by two key elements, carbon and nitrogen. The organic materials used in this study exhibited different C/N ratios according to the applied variations, and the C/N ratio values obtained from laboratory analysis are presented in Table 1.

**Table 1**. C/N Ratio

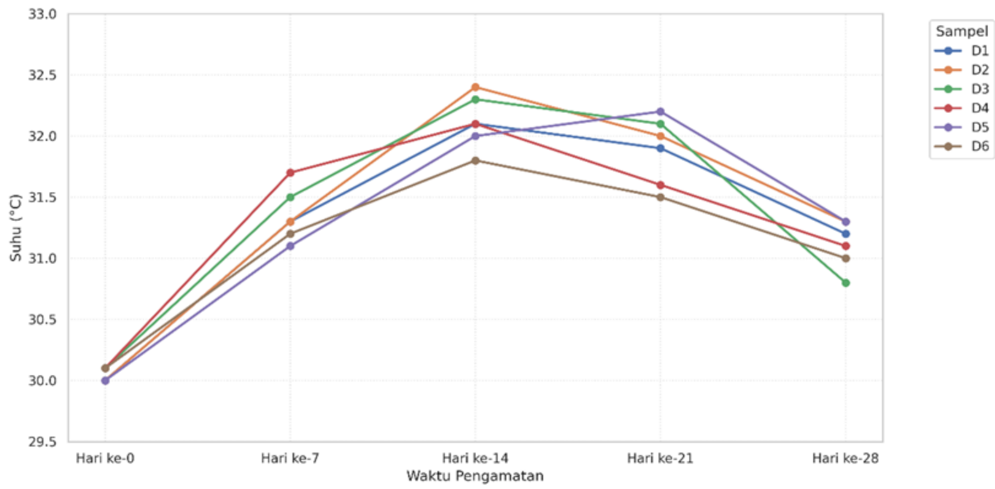
| Digester | C/N Ratio |
|---|---|
| D1 | 14,31 |
| D2 | 12,06 |
| D3 | 16,87 |
| D4 | 11,35 |
| D5 | 9,33 |
| D6 | 12,99 |

The C/N ratio values in all digesters ranged from 9.33 to 16.87, which are below the optimum range for biogas production of 20:1–30:1 [7]. The C/N ratio is a crucial parameter in anaerobic digestion, as it plays an important role in maintaining the nutrient balance of microorganisms between carbon, which serves as an energy source, and nitrogen, which is involved in microbial biomass formation. Non-optimal C/N ratio conditions, particularly under excess nitrogen, may lead to an increase in total ammonia nitrogen (TAN) and the accumulation of volatile fatty acids (VFAs), which can inhibit microbial activity, especially methanogenic bacteria [8]. Indirectly, these conditions also affect pH stability within the digester, where pH fluctuations may reduce the efficiency of the methanogenesis process and result in decreased biogas volume and methane content [9].

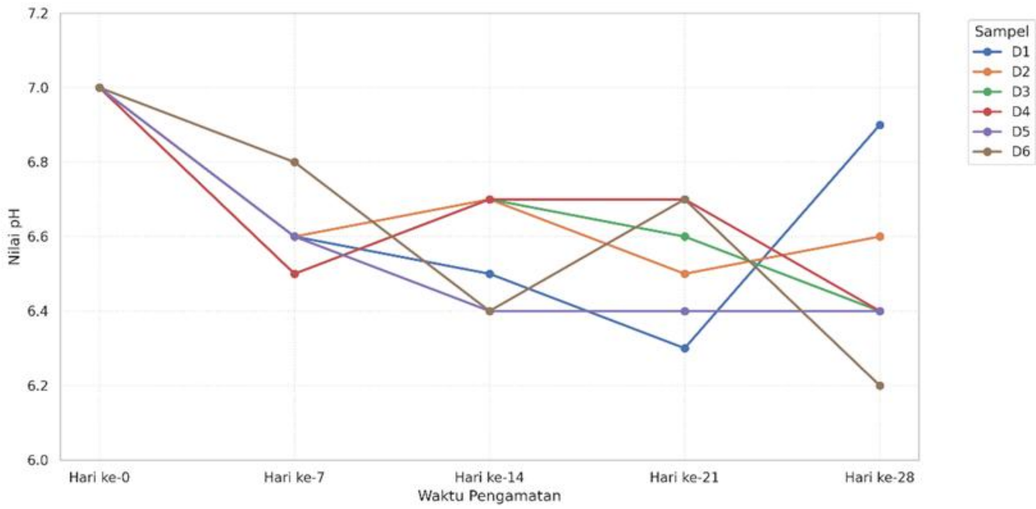
Although the laboratory-tested C/N ratio values were below the optimum range, the digesters still produced biogas under actual operating conditions. This indicates that the laboratory C/N ratio results did not fully represent the actual substrate conditions inside the digester during fermentation. The discrepancy was caused by technical constraints during sampling, particularly the addition of a relatively large amount of water, which diluted the substrate and affected the measured carbon and nitrogen content. Non-ideal water addition may also influence moisture content and temperature inside the digester, ultimately affecting microbial activity during anaerobic fermentation [10]. Therefore, the laboratory C/N ratio values more accurately reflect the substrate condition at the time of sampling rather than the actual condition inside the digester throughout the fermentation process.

**pH and Temperature Measurement Results**

Monitoring pH and temperature is a crucial parameter in the biogas production process through anaerobic biodigesters, as both directly influence the activity of microorganisms responsible for decomposing organic materials such as food waste. An optimal pH supports the fermentation phase, while temperature ensures the metabolic efficiency of methanogenic bacteria.




(a)



(b)

**Figure 2.** (a) Graph of temperature changes during the anaerobic digestion process and (b) graph of ph changes during the anaerobic digestion process

The temperature dynamics during the digestion process showed an increase from the initial condition of approximately 30°C on day 0 to a peak temperature on day 14, with an average of 32.1°C, where the highest value was recorded in digester D3. This temperature rise is associated with exothermic reactions occurring during the hydrolysis and acidogenesis stages, when microorganisms actively degrade complex organic matter into simpler compounds [11]. After reaching its peak, the temperature gradually declined between days 21 and 28, corresponding to reduced microbial activity and heat production. Nevertheless, the entire observed temperature range remained within the optimal range for methanogenesis (30°C–35°C), indicating that the overall thermal conditions of the system were still favorable for methane formation [12]. The relatively higher temperature observed in digester D3 suggests a more intensive fermentation rate, likely related to a substrate composition that was more readily biodegradable.

However, a technical limitation in temperature measurement was identified in this study, as measurements were taken at the gas outlet hose rather than directly inside the digester body. This measurement location does not accurately represent the core temperature of the anaerobic digestion process because the exiting gas had already experienced heat loss to the surrounding environment. Consequently, the recorded temperature data tended to be lower and more stable than the actual internal reactor conditions, making quantitative interpretation of the relationship between temperature and digester performance less precise. Therefore, future studies are recommended to use temperature sensors placed directly within the digestion substrate to obtain more accurate and representative data.

The pH measurements showed greater fluctuations compared to temperature, with values ranging from 6.2 to 6.8 during the observation period. All digesters had an initial neutral pH (±7), indicating that the substrate had not yet undergone significant organic matter degradation. During anaerobic fermentation, pH dynamics reflect the interaction between the acidogenesis and methanogenesis phases. The decrease in pH during the early to mid-phase was mainly caused by the accumulation of volatile fatty acids (VFAs), whereas the increase toward the end of the period indicates the stabilization of methanogenic activity [13]. Digesters with minimal pH fluctuation, such as D2, suggest a balanced biological process and relatively good buffering capacity, while greater pH fluctuations in D6 indicate an imbalance between VFA production and consumption, potentially reducing methanogenesis efficiency [14].

A technical constraint was also encountered in pH measurement, as the substrate samples had to be transferred to a separate container due to limited access to the digester outlet. This method may have caused slight deviations in pH values due to brief exposure to air, meaning that the obtained pH data more accurately represent the trend of pH changes rather than the absolute conditions inside the digester [15].

**Methane Gas Test Results**

The methane gas ($CH_4$) content test was conducted to determine the potential and quality of the biogas produced from the anaerobic fermentation of food waste and cow manure with various composition variations. Methane is the primary component of biogas that determines its energy value and overall quality, making it a key parameter in this study. The $CH_4$ measurements were carried out on day 21, when biogas production is generally at its optimal stage, and the percentage of methane gas in all digesters is presented in Table 2 below.

**Table 2**. $CH_4$ Percentage

| **Digester** | **$CH_4$ (%)** |
|---|---|
| D1 | 19,78 |
| D2 | 22,1 |
| D3 | 0,42 |
| D4 | 18,06 |
| D5 | 0,0017 |
| D6 | 0,0098 |

The results of methane ($CH_4$) content analysis using the Gas Chromatography–FID method showed that none of the digesters produced methane levels ≥50% on day 21. Digesters with a 50:50 ratio of food waste to cow manure (D1, D2, and D4) generated relatively higher methane percentages compared to those with a 74:26 ratio, with the highest value observed in D2 at 22.1%. In contrast, digesters D3, D5, and D6, which contained a lower proportion of cow manure, exhibited very low methane concentrations (<0.1%), indicating that the methanogenesis

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process did not proceed optimally. These differences suggest that substrate composition and inoculum proportion play a significant role in determining the success of methane gas formation [16].

Theoretically, the characteristics of organic materials and the C/N ratio greatly influence methane production. Carbohydrates from rice are easily degradable and serve as an initial energy source for microorganisms, while proteins from side dishes degrade more slowly and may produce ammonia when nitrogen is excessive [17]. Vegetables and fruits, which are rich in moisture and volatile solids, help maintain nutrient balance and system stability. A C/N ratio that is too low may trigger ammonia accumulation, which is toxic to methanogenic bacteria, whereas a ratio that is too high may cause nitrogen limitation for microbial growth; both conditions ultimately reduce methane production efficiency [18]. Therefore, the C/N ratio functions as a controlling environmental factor in the digester rather than the sole determinant of methane percentage.

In addition to the C/N ratio, pH stability is a key factor in the success of methanogenesis, as methanogenic bacteria perform optimally at a pH of 6.5–7.2 [19]. The accumulation of volatile fatty acids (VFAs) due to biological imbalance may lower pH and inhibit methane formation, while excessively high pH caused by free ammonia can also be toxic [20]. Cow manure plays an important role as a natural buffering agent and a source of methanogenic microorganisms; therefore, digesters with sufficient cow manure proportions (D1, D2, and D4) exhibited more stable pH conditions and relatively higher methane production [21]. Conversely, the low cow manure content in D3, D5, and D6 led to system acidification and failure of the methanogenesis stage, even though the hydrolysis process was supported by the addition of EM4 [22].

**Analysis of Electrical Energy Potential Based on Methane Gas Content**

The analysis of electrical energy potential in this study was based on the methane ($CH_4$) content produced from variations in the composition of food waste and cow manure in digesters D1–D6. Methane is the dominant component of biogas and acts as the primary energy carrier; therefore, the magnitude of electrical energy potential depends largely on the $CH_4$ fraction within the biogas [23]. However, the test results indicated that methane concentrations in all digesters were still relatively low, with the highest value reaching only 22.1%. This condition prevented a quantitative analysis of electrical energy potential in terms of actual energy output (kWh).

In addition to the low methane concentration, the total biogas volume was not directly measured in this study. Therefore, the analysis of electrical energy potential was not conducted through absolute calculations but rather through a conceptual approach based on methane fraction. This approach refers to literature stating that 1 $m^3$ of methane gas is equivalent to 11.17 kWh of energy [24], using a hypothetical volume of 1 $m^3$ of biogas as a comparative baseline. Through this method, the $CH_4$ percentage was treated as the relative contribution of methane to the overall biogas energy potential, allowing consistent comparison of electrical energy potential among substrate composition variations, although it does not represent actual electrical energy output.

Based on this approach, digester D2, with the highest methane content of 22.1%, relatively possessed the greatest electrical energy potential compared to the other digesters. Nevertheless, this value indicates that the majority of the produced biogas consisted of non-energetic gases such as $CO_2$, resulting in very limited energy potential. Digesters with a more dominant proportion of food waste, such as D3, D5, and D6, exhibited significantly lower methane content, indicating that increasing the food waste fraction without adequate cow manure support does not favor optimal methane formation. This finding emphasizes the role of cow manure as a source of methanogenic microorganisms as well as a buffering agent in the anaerobic digestion process [25].

In practical field testing, the utilization of biogas as a heat source to drive the Thermoelectric Generator (TEG) system could not be performed optimally. Both theoretically and practically, biogas combustion requires a minimum methane concentration of approximately 45% to produce a stable flame [26]. The $CH_4$ levels obtained in this study were far below this threshold; therefore, combustion using a small stove failed to generate a consistent flame. As a result, the temperature gradient between the hot and cold surfaces required to activate the TEG was not achieved, and measurable electrical energy could not be produced.

Thus, the analysis of electrical energy potential in this study was limited to a relative evaluation based on methane content rather than actual electrical energy quantification. The results indicate that a balanced composition of food waste and cow manure provides the best potential for methane formation; however, increasing $CH_4$ concentration, scaling up the digester system, and optimizing operational conditions are still necessary for biogas to be effectively utilized as a source of electrical energy.

## CONCLUSION

This study demonstrates that variations in the composition of food waste and cow manure influence the performance of anaerobic digestion, particularly in terms of C/N ratio, temperature, pH, and methane gas production. Although the C/N ratios were below the optimal range, the fermentation process still proceeded, with temperature and pH dynamics remaining supportive of microbial activity, especially in digesters with balanced compositions. The digester with a 50:50 ratio of food waste to cow manure produced the highest methane content compared to other variations, highlighting the important role of cow manure as a source of methanogenic microorganisms and a buffering agent within the system. However, the overall methane concentration remained relatively low, preventing quantitative calculation of electrical energy and combustion testing. Therefore, further optimization of substrate composition, operational conditions, and digester scale is required to enable effective utilization of biogas as a source of electrical energy.

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